Climate, Soils and Fertility

Climate of Ohio

The state of Ohio has a wide diversity of climates. Normal annual precipitation ranges from a low of less than 30 inches at Put-in-Bay to a high of more than 44 inches in parts of Clinton and Highland counties. Ohio's climate is typically continental—a wide range of air temperatures and higher precipitation in the spring and summer, and lower precipitation in the fall and winter.

Because there are no mountain ranges between Ohio and the polar regions, there are no effective barriers to the southward spread of Arctic air from northern Canada. Similarly, warm tropical air masses move freely northward in the summer. Storm systems form along the boundary between the major cold and warm air masses, and their paths frequently include the Ohio Valley and the lower Great Lakes.

Average length of the freeze-free period ranges from a high of 200 days along the Lake Erie shore to a low of 140 days in east-central Ohio (Figure 1). The earliest dates with a 50 percent or less chance of frost (32°F) range from April 20 immediately adjacent to Lake Erie and May 15 in southern and east-central Ohio (Figure 2). The earliest freezing temperatures occur about September 30 in east-central Ohio and October 20 along Lake Erie and in southern Ohio (Figure 3).

Most soils in Ohio are saturated during March and early April. Although the growing-season rainfall varies from a low of 17 inches to a high of 25 inches (Figure 4), it may not be adequate for maximum yield unless effective water management practices are used throughout the growing season. Soil moisture declines during June, July and August. By the end of August, available soil moisture usually is reduced 80 percent or more.

Selecting Soils

Soil types for vegetable growing vary greatly in Ohio. Desirable soils are well drained, fairly deep, fertile and have proper pH and good soil structure. Soils with good structure permit maximum penetration of roots, water and air. The amount of crusting in the soil also should be low. Crusting of the soil can be a serious problem in some places in Ohio. Soil crusting can be reduced through the use of amendments to prevent emergence problems.

Sandy or silty loam soils with good organic matter generally are the most satisfactory soils for vegetables. Muck soils are highly desirable for certain types of vegetables. Organic matter in mineral soils should range from 3%-5% to provide good structure, nutrient availability and enhancement of water-holding capacity.

When selecting fields for the production of vegetables, be sure to plan some time in advance so that the fields can be adequately prepared. This means that soil pH tests should be taken and the fields limed if necessary. If subsoil difficulties are present, it may be desirable to plant a deep-rooted legume or sod crop to help overcome this difficulty.

If the field is not properly drained, then it is desirable to have the field tiled in an adequate manner so that subsurface drainage can occur. The past history of weeds in the fields also should be considered, so that serious problems with perennial and annual weeds can be prevented or controlled prior to planting.

Management

The production of vegetables presents some unusual and difficult soil management problems for the commercial grower. Some crops, for example, may require as many as 12 or 15 tractor or truck trips across the field before harvest is completed.

Some Basic Considerations

"Soil texture" and "soil structure" are common terms that can cause confusion. Soil texture describes the mixture of sand, silt and clay particles for a given soil. One useful classification system follows:

- **Coarse-textured soils:** Sands, loamy sands and some sandy loams.
- **Medium-textured soils:** Loams, sandy loams, silt loams, some sandy clay loams and clay loams.
- **Fine-textured soils:** Clay, sandy clays, silt clays, silty clay loams and clay loams.

It is impossible to change the texture of a given soil. The composition of sand, silt and clay is constant.

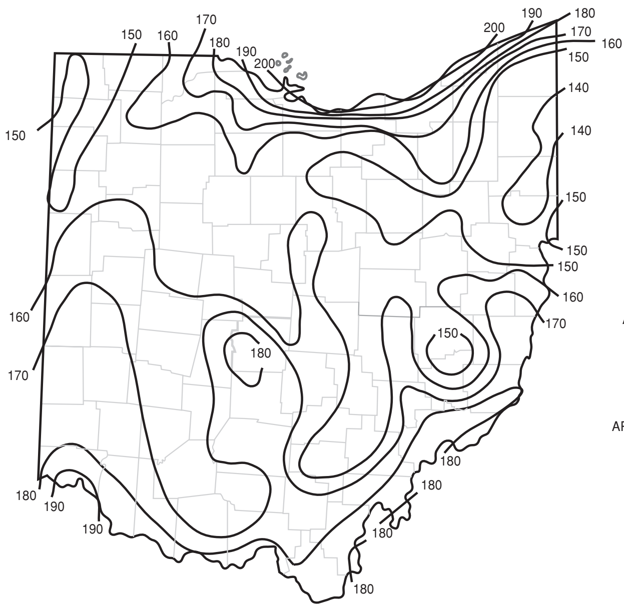

Figure 1. Average number of days without killing frost.

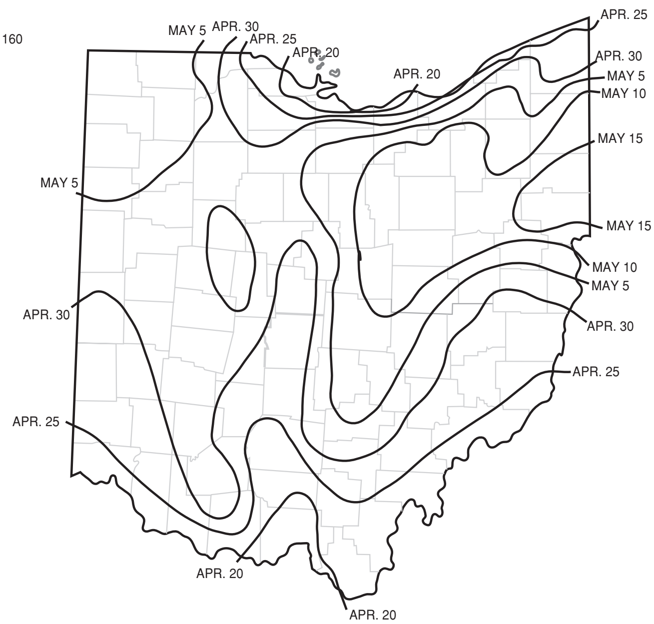

Figure 2. Dates in spring after which there is a 50% or less chance of temperatures falling to 32°F or lower.

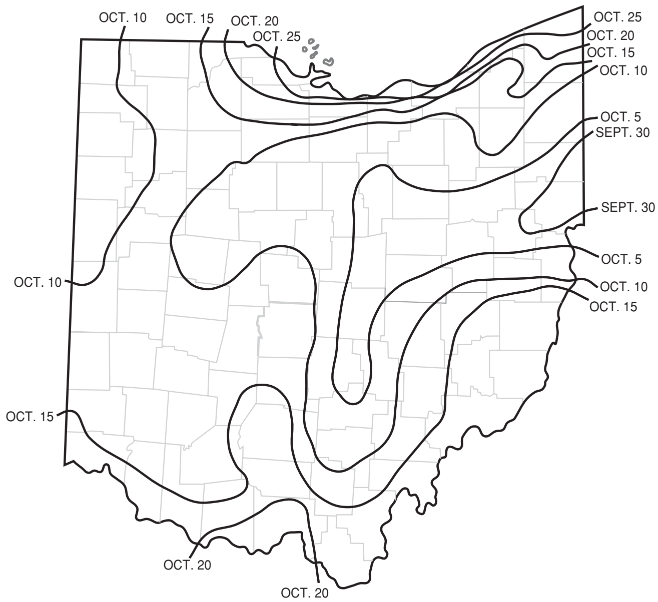

Figure 3. Dates in fall by which there is a 50% chance that the first 32°F temperature will have occurred.

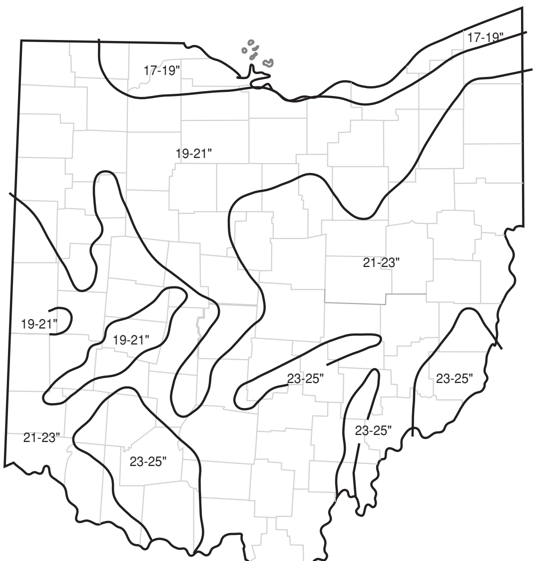

Figure 4. Normal rainfall (inches) for growing season (May through September).

Soil structure refers to the arrangement of the soil particles. These small particles combine to form various kinds of aggregates, depending on the clay and organic matter content. Soil aggregates vary in size or shape and may be held together quite strongly or weakly. Sandy soils, for example, have weak aggregates. Such soils drain well, do not retain much moisture and may require frequent irrigation and fertilization.

In contrast, a clay soil may have more stable aggregates, not drain as well as a sandy soil and retain or even hold tightly certain plant nutrients. Soils with more aggregates may develop compact layers that interfere with root development and water penetration, resulting in poor crop development.

Detailed soil maps are available for all Ohio counties. These maps contain pertinent information on soil types. Information is available from county Extension offices.

Organic Matter/Cover Crops

Organic matter affects the growth of plants and frequently is referred to as the “glue” that holds soil particles together. It also promotes development of soil aggregates, thus improving drainage, soil tilth and soil structure. With sandy and sandy loam soils, the organic matter improves the water-holding capacity. The addition of organic matter to the soil is important to maintain soil structure, but it is not possibie to increase the organic matter content to any appreciable extent.

Organic matter can be added to the soil by various methods using green manure crops, cover crops, crop residues, animal manures, mulches and composts. Some examples of green manure crops are sweet clover, alfalfa, thickly sown field corn and summer seedings of soybeans. These crops generally are plowed under before they are mature. At this stage, the plants usually contain the greatest amount of nitrogen and other nutrients plus an adequate amount of moisture for rapid decay. However, these green manure crops also can be plowed under in the mature dry stage. At this stage of maturity, they do not decompose as readily and additional nitrogen may be needed to aid decomposition.

Cover crops are planted after harvest to protect the soil against erosion and usually are turned in the following spring. Additional nitrogen may be needed to hasten the decomposition of the cover crop. This is especially important with rye. Rye should be plowed under before it is 18 inches tall.

Different cover crops frequently require special soil conditions for optimum growth. For example, alfalfa requires well-drained soils, while Ladino clover grows on poorly drained soils. Some crops, such as rye, have fibrous root systems, whereas others (sweet clover) have a large tap root that can penetrate the soil to considerable depths. Whenever it is possible to use a mixture of these crops, the combination results in more organic matter to plow under.

- **Seeding 1, rye:** this crop is one of the most widely used non-legume cover crops on Ohio vegetable farms. It usually germinates easily in the fall and survives severe winters. Rye should be plowed under by the time it is knee-high, or not later than May 1 if a crop is to be planted that spring. Nitrogen plowed under with rye hastens decomposition and reduces the chances of nitrogen deficiency for the following vegetable crop.
- **Seeding 12, rye and vetch:** hairy vetch fixes most of its nitrogen late in the spring, after May 1. Plowing should be delayed until mid-May or later. This will interfere with spring and early summer vegetables. Vetch seed is somewhat expensive and is suggested for growers planning to allow the rye and vetch to reseed themselves. This mixture currently is not in wide use.
- **Seeding 2, ryegrass; Seeding 13, ryegrass and sweet clover:** ryegrass is established without much difficulty. It can be seeded at the last cultivation of sweet corn, peppers, eggplant or similar crops. Sweet clover can be mixed with ryegrass, but the ryegrass usually grows faster and crowds out the sweet clover. Use yellow sweet clover varieties for summer sowing. Plow down nitrogen with the ryegrass sod, because the sod is heavy and additional nitrogen is needed to decompose it.
- **Seeding 3, sudan grass; Seeding 4, field corn:** field corn can be drilled solid with a grain drill. Both sudan grass and field corn make abundant growth in a short time. They can be used as a summer cover crop following early harvested spring vegetable crops. Plow under nitrogen with these crops.
- **Seeding 5, winter barley:** use only in southern Ohio where winter killing is not as severe. Handle as in the same manner as rye. Root growth is not as extensive as rye or ryegrass.
- **Seeding 6, wheat:** this is a good crop in which to make clover and grass seedings if a vegetable/small grain/sod rotation is being followed. It is popular with potato growers who make clover seedings into wheat.
- **Seeding 7, sweet clover; Seeding 14, sweet clover and orchard grass:** use yellow sweet clover for summer seedings. Lime soils to pH 6.5-7.0 for successful growth. Do not sow later than August 20. Be sure to make spring seedings in a small grain, preferably oats. The sweet clover/orchard grass mixture is an excellent soil-improving combination when seeded in the spring and allowed to remain for 2 years. This combines a deep-rooted legume (sweet clover) and fibrous-rooted grass (orchard grass). This practice may be too costly because land may be out of production.
- **Seeding 8, medium or mammoth red clover:** use this crop in rotation with a small grain. Red clover can be established in soils with a lower pH than required for sweet clover or alfalfa, but it responds with higher yields to a pH of 6.5-7.0.
- **Seeding 9, soybeans:** use this as a summer cover crop. It makes rapid growth but has a limited root system in comparison with other legumes.
- **Seeding 10, alfalfa:** use this crop in rotation where it can stand more than 1 year. Many new strains are available—consult county Extension offices for the latest recommendations. Alfalfa needs lime and other minerals for good growth.

Green Manure Crops for Vegetable Farms			
Seeding Crop Number	**Pounds/Bushel**	**Quantity of Seed per Acre (pounds)**	**Desirable Seeding Dates**
Non-Legumes			
1. Rye	60	90-120 (alone) 90 (mixture)	Sept. 1-Nov. 10
2. Perennial or common ryegrass	24	15-20 (alone) 5-8 (mixture)	Aug. 1-Sept. 15
3. Sudan grass	40	20-30	May 15-July 1
4. Field corn	56	50-60	May 15-July 1
5. Winter barley	48	80-100	2-3 weeks before fly-safe date
6. Wheat	60	90-120	After fly-safe date
Legumes			
7. Sweet clover	60	16-20 (alone) 10-12 (mixture)	March 1-April 15 July 15-Aug. 20
8. Red clover	60	10-15 (alone)	Feb. 1-April 1
9. Soybeans	60	90-100	May 15-July 1
10. Alfalfa	60	12-18	March-April
11. Hairy vetch	60	15-20 (mixture)	Sept. 1-Nov. 1
Mixtures			
12. Rye/vetch		90/15-20	Sept. 1-Oct. 1
13. Ryegrass/sweet clover		5-8 12-15	July 15-Aug. 20
14. Sweet clover/orchard grass		6-8	March 1-April 15

Obtaining Acceptable Stands of Clover and Green Manure Crops

Poor stands can be due to one or more of the following reasons:

1. **Acid soils (low pH):** Clover seedings require a soil pH of 6.5-6.8. Grasses are not as sensitive as clover to acid soil.
2. **Lack of nutrients:** Apply 60-80 lb/A P_2O_5, in a band application with the grain drill at the time of seeding. With banding, fertilizer is placed so that it is reached by the seedlings immediately after germination.
3. **Unfavorable weather after seeding:** If soil is dry at seeding, use irrigation. Light mulches also aid in achieving a desirable stand. Straw, manure, plant residues or any similar material can be used as a mulch. This mulch conserves moisture near the surface, prevents the formation of a crust, reduces soil temperature and protects against winter heaving.
4. **Unsuitable variety:** Plant recommended varieties.
5. **Planting too deep and/or a poorly prepared seed bed:** Plant most grasses and legumes shallow—1/4-1/2 inch deep for small seeds such as clover. This is easily done by using the cultipacker method. Prepare a firm seedbed, finishing with the application of fertilizer and disking. Cultipack the area, broadcast the seed and cover by rolling with the cultipacker. A firm seedbed is necessary during dry conditions to achieve a good stand but is not necessary during wet periods.
6. **Failure to inoculate legumes:** Use appropriate nitrogen-fixing bacteria for inoculation.

Animal Manures and Composts as Fertilizers

Animal manures and composts can provide significant quantities of nutrients. Use only well rotted and aged manures for producing food crops. Fall applications of fresh manure are acceptable. Fresh manures should never be applied to growing food crops due to possible pathogen transmission and potential nitrogen burning of the crop.

Nutrient content of manures varies both among animal species and within each species. Nutrients in composts can vary even more and are dependent on parent material and processing. Test manures and composts to determine potential nutrient contributions and application rates. Avoid using composts of unknown origin or parent material. Improperly made composts, be they of rural or urban origin, can contain heavy metals, inorganic debris, diseases, and insects unwelcome on your fields.

Soil Testing

Soil tests aid vegetable growers in crop management, rotation and fertilizer application programs. Soil tests are most useful only when growers keep accurate records of the amount of fertilizers applied, crop yields and rotation records for each field. In this way, growers discover trends in soil fertility and crop response to applied fertilizers over several years. Efficient vegetable production is achieved by adjusting lime and fertilizer applications to existing soil fertility levels. Net return can be increased because of proper soil fertility and reduction of losses due to physiological disorders caused by an imbalance of plant nutrients.

The standard soil test determines pH, lime index (buffer pH), available phosphorus, exchangeable potassium, calcium, magnesium, cation-exchange capacity and the percent base saturation of calcium, magnesium and potassium. Special tests are available to determine organic matter, available manganese, available boron and available zinc. This last set of tests generally is used if a grower has a specific problem.

Producing Vegetable Transplants—Soil Tests

Vegetable growers and bedding plant producers who use artificial soil mixes (soilless mix) should use the floral crop growing media test. Use the greenhouse test kit for soil mixes. These kits provide information on pH, nitrates and soluble salts.

Interpretation of Standard Soil Test Results

1. Soil pH is a measure of the acidity and alkalinity of the soil. It is a measure of the hydrogen ion concentration in a soil/water solution. This sometimes is referred to as active-soil acidity.
2. The lime test index (sometimes called "buffer pH") measures total soil acidity or reserve acidity. Some hydrogen ions are held by soil colloids and may be released, thus affecting soil pH. The lime test index is utilized to make limestone recommendations. The soils in many areas of Ohio are from limestone parent material and do not require lime because their pH is naturally 6.8 or higher.

   However, there are many regions of the state where soils are acid. A routine liming program must be maintained to keep soil pH in the proper range for maximum growth and quality. Fertilizer application, rainfall, organic matter breakdown and irrigation affect soil pH. For this reason, soil pH and the lime test index must be measured each year in order to determine liming needs. It usually takes lime 4-6 months to correct soil acidity. Most vegetables benefit in a pH range of 6.5-7.0.
3. Phosphorus (lb/A): The figure reported here gives the approximate pounds of actual phosphorus available per acre that the plant can utilize for growth. This element does not move readily in the soil and applied phosphorus is easily fixed and made unavailable to the plant. One hundred pounds of fertilizer phosphate (P_2O_5) will raise the soil phosphorus test levels about 10 lb/A. For this reason, most phosphorus is applied in bands where possible, and starter solutions are recommended for transplants. The amount of phosphorus recommended is based on the soil test value, crop removal and type of crop.
4. Potassium (lb/A): This figure gives the approximate pounds of potassium available per acre. About 50% of the applied potassium is fixed in the soil. Losses of potassium are from crop removal, leaching and soil erosion. The amount of potassium recommended is based on the soil test value, crop removal and type of crop.

5., 6. Calcium and magnesium (lb/A): These soil test values represent the amount of calcium and magnesium available in the soil. The readings generally are low when soils are acid. Levels are sufficient when pH and the lime test index are at proper levels. Most calcium and magnesium is applied through the use of ground limestone (see "Liming and Soil pH," page 17). Gypsum can be used to supply calcium when lime cannot be used because of a pH that already might be 7.0 or above. Epsom salts or Sul-Po-Mag can be used to supply magnesium when there is no need for lime.

7. Cation exchange capacity (CEC) is a measure of the soil's ability to hold exchangeable cations such as hydrogen (H^+), calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^+), sodium (Na), iron (Fe) and aluminum (Al). CEC is measured in terms of milliequivalents (meq) per 100 grams of soil.

$$CEC = \frac{lb\ Ca}{400} + \frac{lb\ Mg}{240} + \frac{lb\ K}{780}$$

$$+ 1.2 \times (70 - \text{Lime Test Index})$$

The CEC is determined by soil type and organic matter. Clay-, silt- and loam-type soils generally have a higher CEC than sandy soil because they have many more exchange sites to hold cations and anions. Soils with a higher CEC generally hold nutrients better than soils with a lower CEC. The following are typical ranges for a particular soil:

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

8. Base saturation is the percentage of the total CEC occupied by basic cations such as calcium, magnesium and potassium. Base saturation is related to soil pH and soil fertility. On acid soils, the percent base saturation of calcium and magnesium is low. Some cations are taken up by plants easier than other cations. For this reason, certain cations should saturate or be at certain high levels on soil colloids in order to provide for balanced soil nutrition.

   The base saturation for calcium should be 60% or above. Magnesium should fall in the range of 10%-15%. Potassium should be in the range of 1%-5%. High potassium levels can reduce the uptake of magnesium.
   Some soil scientists feel that there should be specific calcium-to-magnesium ratios and magnesium-to-potassium ratios (2:1). Most horticulturists feel that if base saturation levels are at the mentioned minimum levels, then it is not important to maintain specific proportions or ratios.

Recommendations

Plant Nutrients

Recommended nutrients are in terms of pounds of actual nitrogen, pounds of P_2O_5 and pounds of K_2O. Growers then must figure how much fertilizer or product must be applied in order to meet the suggested recommendations.

For example, if the soil test calls for an application of 100 lb N, 80 lb P_2O_5, and 100 lb K_2O, and the grower selects a 10-10-10 fertilizer, then 1,000 lb of 10-10-10 must be applied per acre in order to supply the recommended nutrient amount (10% of 1,000, or 0.10 x 1,000 = 100 lb).

If using premixed fertilizer, select the ratio that comes closest to the amount of recommended nutrients. It is not necessary to be exact, providing that any differences are reasonable. Another method of achieving desired nutrient levels, if the suggested fertilizer levels cannot be reached with standard fertilizer ratios, is by first making a base application using a standard fertilizer ratio. Then, apply individual elements to reach the recommended nutrient level.

For example, extra nitrogen can be supplied with ammonium nitrate or extra potassium can be applied with muriate of potash.

Blended fertilizers can be made to almost any desired ratio.

Nitrogen

There is no accurate soil test for available soil nitrogen. Nitrogen recommendations are based on field trials and yield data. Growers should adjust these recommendations according to experience, soil type and variety response.

Petiole-sap Testing

Petiole-sap analysis or "quick-testing" is a rapid diagnostic method that can be used to monitor nutrient levels in a variety of vegetable crops during the growing season. Sap testing is most commonly used for nitrogen, although potassium levels can also be monitored. Sap tests do not supply any information that cannot be obtained through standard plant tissue testing, but they are less expensive and eliminate the delay between the time a sample is collected and laboratory results are available. This can be critically important when a grower suspects a nutrient deficiency in a crop, or is preparing to fertigate or make a sidedress fertilizer application and wants to know what rate is required. Plant nutrient levels can change quickly, especially during rapid growth phases. When a fertilizer decision is made, a grower wants to know the condition of his or her crop today, not what it was last week.

Sap tests measure nutrient concentrations in plant sap squeezed from leaf petioles. Horiba/Cardy meters are the most popular type of sap-testing equipment in use today. These are hand-held, battery-operated meters with ion-selective electrodes for either nitrate-N or K. They have flat sensors that require a small volume of sample and give a direct readout of concentration. Sufficiency levels for many vegetable crops have been developed in Florida and California. On-farm surveys and research in Ohio on a few crops, including pepper, tomato, and cantaloupe, has found those recommendations useful in our conditions as well. Our climate and soils may require different nutrient management methods to reach the same levels, but nutrient sufficiency ranges within the crop appear similar. Ohio growers doing sap tests should use values in the table on the following pages from Florida as initial guidelines, keep records of sap tests and fertilizer applications, and adapt Florida guidelines as necessary to fit their conditions and management system.

Petiole sap tests are relatively simple, give immediate results, and are particularly suited for making timely adjustments in fertilizer application rates when using fertigation. They are designed as a grower-used crop management tool and are a supplement, not a replacement, for a standard soil testing and nutrient management program. Sap tests are not as precise as laboratory analyses, but they are reasonably accurate and sufficiently precise to distinguish between adequate and deficient plant nutrient levels. In other words, they are accurate enough to be used on a practical basis as a decision-making tool that can increase the efficiency of fertilizer use. Yield or quality may be improved by more closely matching nutrient rates and timing with plant needs, the cost of unnecessary fertilizer application can be eliminated, and the potential for environmental harm from leaching or runoff of excess fertilizer is reduced.

Procedures for Sap Testing

Sample collection

- Obtain a representative sample
- Sample the uppermost, recently matured leaves
- Remove the petiole or 'leaf stalk'
- Collect about 25-30 petioles per sample
- Avoid damaged, diseased leaves
- Collect separate samples for different:
  —varieties, planting dates, areas with deficiency symptoms
  —cultural practices, soil types, irrigation sections

Sample handling

- Do not allow petioles to lose moisture after picking
- Strip leaf blades from petioles soon after picking
- Place in closed plastic bags and store in a cooler on ice
- Time of sampling may affect N results; try to sample at a consistent time of day
- Expressed sap should not be stored for long periods (unless frozen)
- Petioles can be stored for 1-2 hours at moderate temperatures, somewhat longer on ice

Analysis and interpretation of results

- Calibrate the meter before use
- Warm petioles to room temperature before pressing and analyzing
- Cut petioles with a clean knife on a clean cutting board and mix the pieces well
- Squeeze sap from a subsample of petiole pieces onto the electrode with a garlic press
- Compare results with previous tests—are levels increasing, decreasing, or staying about the same?
- Compare results with Florida sufficiency levels in the table below
- Adjust fertigation or side-dress fertilizer rates based on sap-test results

Cardy meters for nitrate-N and K petiole-sap testing are available in the United States through two sources: 1) Spectrum Technologies, Plainfield, IL, and 2) Gemplers, Belleville, WI.

Recommendations for sap nitrate-N and K can be found in:

Plant Petiole Sap Testing: Guide for Vegetable Crops, 1994
George Hochmuth
Circular 1144
University of Florida Cooperative Extension Service

Recommendations for sap nitrate-N also can be found in:
Drip Irrigation and Fertigation Management of Vegetable Crops, 1993
Tim K. Hartz
Department of Vegetable Crops
University of California, Davis

Guidelines for Plant Leaf-Petiole Fresh Sap Nitrate-Nitrogen and Potassium Testing

Crop	Crop Developmental Stage	Fresh Petiole Sap Concentration (ppm)	
		NO_3-N	K
Broccoli & Collard	Six-leaf stage	800-1000	NR
	One week prior to first harvest	500-800	
	First harvest	300-500	
Cucumber	First blossom	800-1000	NR
	Fruits three-inches long	600-800	
	First harvest	400-600	
Eggplant	First fruit (two-inches long)	1200-1600	4500-5000
	First harvest	1000-1200	4000-4500
	Mid-harvest	800-1000	3500-4000
Muskmelon	First blossom	1000-1200	NR
	Fruits two-inches long	800-1000	
	First harvest	700-800	
Pepper	First flower buds	1400-1600	3200-3500
	First open flowers	1400-1600	3000-3200
	Fruits half-grown	1200-1400	3000-3200
	First harvest	800-1000	2400-3000
	Second harvest	500-800	2000-2400
Potato	Plants eight-inches tall	1200-1400	4500-5000
	First open flowers	1000-1400	4500-5000
	50% flowers open	1000-1200	4000-4500
	100% flowers open	900-1200	3500-4000
	Tops falling over	600-900	2500-3000
Squash	First blossom	900-1000	NR
	First harvest	800-900	
Tomato *(field)*	First buds	1000-1200	3500-4000
	First open flowers	600-800	3500-4000
	Fruits one-inch diameter	400-600	3000-3500
	Fruits two-inch diameter	400-600	3000-3500
	First harvest	300-400	2500-3000
	Second harvest	200-400	2000-2500
Tomato *(Greenhouse)*	Transplant to second fruit cluster	1000-1200	4500-5000
	Second cluster to fifth fruit cluster	800-1000	4000-5000
	Harvest season	700-900	3500-4000
Watermelon	Vines six-inches in length	1200-1500	4000-5000
	Fruits two-inches in length	1000-1200	4000-5000
	Fruits one-half mature	800-1000	3500-4000
	First harvest	600-800	3000-3500

Adapted from: George Hochmuth, Plant Petiole Sap Testing
University of Florida Cooperative Extension Service
Circular 1144, September 1994

Fertilizer and the Environment

Both natural (e.g., manures, composts) and synthetic sources of nitrogen and phosphorus have the potential to be lost from the field and contribute to pollution. Vegetable producers can minimize environmental impacts and improve fertilizer use efficiency with proper management. Growers should know their crops and use soil and plant testing to support their fertilizer decisions.

Split applications of nitrogen are generally more efficient than complete preplant applications. They do, however, require the grower to pay attention to crop growth and apply sidedressings at appropriate times, before the crop becomes stressed, and early enough to allow maturity of crops such as processing tomatoes and squash and pumpkins.

Banding of phosphorus at planting, with or without some phosphorus being broadcast/incorporated, is generally more efficient than broadcasting all phosphorus. Sidedressing of phosphorus is not recommended due to the element's lack of mobility in soils.

Potassium and the minor elements are generally not significant contributors to groundwater pollution but should be managed properly to minimize costs and maximize use efficiency.

Minimizing soil erosion and proper irrigation scheduling will also improve fertilizer use efficiency and reduce losses from the field.

Methods of Application

Fertilizer Programs

Once the total amount of nutrients is recommended on the soil test, a suggested method of application follows, which represents efficient fertilizer placement and utilization. This application method is only a suggestion; it may not agree with individual cultural practices or equipment. In such cases, the total amount of nutrients recommended should be applied using individual discretion.

Usually, 50%-60% of the recommended nitrogen and all of the phosphorus and potassium fertilizer should be applied in a preplant application and disked into the soil, especially when rates of a complete fertilizer exceed 400-500 lb/A.

Band application is recommended for many vegetable crops and seeding operations. This is an efficient way to apply fertilizer, and much of the phosphorus and potassium fertilizer can be applied this way. **Note:** Banding fertilizer rates should not exceed 80-100 lb of nitrogen plus potassium combined, because seed injury can result.

Additional nitrogen is provided though sidedress applications when the plants are still young. These sidedressings are especially important with such crops as sweet corn, broccoli and cabbage. Extra nitrogen also may be needed when there are leaching rains. Soil test recommendations should be followed for the amounts of actual nitrogen.

Liquid v. Dry Fertilizer

(Source: Michigan State University)

Liquid fertilizers are equivalent to dry fertilizers when applied in amounts that supply an equal amount of plant nutrients. Liquid fertilizers also can burn seeds as easily as dry fertilizers if applied improperly. The degree of a fertilizer's ability to burn is based on the salt index. The higher the index, the greater the ability to burn seeds. Additional information on salt indexes is available in *Knott's Handbook For Vegetable Growers*, Lorenz and Maynard, editors, J. Wiley & Sons, publisher.

Liquid fertilizers are easier to handle than dry fertilizers. Certain pesticides can be mixed with liquid fertilizers, and they also can be applied through irrigation water. Disadvantages are that special pumps, storage tanks and applicator tanks are required with liquid fertilizers. Also, the addition of magnesium, manganese and other micronutrients is difficult and may result in sedimentation.

The critical factor is whether the cost of a pound of nutrient is cheaper in a dry or liquid form. Also, the cost of application, handling and tanks should be accounted for when comparing liquid and dry fertilizers. The advantages and disadvantages can be seen clearly only through this analysis.

Foliar feeding can be used to apply small amounts of nitrogen, magnesium and other micronutrients to eliminate temporary deficiencies. In these cases, generally small amounts of nutrients are needed, and these can be easily supplied to the leaves.

However, foliar feeding should not be thought of as a substitute for regular fertilization because of the amount of fertilizer required for growth. Sufficient amounts of fertilizer applied to the leaves would result in the burning of the plants, and the use of multiple applications is not economically practical.

Fertigation

See page 27.

Liming and Soil pH

Soil pH is a measure of the degree of acidity or alkalinity in a soil. The native pH of most Ohio soils varies from quite acid (pH 5.0 or lower) in eastern Ohio to quite alkaline (pH 7.5 or higher) in parts of western and northwestern Ohio. Most vegetable crops on mineral soils prefer a pH range of 6.0-7.0. On muck soils, a pH of 5.0-6.0 is considered adequate.

On mineral soils with pH above 7.4, micronutrient deficiencies are most likely to occur of such elements as manganese, boron and iron.

Lime neutralizes excess soil acidity and also supplies calcium and magnesium, which are necessary for plant growth. The amount of lime needed is determined by a soil test (see "Soil Testing," page 12). Acid soils restrict the uptake of nutrients such as phosphorus and potassium and allow others, such as aluminum and manganese, to become toxic.

Physiological disorders such as blossom-end rot, poor seedling emergence and poor stands also are the result of acid soils. Liming should be thought of as a regular practice because soil pH can vary with time.

The most common cause of lower soil pH is the addition of chemical fertilizers. Other factors affecting soil pH are the breakdown of organic matter, calcium removal by the crop at harvest and rain, which leaches liming materials from the soil.

Soil pH and Plant Nutrients

Nitrogen

One of the key soil nutrients is nitrogen (N). Plants can take up N in the ammonium (NH_4^+) or nitrate (NO_3^-) form. At pHs near neutral (pH 7), the microbial conversion of NH_4^+ to nitrate (nitrification) is rapid, and crops generally take up nitrate. In acid soils (pH < 6), nitrification is slow, and plants with the ability to take up NH_4^+ may have an advantage.

Soil pH also plays an important role in volatization losses. Ammonium in the soil solution exists in equilibrium with ammonia gas (NH_3). The equilibrium is strongly pH dependent. The difference between NH_3 and NH_4^+ is a H^+. For example, if NH_4^+ were applied to a soil at pH 7, the equilibrium condition would be 99% NH_4^+ and 1% NH_3. At pH 8, approximately 10% would exist as NH_3.

This means that a fertilizer like urea (46-0-0) is generally subject to higher losses at higher pH. But it does not mean that losses at pH 7 will be 1% or less. The equilibrium is dynamic. As soon as a molecule of NH_3 escapes the soil, a molecule of NH_4^+ converts to NH_3 to maintain the equilibrium.

There are other factors such as soil moisture, temperature, texture and cation exchange capacity that can affect volatilization. So pH is not the whole story.

The important point to remember is that under conditions of low soil moisture or poor incorporation, volatilization loss can be considerable even at pH values as low as 5.5.

Soil pH is also an important factor in the N nutrition of legumes. The survival and activity of Rhizobium, the bacteria responsible for N fixation in association with legumes, declines as soil acidity increases. This is the particular concern when attempting to grow alfalfa on soils with pH below 6.

Phosphorus

The form and availability of soil phosphorus (P) is also highly pH dependent. Plants take up soluble P from the soil solution, but this pool tends to be extremely low, often less than 1 lb/ac.

The limited solubility of P relates to its tendency to form a wide range of stable minerals in soil. Under alkaline soil conditions, P fertilizers such as mono-ammonium phosphate (11-55-0) generally form more stable (less soluble) minerals through reactions with calcium (Ca).

Contrary to popular belief, the P in these Ca-P minerals will still contribute to crop P requirements. As plants remove P from the soil solution, the more soluble of the Ca-P minerals dissolve, and solution P levels are replenished. Greenhouse and field research has shown that over 90 percent of the fertilizer P tied up this year in Ca-P minerals will still be available to crops in subsequent years.

The fate of added P in acidic soils is somewhat different as precipitation reactions occur with aluminum (Al) and iron (Fe). The tie-up of P in Al-P and Fe-P minerals under acidic conditions tends to be more permanent than in Ca-P minerals.

Potassium

The fixation of potassium (K) and entrapment at specific sites between clay layers tends to be lower under acid conditions. This situation is thought to be due to the presence of soluble aluminum that occupies the binding sites.

One would think that raising the pH through liming would increase fixation and reduce K availability; however, this is not the case, at least in the short term. Liming increases K availability, likely through the displacement of exchangeable K by Ca.

Sulfur

Sulfate (SO_4^{2-}) sulfur, the plant available form of S, is little affected by soil pH.

Micronutrients

The availability of the micronutrients manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and boron (B) tend to decrease as soil pH increases. The exact mechanisms responsible for reducing availability differ for each nutrient, but can include formation of low solubility compounds, greater retention by soil colloids (clays and organic matter) and conversion of soluble forms to ions that plants cannot absorb.

Molybdenum (Mo) behaves counter to the trend described above. Plant availability is lower under acid conditions.

Conclusion

So, soil pH does play a role in nutrient availability. Should you be concerned on your farm? Be more aware than concerned. Keep the pH factor in mind when planning nutrient management programs. Also, keep historical records of soil pH in your fields. Soils tend to acidify over time, particularly when large applications of NH_4^+ based fertilizers are used or there is a high proportion of legumes in the rotation.

Recent years have shown the pH decline occurring more rapidly in continuously cropped, direct-seeded land. On the other hand, seepage of alkaline salts can raise the pH above the optimum range. So, a soil with an optimum pH today may be too acid or alkaline a decade from now, depending on producer land management.

Types of Lime

Calcitic lime or high calcium lime (50%-56% CaO, 1%-4% MgO) is the most soluble form and is used when calcium is low and magnesium high. It generally reacts the fastest and is the most common form available in some areas.

Magnesian or hi-mag lime (32%-42% CaO, 5%-15% MgO) is intermediate in solubility and should be used where pH, calcium and magnesium are low. The continued use of liming materials high in magnesium increases the base saturation of magnesium and decreases calcium saturation, which may result in deficiencies of calcium during stress periods.

Dolomitic lime (30% CaO, 20% MgO) should be used where magnesium is particularly low. However, this is the least soluble of the materials.

Hydrated lime (60% CaO, 12% MgO) reacts most rapidly with the soil, but the effect is only temporary. This material is caustic to humans and plants, and care must be taken not to burn plants. Hydrated lime should be used only in emergencies, when rapid changes are needed in soil pH.

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

Lime Recommendations

Why re-liming is necessary: More than one application of lime is necessary because lime (Ca and Mg) is removed in harvested crops and by leaching and erosion. Lime is also needed to neutralize acidity produced by acid-forming fertilizers.

When lime applications are necessary to correct subsoil acidity, the lime requirement for pH 6.8 is used. The pH level in the topsoil should be 6.8 or above to provide downward movement of the lime. Only where the surface pH is maintained near 6.5 will the subsoil pH increase. Because this downward movement takes several years, the sooner the lime is applied, the better.

Recommendations of more than 4 tons per acre usually should be applied in split application to achieve a more thorough mixing with the acidic soil. Half the lime should applied before plowing and half before soil fitting. For best results, the lime should be applied at least six months before seeding a legume.

When a maintenance application (2 tons or less per acre) is recommended, it can be applied at any time in the cropping sequence.

Fluid Lime

Finely ground limestone reacts faster than normal limestone. In fluid lime, 100% of the liming material must pass through a 100-mesh screen, nearly 80%-90% must pass through a 200-mesh screen. The higher the mesh size, the finer the liming material. Dust problems result from spreading fine lime, so water is used as a carrier in fluid lime. Other dispersing agents can be added to the mixture.

The principles of effectiveness of ground agricultural lime also apply to fine or fluid lime. Lime suspensions do not possess any special capabilities as compared with conventional agricultural lime that contains a high degree of 60-mesh or finer particles.

Secondary and Micronutrients

Secondary and micronutrients of concern in Ohio are calcium, magnesium, boron and manganese. Sulfur and zinc also may be of concern, but evidence is not available documenting overall deficiencies in the state.

Calcium and magnesium usually are deficient on acid soils. Magnesium can become deficient with the application of excessive potassium. The addition of calcitic or dolomitic lime generally solves most calcium and magnesium deficiency problems (see "Liming and Soil pH," above). When calcium is deficient, and there is no need to increase soil pH, the use of gypsum will supply calcium.

Similarly, additional magnesium can be added by using epsom salts or Mag-Ox, with the latter being the most economical. Foliar sprays of epsom salts at the rate of 10-15 lb/100 gal/A also can be used to solve temporary magnesium deficiencies.

Manganese deficiency is the most common micronutrient deficiency problem in the northwest and western parts of the state. Manganese deficiency occurs primarily on the lakebed and fine-textured dark-colored soils with high pH. Cool, wet environments tend to intensify manganese deficiency. Beans, beets, onions, spinach and tomatoes have high requirements, but deficiencies also are reported for cucumbers, peppers and turnips.

Manganese sulfate at the rate of 2-4 lb/100 gal/A will eliminate deficiency problems. Fungicides with manganese also help control deficiencies.

Vegetables such as the cole crops (broccoli, cabbage and cauliflower) have a high requirement for boron. This element is one of the most common micronutrient deficiencies in vegetable crops. Deficiency symptoms include browning of cauliflower heads, cracked stem of celery, blackheart of beets and internal browning of turnips. Additional boron can be added to the soil using Borax (10.6% B) at 10-25 lb/ A (mineral soils) or 25-50 lb/A (muck soils); or Solubor (20.5% B) at 5-12 lb/A (mineral soils) or 12-25 lb/A (muck soils). It is important not to exceed 1-2 lb of actual boron/A to avoid boron toxicity in subsequent vegetable crops.

Applications of boron are most effective if applied with the fertilizer preplant or at the time of transplanting. Foliar applications middle or late season are not as effective as early granular or foliar applications in preventing boron deficiency problems.

Deficiencies of other micronutrients are rare. If they do occur, they are related to very specific causes.