



Crop Management in the Field

NUTRIENT MANAGEMENT GUIDE FOR NEW ENGLAND VEGETABLE PRODUCTION



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Acknowledgements

The author gratefully acknowledges information and contributions over many years from numerous faculty, Extension professionals and growers. These include Allen Barker, John Baker, Steven Bodine, Douglas Cox, Vern Grubinger, Masoud Hashemi, Joseph Heckman, Stephen Herbert, Ronald Kujawski, Fred Magdof, Frank Mangan, Thomas Morris, Eric Sideman, Petrus Veneman, and Robert Young. The author wishes to especially thank John Spargo for reviewing this publication and providing helpful comments and suggestions as well as photographs. Also, Ruth Hazzard for her review, comments, and photographs. The author wishes to thank Andy Cavanagh and Zara Dowling for coordinating the review, editing and publishing process, and for their work on illustrations.

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Cover photos by John Spargo (top), John Howell (left), Andy Cavanagh (center), Ruth Hazzard (right); Page 3: John Spargo; Page 4: Ruth Hazzard. Other figures as labeled. Tables 3-6 were compiled by John Howell and are also published in the New England Vegetable Management Guide.

Funding

University of Massachusetts Extension
USDA Natural Resources Conservation Service, Massachusetts

Design and Production

Sunny Meidell, Print Services of UMass Amherst 2012



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Introduction

Soils are one of a farmer's most important resources. A high quality soil is said to be healthy if it provides adequate nutrients and water for crop production, has a diverse population of soil microbes and adequate organic matter. Soil health is fundamental to profitable and sustainable production. How we manage nutrients, organic matter and microbial populations is key to building soil health. This manual is intended to help the reader understand more about soils—some of the basics about what happens in the soil and how it impacts crops, and also to offer some insight on soil and nutrient management practices and how they affect soils, crop productivity and profit.

The first part of this manual discusses the basics, including the physical, chemical and biological properties of soil. These are quite interdependent. Each of these aspects affects the other two. Developing a healthy soil requires attention to all three. The second part is about management practices to achieve healthy soils. It is also about the various sources of nutrients and soil amendments and how the management of these resources is necessary for optimum vegetable crop production.



Part I: Soil Basics

This section is about the physical and chemical properties of soils, soil organic matter and biology. These soil properties are very much interconnected and it is difficult to discuss one aspect by itself.

Physical Properties of Soil

Soil Texture

Soils are composed of solid particles which have spaces between them. The soil particles consist of tiny bits of minerals and organic matter. The areas between them are called pore spaces and are filled with air and water. Pore spaces also provide room for plant roots, microbes and other soil organisms. It is desirable for an agricultural soil to have about equal volumes of soil particles and pore space. Ideally, organic matter will account for 5 to 8% of the weight of soil particles. Moisture content varies considerably with factors such as soil drainage and the amount and frequency of rain or irrigation. For most agricultural crops, conditions are best when the pore space is filled about equally with water and air (See Figure 1).

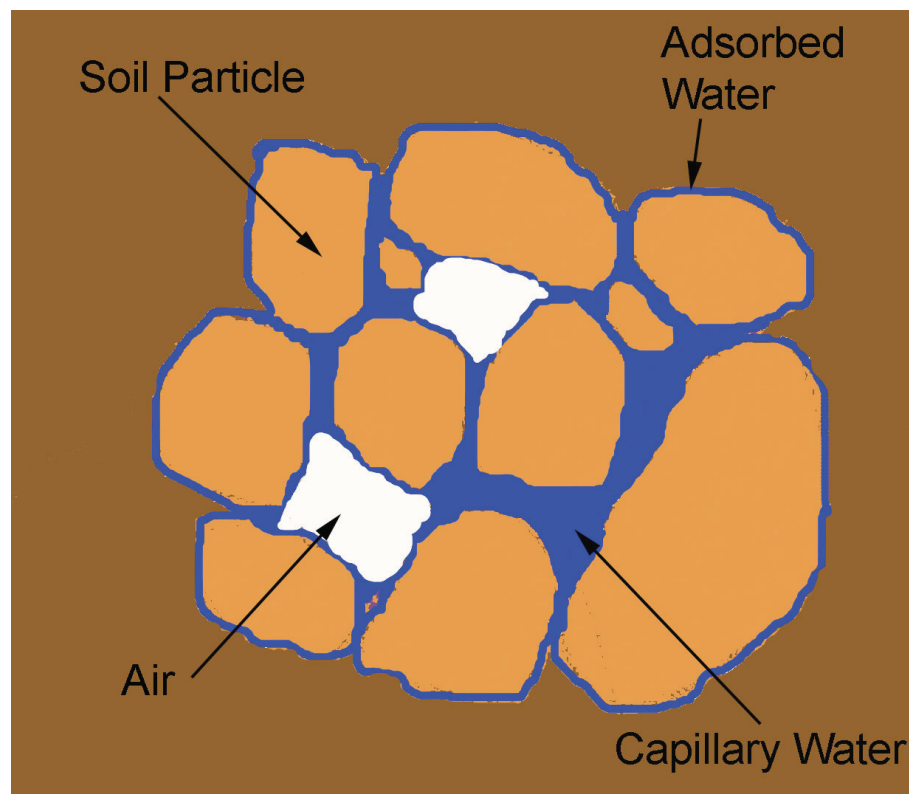


FIGURE 1

Soils contain various sized particles. The sizes of the pore spaces between them varies accordingly. These spaces contain air and water. The water is attracted to the particle surfaces. Under ideal conditions, the pore spaces are filled about equally with water and air. *Adapted by Zara Dowling*

Mineral soil particles are derived from rock which has been broken down into smaller and smaller pieces over many thousands of years. This process is referred to as “weathering” and is caused by physical, chemical and biological factors. Physical weathering is a result of mechanical activity. Wind, running water, falling rain, glaciers, freezing and thawing and root growth are typical abrasive and grinding forces that cause physical weathering. Chemical weathering results from the many chemical reactions that occur continuously in our soils. As some of the mineral components of rock are dissolved by water or acids, small fragments break off. Over time rock material is converted to many tiny fragments. Microbes and plants play an important role by creating many of the organic and inorganic acids that contribute to this process.

Mineral soil particles vary considerably in size. These particles are grouped according to size. Beginning with the largest, they are classified as gravel, sand, silt and clay (Table 1). Sand and gravel particles can be seen with the naked eye, although some of the smallest sands may better be seen with a hand lens. Silts are microscopic. This puts them in the same general size range as most microbes, such as bacteria and fungi. Clay particles are too small to be visible under a standard microscope, and can only be seen with the aid of an electron microscope. Humus particles, which are derived from organic matter, are in the same size range as clay. Clay and humus particles are much smaller than microbes. These particles are called colloids, and are so small that when they are added to water and shaken they will remain in suspension for a very long time (weeks or months). Sands and silts will settle out within minutes or hours.

Table 1. Classification of mineral particles according to size. The proportion of these particles determines Soil Texture.

Soil particle size classes (diameter, mm)			
>2.0	2.0-0.05	.05 to .001	< .001
Gravel	Sand	Silt	Clay
Particles visible with the naked eye		Particles visible under a microscope	Particles visible under an electron microscope

Each of these particle size groupings provide certain advantages and disadvantages. Sands have relatively large pore spaces which provide good drainage. They facilitate aeration, which is the movement of oxygen into and carbon dioxide out of the soil. A sandy soil is easily tilled and provides little restriction to root growth. However, such soils retain little water and nutrients. On the other hand, clays have tiny pore spaces and tend to hold moisture and nutrients very well. They are poorly drained, restrict root growth and are difficult to till. Silts are in between these extremes.

Soil texture

Soil texture is the proportional amount of sand, silt and clay present in a particular soil. A soil textural triangle (Figure 2) is used to determine the textural class of soil according to the percentages of sand, silt and clay. These percentages can be determined from a mechanical soil analysis, available at most soil testing laboratories. Note that the word “loam” does not refer to a specific group of particles, but is used to describe mixtures of sand, silt and clay. Loams provide a desirable combination of sand, silt and clay, that provides the advantages of each, while minimizing their shortcomings.

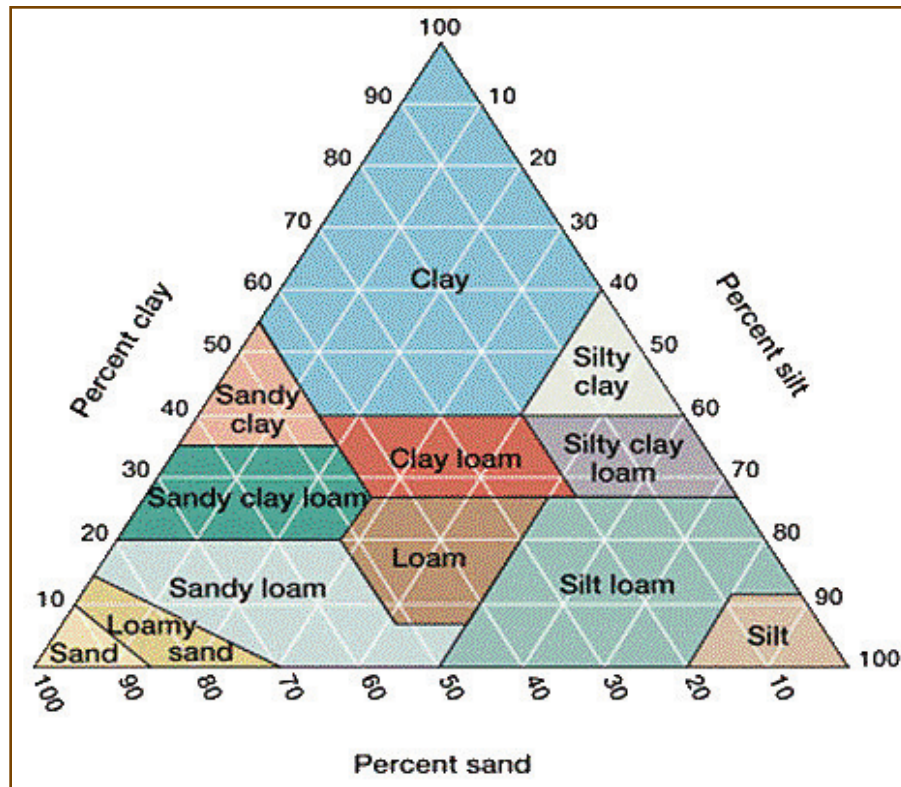


FIGURE 2
The USDA soil textural triangle. To use the textural triangle, draw a horizontal line to the right of the percent clay; downward and to the left from the percent silt; and up and to the left from the percent sand. These three lines will intersect at a point inside the triangle indicating the soil textural type.

Determining Soil Texture by Feel

The most accurate way to determine texture is with a laboratory analysis. However a reasonable estimate can be made by using the steps described below:

The first and most critical step in the texture-by-feel method is to knead a walnut-sized sample of moist soil into a uniform putty-like consistency, slowly adding water if necessary. It is helpful to crush small clumps of clay when the soil is still fairly dry. This step may take a few minutes, but is important because these clumps may feel like sand grains. This would be misleading. The soil should be moist, but not glistening (Figure 3).

While squeezing and kneading the sample, note its malleability, stickiness and stiffness, all properties associated with clay content. A high silt content makes a sample feel smooth and silky, with little stickiness or resistance to deformation. A soil with significant sand content feels rough and gritty and makes a grinding noise when rubbed near one's ear.

Get a feel for the amount of clay by attempting to squeeze a ball of properly moistened soil between your thumb and the side of your forefinger, making a ribbon of soil. Make the ribbon as long as possible until it breaks from its own weight (Figure 4).

Interpret as follows:

1. Soil will not cohere into a ball; falls apart: **sand**
2. Soil forms a ball, but will not form a ribbon: **loamy sand**
3. Soil ribbon is dull in color and breaks off when less than 2.5 cm (about one inch) long and
 - a. grinding noise is audible, has a gritty feel: **sandy loam**
 - b. smooth, floury feel, some grittiness, slightly audible grinding: **silt loam**
 - c. only slight grittiness and smoothness, grinding not audible: **loam**
4. Soil exhibits moderate stickiness and firmness, forms ribbons 2.5-5 cm long, and
 - a. grinding noise is audible and grittiness is prominent: **sandy clay loam**
 - b. smooth, floury feel is prominent, some grittiness, grinding not very audible: **silty clay loam**
 - c. slight grittiness and smoothness, grinding not audible: **clay loam**
5. Soil has dominant stickiness and firmness, forms shiny ribbons longer than 5 cm and
 - a. grinding noise is audible, grittiness is the dominant feel: **sandy clay**
 - b. smooth, floury feel is prominent, no audible grinding: **silty clay**
 - c. only slight grittiness and smoothness, no audible grinding: **clay**



FIGURE 3

This ball of soil has the correct amount of moisture to determine the soil texture by feel; it is moist enough to hold together, but not dripping wet. *Courtesy of Nancy Howell*



FIGURE 4

To form a ribbon, squeeze the soil between thumb and index finger and push the soil out beyond the fingers.
Courtesy of Nancy Howell

Soil texture is determined solely by the sizes of the mineral particles. Weathering can change the size of these particles, but only over thousands or millions of years. For all practical purposes, the texture of the soil does not change except for loss or deposition of soil due to erosion. One can also haul in new soil, but this is rarely practical in agriculture.

Soil texture has a major effect on the physical and chemical characteristics of soil. Sandy soils have rather large particles and large pore spaces (macro pores). Clay soils have very tiny particles with very small pore spaces (micro pores), but because they have many more pore spaces, clay soils have greater total pore space than sandy soils. Remember that clay and humus particles and the pore spaces between them are smaller than microbes. Bacteria and other microbes can not exist in these tiny pores. It is also difficult for roots to grow in a soil dominated by clays. Capillary action is much greater in micro pores than in macro pores. Clay soils absorb and retain much more water than sandy soils, but are typically poorly drained and not well aerated. Aeration is an important process which allows oxygen to enter the soil and carbon dioxide to leave. Plant roots and microbes require oxygen for respiration and will die without it.

Loams combine some of the moisture retention characteristics of the clays with the aeration of the sands and are widely considered the best agricultural soils. Sandy soils are coarse-textured and are often referred to as *light* because they are easy to work. Clay soils are fine-textured and their particles will bond tightly together when they dry out after being wet. These soils can become very hard and difficult to work and are often called *heavy*. Keep in mind that the terms “heavy” and “light” refer to the ease with which the soil can be worked and not to its weight (a sandy soil actually weighs more than a clay soil). Nothing has been said about organic matter. That’s because a soil’s texture is determined by the sizes of its mineral particles, not its organic particles. It sounds strange to most people that the word loam has nothing to do with organic matter. Although organic matter has nothing to do with soil texture, it is vitally important regarding soil **structure**.

Soil Structure

While soil texture is based on the sizes of mineral particles, **soil structure** is the grouping or arrangement of those particles along with organic matter. Vehicular and foot traffic over a soil tends to push particles close together, reducing pore space. In such cases, soils are often said to have a *compact* or *hard-packed* structure. This condition interferes with root growth, microbial activity, drainage and aeration. On the other hand, soils that are not compacted are said to have a *loose* structure. Soils containing significant amounts of silt and clay are more likely to become compact than those that consist primarily of sand. Soil texture does not change, but structure does. Traffic, tillage, rain and irrigation, and freezing and thawing all can change structure. Soil structure can be improved by a process called *aggregation* or *granulation* (See Figure 5). In this process, individual particles of clay, humus, silt and sometimes sand are held together to form crumb-like aggregates or granules. (Humus will be discussed later under *Chemical Properties* and *Organic Matter*.)



FIGURE 5
A well aggregated soil is loose with noticeable granules or crumbs. *Courtesy of Masoud Hashemi*

A granule consists of many thousands of tiny particles clumped together. A well aggregated soil has tiny pores within the granules that retain moisture and larger pores between them which facilitates drainage, aeration and root growth. Aggregation can be thought of as a two step process. Individual particles of clay and humus are held together by chemical bonds with calcium and magnesium, forming very tiny aggregates (this will be discussed under *Chemical Properties*). These tiny aggregates are then glued together by sticky substances created by decaying organic matter and by organisms such as snails or earthworms which eat organic matter (See Figure 6). It is often said that organic matter is the sticky stuff that glues soil together.

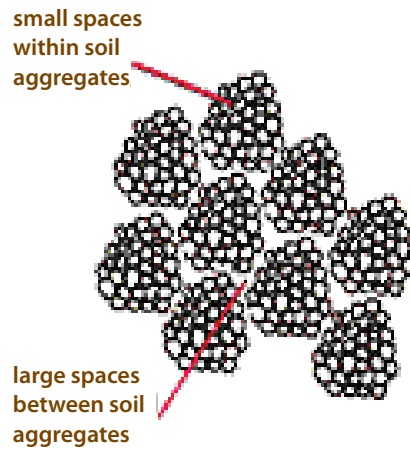


FIGURE 6

Soil aggregates contain many individual mineral and humus particles glued together to form larger granules. The pore spaces within the aggregates are small and those between the aggregates are larger.

Freezing and thawing and the movement of roots contribute to aggregation. Tillage at proper levels of soil moisture can aid this process, but excessive tillage in an effort to prepare a fine seed bed, especially when soils are dry, will destroy soil aggregates. Impact of water droplets from rain or irrigation also destroys soil aggregates on the surface. When the surface dries, a crust is often formed which can inhibit seedling emergence and infiltration of water into the soil. Machinery operations and foot traffic, especially on wet soils, crush granules. It is important to be aware of factors that influence the stability of soil aggregates and use any practical measures to protect them. These include:

- Minimize traffic over soils, especially when they are wet
- Use mulches to protect aggregates from the impact of droplets from rain or overhead irrigation.
- Use drip irrigation.
- Use cover crops to protect otherwise bare soil.
- Maintain good levels of soil organic matter
- Maintain high levels of calcium and magnesium

Organic matter not only improves the structure of fine-textured soils; it is equally beneficial for coarse textured soils, but in a different way. Coarse textured soils have a high proportion of macro pores, facilitating gas exchange and water movement. However, due to a low proportion of micro pores, these soils do not retain moisture. This makes frequent irrigation a necessity during dry periods. Organic matter substantially increases the proportion of micro pores, greatly improving the water holding capacity of a coarse-textured soil. It is estimated that for each per cent organic matter, the top twelve inches of soil can hold an additional ½ inch of rain or irrigation water. This does not reduce the amount of moisture used by plants, but increases the length of time allowed between irrigation or rain events.

Chemical Properties of Soil

Introduction

A discussion about a soil's chemical properties is really about fertility and pH. A soil test provides information about a soil's chemical properties. The soil test report indicates the levels of the various nutrient elements in our sample as well as soil pH, buffer pH, cation exchange capacity, base saturation and organic matter. Although these terms may sound a bit intimidating, it doesn't require a chemistry background to understand and use them for practical soil and nutrient management.

Essential Elements

Essential elements are nutrients that are required by plants. If any of these are not available, a plant can not live. Not only are these nutrients essential, but must also be available in sufficient amounts to support optimum growth and production. Thirteen of these are mineral elements meaning that they are derived from soils. Six of these are called **macro-nutrients** because plants use them in rather large amounts. Seven more are called **micro-nutrients**. These are every bit as important as major elements, but are used in very small amounts.

Macro-Nutrients

Nitrogen (N)
Phosphorous (P)
Potassium (K)
Calcium (Ca)
Magnesium (Mg)
Sulfur (S)

Micro-Nutrients

Iron (Fe)
Zinc (Zn)
Manganese (Mn)
Boron (B)
Copper (Cu)
Molybdenum (Mo)
Chlorine (Cl)

Sometimes N, P and K are called primary elements because they are applied in large amounts and Ca, Mg and S are referred to as secondary elements because they are used in somewhat smaller amounts.

In addition to mineral elements, carbon (C), hydrogen (H) and oxygen (O) are essential elements used in large amounts. Plants obtain these from air and water.

It is important to note that most of the nutrients are referred to in their elemental form when referring to fertilizer grades or recommendations. For example, when a fertilizer or amendment is said to contain ten percent nitrogen, this refers to the actual amount of N. However in the case of phosphorous and potassium, it is not straightforward. Fertilizer grades for phosphorous are actually in terms of phosphoric acid, or P_2O_5 , rather than elemental P. If a fertilizer label indicates ten per cent P it is actually ten per cent P_2O_5 . P_2O_5 contains only 44% P, so if a fertilizer grade lists ten percent P_2O_5 , it contains 4.4 percent elemental P. In a similar way, fertilizer grades of potassium are expressed as K_2O rather than simply K. K_2O contains 88% elemental K. A fertilizer with ten percent K_2O actually contains 8.8 percent K. Fertilizers don't actually contain P_2O_5 and K_2O , but use other forms to supply equivalent amounts of P and K.

Cation Exchange Capacity

Ions are elements or combinations of elements (molecules) which have an electrical charge. Anions have a negative ($-$) charge and cations (pronounced cat-eye-ons) have a positive ($+$) charge. Cations may have a single charge ($+$), a double charge ($++$) or triple charge ($+++$). Plants take up nutrients from the soil either as cations or anions. Many of the nutrient elements are cations. These include ammonium nitrogen (NH_4^+), Ca^{++} , Mg^{++} , K^+ , Fe^{+++} , Mn^{++} , Zn^{++} , and Cu^{++} . Other cations of importance are H^+ , aluminum (Al^{+++}) and occasionally, sodium (Na^+). Cations are attracted to negatively charged surfaces of clay and humus colloids (See Figure 7). This attraction is called adsorption. It works much the way metal filings are attracted to a magnet. Generally, this attraction is strong enough to prevent the loss of cations through leaching. A very small proportion of cations is dissolved in the water in the soil. They are available for uptake by plant roots. As plants use nutrients, more cations will move into solution and be available to plants. Cations in solution can leach if there is heavy rainfall, but because the vast majority are adsorbed onto colloids, leaching losses are usually minimal. Cation exchange capacity (CEC) is a measure of the number of adsorption sites in a soil and is an important indicator of the soil's ability to retain and supply cations for plant use. CEC is reported as milliequivalents per 100 grams of soil (meq/100 g). A soil with a CEC of one meq/100 g has 600,000,000,000,000,000,000 adsorption sites in 100 grams (about 1/4 lb) of soil. The CEC of agricultural soils ranges from below 5 in sandy soils with little organic matter to over 20 in certain clay soils and those high in organic matter. As discussed earlier, soils consist

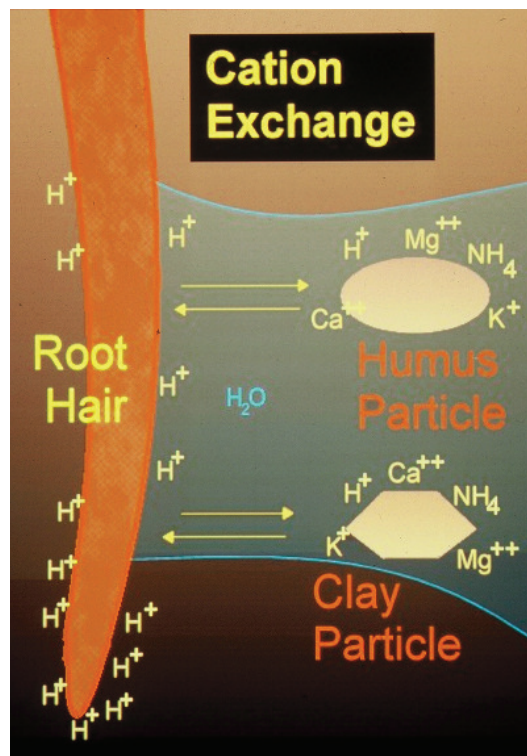


FIGURE 7

Cation exchange capacity measures the ability of a soil to hold cations and make them available to root hairs in exchange for H^+ . Courtesy of Paul Sachs, North Country Organics.

primarily of three sizes of mineral particles; sand, silt and clay. Of these, clay is the only group that makes a significant contribution to CEC. However, there are several types of clays, and they vary considerably in their CEC. Clays in New England soils typically have a low CEC. In most of New England soils, humus, which is derived from organic matter, is the primary contributor to CEC. Not only does organic matter improve the physical properties of soil, it also plays a vital role in soil fertility by increasing CEC. A soil with a low CEC has little ability to store nutrients and is susceptible to nutrient loss through leaching. A CEC is between 10 and 15 meq/100 g is desirable. A higher level is good, but difficult to attain in New England.

Anion exchange occurs in southern and tropical soils, but is negligible in this region. An anion such as nitrate (NO_3^-) is very soluble and is not held by soil particles. It is, therefore, highly subject to leaching. P is taken up as an anion also, but is not very soluble and therefore is not easily leached.

Soil pH and Liming

One of the most important aspects of nutrient management is maintaining proper soil pH. Soil pH is a measure of soil acidity or alkalinity. A pH of 7.0 is neutral. A pH below this indicates an acid soil and a pH greater than 7.0 indicates an alkaline soil (See Figure 8). Most vegetables grow best when the soil pH is between 6.5 and 7.0 or slightly acid. Acidity is due to the presence of hydrogen cations (H^+) in the soil. As the concentration of H^+ increases, the soil is more acid (lower pH). Alkalinity is caused by hydroxyl ions (OH^-). As these ions increase, the soil becomes more alkaline (higher pH). Most soils in the eastern United States are naturally acid and need to be limed periodically to keep the pH in the range of 6.5 to 7.0 which is optimum for most vegetable crops. Soil pH is important because it affects the availability of nutrient elements for plant uptake (See Figure 9).

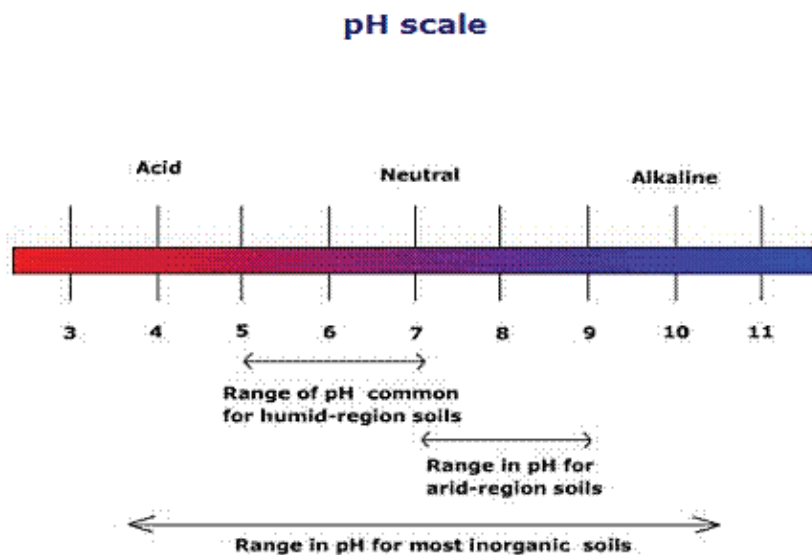


FIGURE 8
The pH scale runs from 0 to 14. pH 7 is neutral; soils below this are acid and those above are alkaline. Most vegetables grow best between pH 6 and 7 (slightly acid). Courtesy of Michael Ritter, University of Wisconsin.

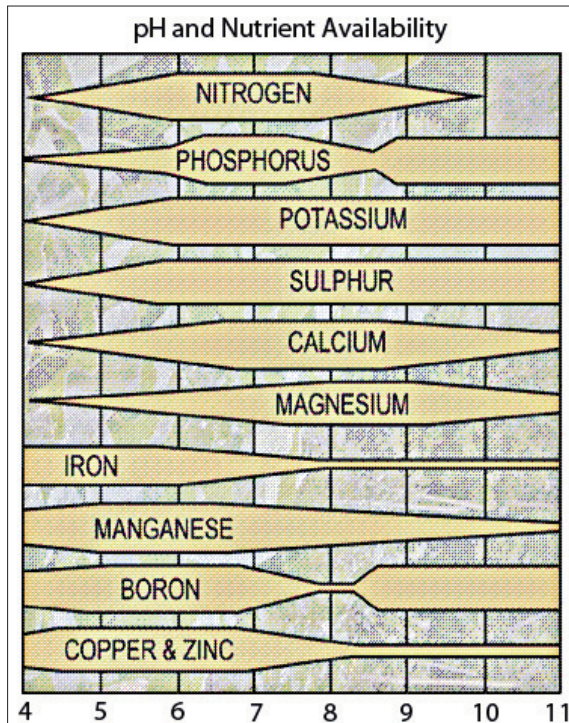


FIGURE 9

Soil pH affects the availability of nutrients. Major elements are most available at pH levels in the mid 6's and above while most minor elements are most available a low pH levels. Soil pH's between 6 and 7 provide for good availability of major and minor nutrient elements.

As the soil pH falls below pH 6.0, the availability of N, P, K and S becomes increasingly restricted and there are reduced levels of Ca and Mg. Most of the trace elements become more available under acid conditions and there may even be toxic levels of iron and manganese. This is also the case with aluminum which is not a nutrient element. Under alkaline conditions, the availability of most trace elements is reduced. Phosphorus availability becomes limited above pH 7.5. When the soil is slightly acid there is adequate availability of macro and micro nutrients.

Many of the so called *acid loving* plants such as blueberries are not efficient in taking up iron. They grow better when soil pH is low, increasing the availability of iron. There are several factors that make soils acid:

1. Conversion of ammonium-N (NH_4^+) to nitrate-N (NO_3^-) occurs during two reactions that are made possible by two types of bacteria. The net reaction is shown below, during which H^+ is released as a by-product, thus increasing soil acidity.



2. Water from rain or irrigation reacts with carbon dioxide in the soil pore spaces creating carbonic acid. This is why soils in the eastern half of the U.S. tend to be acid while those in the arid west are more alkaline.

3. Parent materials from which the soil was formed may be acidic. These include granite, sandstone and shale which are common in New England, the Appalachian states and the Great Lakes areas. On the other hand, soils developed from calcareous minerals such as limestone, tend to be alkaline. These soils exist in the some areas of the Berkshires.
4. When plants take up cations, the roots release H^+ to maintain a balance. The added H^+ makes the soil more acid. Conversely, when anions are taken up, hydroxyl ions are released, reducing acidity. Since plants take up more cations than anions, the net result is increasing acidity.
5. Other chemical reactions and decay of some organic materials contribute to soil acidity, but these are generally not as significant as the other factors above.
6. Over multiple seasons there is a net loss of basic cations that are removed by crop harvest, with an associated increase in acidity.

Lower pH soils are desirable for "acid-loving" plants such as blueberries and rhododendrons. Potatoes are often thought of as "acid loving" plants. They are not. They are acid tolerant and will grow reasonably well at soil pH levels down to about 5.0, but will grow better at pH 6.0 to 6.5. The only reason for growing potatoes on acid soil is to manage potato scab, a disease which is not active at pH levels below 5.3. Scab resistant varieties grow well at pH 6.0 - 6.5.

Soil pH also affects microbes. This has important implications for plant growth and will be discussed in *Biological Aspects of soil*.

Lime is used to raise soil pH. Agricultural limestone consists of calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$). These materials are mined and ground into small particles. If lime consists primarily of calcium carbonate with little magnesium carbonate it is called calcite or calcitic lime. Dolomitic limes contain significant amounts of magnesium carbonate as well as calcium carbonate. Dolomitic lime gets about one-half of its neutralizing ability from $MgCO_3$. Besides raising soil pH, lime is the most economical source of Ca and Mg for crop nutrition.

Other liming materials include burnt lime and hydrated lime. Burnt lime is made by burning calcium carbonate which leaves calcium oxide. Water is then added, resulting in hydrated lime. These materials are fast acting in the soil, but do not provide a long lasting effect. Hydrated lime was used by quite a few growers in the past. It has become much more expensive than ground limestone due to high costs of energy needed for the burning process and is not widely used. Burnt lime and hydrated lime are very caustic and difficult to handle. They are not approved for organic use.

The neutralizing power of lime is indicated by its calcium carbonate equivalence. Pure calcium carbonate has a calcium carbonate equivalence of 100%. Lime contains varying amounts of impurities, which reduce its calcium carbonate equivalence. Dolomitic limes with very little impurities have a calcium equivalence a few percentage points above 100%. Recommendations are based on an assumed calcium carbonate equivalence of

100%. If your lime is lower than this you will need to apply more than the recommended amount, and if it is higher, as in with some dolomites, you will need less. To determine the amount of lime to apply, divide the recommended amount by the per cent calcium carbonate equivalence of your lime and multiply by 100. For example, if the lime recommendation is 2 tons per acre and the lime you are going to apply has a calcium carbonate equivalence of 72% you should apply at the rate of 2.7 tons per acre according to the following calculation:

$$\frac{\text{recommended amount} \times 100}{\text{calcium carbonate equivalence (\%)}} = \text{amount of product needed}$$

OR

$$\frac{2 \text{ tons/A} \times 100}{72\%} = 2.7 \text{ T/A}$$

By law the calcium carbonate equivalence of the lime you are purchasing must appear on the bag, or on the delivery slip for bulk lime. NOTE: Calcium carbonate equivalence is sometimes called neutralizing value.

The speed with which lime reacts in the soil is dependent on particle size and distribution in the soil. Small particles work faster than larger particles because they dissolve more rapidly. To determine fineness, lime particles are passed through sieves of various mesh sizes. A 20 mesh sieve has 20 openings per linear inch, or 400 openings per square inch (20 x 20), a 60 mesh sieve has 3,600 (60 x 60) openings per square inch and a 100 mesh sieve has 10,000 openings per square inch (100 x 100). Lime particles that pass through a 100 mesh sieve are very fine and react rapidly--within a few weeks. Coarser material in the 20 to 30 mesh range will dissolve slowly and react over a longer period such as one to two years. Medium sized particles of about 60 mesh can react in a month or two. Agricultural ground limestone usually contains both coarse and fine particles. About half of a typical ground limestone consists of particles 60 mesh and smaller and are fine enough to react within a few weeks or months. Information about particle size must be on the bag or provided by your supplier. Super fine or pulverized lime is sometimes used for a quick fix because all of the particles are fine enough to react rapidly. Pelleted lime is made by forming lime particles into small pellets held together with a soluble glue. Moisture in the soil dissolves the glue, after which the lime works the same as regular ground lime, based on the fineness of the particles before pelletizing. The major advantage of pelleted lime is that it is easier to handle and is less dusty than ground lime. It is more expensive than regular ground lime and is more popular for landscaping than commercial agriculture.

Wood ashes can also be used to raise soil pH. The calcium carbonate equivalence of wood ashes varies considerably, typically ranging from 30 to 50%. They are chemically similar to burnt lime and supply K as well as Ca and Mg. **CAUTION:** Do not over-apply wood ashes. There are many cases where wood ashes were spread in a concentrated area causing soil pH to become extremely high (greater than 7).

Lime will react most rapidly if it is thoroughly incorporated to achieve intimate mixing with soil particles. Mixing is best accomplished when lime is applied to a fairly dry soil and disked (preferably twice) or roto-tilled into the soil. When spread on a damp soil, lime tends to cake up and doesn't mix well. A moldboard plow has little mixing action and can bury lime too deep for good results in the first year. It is usually best to apply lime after plowing. If soil pH is monitored yearly and lime is applied before the soil becomes very acid, a rapid reaction is not needed and one can be less particular about incorporation or the use of very fine lime.

Buffer pH

In addition to soil pH, many soil tests provide a reading called buffer pH (sometimes called lime index). Soil pH is a measure of hydrogen ion (H^+) concentration in the soil solution. This is called **active acidity**. It is an indicator of current soil conditions. When lime is added to a soil, active acidity is neutralized by chemical reactions of H^+ with Mg and Ca carbonates from limestone. However, there is also H^+ attached to soil colloids and is released into the soil solution to replace those neutralized by the lime. These adsorbed H^+ are called **reserve acidity**. To effectively raise the soil pH there must be enough lime to neutralize both active and reserve acidity. At a given pH, soils with a high CEC will have a higher reserve acidity than those with a low CEC. Buffer pH is a measure of reserve acidity and is used by the soil testing laboratory to calculate lime requirement. Low buffer pH readings indicate high amounts of reserve acidity and therefore high amounts of lime will be recommended. Buffer pH is used only for calculation of the lime requirement and should not be confused with soil pH. **Soil pH** is the value of importance to growers.

As mentioned above, a soil with a high CEC will require more lime to raise pH a given amount than one with a low CEC. However, once the desired pH is achieved, it will be more stable in the soil with high CEC and liming will be required less frequently.

Base Saturation

The cations Ca^{++} , Mg^{++} , K^+ and H^+ normally account for nearly all cations adsorbed on soil particles, although trace elements that are cations are also present in minute quantities. Ammonium-N (NH_4^+) may be present in significant quantities after an application of fertilizer, but it is usually converted to NO_3^- in a week or two. Ca^{++} , Mg^{++} , and K^+ are called bases because they raise soil pH while H^+ is acidic and lowers pH. If all of the adsorbed cations are bases and none are acidic, there would be a 100% base saturation, and the soil pH would be about 7 (neutral) or above. In acid soils there are acid cations present and the per cent base saturation is less than 100. Besides having sufficient quantities of Ca, Mg and K in the soil, it is important that they be in balance with each other because an excess of one of these can suppress the uptake of another. As a general rule a Ca: Mg:K ratio of about 20:4:1 is desirable. When expressed as per cent base saturation, desired levels are: Ca 65-80%; Mg 5-15%; and K 2-5%.



FIGURE 10

Blossom end rot of tomatoes due to lack of sufficient Ca in the fruit. This may be due to low Ca in the soil, an imbalance between Ca and other cations, moisture stress or root damage. *Courtesy of John Howell*

It is important to select liming materials based on Ca and Mg content with the aim of achieving desired base saturation ratios. If the Mg level is low, a lime high in Mg (dolomite) should be used. Lime high in calcium (calcite) is preferable if Mg is high and Ca is low. A lot of the lime in some areas of New England is dolomitic. If this is applied routinely, the Ca/Mg ratio can be out of balance and calcium related disorders are likely (See Figure 10). If a soil test indicates the need for Ca as opposed to Mg, calcitic lime should be used. It is important to insist on the correct type of lime.

Many soil scientists are skeptical about using base saturation in formulating nutrient recommendations. The author feels that it is helpful in planning programs for vegetable crops, especially those that are susceptible to disorders related to an insufficiency of Ca. It is important, however, not to use base saturation as the sole indicator of the need for K, Mg and Ca, but rather, in conjunction with the levels of these nutrients in the soil. Listed below are some crops and their Ca related disorders:

Tomatoes	blossom end rot and possibly cracking
Lettuce and other leafy greens	tip burn of younger leaves
Onions	poor growth and crop establishment
Carrots and parsnips	cavity spot
Celery	black heart

Biological Components of Soil

There are many types of organisms living in the soil. Some are large enough to be seen by the naked eye. They are called macrobes and include many insects, mites and earthworms. The vast majority of soil organisms are tiny and can only be seen with the aid of a microscope. They are microbes. The best known are bacteria, fungi, actinomycetes, nematodes, algae and protozoa. These may conjure up visions of disease-causing pathogens, but the great majority of soil organisms are beneficial or at least not harmful to plants. Some of the beneficial microbes and macrobes actually attack others including the pathogens. Some simply compete for space and food in the soil to the detriment of pathogens. Some microbes live in association with plant roots, helping to obtain nutrients. Microbes decompose organic matter, making the nutrients they contain available for crops. Only a few microbes are pathogens.

Macrobes often begin the initial consumption of organic residues. They pass the waste products through their bodies. These waste products are easy for microbes to consume. Macrobes such as earthworms and ants take organic residues from the surface and bring them down into the soil. They are nature's incorporators. They do not incorporate residues as rapidly as tillage, but they are effective in the longer run and are helpful in minimum tillage systems.

A healthy soil has a large and diverse population of organisms. To create this, conditions in the soil must be favorable to these organisms. The soil's physical characteristics should provide a good home for them. As mentioned earlier, silt particles are microscopic, which puts them in the same general size range as microbes. Clay particles are much smaller and the pore space between them is too small for microbes. Soils should be loose and well aggregated with pore spaces large enough for microbes. It is also critical to maintain adequate soil organic matter which is food for microbes. A small amount of healthy soil contains billions of microbes (See Table 2).

Table 2. Types and numbers of microorganisms in a healthy soil.

Microbial type	Population (cells/gram of soil)
Bacteria	300,000 - 200,000,000
Actinomycetes	100,000 - 100,000,000
Fungi	20,000 - 1,000,000
Protozoa	10,000 - 100,000

Bacteria

Bacteria are single-celled organisms. They are usually the most numerous soil microbes, especially when the pH is in the sixes or higher. Bacteria are inactive when the pH is below 6. Most of the bacteria in agricultural soils are *aerobic*, meaning that they require oxygen, and are dependent on soil aeration. Bacteria are greatly influenced by soil temperature. There is little activity when soil is around 40° F, but it increases dramatically as temperatures rise and is greatest in the upper 80's. Such soil temperatures are quite common in the upper several inches under sunny conditions, even though the air temperature may be in the 70's or 80's. Most soil bacteria consume dead organic matter. Under favorable soil pH and temperature, bacteria do much of the work of consuming soil organic matter. Much of the nutrients consumed by bacteria are held in their bodies. This process is called *immobilization*. Later, when the bacteria die, these nutrients will be released and are available for uptake by plants.

Fungi

Fungi are multi-celled and more complex than bacteria. They consist of thread-like *hyphae* which form a tangled mass called a mycelium. The *mycelium* may be visible to the naked eye, although the individual strands of hyphae are microscopic. Fungi are not as numerous as bacteria, but because of their larger size they may account for the greatest total mass of the soil microbes. Fungi predominate in acid soils because they are not as sensitive to pH as bacteria. Fungi are damaged when the mycelia are disturbed by plowing, harrowing and cultivating. This can be alleviated somewhat by using minimum tillage systems. Some fungi are mycorrhizae. They have a beneficial relationship with plants. They infect roots and obtain foods from the plant. In return, the mycelia explore the soil for water and nutrients, and provide them to the plant roots. This increases the effective size of the root system up to ten-fold. The various species of mycorrhizae are specific to groups of plants. Some vegetable families including the brassicas, beets and spinach do not form associations with mycorrhizae. Tillage and crop rotation make it difficult to establish mycorrhizae. Minimum tillage can mitigate this, but crop rotation is an important practice which should be maintained. Unfortunately, the value of these fungi is less to vegetable crops than it is for perennial crops. Blueberries are highly dependent on mycorrhizae because they have no root hairs.

Actinomycetes

Actinomycetes resemble fungi in that they form a network of threads. They have been classified as fungi and bacteria at various times, but are now classified in a category of their own. They are somewhat more tolerant of acid conditions than bacteria and are active down to pH of about 5.3, although they prefer neutral to slightly alkaline conditions pH 6 to 8. One of the few pathogenic actinomycetes is responsible for potato scab. The reason for growing potatoes on acid soils to control scab. Otherwise potatoes grow well at higher pH levels. Actinomycetes are tolerant of dry soils. Some actinomycetes produce chemicals that interfere with the growth of other microbes. The antibiotic streptomycin is produced by one of the actinomycetes. These organisms also produce volatile chemicals called terpenes which give newly tilled soil that earthy smell.

Protozoa

Protozoa are single-celled animal-like organisms. They live in soil water and can move about. They feed on other microbes, mostly bacteria, and in doing so they make N available to plants. The bacteria contain more N than the protozoa require, so the excess is excreted as a plant-available nutrient.

Organic Matter

During the discussions about physical, chemical and biological properties of soils it became apparent that soil organic matter (SOM) plays an important role. Soil organic matter (SOM) improves aeration of clay soils, helps build aggregates and improves over-all tilth. It is estimated that for each percent SOM, the soil can hold an additional half inch of rain or irrigation water. In New England soils, SOM is the chief contributor to cation exchange capacity, a measure of a soil's ability to retain nutrients. Microbes break down organic matter as they consume it for food and in the process release nutrients which can be used by plants. Because of its important roles in the physical, chemical and biological properties it is considered the key to soil health. Addition of organic matter does not guarantee good soil health, but it is a critical step toward achieving it.

What is Organic Matter?

By definition, organic matter contains carbon, which is a source of energy for organisms (microbes and macrobes) in the soil. Organic matter provides food for a diverse population of microbes and this helps prevent any one type of organism, such as a plant pathogen, from dominating.

SOM is continuously being produced and broken down by plants and animals. Dr. Fred Magdoff of the University of Vermont coined an appropriate statement: "There are three kinds of SOM; 'the living, the dead, and the very dead'". The living fraction of the SOM is made up of living plants and animals including microbes that are found in the soil. When they die, stalks, leaves and other plant parts retain recognizable characteristics for a while. This is the dead fraction of the SOM. Sooner or later the dead organic matter decays and cannot be recognized for what it was and eventually becomes humus. This is very dead organic matter. The dead organic matter is referred to as active because it is being decomposed by microbes. The very dead is called inactive organic matter because there is little food left for microbes and decomposition has essentially ceased. (Figure 11) Some organic matter is consumed by animals and passed through their bodies and excreted as manure. Manure is active organic matter even though most of the original feed is no longer recognizable.

SOM is broken down by microbes as they consume it for food. Any factor that affects soil microbial activity also influences decomposition. In the microbe, respiration combines most of the carbon from SOM with oxygen to form carbon dioxide (CO₂) gas. As this process continues, the concentration of CO₂ in the soil pore spaces increases while that

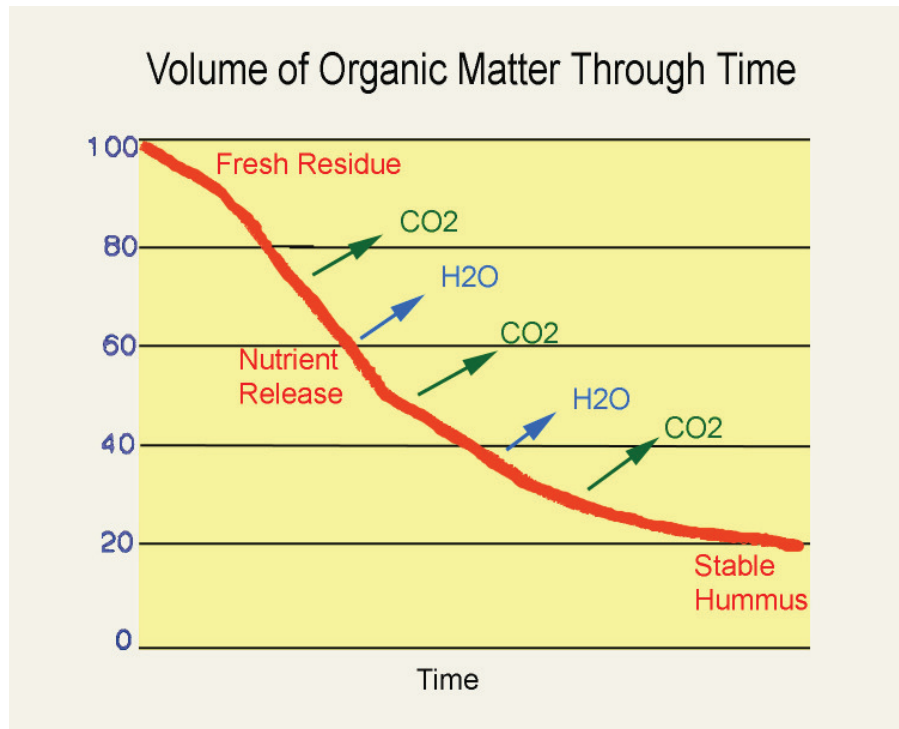


FIGURE 11
As microorganisms decompose organic matter, nutrients are released into the soil. Carbon dioxide and water are given off during respiration and the volume of the organic matter decreases dramatically. The end product is humus, which is resistant to further decay. *Courtesy of Masoud Hashemi*

of oxygen decreases. For this process to continue, excess CO₂ must be removed and replaced with oxygen. This requires an exchange of oxygen and carbon dioxide gases between the atmosphere and the soil pore spaces. This is called aeration. Gas exchange can be restricted if the soil is compacted. If there is too much water in the pore spaces, there will be insufficient oxygen. This slows the rate of SOM decomposition. While excess water inhibits decomposition, a certain amount is necessary to support microbes. Therefore, conditions of moisture stress can also be expected to slow the decomposition of SOM.

Although soil aeration is desirable, increased oxygen speeds microbial activity. This increases the rate or decay of soil organic matter. Tillage loosens the soil and thus increases aeration. One way to reduce the loss of organic matter is to reduce tillage. Organic matter breaks down rapidly in sandy soils, which are naturally well aerated. It is difficult to build and maintain good levels of organic matter in sandy soils.

As mentioned earlier, soil microbes are influenced by pH. This is especially true of bacteria. Under acid conditions (below pH 6), bacterial activity is greatly reduced. Soil fungi responsible for break down of SOM are generally less affected by low pH.

Actinomycetes prefer a neutral pH, but are active down to a pH of about 5.3, below which they cease activity. In most cases, however, bacteria are responsible for most of the decomposition of SOM, and as a rule this process is markedly slowed if pH levels drop below 6.0. Acid bogs have accumulated a great deal of organic matter because decomposition is very slow due to low pH and excess water.

Soil temperature has a marked influence on microbial activity with the optimum being in the 80° to 100° F range. There is some decomposition at lower temperatures, but it is very slow. In the South where soils are warm for most of the year, there is more annual decomposition of SOM than in the North and generally soils are lower in organic matter.

Organic matter consists of numerous compounds which vary greatly in their ease of decomposition. Sugars, starches and proteins are rapidly decomposed by microbes while lignins, fats and waxes are resistant to this process. Under favorable conditions, bacteria will rapidly decompose sugars and starches and some proteins. These compounds make up a large proportion of the volume of organic matter. The result is a rapid reduction of in the volume of organic matter as can be seen by the shrinkage of a new compost pile. Fungi and actinomycetes are slow acting, but will eventually consume cellulose, fats and waxes, leaving mostly lignins. Lignins are the building blocks for the dark colored material called humus. Humus continues to decompose, but at a very slow rate. Undisturbed, humus can last thousands of years. Tillage increases aeration, and therefore, the decomposition, of humus but still at a much slower rate than other organic compounds.

Humus has several important functions in the soil. As noted earlier, humus is the most important type of colloid contributing to cation exchange capacity in New England soils. Humus binds with mineral soil particles, which produces aggregates which are important to soil structure. Humus increases the moisture holding capacity of soil. There has been some discussion about biochar. This is made by partially burning wood under limited oxygen somewhat like making charcoal. Biochar may improve CEC, but unlike other organic matter does not support soil microorganisms and does not provide nutrients.

In summary, a moist, warm, well aerated soil with a pH between six and seven provides ideal conditions for decomposition of SOM. These are the conditions that promote optimum growth of most vegetable crops. It seems clear that productive farming practices are usually quite destructive to SOM! But this isn't as bad as it sounds. Imagine what would happen if SOM didn't break down. We would be buried under tons of undecomposed dead plant material. The decomposition of SOM is a beneficial process. It provides energy for a diverse group of soil microbes, releases nutrients for plant growth and leaves us with humus. The challenge is to prevent excessive decomposition, replace what is lost and, if practical, increase SOM.

Adding to Soil Organic Matter

Four sources of organic matter on farms are: Compost, manure, crop and weed residues, and cover crops. Ideally all types should be added to soil. Unfortunately this is not practical for most vegetable growers. It is a challenge for most vegetable growers to obtain enough of these materials to increase soil organic matter.

Compost quickly comes to mind when thinking of ways to add organic matter to the soil. Everyone from homeowners to farmers can make compost. Most farmers don't have enough raw materials to satisfy their needs. Some are bringing in additional materials such as municipal yard wastes to compost on site (Figure 12). Others are purchasing compost from the increasing number of commercial composters. Regardless of the source, compost should be finished before use. Finished compost has no recognizable bits of matter and will not heat up after turning. Compost should also be tested for nutrient content. During the composting process, N is released in the ammonium form. Ammonium is alkaline, causing the pH of the compost to be high. The ammonium is then converted to nitrate which is an acidifying process. In the end, finished compost should have a low ammonium content, high nitrate level and pH near neutral. Repeated use of compost high in a particular element could cause a nutrient imbalance. Compost should be tested before use to avoid this problem.

Compost samples for testing can be sent to:

Soil Testing Lab
West Experiment Station
University of Massachusetts
Amherst, MA 01003

For more information on submitting samples go on the web site:

www.umass.edu/soiltest
or phone (413) 545-2311.

A compost test provides important information. This includes: Percent organic matter, pH, soluble salts, total nutrient content, C:N ratio, ammonium and nitrate N.



FIGURE 12

Compost is available from commercial operations. Some growers are composting material on their farms. *Courtesy of Masoud Hashemi*

Manure

Animal manure is an excellent source of nutrients and organic matter. About half of the nitrogen in fresh dairy manure and 75% of the nitrogen in poultry manure is in the form of ammonia. Ammonia is subject to loss through volatilization if not incorporated immediately after spreading. In the soil, ammonia is converted to nitrate and is available for plant use. However, nitrate is subject to leaching and large applications should generally be avoided. There are times when readily available nitrogen is needed, but fresh manure should be applied with caution. Many people prefer to compost manure before field application. This stabilizes the nitrogen, making it available over a longer period. Manure can be mixed with other materials for composting. CAUTION: Manure contains E. coli and other bacteria that can make people seriously ill. For safety, manure should not be applied within 120 days of harvest of food crops, unless it has been fully composted.

Cover Crops

Cover crops are gaining favor as a way of increasing organic matter. Winter cover crops have been used for years, primarily to protect soil from erosion. After harvest, some N remains in the soil and is subject to leaching. Winter cover crops can take up much of the left-over N and prevent it from leaching. Cover crops used for this purpose are often called catch crops. Nitrogen is returned to the soil as cover crops decompose the following season. Winter rye has been an old stand by. It can germinate and make quite a bit of growth, even if planted as late as October. Winter rye is efficient at taking up left over N; however, it should be sown by the middle of September for maximum benefit. It remains green over the winter and resumes growth early in the spring. It adds little organic matter if plowed under in early Spring while still small. If allowed to grow until late May, it can reach three to four feet and contribute a fair amount of organic matter. However, plowing under large rye results in large clumps, making it difficult to plant small-seeded crops. Mature rye has a high carbon-to-nitrogen ratio requiring the use of extra N when planting (See Carbon-to Nitrogen Ratio below).



FIGURE 13

Hairy vetch is a legume that can produce a considerable amount of N if allowed to grow long enough. It is well suited to use as a winter cover crop depending on the harvest and planting dates of the preceding and succeeding crops. *Courtesy of John Spargo*

Some growers prefer oats as a winter cover. Oats should be planted in late summer to make good growth in the fall. Oats winter kill and don't re-grow in the spring, making it easy to incorporate them into the soil. If there is time to make good growth in the fall, oats can contribute several tons of organic residue per acre.

Hairy vetch is a legume that some farmers are using as a winter cover. If planted in mid August and plowed under in spring, it can grow enough to contribute 100 lb or more of nitrogen per acre. Hairy vetch can be planted as late as mid-September, but it won't grow much in the fall, and must be allowed to grow until late May to reach its potential for nitrogen contribution. Most farmers who use vetch plant it in combination with rye or oats (See Figure 13 for vetch). This practice may increase total biomass but reduce total amount of available N.

A number of vegetable growers are growing a summer cover crop to increase SOM. This may involve taking a field out of vegetable production for a season, but an early vegetable crop can be grown and followed by a summer cover crop. A good choice is sorghum-sudan grass (See Figure 14). This is a fast growing plant that looks like skinny corn. It can produce a high amount of organic matter if planted by early July. It grows up to twelve feet tall and is difficult to turn under. However, this can be made more manageable by mowing the crop two to three times during the season, whenever it reaches three to four feet. The crop will regrow after mowing, but total biomass is a bit lower than if it is not mowed.

Another summer cover crop is buckwheat. It covers the ground rapidly, smothering some weeds. However, it does not produce much biomass.

It is sometimes said that cover crops increase soil nutrients. Actually, the only cover crops that produce nutrients are legumes which fix N from atmospheric sources. Other cover crops help to conserve nutrients, especially N, by taking up surpluses and preventing leaching loss. Some long-term, deeply rooted cover crops can bring some nutrients up from deep in the soil where they are out of the reach of crop roots and make them available as they break down. These are the most commonly used cover crops, but there are many others. See Additional Resources (pg. 48) for more on cover crops.



FIGURE 14

Sudan-sorghum is a summer cover crop that can produce a large amount of biomass. It can be successfully grown following an early vegetable crop. *Courtesy of John Howell*

Carbon to Nitrogen Ratio

As discussed, organic matter is broken down by microbes that use carbon for energy. Microbes also have a high requirement for nitrogen. They need about one N atom for each 25 to 30 carbon (C) atoms. This is a carbon-to-nitrogen ratio (C:N) of 25:1 to 30:1 or simply 25 to 30. If the organic matter has a higher C:N, microbes will need more nitrogen than is in the organic matter and will take it from the soil. Microbes are more efficient than crops in obtaining nitrogen from the soil. If there is not enough nitrogen for both the microbes and the crop, the crop will not obtain what it needs. Eventually there will be a net gain in nitrogen when the microbes die, but crops can suffer in the short term (See Figure 16). If organic matter with a high C:N is applied to soil shortly before planting a crop, additional nitrogen may be needed to meet the needs of both the microbes and the crop. Organic matter with a C:N of less than 30 should not be a problem. If the C:N is below 20, the organic matter can contribute nitrogen for crop use as it decomposes. (See Table 3 for examples of C:N's of some sources of organic matter.)

The C:N ratio should be considered when incorporating a cover crop into the soil. In recent experiments peppers were planted following: 1) no winter cover crop; 2) winter rye, or 3) winter rye plus hairy vetch. The cover crops were plowed down at the end of May. On plots with no nitrogen added the plants following rye were stunted and yellow compared to those following no cover crop. At the time of incorporation rye would have a C:N ratio well over 30 causing a reduced availability of nitrogen to the peppers. The peppers following vetch/rye grew better than either of the other treatments. Apparently, the vetch contained enough nitrogen to supply the needs of both the microbes and peppers. (F. Mangan and J. Howell, 1994, UMass)



FIGURE 15
Succulent spring oats and field peas have a low C:N ratio and provide nitrogen to the subsequent crop. *Courtesy of Ruth Hazzard*

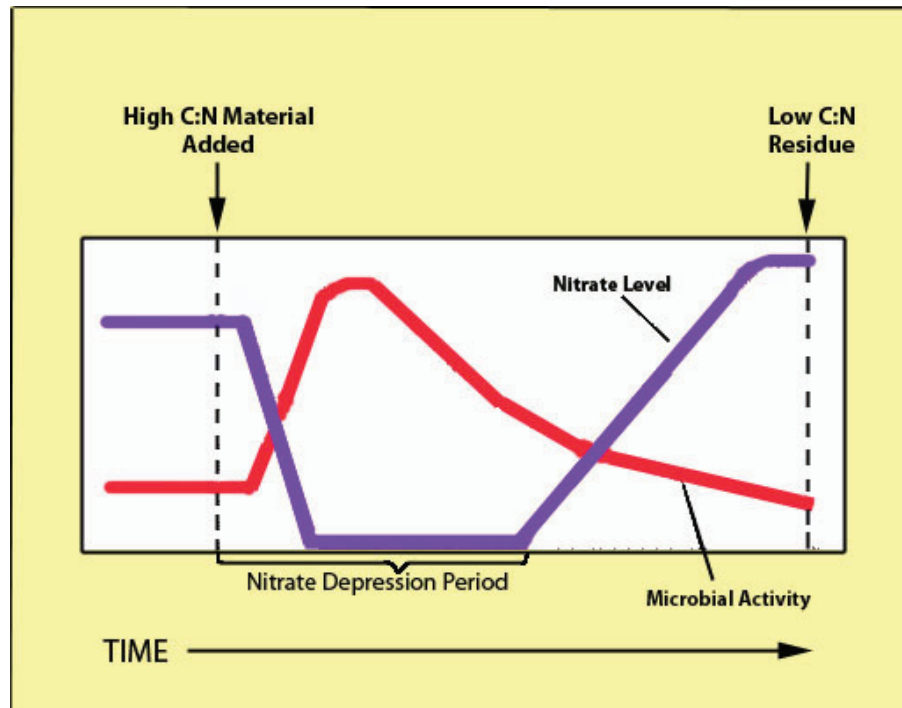


FIGURE 16

When fresh residues are added to the soil there is a rapid increase in microbial activity. If the residues have a high carbon to nitrogen ratio (C:N), the microbes will take N from the soil, likely causing a deficiency. After the residues are decomposed, many of the microbes die and N is released from their bodies. This restores N to a level that is somewhat higher than it was originally, but crops could have suffered for a period.

Table 3. Typical carbon-to-nitrogen ratios of common materials.

Material	C:N
Legume hay	15-19:1
Non-legume hay	24-41:1
Corn stalks	42:1
Oat straw	70:1
Rye straw	82:1
Cow manure	8:1
Finished compost	17-20:1
Agricultural soils	10-12:1
Hardwood sawdust	500:1

Note: Straw, hay and corn stalks will have a lower C:N when green than when brown.

Crop residues contribute nutrients and organic matter if they are returned to the soil. Residues are usually returned by incorporating them directly into the soil, but on a small scale, they can be removed from the field, composted and then returned to the soil. Crops vary considerably in the amount of organic matter and nutrients their residues contribute. An acre of corn stalks can contain several tons of organic matter. About two-thirds of the nutrients taken up by a corn crop go into the stalks and leaves. This is returned to the soil if only the ears are harvested and the stalks are plowed under as with sweet corn. Some sweet corn growers sell their corn stalks to dairy farmers who chop them for silage. The going price is fairly low because the feed value of stalks without ears is reduced. This doesn't pay the cost of fertilizer to replace the nutrients lost in the stalks, not to mention value of the organic matter. On the other hand, crops such as onions or cabbage leave little in the field after harvest (See Table 4). From this you can estimate the nutrient value in residues of various crops.

Table 4. Approximate Amounts of Nutrients Removed by Crops

Vegetable		Yield (per acre) ¹	Nutrient Removal (lb/acre) ²				
			N	P ₂ O ₅	K ₂ O	Ca	Mg
Snap Beans		250 bu	30	20	35	7	3
Broccoli	heads	10,000 lb	20	2	45		
	other		145	8	165		
	TOTAL		165	10	210		
Cabbage		20T	125	30	130	28	10
Carrots	roots	25T	80	20	200		
	tops		65	5	145		
	TOTAL		145	25	345		
Cauliflower		6T	45	18	43	4	3
Celery	tops	50T	170		380		
	roots		25		55		
	TOTAL		195	80	435	110	27
Cucumbers		24T	100-200	33-72	100-400		
Kale		10T	125	30	110	50	10
Lettuce		15T	75	35	150	13	5
Muskmelons	fruit	11T	95	17	120		
	vines		60	8	30		
	TOTAL		155	25	150		
Onions	bulbs	20T	110	20	110	12	14
	tops		35	5	45		
	TOTAL		145	25	155		
Peppers	fruit	12T	50	6	55		
	plants		100	6	95		
	TOTAL		150	12	150		
Potatoes	tubers	300cwt	90	30	150	3	8
	vines		60	15	60	9	12
	TOTAL		150	45	210	12	20
Spinach		10T	100	25	100	24	10
Sweet Corn	ears	15T	55	8	30		
	stalks		100	12	75		
	TOTAL		155	20	105		
Sweet Potatoes	roots	15T	80	16	120		
	vines		60	4	40		
	TOTAL		140	20	160	10	15
Tomatoes	fruit	30T	110	48	180	15	15
	vines		90	30	100	24	21
	TOTAL		200	78	280	39	36

¹These are assumed yields. Your expected yields may vary depending on other conditions. Adjust application rates accordingly.

²Amounts removed vary greatly depending on information source.

Part II: Soil and Nutrient Management

Soil Testing

Soil testing is essential to effectively manage soil nutrients, optimize production and minimize costs. Guessing or using the “shotgun” approach to fertilizing wastes money and can reduce yield and quality. It also increases environmental risks. Soil tests provide useful information as to the status of soil fertility, but accuracy requires care in sampling fields.



FIGURE 17
A soil probe facilitates sampling. *Courtesy of R. Hazzard*

Samples should be representative of a fairly uniform area. A soil sample should consist of 12-15 of sub-samples taken from around the field. This is necessary to avoid being misled by one or two samples taken from a spot that may be higher or lower in fertility than the field as a whole. Sub-samples should be taken to a depth of six to eight inches and should consist of a uniform slice from top to bottom. The sub-samples should be combined to create a composite sample for testing. If using a spade, a hole should be dug to the desired depth and a uniform slice taken from the side of the hole. A much easier method is to use a soil sampling tube or auger (See Figure 17). This makes it easy to remove a uniform core of soil that runs from the surface to the desired depth.

It is important that the area being sampled is reasonably uniform. Areas with different soil texture, slope or cropping or fertilizing histories should be sampled separately. Field size is not as important as variability within the field. A single composite sample from a large uniform field is suitable while a smaller, but variable field should be divided into several areas that are fairly uniform.

A composite sample should consist of about one cup of soil. Samples should be air dried on a non absorbent surface and shipped to the soil testing laboratory UMass soil testing lab (address on page 21) NOTE: The standard soil test does not include organic matter. Be sure to ask that it be included.

Interpreting Soil Test Results

Soil test reports indicate the status of several chemical aspects of the soil. These include: nutrient levels, soil pH; buffer pH (some labs don't report this, but use it to determine lime requirement); cation exchange capacity (CEC); and percent base saturation. These aspects were discussed in *Chemical Properties* in Part I. In addition, most labs also determine organic matter content.

Laboratories use methods designed to provide a good estimate of the **available** amounts of nutrients in the soil. In the lab, a soil sample is dried and then treated with an extracting solution that dissolves nutrients in the sample. Some of the nutrient elements are in chemical forms that are not available to plants. An extracting solution is chosen that will dissolve only the nutrients that are in available forms. This solution is then used to determine nutrient levels. Several extracting solutions are available. Soil testing laboratories use a solution that works well with soils that predominate in the region they serve. There is an advantage in using a local soil testing laboratory.

Determining Nutrient Needs Based on Soil Tests

Soil pH: The lab report will recommend the amount of lime to apply based on the buffer pH and the crop(s) to be grown. Lime can be applied any time, but fall is preferred to allow several months to raise the pH.

The University of Massachusetts Soil Testing Laboratory reports nutrient levels in two ways. The first is in parts per million (ppm). This is of more interest to scientists than to growers. The report also uses the values of low, medium, high and very high. These are useful for growers in assessing the nutrient status of a soil. Note that some labs use the word optimum in place of high and *above optimum* or *excessive* in place of very high.

The point at which medium and high meet is called the *critical level*. (See Figure 18) This means that if a nutrient is below that point (medium or low), most plants will benefit if more of the nutrient is applied. If the nutrient content is above the critical level, plants will not be expected to benefit from the application of more of the nutrient. If the nutrient is in the very high range additional applications may cause an imbalance and inhibit uptake of other nutrients. For example, excess K can inhibit uptake of Ca and Mg. Excess P may run-off fields into water bodies and resulting in algae blooms, impacting water quality. Excess P may also tie up some zinc.

Most crops will do reasonably well if nutrients are maintained in the high range. This is appropriate for fields of mixed crops where it is not practical to treat each crop differently. If a large amount of a single crop is to be grown in a field, nutrient application should be tailored to the needs of the crop.

Requirement of specific nutrient elements varies from crop to crop. This is illustrated in Table 4 (p.30). This is especially so with K. As an example, snap beans can be expected to use about 35 lb of K₂O per acre compared to 340 for carrots and 280 for tomatoes. Using this information, the *New England Vegetable Management Guide* has tables for each crop that recommend the appropriate amount of P and K to apply depending on soil test level

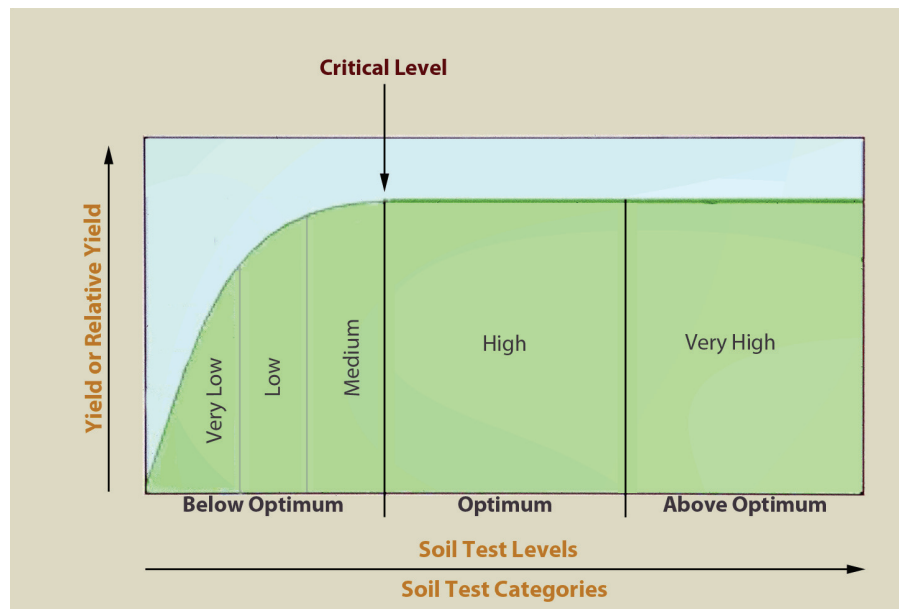


FIGURE 18 When a nutrient is in the high (optimum) range, it is not likely to limit the growth of most crops. Generally, when growing mixed crops, a practical approach to soil fertility is to maintain high/optimum levels. In fields with a large amount of a crop, it is practical to tailor nutrient application to the specific needs of the crop as indicated by the tables in the *New England Vegetable Guide* and/or the UMass soil test recommendations. *Courtesy of Masoud Hashemi*

and the needs of the crop. The UMass Soil Testing Lab makes recommendations based on these tables. It is important to note that these recommendations are based on crop removal for good yields. If there are factors other than nutrients that limit production, the expected crop removal will be less. In these situations, reduced fertilization is appropriate for the smaller expected crop yield. Extra fertilizer cannot overcome other limiting factors.

The goal of a management program should be to supply needed nutrients based on a soil test. This is best done by applying those nutrient elements that are needed while avoiding additions of those that are already adequate. This involves selection of materials that will supply those nutrients. Application of blended fertilizers and soil amendments may supply unnecessary nutrients as well as those that are needed. This is often the case with P, which is frequently very high. Continued use of such materials can lead to nutrient imbalances and excess levels. Continued use of compost has also led to excessive levels of some nutrients. This has happened with N and P. Soils should be tested regularly so application of unnecessary nutrients can be avoided. Some people apply nutrients even though there are adequate levels according to the soil test. They do this "Just to be sure it's there". This is an unwise practice.

Cornell Soil Health Test

This test measures certain physical and biological factors in addition to chemical analysis. These include aggregate stability, water holding capacity, compaction factors, organic matter and active carbon and mineralizable nitrogen. The report indicates the current status of these factors and offers suggestions for improving them if necessary. For more information see the web site: soilhealth.cals.cornell.edu

Sources of Nutrients

Nutrient sources can be classified as synthetic or natural. Natural fertilizers may be compost, plant or animal meals or minerals that are ground into powders. Most, but not all of these are approved for organic production. In addition, crop residues provide nutrients as they decompose. Synthetic fertilizers are manufactured from raw materials including minerals and petroleum. They provide a concentrated and readily available source of nutrients. They are not approved for organic production. Many people refer to the synthetics as *chemical fertilizers*. This may be misleading because all nutrient elements are chemicals regardless of their source. Synthetic materials also are frequently called *commercial fertilizers*. Many of the organically approved materials are produced and sold commercially in a manner similar to synthetics. The discussion here will refer to fertilizers as natural, organically approved and synthetic.

Natural Fertilizers

Natural fertilizers fall into two broad categories; organic (carbon-based) material that are derived from plant or animal products and mineral or rock powders. Approximate nutrient content is listed in table 5.

Most, but not all, natural fertilizers are approved for organic production. Muriate of potash (potassium chloride) is a natural material, but it is prohibited by organic standards. Chilean nitrate (a natural form of sodium nitrate) was allowed with restrictions, but was prohibited for organic use in Fall of 2012. The Organic Materials Review Institute (OMRI) is a good source for up-to-date information about materials for organic production. For the most current list, visit the OMRI web site at: www.omri.org. It is possible that the local certifying agency does not approve a material that is OMRI listed, so growers should check with their certifier.

Manure is an excellent source of nutrients and is a good amendment that supports soil health. However, as manure ages and decays, considerable nutrient loss occurs. This is especially true with N. Manure has to be stored from the time animals produce it to when it is used. The best way to preserve nutrients is to store manure as a liquid in covered tanks. This is expensive and limited to dairy farms. It also requires specialized application equipment. When manure is spread on fields, much of the N is in the ammonia form and will evaporate if left on the surface. To reduce this loss, manure should be incorporated within a few hours of application. Unfortunately, most vegetable growers have little or no access to manure.

Manure may contain pathogens such as *E. coli* and salmonella. If manure is used, vegetables should not be harvested within 120 days of application. This is a requirement for organic production and a good practice for everyone. In most cases, the manure should be applied in the fall or to a non-food rotation crop. Fall-applied manure should be incorporated immediately and a winter cover crop should be planted to protect N from leaching.

Manure can be made safe from contamination by composting it. To accomplish this, it is essential that the process insure that all parts of the manure are exposed to high temperatures to kill pathogens. Some large poultry operations are making fertilizer pellets from pasteurized manure and selling it as a fertilizer with a guaranteed analysis. These products are heated (pasteurized) and are not considered to be fresh manure. The 120 day restriction does not apply.

Compost can provide good levels of soil fertility, especially after several years of application. In addition to fertility, compost supplies organic matter and improves soil health. Typically, compost contains levels of available nutrients that makes it equivalent to a 1:1:1 fertilizer. Additional nutrients will be released over a number of years as the compost continues to break down. Compost should be tested before use because there are variations in nutrient content depending on ingredients and handling methods. In some cases, certain ingredients contribute high amounts of a particular nutrient. There have been cases where repeated use has caused toxic boron levels or extremely high soil pH. Testing before use can prevent these problems.

The usual recommendation is to wait until compost is *finished*. However, some growers apply it sooner. This provides active organic matter and will support a greater level of microbial activity in the soil. In such cases, the ammonium-N level may be high and compost should be applied and incorporated a few weeks before planting to allow conversion to nitrate-N. There may also be a high C:N which could temporarily limit N availability.

Some growers apply undecomposed compost ingredients directly to the soil and incorporate it. This is called sheet composting. C:N can also be an issue here, and bits of undecomposed materials can interfere with seeding. If this method is used, it is best done in the late summer or fall.

Many vegetable farms lack sufficient ingredients to meet composting needs. This is especially true on moderate to large size operations. Some growers purchase compost and others accept yard wastes or food wastes from super markets to make compost. As a source of nutrients, compost is expensive in the short run because only a small percentage of the nutrients are available the first year. After the first year, compost continues to provide diminishing amounts of nutrients for a number of years. If compost is applied annually, substantial nutrient levels can be achieved and maintained. This will reduce or eliminate the need for other fertilizers. The need for lime is usually reduced and, in some cases, eliminated. As with other nutrient sources, soil should be tested regularly to avoid excesses or imbalances. There are many cases where nutrient levels have reached extremely high levels after many years of compost application. Do not assume that because compost is beneficial to the soil that it can't be over-applied!

Meals and emulsions. There are a number of meals available as fertilizers. These include alfalfa and soybean meals. Blood, bone, fish and cotton seed meals are made from processing by-products. There are also emulsions made from fish and seaweeds. They are listed in Table 5.

Rock powders and mineral deposits are mined, ground up and made available for sale to growers. Ground lime is perhaps the most well know, but others include rock phosphate, colloidal phosphate, green sand, granite dust, sup-po-mag and potassium sulfate. Solubility of these materials varies and is influenced by the fineness of grind. Limestone dissolves fairly rapidly if it is finely ground. Sul-po-mag and potassium sulfate are quite soluble. Rock phosphate, colloidal phosphate, green sand and granite dust release nutrients very slowly. Continued use of rock and colloidal phosphates can result in excessive level of P over time.

Synthetic Fertilizers

Synthetic fertilizers are manufactured using a number of ingredients. Synthetic materials are not permitted for use in organic agriculture. However, these fertilizers account for most of the nutrients applied to non-organic or "conventional" farms. While many of the synthetic fertilizers supply a single nutrient, many are designed to provide two or three or even more. The so called "complete" fertilizers supply N, P and K. In the early days of knowledge of plant nutrition, it was thought that these three elements were the only ones that were needed, so any material that supplied all three was considered complete. The term is still used today, although we are aware of at least 14 essential mineral nutrients. Even though these fertilizers are not really complete, they account for the most commonly applied nutrients. Table 6 lists the fertilizers and their nutrient contents that are discussed below.

Fertilizer analysis refers to the percentage of nutrients in a product. Blended fertilizers contain more than one material to supply N, P, K and sometimes other nutrients. These blends can have varying percentages of nutrients and can be customized to meet the needs of specific crop and soil situations.

Table 5: Fertilizers Approved for Organic Production

Typical Nutrient Content (by Weight) of Organic Materials
(Nutrient content varies)

	N (%)	P ₂ O ₅ (%)	K ₂ O (%)	Mg (%)	Relative Availability
Alfalfa meal	3	0.5	2.5	0	slow/med
Dried blood	12	1	0.5	0	med/rapid
Bone meal (steamed)	3	15	0	0	med
Bone char	0	32 (16 available)	0	0	med
Compost (mature)	1	1	1	0	slow
Cottonseed meal	6	2	2	0	slow/med
Dried poultry manure	4	3	3	0	med
Hydrolyzed feather meal	12	0	0	0	med
Fish emulsion	5	2	0	0	rapid
Fish meal	9	7	0	0	
Bat guano	6	9	2	0	med
Manure (fresh)					
Dairy	0.5	0.2	0.5	0	med
Horse	0.5	0.2	0.5	0	med
Sheep	1.5	0.5	1	0	med
Poultry (broiler)	1.5	3	2	0	med/rapid
Peanut meal	8	1	0	0	slow/med
Soybean meal	7	2	2	0	slow/med
Wood ashes	0	2	5	0	rapid

Typical Nutrient Content (by Weight) of some Mineral Deposits

(Availability varies with soil pH, origin, and depends largely upon fineness of grind)

	N	P ₂ O ₅	K ₂ O	Mg	Relative Availability
Colloidal phosphate	0	20 ¹	0	0	very slow
Granite dust	0	0	4	0	very slow
Green sand	0	1	7	0	very slow
Rock phosphate	0	30 ²	0	0	very slow
Chilean nitrate*	16	0	0	0	rapid

1 - about 3% available

2 - about 2% available

3 - Chilean nitrate is no longer allowed for organic production.

*Potassium sulfate from natural sources is permitted; manufactured forms are not.

The list of fertilizers allowed for organic production is subject to periodic changes by the National Organic Standards Board. Check with your local organic certifier.

Table 6: Plant Available Nutrient Percentages for Different Fertilizer Sources

Fertilizer Source Material	Total Nitrogen - N (%)	Phosphoric Acid - P ₂ O ₅ (%)	Water Soluble Potash - K ₂ O (%)	Combined Calcium - Ca (%)	Combined Magnesium - Mg (%)	Combined Sulphur - S (%)
Ammonium sulfate	21					23
Ammonium nitrate	33-34					
Anhydrous ammonia	82					
Calcium nitrate	15			19		
Diammonium phosphate	18	46				
Epsom salts					10	13
Granulated sulfur						90-92
Gypsum				19-23		15-18
Monoammonium phosphate	11	48				
Muriate of potash			60			
Nitrate of potash	13		44			
Nitrate of soda-potash	15		14			
Nitrate of soda	16					
Superphosphate		20		18-21		11
Sul-po-mag			22		11	23
Sulfate of potash			50			17
Triple superphosphate		44-46		13		
Urea	45-46					

Nitrogen Fertilizers

Most synthetic nitrogen fertilizers are made by fixing atmospheric nitrogen (N₂) using natural gas. This produces anhydrous ammonia (NH₃), which is a gas. It can be applied to fields by injecting it into the soil with special equipment. This is the least expensive form of nitrogen and is used on large farms in some parts of the country. In the northeast, other, more easily handled forms are popular. These are made by treating ammonia with other chemicals. Examples are given below:

Ammonia + Carbon dioxide	→ Urea
Ammonia + Oxygen	→ Ammonium nitrate
Ammonia + Sulfuric acid	→ Ammonium sulfate
Ammonia + Calcium carbonate	→ Calcium nitrate
Ammonia + Potassium carbonate	→ Potassium nitrate
Ammonia + Sodium carbonate	→ Sodium nitrate

Urea is the least expensive form of nitrogen that is commonly used in the northeast. It contains about 46% N. It can be used by itself, but is often a source of N in fertilizer blends. Urea is converted to ammonia after application to the soil. If left on the surface, much of the N will be lost due to volatilization of the ammonia. Urea should be incorporated into the soil during or shortly after application. Since all of the N in urea is subsequently converted to ammonium-N, there will be considerable acidity formed as the ammonium is subsequently converted to nitrate.

Ammonium nitrate is no longer readily available because it can be used in bomb making. However, modified versions such as calcium ammonium nitrate are available. While regular ammonium nitrate has a 33% N content, calcium ammonium nitrate has about 28% N.

Ammonium sulfate is not used as much in vegetable production as urea or ammonium nitrate. It is very acidifying, but does supply some S. It contains 21% N and 23% S.

It should be noted that high levels of ammonium in the soil can be toxic to some soil organisms.

Calcium nitrate contains no ammonium and therefore does not have an acidic reaction in the soil (it actually has a slight alkaline reaction). It contains about 15% N and 19% calcium. It is preferred for sidedressing vegetable crops that are sensitive to calcium deficiency. Ammonium is a strong competitor for plant uptake of calcium. If high amounts are sidedressed, it can inhibit calcium uptake. Urea is not a good choice for sensitive crops because all of the nitrogen is converted to ammonium. Ammonium nitrate has less ammonium and is not as great an issue. Calcium nitrate is a good choice because all the nitrogen is in the nitrate form and does not compete with calcium for plant uptake. The calcium that is supplied by this fertilizer is an added benefit, but more important is the fact that there is no ammonium.

Potassium nitrate is not widely applied, but is useful when potassium is needed as well as nitrogen. Normally all of the needed potassium is applied at planting or even in the fall, but on low CEC soils it is subject to leaching. In such situations application of some potassium near planting and the remainder as a sidedress is appropriate.

Sodium nitrate is not as widely used as a nitrogen source. It has the disadvantage of adding sodium to the soil which is to be avoided. Sodium competes with other cations for plant uptake. It also causes some destruction of soil aggregates.

Phosphate Fertilizers

Synthetic phosphate fertilizers are made from rock phosphate. Examples are given below:

Rock phosphate + 70% Sulfuric acid	→ Super phosphate
Rock phosphate + 90% Sulfuric acid	→ Phosphoric acid
Rock phosphate + Phosphoric acid	→ Triple super phosphate
Phosphoric acid + Ammonium	→ Ammonium phosphate

Triple super phosphate is more common today than superphosphate. In fact, triple superphosphate is often sold as superphosphate. Ammonium phosphate is the most commonly used phosphorous fertilizer. There are two similar types of this material: monoammonium phosphate and diammonium phosphate. They supply ammonium as well as phosphorous.

As mentioned in the discussion about natural fertilizers, rock phosphate is quite insoluble. The synthetic phosphate products above are much more soluble and readily available for plant uptake. It should be noted that most of the applied phosphorous, regardless of its source, undergoes reactions in the soil, making it unavailable to plants. When soil levels of phosphorous are low, high rates are recommended to compensate for this. After

years of application, available phosphorous may reach the high to very high range, and applications can be reduced or eliminated. For the most part, phosphorous should not be applied if the level is very high or above optimum. Phosphorous does not readily leach, but is subject to run-off. When this happens, it can end up in water bodies. Phosphorous is a limiting factor in algae growth in fresh water bodies. Any additional amounts are likely to cause algae blooms, which are unsightly and can cause fish kills. Excess P can also react with Fe and Zn, making these elements unavailable to plants.

Phosphorous is not easily taken up by plants when the soil is cool. For this reason a common practice is to apply some starter phosphorous in a band about two inches to the side and below the seed. This provides a high concentration that seedling roots can reach easily. There is some question about the need for starter P if the soil test shows very high levels.

Potassium Fertilizers

Muriate of potash (potassium chloride) is the most widely applied potassium fertilizer. It contains 60% K₂O. It is very soluble and readily available to plants. It is a natural material, but is not approved for organic production due to its high Cl content.

Potassium sulfate (sulfate of potash) contains 49% K₂O and 17% sulfur. It is the preferred material for some crops such as potatoes which are sensitive to high levels of chlorine. This is a more expensive form of potassium than muriate of potash. It is allowed for organic production if it is mined and not manufactured.

Sul-po-mag (sulfate of potash magnesia) is useful where magnesium is also needed. It is allowed for organic production.

Calcium, Magnesium and Sulfur Fertilizers

Lime is normally the most economical source of calcium and magnesium. However, if soil pH is high, but one of these nutrients is needed, there are a few sources which do not alter soil pH. Calcium sulfate (gypsum) and magnesium sulfate (Epsom salts) supply Ca and Mg respectively without changing pH. They also provide sulfur. Sul-po-mag also supplies Mg and S as well as K as noted above.

Micro-Nutrients

Micro-nutrients are not usually needed in fertilizers. On some coastal soils, manganese has been deficient. Manganese can be added to fertilizers and it is generally best to maintain soil pH in the low sixes in fields where this has been a problem. Fields where manure or compost is used are unlikely to have a deficiency of micro-nutrients.

Additional boron may be required for cabbage family crops which have a high demand for this element. Although few problems have been noted in New England, some crops can be sensitive to high boron levels if they follow a crop to which it has been applied. Enough boron should be applied to meet the needs of the current crop, but care should be taken to avoid excess levels which could carry over to successive crops. The addition of two lb of B/acre is generally adequate for cabbage and other brassicas including root crops while cauliflower responds better to five lb/acre. B should be added at planting rather than side dressing later.

Managing Nutrients

A nutrient management program should have several goals:

- Provide adequate supplies of nutrients to enable optimum crop production
- Provide an appropriate balance of nutrients to achieve best quality
- Avoid excess application of expensive nutrients and minimize or avoid environmental impact
- Manage nutrients so as to improve and maintain soil health

As mentioned earlier, regular soil testing is essential to a good nutrient management program. If a fertilizer or soil amendment program seems to work well, it is tempting to simply continue with it. However, without regular testing, certain nutrients can build up and become a serious problem that may take many years to overcome. Following is a discussion about individual nutrients, sources, application techniques and timing.

Nitrogen

Nitrogen can be the most difficult nutrient to manage. Unlike other nutrients, nitrogen levels and forms change considerably from one time of year to another. For this reason, most soil labs do not routinely test for N. During the winter and early spring, levels of soil ammonium and nitrate nitrogen are normally quite low. As the soil warms in the spring, microbial activity increases and nutrients, including nitrogen, are mineralized from organic matter. If the soil is warm (70's), pH is in the sixes and there is adequate, but not excessive moisture, 20 to 40 lb/acre of N can be released for each percent organic matter. In soils with high levels of organic matter, this can supply much of the crop's nitrogen requirement.

When crops are planted early, there is little mineralized nitrogen because the soil has not warmed fully. In such cases, a small amount of starter nitrogen is helpful. If the nitrogen is broadcast, 40 or 50 lb/acre is usually ample. If banded, a lesser amount should be used because it is concentrated near seedlings. Check the New England Vegetable Management Guide for suggested application rates for each crop. Note that the recommendations provided on a University of Massachusetts soil test report are based on the information in the Guide.

Nitrogen is easily leached and, if all of it is applied at planting, some is likely to be lost if there is significant rain. It is usually best to apply it in a split application. Most crops use relatively little nitrogen in the early growth stages, but require increasing amounts as they grow larger (See Figure 19). A small amount can be applied at planting either broadcast or in a band. More can be applied later as crop needs increase. This is usually done by side dressing nitrogen in a band near the row or broadcasting it over the field (top dressing). In either case, this is often combined with cultivation. It can also be applied in irrigation water. This will be discussed below. In some crops, such as snap beans which have a small nitrogen requirement, it is usually all applied at planting.

Slow release N fertilizers, such as sulfur-coated urea, have become popular. Since they release N over a period of time, they can be applied at planting with little risk of losing a lot of N due to leaching. N is released as crops grow and their demand increases. Ammonium should not build up to high levels since it is being released slowly and then converted to nitrate.

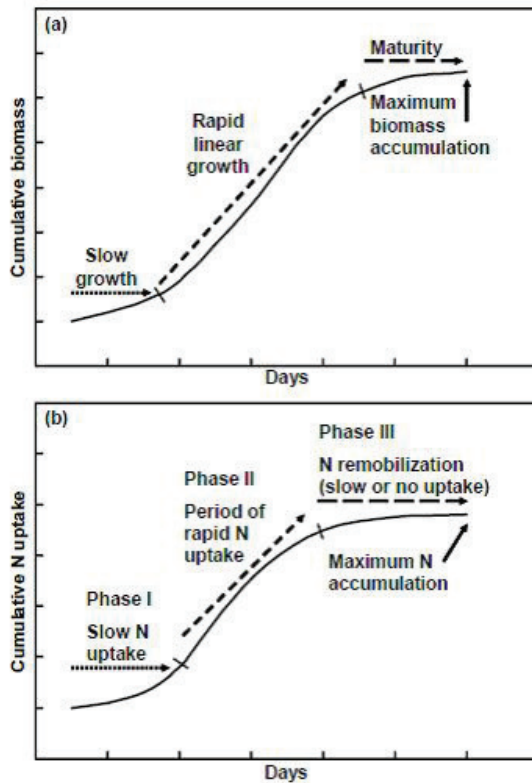


FIGURE 19
 Typical biomass accumulation curve (a) and N accumulation curve (b) for annual crops. Courtesy of Joseph Heckman, Rutgers Cooperative Extension.

As mentioned earlier, a nitrate form of nitrogen is best for side dressing crops susceptible to calcium related disorders. It is common to apply urea or ammonium forms at or just before planting. This usually is converted to the nitrate form in a few weeks, so ammonium is not present when the crop is most likely to be damaged. Later, when supplemental nitrogen is needed, urea and ammonium sources should be avoided. When organic matter is supplying N, ammonium does not build up to high levels since it is being released slowly and then converted to nitrate.

Fertigation

Many vegetable growers are applying supplemental nitrogen through a drip irrigation system. This is called *fertigation* and involves injecting soluble fertilizer (usually N) into irrigation water. Once the drip irrigation system is set up, it is easy to apply fertilizer. This is usually done weekly and is a more efficient use of nitrogen than conventional side dressing or top dressing. It can also be done daily, but there is little advantage compared to weekly applications. With conventional side or top dressing, it is common to apply 50 or 60 lb of nitrogen per acre. With a drip system, it can be applied at seven to ten lb/acre weekly.

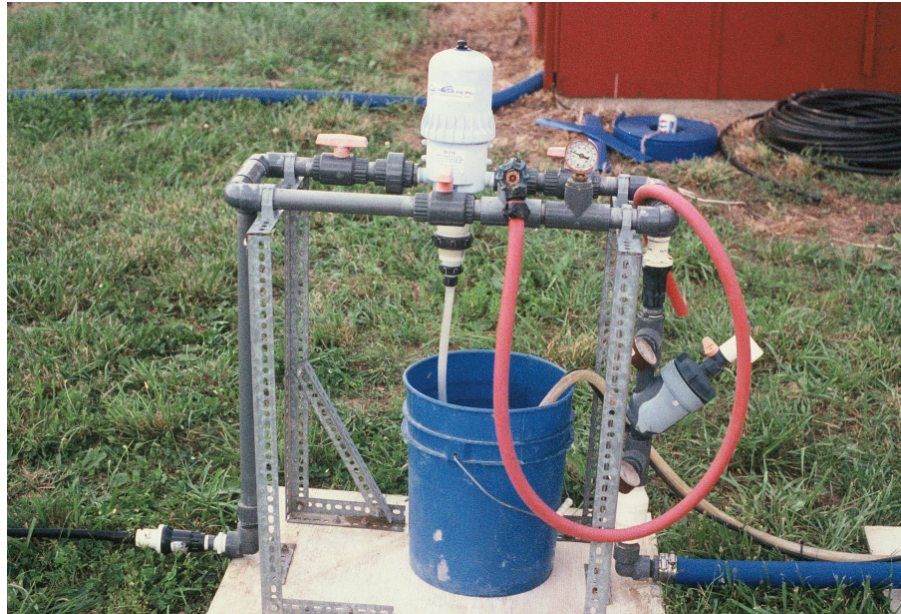


FIGURE 20
In fields where drip irrigation is used, a fertilizer injector is an easy and practical way to apply supplemental N during the growing season. *Courtesy of J. Howell*

An injector is used to mix a concentrated fertilizer solution from a tank or barrel into a stream of irrigation water as it flows out to the field (See Figure 20). A soluble form of fertilizer should be used. The most common material applied through a drip system is calcium nitrate. Greenhouse grade fertilizer should be used. Fertilizer dealers also can provide liquid calcium nitrate in bulk tanks. This eliminates the need for mixing. Do not use field grade dry calcium nitrate. The granules are coated with a wax to prevent them from absorbing moisture from the air and caking. The wax makes it difficult to dissolve the material in water and can clog the drip system. Fertilizers should be injected before the water flows through the filter to eliminate any particles that could clog emitters.

The easiest way to apply the proper amount of fertilizer is to use the batch method. To do this it is necessary to know the number of acres to be irrigated at one time, the amount of nitrogen to be applied and the percent of N in the fertilizer. First, use the formula below to determine the amount of fertilizer needed per acre to supply the desired amount of nitrogen

$$\frac{\text{desired amount of N} \times 100\%}{\text{percent N in the fertilizer}} = \text{amount of fertilizer per acre}$$

Example: Seven lb of N/acre is to be applied using calcium nitrate containing 15% N:

$$\frac{7\text{lb N/A} \times 100\%}{15\%N} = 47\text{ lb calcium nitrate/A}$$

The next step is to add 47 lb of calcium nitrate to the stock tank for each acre that will be watered at one time. Then run the system until all the lines are charged and start the injection. Run the system until all the fertilizer is injected, then continue with water only until all the lines are flushed. If fertilizer is left in the lines, it is likely that algae will grow and then clog the system. Adjust the injector so that it takes at least 20 minutes to inject all the fertilizer. However, it should not take so long that crops are over-watered.

Pre-Sidedress Nitrate Test

In some fields there may be enough soil organic matter to supply nitrogen, eliminating the need for supplemental side dress or top dress applications. To determine if organic matter is releasing enough nitrogen, a pre-side dress soil nitrate test (PSNT) can be used. Samples for this should be taken several days prior to the time when an application would be made.

Samples for the PSNT should consist of a well-mixed composite of 15 to 20 cores or slices of soil to a depth of twelve inches. This is similar to the method for regular soil sampling except for the increased depth of sampling. In some fields it is difficult to obtain samples to a depth of twelve inches. In such cases sampling should be done as deeply as possible. Avoid sampling fertilizer bands that have received extra nitrogen. About one cup of the composite sample should be air dried to stabilize the nitrate. A good method is to spread a thin layer on a non-porous surface such as dinner plate or wax paper. Do not place damp samples on absorbent material because it can absorb some moisture and also some of the nitrate. The drying step can be skipped if it can be delivered to the lab with 24 hours. The lab will run the test within one business day of receipt. (Avoid Friday delivery.) The lab will mail the results and will also email or FAX them if requested.

Research using the PSNT has been conducted in peppers, winter squash, pumpkins and sweet corn in Massachusetts and other northeastern states. These studies have shown that if the the nitrate-N level is 30 parts per million (ppm) or higher there is no benefit in applying more nitrogen. In fact, in many cases additional nitrogen has reduced yield. If however, the level is below 30 ppm, additional nitrogen is usually beneficial. Experience has indicated that other vegetable crops behave similarly. With sweet corn, there is no benefit if the PSNT indicates that nitrate-N is 25 ppm or more.

Phosphorous

Phosphorous is not very soluble and should be placed where is needed. If it is broadcast and left on top of the soil, there will be little movement down into the root zone. Phosphorous should be incorporated into the soil to place it in the root zone.

Broadcasting will provide for a general build-up of P in the soil. As mentioned earlier, most of the P is fixed in the soil and therefore amounts in excess of the crop requirement must be applied if general increase in soil level is desired. It may take years to achieve a high level. If phosphorous is already in the high range, a grower has two good options. One is to apply none for the year and use what is in the soil. Another is to apply the amount the crop is expected to use, thus maintaining the high level. If phosphorous is very high, it should not be applied until the level has come down to the high level. This could also take years, depending on how high the level is. Some growers have applied large amounts of rock phosphate over a number of years in an effort to build P levels. Although rock phosphate is slow to release P, soil levels can eventually become *very high*. There

are numerous examples where this has resulted in excessive soil P. For example, on some fields where rock phosphate has been used, levels are now up around 200 ppm whereas 30 ppm is considered very high (also called excessive). This creates a serious problem if there is any run-off, eventually ending up in a water body. When P levels are too high, none should be added until they come down, which could take many years. This precludes the use of compost or manures and any other materials containing P. This makes it difficult to maintain soil organic matter and soil health.

Fields that have had consistent manure applications also develop very high P levels after a number of years. Certainly high P levels can and do result from years of synthetic fertilizer application, but the highest levels have occurred where high amounts of rock phosphate and/or manure have been used.

As mentioned earlier, P should not normally be applied if the level is very high. However, plants can not easily take up this nutrient when soils are cool. For this reason, it is common to apply a small amount of P (20 to 40 lb P₂O₅/A) in a band at planting, even if it is already in the optimum range. This is some question as to whether or not this is really necessary if P is very high (above optimum).

Phosphorous, if needed, should be applied at planting, either broadcast, or in a band or both. Unlike nitrogen, P is not very soluble and there is no risk of leaching loss. There is little if any benefit in side dressing P because it cannot be incorporated very well at that time.

While rock phosphate is very slow to release P, fresh manure, bone meal and synthetic sources, especially ammonium phosphate, are fairly rapid. Compost is intermediate in the speed of release. A good strategy for organic growers with soils low in P, is to use bone meal in a band at planting to provide a ready supply to plants. Compost or manure can be broadcast to build P levels over time. Moderate amounts of rock phosphate are also appropriate for a few years. From an economic standpoint, rock phosphate is expensive. Compost and manure may be also, but they provide organic matter and most nutrients in addition to P. Bone meal is also expensive and should be applied in a band rather than broadcast over the whole field.

Potassium

Potassium is quite soluble and is somewhat susceptible to leaching in soils with low CEC's. Normally all of the needed K can be applied at planting, either as a broadcast, band or combination of these. Crops such as tomatoes, carrots and beets have high K requirements. If they are growing on soils with low CEC, it is a good idea to apply it as a split application as is done with N. In such cases, potassium nitrate is a good material to use for sidedressing because it supplies K and nitrate-N. This material is available in forms that dissolve well for use with drip irrigation.

Synthetic fertilizers release K rapidly. Potassium sulfate and sul-po-mag are approved for organic production and are also rapidly available. Green sand is very slow to release K. Potassium is released fairly rapidly from compost, manure and other organic materials. This is because the element K does not become part of other molecules in the plant. When the plant material decays, K is released more rapidly than other elements which are part of complex molecules in the plant.

A Note about Starter Fertilizers

Starter fertilizers provide a concentrated source of nutrients close to the young plant. However, all nutrients are salts and if the salt level is too high, plant injury occurs. Salts have an affinity for water and draw soil moisture toward them and away from plant roots. If the salt effect is too great, the roots are injured. This is often called burning because the roots turn brown as if singed in fire. Nitrogen and potassium fertilizers have a high salt index and are most likely to injure roots. Phosphorous has a low salt index and is less likely to burn. It is generally recommended that starter fertilizers used on corn supply no more than 80 lb/acre of N and K combined. This is about 5.5 lb of N + K per 1,000 feet of row if rows are 36 inches apart. If vine crops are planted at a wider row spacing, the amount per 1,000 feet of row should stay the same, but the total amount per acre will be less.

Fertilizer Application Equipment

Application equipment must be adjusted and operated so as to apply the desired amount of fertilizer in an even manner. The owner's manual is invaluable in calibrating applicators. After making the adjustments according to the manual, it is wise to check the application in a sample area before treating the whole field. Fertilizer materials vary in the way in which they flow through a spreader. It may be necessary to adjust for these variations when switching materials. There are a number of ways to do this, but an easy method is to apply a measured amount of fertilizer to determine the size of the area covered. If it is over or under the desired amount the applicator can be adjusted and rechecked. If the owner's manual is missing, a trial and error method can be used. Choose a setting thought to be about right and check it as outlined above. Make necessary adjustments and recheck. Repeat the process until the desired rate is attained.

With broadcast applicators, it is usually wise to overlap applications to achieve uniformity. The owner's manual will indicate how much to overlap. If there is no manual it is good to overlap by 50% to even out irregularities. When doing this, everything will receive a double application, so the spreader should be set to apply half the desired amount. See the New England Vegetable Management Guide for additional information.

Application of Trace Elements

The uniform application of trace elements is tricky because very small amounts are needed (a few pounds per acre) and applicators can not properly apply these low levels. A good method is to ask fertilizer dealers to blend the needed micronutrient(s) into other fertilizer materials. If this is not appropriate, most trace elements can be dissolved in water and applied through a sprayer. This works well since sprayers are capable of applying very small amounts of material evenly.

Reduced Tillage

Standard tillage operations can have a negative impact on soil health. A common practice in vegetable production is to use a moldboard plow and one or more passes with a disc harrow. These operations are sometimes followed by passes with cultipackers or bedders. All this has a number of negative effects on soil:

- aggregates are destroyed
- organic matter decomposes rapidly due to increased aeration
- beneficial organisms are lost
- plow pans are formed due to moldboard plowing
- equipment traffic compacts soil, resulting in restricted root growth, poor drainage, and run-off

There are a number of ways to reduce tillage. Deep zone tillage is one of the more promising ways for vegetable farms. It is a combination of strip tillage and subsoiling. Machines for deep zone tillage consist of a lead coulter, followed by a subsoiler, a pair of fluted coulters and finally by a rolling basket (See Figure 21). Equipment is adjusted to prepare a narrow planting zone that is 6-10 inches wide, with crop residue left undisturbed between strips.

With deep zone tillage, crop roots are not restricted to the shallow soil above the plow pan, but can grow down into the slit created by the subsoiler. This allows them to obtain water from the deeper zone. The narrow tilled strip is raised slightly and warms quickly, often allowing for earlier planting in the spring. The residue-covered area between rows reduces erosion and helps trap rainfall, so that water has time to move into the soil. The residue breaks down more slowly than if it were incorporated into the soil, but in the long run organic matter increases in the soil more than in conventionally tilled fields. With this comes an increase in beneficial organisms and soil water retention. (See Figure 21)

A recent survey of 55 vegetable farms in Connecticut showed that 90% of the conventionally tilled fields had plow pans compared with 33% of those which were managed with reduced tillage. The reduced tillage fields also had almost twice as much organic matter. *Jude Boucher, University of Connecticut*

Deep zone tillage requires about 40 horsepower per shank. Overall, fuel use is reduced considerably because there are fewer trips over the field. Labor costs are also reduced in this way.

Minimum tillage (sometimes called “no-till”) involves using a no-till planter to sow crops directly through surface residues. The residues then serve as a mulch. This is successfully being practiced by some growers for large seeded crops such as winter squash, pumpkins and sweet corn.

Summary

Operating a profitable vegetable farm requires a great deal of skill and knowledge. Managing nutrients and soils in an economically and environmentally sound way is especially challenging for most vegetable growers. Manure is an excellent resource for building healthy soils, but is not available to most growers. Compost, is more available, but usually in less than ideal quantities. Long rotations with hay crops is an excellent way to build soil health, but is not economically viable for most growers with a limited amount of land.



FIGURE 21
Deep zone tillage into a winter rye crop which was killed in early spring. *Courtesy of Andy Cavanagh*

There are many practices that are ideal, but growers have to choose those that are reasonably practical in their own situations. Sometimes, things that don't seem too practical at first can be modified and adapted to fit the farm. Careful use of nutrients can insure the best yields and quality possible at minimum financial cost and risk to the environment. Hopefully, this publication has provided ideas that will prove useful to vegetable growers.

Additional Resources

Building Soils for Better Crops. SARE Outreach Publications, PO Box 753, Waldorf, MD 20604-0753. Phone: 301-374-9696. <http://www.sare.org/Learning-Center/Books>

Howell, J. and Hazzard, R.V., editors. 2011. 2012-2013 New England Vegetable Management Guide. UMass Extension Publication. 250 pp. www.nevegetable.org

Managing Cover Crops Profitability. SARE Outreach Publications, PO Box 753, Waldorf, MD 20604-0753. Phone: (301) 374-9696. www.sare.org/Learning-Center/Books

On Farm Composting Handbook. NRAES, PO Box 4557, Ithaca, NY 14852-4557. Phone: 607-255-7654. www.nraes.org

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