Soil Fertility on Organic Farms

by Keith R. Baldwin

Throughout this manual we have discussed how organic farmers strive to build healthy soil in order to create the best possible environment for plant growth. A healthy soil is primarily defined by its fertility, which in turn depends largely on the interactions of its physical, chemical, and biological properties.

Of those three essential soil properties, organic farmers perhaps give greatest emphasis to the *biological properties* that work to create long-term pools of nutrients for plants. Much of their attention, however, is also devoted to the soil's physical and chemical properties that are vital to plant growth.

In this publication, we'll discuss the factors influencing the physical, chemical, and biological properties of soil. Much of the discussion on such topics as nutrient management and fertilization will, by necessity, be complex and contain some technical language, formulas, and mathematics.

We will organize our discussion around these topics:

- **The organic approach to soil fertility.** Organic farmers use management practices that enhance basic soil properties.

Figure 1. From the uplands to the low-lands, the fertility of its soils determines every farm's productivity and future. (Photo courtesy of USDA)

Contents

- **Soil testing and the sufficiency level approach.** Most testing labs rate soil nutrient levels based on the premise that farmers "fertilize the crop, not the soil." We'll explain how to convert those soil test values to nutrient application rates.
- **Nutrient management on organic farms.** Its goals are to feed the soil, not just a single crop, and to avoid over-applying nutrients.
- **Using manures, composts, and legumes.** We'll describe how these materials can be analyzed and how to calculate proper application rates for these nutrient sources.
- **Using commercial nutrient sources**, including lime, mineral dusts, humates, and plant and animal byproducts.
- **Environmental and regulatory considerations** that relate to soil fertility on organic farms.
- **Recommended reading** for further study on the complex subject of soil fertility.

In a practical sense, organic farmers take pains to regularly evaluate the physical, chemical, and biological properties of a soil and employ management practices that enhance them.

THE ORGANIC APPROACH

A soil's *physical properties* determine how well a plant's roots grow and proliferate. Plant roots thrive in soil that has good aggregate stability (tilth), porosity, infiltration, drainage, water-holding capacity, bulk density, and resistance to crusting and compaction. An extensive root system that explores more soil volume naturally has access to more soil moisture and nutrients.

Managing Soil Chemistry

A soil's biological properties determine the overall efficiency of nutrient cycling and retention for plant use.

Organic farmers provide sites for nutrient retention by adding compost and animal and green manures, which increase organic or *humic matter content*. In the process, the *cation exchange capacity* is increased. Cations are positively charged nutrients, such as potassium, calcium, and magnesium. Additions of organic matter increase the negative charge in soils, increasing the capacity to attract and retain cations.

Organic farmers also manage soil chemistry by controlling soil acidity. Soil acidity is determined by measuring pH. A pH of 7 is neutral. Values below 7 represent increasing acidity, and those above 7 represent increasing alkalinity. Soil pH influences the availability of plant nutrients. For example, a soil pH of about 6.5 limits the availability of potentially toxic nutrients, such as zinc and copper. This is very important because excessive amounts of these elements can build up in fields where animal manures are used as nitrogen sources over several growing seasons.

Soil *chemical properties* control the availability of nutrients to plants. Nutrients must be present in sufficient quantities, or yields will be limited. As a consequence, the primary focus of fertility management on many conventional farms has been the application of chemical fertilizers. Less attention has been given to other soil management practices that also contribute to fertility. In contrast, most organic farmers take a much broader long-term approach to building soil fertility. For example, organic farmers strive to increase *cation exchange capacity*, thereby increasing nutrient storage.

Organic farmers also work to enhance soil biological properties. Soil organisms control many important processes, such as nutrient cycling. In a process called *mineralization*, microbes break down organic plant and animal residues to produce plant nutrients. Plant roots take up these inorganic nutrients and convert them into organic forms, such as leaf, stem, and root tissue. When these plants die, the nutrients are recycled once again.

Soil organisms also promote the development of soil structure by excreting chemicals that bind soil particles together into aggregates. An aggregated soil is said to have good soil *tilth*. Typically, soils with good tilth have good water infiltration and drainage, and are easy to work.

SOIL TESTING AND THE SUFFICIENCY LEVEL APPROACH TO FERTILITY

Whatever the approach a farmer takes to managing fertility, soil testing will help determine the proper application rates of lime to adjust soil pH and the current availability of nutrients in the root zone. Soil tests can help farmers avoid over-application of expensive nutrients. Over-application can cause pollution when nutrients leach from or run off farm fields into water supplies.

Important Crop Nutrients

N = nitrogen
P = phosphorous
K = potassium (potash)
Ca = calcium
Mg = magnesium
Mn = manganese
S = sulfate
Zn = zinc
Cu = copper
Na = sodium

Soil Test Index Values

Many soil testing labs subscribe to the *sufficiency level* concept of fertilization. They use a rating scale or index to indicate whether or not a soil's nutrient content is *sufficien*t to meet yield expectations. A soil test report provides index values for most of the important crop nutrients. Although the sufficiency level approach can increase soil nutrient test values, its chief goal is not to build a *nutrient bank account* in the soil.

The sufficiency system helps reduce leaching losses of mobile nutrients, such as potassium, in highly weathered soils with a low *cation exchange capacity* (CEC), such as the soils found in the Southeast. The CEC measure on a soil test reflects a soil's ability to hold mineral nutrients, such as calcium and potassium, as well as many important micronutrients, such as zinc and copper.

Most soil testing labs do not routinely analyze a submitted soil sample for nitrogen (N) because soil nitrogen status can change rapidly, in part depending on weather conditions. Thus, there are no sufficiency index values for soil N. Nitrogen recommendations are usually based on realistic yield expectations for different crops on different soils in different regions of the state. Many years of field experiments under a wide range of soil and climatic conditions have determined the N fertilization rates that will achieve realistic yields for various crops.

In addition, no credit is given on the soil test report for residual soil nitrogen from previous fertilizer and manure applications or green manure cover crops. Farmers must determine *N credit* (the residual N in soil available to the next crop) based on the previous fertility practices they have used on their farms. They can then subtract that credit from the soil test recommendations for the next crop. Determining realistic yield expectations and N credits are discussed later in this publication.

Soil Test Index Values and Crop Responses. Table 1 describes the relationship between the soil test index values reported by the North Carolina Department of Agriculture and Consumer Services (NCDA & CS) soil testing lab and predicted crop responses to fertilizer on mineral soils.

The soil test index ratings in Table 1 can be defined as follows:

- **Very Low** – Expect less than 50 percent of the crop yield potential if the indicated nutrient is not added. A large portion of the nutrient requirement must come from fertilization.
- **Low** – Expect 50 to 70 percent of the crop yield potential if the indicated nutrient is not added. Expect a yield increase if the nutrient is added. A portion of the nutrient requirement must come from fertilization.
- **Medium** – Expect 75 to 100 percent of the crop yield potential if the indicated nutrient is not added. Expect a yield increase if the nutrient is added. A small portion of the nutrient requirement must come from fertilization.
- **High** – Do not expect a yield increase if the nutrient is added. No additional fertilizer is needed.
- **Very High** – Do not expect a yield increase if the nutrient is added. The soil can supply much more than the entire crop nutrient requirement. Additional fertilizer should not be added to avoid nutritional problems and adverse environmental consequences.

Converting Soil Test Index Values to Nutrient Application Rates.
When comparing test results among laboratories, it may be helpful to convert all laboratory values to the same units (for example, to pounds of nutrient per acre). The conversion factors are given in Table 2 and are based on a volume of soil to a depth of 20 centimeters (7.9 inches). Please note that milligrams per cubic decimeter equals parts per million (mg/dm^3 = ppm); mg/dm^3 times 2 equals kilograms per hectare (kg/ha); kg/ha times 0.891 equals pounds per acre (lb/acre).

Here's an example of how to convert the NCDA & CS index values to pounds of nutrient per acre. Suppose the soil test shows a P-I of 30, a Mg-% of 7, and a CEC (cation exchange capacity) of 5:

Calculation 1. Converting a soil test index value to a nutrient (lb/acre):

P-I x 2.14 = P (lb/acre), or
30 x 2.138 = 64.14 lb/acre

Mg-% x CEC x 2.17 = Mg lb/acre, or
7 x 5 x 2.17 = 75.95 lb/acre.

Table 1.Relationship between soil test index values and crop response						
Soil Test Index		**Expected Crop Response to Nutrient Application**				
Range	**Rating**	**P***	**K****	**Mn**	**Zn**	**Cu**
0-10	Very low	High	High	High	High	High
10-25	Low	High	High	High	High	High
26-50	Med	Low	Low	None	None	None
51-100	High	None	None	None	None	None
100+	ery High	None	None	None	None	None

*For soils in the ORG (organic) class, these are the ranges for P Ratings: Low, 0-16; Medium, 16-30; and High, 30+.

**Phosphate and potash recommendations above an index value of 50 are designed to replenish nutrients removed by crops and for building purposes.

Table 2. Factors for converting the NCDA & CS soil test index values to other equivalent values (Source: Tucker and Rhodes, 1987)

Nutrient	mg/dm	kg/ha	lb/acre
P-I	1.20	2.40	*2.14
K-I	1.955	3.91	**3.48
Ca-% x CEC	200.0	400.0	3.56
Mg-% x CEC	121.6	143.2	2.17
Na	230.0	460.0	409.86
Mn-I	0.16	0.32	0.285
Zn-I	0.04	0.08	0.071
Cu-I	0.02	0.04	0.036
S-I	0.40	0.80	0.713

*P

**K

These NCDA & CS conversion factors assume the weight per unit volume of the soil sample is 1.0 gram per cubic centimeter (gm/cm^3). For a direct comparison with labs that calculate and report nutrients on a mass basis, the NCDA results must be divided by the weight per unit volume (W/V) value on the NCDA & CS soil report.

Fertilizer recommendations are normally stated in pounds of phosphate (P_2O_5) and potash (K_2O) per acre or per 1,000 square feet. The NCDA conversion factors calculate pounds of P and K per acre. To convert P to P_2O_5, multiply by 2.29. To convert K to K_2O, multiply by 1.2. An example follows:

Calculation 2. Converting P to P_2O_5 :

64.14 lb P per acre × 2.29 = 147 lb P_2O_5 per acre

Nutrient availability. Not all 147 pounds of P_2O_5 should be considered as *plant available*. The NCDA laboratory procedure that measures P in a soil sample attempts to measure the portion of total soil P that would be available to plants. The 147 pounds of P_2O_5 in the above example would, in all likelihood, vary depending on the quality of the soil sample (whether it truly represents field conditions), tillage practices, environmental conditions, and crop species or cultivar. However, the relationship of *lab* P to *plant-available* soil P is a good approximation that is useful when comparing NCDA & CS soil test reports to reports from other soil laboratories.

In summary, these calculations show that a field with a P index (P-I) value of 30 has approximately 147 pounds of *plant-available* P_2O_5 per acre. A soil P-I value of 30 is in the medium range (Table 1). Without additional P_2O_5, a farmer can expect to achieve 75 to 100 percent of the crop yield potential. One would expect that additional P_2O_5 would increase yield because a P-I value of 30 falls on the low end of the range.

Knowing the pounds of plant-available P_2O_5 (or K_2O) in a field is useful when planning a nutrient management program. For example, a value for plant-available P_2O_5 per acre can be used to evaluate how much additional P_2O_5 to apply.

EXAMPLE

How To Raise Soil P-index (P-I) Levels

Suppose a farmer with a P-I value of 30 wants to bring his P-I value up to 75. Using the equations outlined above, the farmer calculates that a P-I of 30 has approximately 147 pounds of plant-available P_2O_5 per acre (30 × 2.14 × 2.29 = 147). A soil with a P-I of 75 has approximately 367 pounds of plant available P_2O_5 per acre (75 × 2.14 × 2.29 = 368). The farmer needs to apply an additional 221 pounds of P_2O_5 (368 – 147 = 221) to achieve a P-I of 75. If the farmer chooses to use rock phosphate as a fertilizer, and the rock phosphate has a nutrient analysis of 0-2-0 (the analysis indicates the percent N-P-K in the fertilizer, respectively), he or she can calculate the rock phosphate fertilizer needed to bring the P-I to 75.

The standard calculation for the amount of fertilizer to apply per acre is the recommended rate of nutrient divided by the percentage of the nutrient contained in the chosen fertilizer. Since the rate of nutrient required is 221 pounds and the percent P_2O_5 in the fertilizer is 2 percent (.02), then the required application rate is 11,050 pounds or 5.5 tons per acre (221 ÷ .02 = 11,050).

Soil Organic Matter Content

One of the most common objectives of organic farming—increased soil organic matter content—is difficult to measure. Soil samples from the same area of a farm may differ widely, based on the site-specific nature and properties of soils, the variability of the organic matter source (such as bark, leaves, or green manure) in the soil sample, and the state of decomposition of the organic matter. Soil organic matter content can be measured directly or indirectly by measuring soil *humic matter* content. Different labs in different states may choose to measure and report one or the other. Humic matter, the most reactive component of soil organic matter, is a key component of nutrient retention in soil.

Therefore, it is impossible to be 100 percent accurate in measuring the total soil organic matter content by determining the humic matter content. Humic matter values on soil tests are generally much lower than the actual soil organic matter content, particularly in soils high in organic matter. For example, some organic soils show less than 10 percent humic matter, although the soil organic matter content may be 50 percent or more. Organic farmers who want a ballpark estimate of soil organic matter content can use the following equation to convert humic matter (HM) to organic matter (OM) (Weber et al., 1987):

Calculation 3. Converting humic matter to organic matter:

$$OM\% = [(HM\% - 0.16) \times 2.7]$$

Increases in the humic matter index in a soil test may provide organic farmers with indicators of improvements to soil quality. A farmer may want to include humic matter as an evaluative parameter when preparing the soil improvement program for a certification application.

Soil Test Red Flags

Soil tests can show a farmer where manure and other organic materials have been applied over many years. Applications of some types of organic amendments should be ended if soil tests show zinc index values greater than 450, copper index values greater than 1,000, and soil pH values of 6.5 or higher (for organic materials with significant liming value). Where a soil phosphorous index is greater than 150, P applications should be limited to crop removal levels.

NUTRIENT MANAGEMENT ON ORGANIC FARMS

Many organic farmers speak about the importance of a proper balance of nutrients in the soil for plant growth. They use the Basic Cation Saturation Ratio method for estimating crop nutrient requirements. This approach is based on an ideal ratio of exchangeable bases (in particular Ca++, Mg++, and K+) held at cation exchange sites. Farmers believe that an ideal ratio will optimize plant nutrient utilization and crop yield. These are the ideal ratios:

Ca:Mg 6.5:1
Ca:K 13:1
Mg:K 2:1.

If they were ideally balanced, 85 percent of the exchange sites would be occupied by Ca++, 10 percent by Mg++, and 5 percent by K+. If these ratios are not present, then a farmer assumes that a deficiency exists in one or more of these nutrients. This approach is most commonly used for soils in the Midwest that have a relatively high CEC and a naturally high soil pH. Under those conditions, the assumptions may be fairly reliable.

Many organic farmers use the *Basic Cation Saturation Ratio* approach.

Feed the Soil Approach

Many organic farmers prefer to base fertility management on a *feed the soil* approach. The purpose of this approach is twofold. When organic nutrients are added to the soil, microbial activity increases. In this sense, organic farmers are “feeding the microbes.” Increased microbial activity improves soil physical properties. For example, when microbial activity increases, soil tilth improves. In addition, microbial activity speeds nutrient cycling, increasing the availability of nutrients for plant uptake (when mineralization exceeds immobilization by microbes).

This strategy also seeks to build a *nutrient bank account* and maintain a healthy balance of nutrients in the soil. That balance is maintained in various nutrient pools. Nitrogen pools, for example, include inorganic N, microbial biomass N, readily available or mineralizable (labile) organic N, or unavailable (recalcitrant) organic N. In soils with enhanced nutrient cycling, N cycles in and out of these pools and into forms available for crop uptake. In theory, N application rates in this kind of enriched soil can then be based on N *removal rates* for harvested crops.

Farmers should be cautious, however, when basing a nutrient application rate on crop nutrient removal. This is because nutrient cycling systems in soils are not 100 percent efficient. That is, they "leak." Basing an N application rate solely on N removal by crops can seriously underestimate a crop's nitrogen needs. In addition, any losses of nutrients to leaching, runoff, and immobilization (in microbial biomass) results in fewer available nutrients for crop uptake.

Nutrients out must be replaced by *nutrients in*.

Crop Use Efficiency. Regardless of rooting conditions, crop roots will not find all of the applied nutrients. Some crops are much more efficient than others at finding and taking up nutrients. For example, a cucumber crop may take up as little as 20 to 25 percent of applied N fertilizer. The *N use efficiency* of cucumbers, therefore, is 25 percent. The N use efficiency of corn is only 50 percent. Corn may uptake only 50 pounds from a 100-pounds-per-acre application of fertilizer. Nutrient uptake is influenced by the density of plant roots, which in turn is influenced by the soil's physical, chemical, and biological properties. Even when soil quality is excellent, plant roots may explore less than 5 percent of the entire soil volume. Many other factors contribute to inefficient use of applied nutrients, such as fertilizer placement, rainfall and irrigation amounts, and soil temperature.

The feed-the-soil approach stops short when nutrient concentrations in soils are already very high. In these cases, feeding the soil can result in nutrient additions that increase the potential for environmental pollution or plant toxicity.

Avoiding Over-applications of Phosphorus and Potassium

In some instances, basing fertilization rates on crop nutrient removal calculations is useful—for example, when farmers use manure to meet crop nutrient requirements. Where soil tests show that P and K values are very high and no additional P or K is recommended, a manure application rate calculation that is based on crop N needs will *oversupply* P and K. This is because manure contains significant amounts of these nutrients. In these cases, the most sustainable practice may be to apply manure based on the plant removal rates of P or K. Any resulting shortfall in the crop N requirement can be met with another N source that doesn't contain P or K.

Over-application of P is especially problematic when organic amendments are applied to soil surfaces, as when using no-till systems or perennial cover crops. Although N may be lost by many means in a no-till system (leaching, runoff, and denitrifica-tion, for example), P is typically lost through erosion, runoff, and subsurface flow. Losses of soil P to streams and rivers through these processes can degrade water quality in lakes, reservoirs, and marine estuaries.

Additions of manures, composts, and other organic byproducts can and do result in a buildup of available P in organic farm fields over time. For this reason, it makes sense to calculate P application rates based on the P removal rates (where soil is sufficient in P). In any case, calculations of crop removal rates of P and K are useful in accounting for additions and removals of nutrients from farm fields over time. Growers with computers can keep a nutrient balance sheet in a spreadsheet program. Table 3 shows nutrient removal rates by agronomic crops in the Southeast.

Avoiding Over-applications of Nitrogen

Nitrogen application rates for a particular crop grown on a particular soil in a particular field should be based on a *realistic yield expectation* (RYE) for that crop grown in that field. A number of soil-related factors can affect the realistic yield expectation, including these:

- depth to subsoil, rock, or other limiting horizons
- organic matter content
- permeability, infiltration, and drainage
- landscape position
- climate

Fertility management strategies can overcome many of these site-specific properties, but farmers will have to spend more time and money in terms of irrigation, nutrients, labor, and skill to achieve high yields on poorer soils. Production costs will, of course, increase under these circumstances.

Table 3. Nutrient removal at harvest for southeastern crops (Source: Hodges, 1998)

Crop	Average Yield	Nutrient Removal Rate: Nitrogen		P_2O_5		K_2O	
		pounds per acre and per unit of yield*					
Bermudagrass	4 tons/acre	184.0	(46.0)	48.0	(12.0)	200.0	(50.0)
Soybean	40 bu/acre	160.0	(4.00)	32.0	(0.80)	56.0	(1.4)
Corn	100 bu/acre	75.0	(0.75)	44.0	(0.44)	29.0	(0.29)
Cotton	1.5 bales/acre	46.5	(31.0)	18.0	(12.0)	21.0	(14.0)
Wheat	50 bu/acre	57.5	(1.15)	27.5	(0.55)	17.0	(0.34)

*Values in parentheses indicate pounds of nutrient removed per unit of yield.

Determining a Realistic Yield Expectation. The best method of determining the realistic yield expectation is to use historic production records for each field. Most certification agencies require that organic farmers keep these records. To obtain a truly representative value, farmers can average the three highest economic yields (yields that provide the highest net returns) in the last five years that the crop was grown. Unfortunately, data is sometimes not available on a field-by-field basis, especially where a new crop is being grown.

Crop yield potentials for conventionally produced crops can often be found in the Natural Resource Conservation Service (NRCS) database. Where actual yields are not available, the NRCS database values give reasonable estimates of yields for various crops on specific soils under high levels of management (such as fertilizer, other chemical inputs, and proper tillage). The number of crops included in the database is limited. In some cases, the yield potentials are inferred from soils with similar properties.

Calculating a Nitrogen Application Rate. Once a realistic yield expectation for a field has been determined, an appropriate nitrogen rate can be calculated by multiplying the realistic yield expectation by a *suggested N application rate*. Suggested N application rates for agronomic crops are given in Table 4. Information for vegetable crops is not available at this time. For crops not listed, recommended N rates must be determined from personal experience, a reliable consultant, or local farmers.

Table 4. N fertilization rates based on realistic yield expectations (RYE)
(Source: Hodges, 1998)

Crop	Suggested Nitrogen Application Rate
Annual ryegrass (hay*)	40.0 to 50.0 lb N/dry ton
Bermudagrass (hay*)	40.0 to 50.0 lb N/dry ton
Corn (grain)	1.0 to 1.25 lb N/bu
Corn (silage)	10.0 to 12.0 lb N/ton
Cotton	0.06 to 0.12 lb N/lb lint
Millet (hay*)	45.0 to 55.0 lb N/dry ton
Oats (grain)	1.0 to 1.3 lb N/bu
Rye (grain)	1.7 to 2.4 lb N/bu
Small grains (hay*)	50.0 to 60.0 lb N/dry ton
Sorghum (grain)	1.5 to 2.0 lb N/cwt
Soybeans (in special cases)	3.8 to 4.0 lb N/bu
Tall fescue (hay*)	40.0 to 50.0 lb N/dry ton
Wheat (grain)	1.7 to 2.4 lb N/bu

*Annual maintenance guidelines. NRCS standards require that the nitrogen rate be reduced by 25 percent if fields are grazed.

Note that the lower ends of the ranges shown in Table 4 are typical for the most productive soils under nonirrigated conditions. These are soils with above-average available water-holding capacities, good infiltration rates, and high residual nitrogen. Nitrogen requirements can be even lower with well-managed irrigation practices. The higher end of the range should be used for soils that are associated with reduced nitrogen uptake efficiency, little water-holding capacity, and low residual nitrogen.

RYE and Nitrogen Application Rates for Organic Farms. The NCDA & CS Agronomic Division bases its nitrogen application recommendations on these factors:

- average yields of crops in various regions of the state,
- plant-available nitrogen (PAN) contained in the fertilizer materials (organic and inorganic), and
- relationships between the amount of PAN applied and the resulting yield response. These relationships have been determined over many years by field experiments in North Carolina.

It is important to note that typical yield response curves (the relationship of yield response to increasing nutrient application rate) may not always apply to organic farms. The ratings do not reflect the application of N on highly fertile, organically managed soils that already have a residual pool of relatively available organic N (which includes microbial biomass N).

Consequently, many organic farmers reduce the recommended N application rate on such high-quality soils. Applications of organic fertilizers and green manures, coupled with the enhanced N cycling by soil microbes, continually replenish the plant-available N pool. Organic farmers also believe that a greater amount of applied N is taken up and used in their cropping systems because their soils are simply more efficient at using fertilizers. In other words, nutrient use efficiency is higher. Improved crop yields are achieved with lower inputs of N because of all the good synergies generated by the physical, chemical, and biological processes taking place in high-quality, organically managed soils.

Constructing a yield response curve. In the absence of yield response curves for organic operations, organic farmers must construct their own curves to determine N application rates that produce realistic yields of specific crops. Farmers can start with one year's data on N application rates and the crop yields they produce. The data can be expanded over several years of production that represent a range of growing conditions. The data can be averaged to provide a better estimate of realistic yields and N rates that produce those yields.

All of this will require dedicated record-keeping. Curious farmers can experiment by applying different rates of N to different fields and recording the various yields that are achieved. By plotting the results of several years' experiments on graph paper, with the N application rate on the X-axis and crop yield on the Y-axis, farmers can determine the highest yield that can be expected in most years and the N application rate that achieves it.

Calculating N removal rates. Organic farmers who have a soil bank account flush with N often estimate the amount of N they must apply by the amount of N removed from the soil by crops. As discussed previously, N removal rates represent a *minimum* N application rate. It may be necessary to apply more N than is indicated by N removal rates.

To determine actual N needs for a given crop, organic farmers must estimate N uptake efficiency and N availability in pools of microbial, organic, and mineral N. Factors affecting these adjustments include soil quality, crop rooting characteristics, the macro and microclimate, potential for nutrient losses, and the character of organic fertilizers and amendments. Past fertility practices must also be considered. These include ongoing mineralization of soil organic matter from previous organic amendments, from applications of organic fertilizers, and from legume cover crops and green manures. Farmers must account for the mineralization rate of the organic fertilizers and whether and when nutrients are released in relation to crop needs. These factors are discussed in the section on "Using Manures, Composts, and Legumes."

Tissue Analysis

It's a good idea to have plant samples analyzed periodically to determine if crops are receiving adequate levels of nutrients. Many public and private laboratories will analyze nutrient concentrations in plant leaf tissue. Results indicate the nutritional status of plants, identify deficiencies or toxicities, and provide a basis for determining whether additional applications are needed, such as a sidedressing or foliar application.

Taking a Sample. Laboratories like the Plant Advisory Service of the North Carolina Department of Agriculture and Consumer Services (NCDA) have recommendations for the most appropriate plant part to sample, and when and how often to sample. Commonly, the most recent mature leaf (MRML) is the best indicator of plant nutrient status. The MRML is the first fully expanded leaf below the growing point. The laboratory analysis requires less than 1 gram of tissue. However, a good sample contains enough leaves to represent the total area sampled. For example, 8 to 15 tomato leaves should be adequate. Take separate samples from separate fields or management zones, or from production areas where problems exist.

Interpreting Results. The Plant Advisory Service uses a sufficiency range approach for primary interpretation of the laboratory results. Concentrations of essential elements measured in the laboratory are converted to a standard index scale of 0 to 124.

- Index values of 0 to 24 represent a deficiency in a particular nutrient.
- Sufficiency values from 25 to 49 are low.
- An index value of 50 to 74 is within the sufficiency range for an essential element.
- High index values (75 to 99) indicate the element is more than adequate and there may be "luxury" consumption. (Normally this is not detrimental to growth or yield but may influence the quality of some crops.)
- Index values of 100 to 124 and greater represent excesses of nutrients in plant tissue. Plants will tolerate excess macronutrients (for example, K^+) but they are very sensitive to excessive micronutrients.

Crop Rotations

Farmers must consider long-term cropping plans or rotations when designing a fertility management plan. If it is agronomically feasible, nutrient application and utilization can be considered for the entire cropping cycle rather than on a crop-by-crop basis. All soil management plans should include a description of the normal cropping sequence, the nutrient needs, and the nutrient removal rates of all crops in the system.

The National Organic Program Rule requires a *Crop Rotation Practice Standard*. The producer must implement a crop rotation plan that includes, but is not limited to, sod, cover crops, green manure crops and catch crops. These crops must provide the following functions (USDA, 2000):

- Maintain or improve soil organic matter content.
- Provide for pest management in annual and perennial crops.
- Manage deficient or excess plant nutrients.
- Provide erosion control.

For more information on crop rotations in organic agriculture, see the publication entitled "Cover Crops on Organic Farms" in the *Organic Production* publication series.

Nutrient Placement

In the absence of chemical or biological inhibitors, roots grow and proliferate in soils with good tilth. However, where root growth is restricted, placement of fertilizer near the developing root is important. Generally a placement that is 2 inches below and 2 inches to the side of the seed or transplant will ensure that nutrients will be available to the crop.

Restricted root growth will occur in compacted soils with high bulk density values or with compacted soil horizons. In these cases, nutrient uptake efficiency may improve if fertilizer placement reduces the distance between fleshy or tap roots and fertilizer material, particularly when fertilizer nutrients are relatively immobile in soil. This is particularly critical where soil test levels are low; in seasons when root growth is slowed due to cold weather; or for plants with restricted root systems due to other physical, chemical, or biological factors, such as nematode damage.

USING MANURES, COMPOSTS, AND LEGUMES

Nutrients in commercial fertilizers are highly soluble, so nutrient availability is quite predictable and nutrients are quickly available to plants. Organic fertilizers, however, vary widely in how and how quickly they make nutrients available for crops. Nutrient availability depends on the source, whether it be manure, compost, or a cover crop used as green manure. In general, these organic fertilizers mineralize and release nutrients, such as N and sulfur, at a very slow rate.

The application method also affects nutrient availability. When applied to the surface of some soils, nutrient sources containing urea or ammonium N can be lost as a gas through a process called *volatilization*. The volatilized (or vaporized) N is usually in the form of ammonia. If manures are broadcast and not incorporated, estimates of manure ammonium N losses are 55 to 75 percent (depending on the manure source) in North Carolina. If incorporated within 48 hours, losses can be reduced to 10 to 25 percent. If manures and other organic wastes are left on the surface, *denitrification losses* can also occur when the waste becomes saturated. Nitrate N in the waste can be converted to gaseous N_2O, which is a greenhouse gas.

Analyzing Manures and Composts

Many public and private laboratories will analyze manure and compost samples, interpret the analytical results for farmers, and provide fertility management recommendations. The following procedures are recommended for sampling manure and compost:

Fresh Poultry Litter. The concentration of nutrients in poultry litter varies widely, both from house to house and within each house. Collect waste cores or slices from 10 to 12 locations in each house. Cores or slices should extend from the top to the bottom of the accumulated waste. Take samples around waterers, feeders, and brooders in proportion to the space these areas occupy in the house. Combine the collected materials in a plastic container. Mix thoroughly. Take a 1-quart subsample from this mixture, and send it to the laboratory.

Stockpiled Litter. Ideally, stored litter has an impervious surface beneath it and a cover over it. Uncovered waste develops a weathered exterior that may not accurately represent the majority of the material. Rainfall moves water-soluble nutrients through the pile. If the litter becomes saturated with water, nitrogen will be lost from the pile by denitrification. If the litter is unprotected and used over an extended period, take new samples before each application. Always sample to a depth of at least 18 inches at six or more locations.

Composts. Use the same storage and sampling procedures recommended for stockpiled litter. Although nutrients are somewhat stabilized in these materials, leaching of mobile nutrients can occur during rains. Therefore, periodically test a sample of unprotected compost to monitor changes.

Liquid Wastes. To sample liquid manures from a lagoon, collect a 1-quart sample in a plastic container. Leave 1 inch of air space in the top of the container so the sample can expand. Refrigerate samples held for a day or more before shipping. If the lagoon from which the sample is taken is a two-stage system, draw samples from the lagoon that will be pumped. Do not include floating debris and scum in the samples. Take 1 pint of liquid from a minimum of eight sites around the lagoon. A 10-foot rod with a 1-pint container attached to the end serves as a good sampling device. Collect samples at least 6 feet from the edge of the lagoon at a depth of about 1 foot. After collecting 1 pint from each sample site, mix the samples thoroughly and submit 1 quart of the mixture to the laboratory.

Laboratories report the total concentrations of nutrients in the waste materials and usually predict the fraction of the total nutrients that will be available (in pounds per ton of material) to the first crop following application. Nutrient availability can vary considerably from year to year. Many variables, including the type of waste product (and its resistance to decomposition) and environmental factors (such as soil type, rainfall, temperature, and general soil tilth) influence how fast nutrients will be released from manure and other organic materials.

Although a lab report provides useful information, it must be adjusted to reflect local conditions at the time of application. For example, in a wet, dry, or cold spring, microbial activity is reduced and the release of nutrients from decomposition of the waste material will be reduced. Depending on the severity of conditions, 0 to 25 percent of the nutrients reported as available by the lab may actually become available to the crop. In a warm, moist spring, however, as much as 75 percent of the nutrients can become rapidly available to the crop in the first month after application. In both cases, the remainder of the reported available nutrients should be released by microbial activity in the second and third month after application.

Applying Manures

In the absence of a laboratory analysis, average nutrient values for various manures (see Table 5) represent an acceptable option for developing nutrient management plans.Table 6 contains the first-year availability coefficients used to determine plant-available nutrients in manure.

Table 5. Nutrient composition of manures (Source: Hodges,1998)

	Nutrient Composition					
	NH_4-N	Total N	P_2O_5	K_2O	Cu	Zn
Manure Type	lb per ton					
Poultry	10	26	17	11	N/A	N/A
Broiler litter	11	72	78	46	0.45	0.63
Turkey litter	16	57	72	40	0.51	0.64
Stockpiled litter	8	36	80	34	0.27	0.55
Swine manure	7	13	12	9	0.15	0.35
Dairy manure	3	10	6	9	0.02	0.1
	lb per acre-inch					
Swine lagoon effluent	111	136	53	133	0.3	1.5

Table 6. First-year availability coefficients for different manures (Source: Hodges,1998)

	Application Method		
	Soil-incorporated	Broadcast	Irrigated
Manure type	P_2O_5 and K_2O Availability Coefficients		
All types	0.8	0.7	0.7
	N availability coefficients		
All litters	0.6	0.5	N/A
Layer manure	0.6	0.4	N/A
Scraped swine manure	0.6	0.4	N/A
Swine lagoon effluent	0.8	0.5	0.5

To obtain the plant-available nutrient content of an organic fertilizer, multiply the total concentration from the waste analysis (Table 5) by the appropriate availability coefficient for the source, application method, and nutrient in question.

Calculating an Application Rate for Manure. The tons of manure to apply per acre equals the *recommended amount of priority nutrient* in pounds per acre, divided by the *plant-available nutrient*, which is the total priority nutrient concentration in pounds per ton of the source material times the appropriate availability coefficient. So the first step is to calculate the amount of plant-available nutrient in the manure.

For example, broiler litter contains 72 pounds per ton of total nitrogen (Table 5) and the availability coefficient for soil-incorporated litter is 0.6 (Table 6). Suppose the recommended nitrogen application rate for the crop is 100 pounds per acre:

Calculation 4. Calculating a manure application rate:

Step 1. Calculate the plant-available nutrient (lb/ton):
Total Priority Nutrient Concentration (lb/ton) x Availability Coefficient

Step 2. Calculate the application rate (ton/acre):
Recommended Amount of Priority Nutrient (lb/acre) ÷ Plant-available Nutrient (lb/ton)

Calculation 5. Calculating a manure application rate based on the recommended nitrogen application rate:

Step 1. Calculate plant-available nitrogen (lb/ton): 72 (lb/ton) x 0.6 = 43.2 (lb/ton)

Step 2. Calculate the application rate (ton/acre):
100 (lb/acre) ÷ 43.2 (lb/ton) = 2.3 (ton/acre)

This application rate can be converted into pounds per 1,000 square feet by multiplying by 46:

Calculation 6. Converting ton/acre into lb/1,000 sq ft:

2.3 (ton/acre) x 46 = 106 (lb/1,000 sq ft)

The availability of phosphorous (P) and potassium (K) in manure is somewhat higher than nitrogen (N). The availability coefficient of both P and K for incorporated manure is 0.8. When the manure application rate is based on plant-available N, P and K may be over- or under-supplied, depending on the crop P or K requirements. With vegetable crops, recommended P application rates are somewhat lower than N rates and K rates are somewhat higher. Thus, when manures are used as N sources for vegetable crops, P tends to be over-applied and K under-applied.

Consider the application rate for broiler litter calculated above based on the recommended amount of N. The P recommendation for cabbage is 50 pounds per acre (where the soil test P-I is in the *high* range) (Sanders, 1999). What happens if 2.3 tons per acre of broiler litter is incorporated in a cabbage field prior to planting and the litter has 78 pounds of P_2O_5 per ton (Table 5)?

Calculation 7. Determining the effect of a manure application in relationship to P:

Total P_2O_5 applied:
2.3 (ton/acre) x 78 (lb/ton) = 179.4 (lb/acre)

Approximately 80 percent of this P_2O_5 is available (Table 6).
Plant-available P_2O_5 supplied:
179.4 (lb/acre) x 0.8= 144 (lb/acre)

Thus, P_2O_5 is *over-applied* by 94 lb/acre:
144 (lb/acre) - 50 (lb/acre) = 94 lb/acre.

On the other hand, tomatoes have a relatively high K recommendation of 100 pounds per acre (where the soil test K-I is in the *high* range). What happens if 2.3 tons per acre of litter are applied to a tomato field and the litter has 46 pounds of K_2O per ton (Table 6)?

Calculation 8. Determining the effect of a manure application in relationship to K:

Total K_2O applied:
2.3 (ton/acre) x 46 (lb/ton) =s 106 (lb/acre)

Approximately 80 percent of this K_2O is available (Table 6).
Plant-available K_2O applied:
106.4 (lb/acre) x 0.8 = 85 (lb/acre)

K is *under-applied* by 15 lb/acre:
85 (lb/acre) - 100 (lb/acre) = - 15 (lb/acre)

These calculations demonstrate how P and K can be oversupplied when manure is applied based on N as a priority nutrient. In soils that receive frequent applications of manures and composts derived from manures, soil P and K index values tend to be *high*. If a manure application rate is based on P or K as the priority nutrient (rather than N) and the soil test report calls for no additional P or K, the manure application rate should be based upon crop removal rates of P or K. Removal rates are based on the amounts of P and K in the harvested portion of the crop that is physically removed from the site. Where P and K index values are *low*, however, growers can calculate application rates based on either element as the critical nutrient.

Using Mechanical Applicators.

Mechanical applicators can apply manure, litter, and wastewater at varying rates and patterns, depending on forward travel or PTO speed (or both), gear box settings, gate openings, operating pressures, spread widths, and spread overlaps. Calibration defines the combination of settings and travel speed needed to apply manure, litter, or wastewater at a desired rate and to ensure uniform application.

Calibrating liquid spreaders. Liquid spreader capacities are normally rated by the manufacturer in gallons. When using these machines, multiply gallons by 0.0042 to get tons.

Calibrating solid and semi-solid spreaders. Solid and semi-solid spreaders are rated by the manufacturer either in bushels or cubic feet (multiply bushels by 1.24 to get cubic feet). Most spreaders have two rating capacities: (1) struck or level-full and (2) heaped. Because manures and litters have different densities, an on-farm test should be completed:

1. Fill a 5-gallon bucket full of the material to be spread, and make sure that the material is level to the top of the bucket. Do not pack the material in the bucket but ensure that it settles similar to a loaded spreader.
2. Weigh the full bucket and then empty.
3. Multiply the weight of the contents by 1.5 to get pounds per cubic feet.
4. Multiply this value times the cubic feet capacity of the spreader, and divide by 2,000 to get the tons of material in a spreader load:

Calculation 9. Determining the amount in a spreader load based on the spreader's cubic feet capacity:

Manure Weight (lb) x 1.5 x Spreader Capacity (cu ft) ÷ 2000 = Spreader Load (ton)

The following method is often used for calibrating solid and semi-solid spreaders:

1. Measure a tarp or plastic sheet of about 100 square feet (such as 9 by 12 feet or 10 by 10 feet) for exact surface area (length times width).
2. Weigh the tarp using a set of spring-tension or platform scales.
3. Spread and pin the tarp on the field surface.
4. Operate the spreader at its normal settings, speed, and overlap. With a rear discharge spreader, make three passes: the first directly over the center of the sheet, and the other two on opposite sides of the center at the normal spreader overlap spacing.
5. Weigh the tarp again with the collected manure in it.
6. Subtract the empty sheet weight from the total weight to get the weight of the collected manure.
7. Multiply the pounds of collected manure by 21.8, and divide by the collection area of the sheet in square feet to get the application rate in tons per acre.
8. Repeat the procedure using different settings or speeds to obtain the desired application rate.

The formula for this procedure follows:

Calculation 10. Determining a spreader application rate in tons per acre:

Collected Manure (lb) x 21.8 ÷ Collection Area(sq ft) = Application Rate (ton/acre)

To determine the uniformity of spread and the amount of overlap needed, follow these steps:

1. Place a line of small pans or trays equally spaced (2 to 4 feet apart) across the spreader path. The pans should be a minimum size of 12 inches by 12 inches *or* 15 inches in diameter, and no more than 24 inches by 24 inches, and 2 to 4 inches deep.
2. Make one spreading pass directly over the center pan.
3. Weigh the contents caught in each pan, or pour the contents into equally sized glass cylinders or clear plastic tubes.
4. Compare the amount in each.
5. Find the effective spread width can be found by locating the point on either side of the path center where the manure contents caught in the containers is half of what it is in the center. The distance between these points is the effective spread width. The outer fringes of the coverage area beyond these points should be overlapped on the next path to ensure a uniform rate over the area. *M*, *W*, *steeple*, or *lopside* patterns are not satisfactory, and one or more of the spreader adjustments should be made.

The National Organic Program Final Rule requires that raw animal manure must be either

- composted,
- applied to land used for a crop not intended for human consumption,
- incorporated into the soil at least 90 days before harvesting an edible product that does not come into contact with the soil or soil particles, or
- incorporated 120 days before harvesting an edible product that does come into contact with the soil or soil particles.

Applying Packaged Manure-based Products

One of the most common types of packaged, nonconventional soil amendments used by organic farmers is the manure-based blended fertilizer. These products usually have 2 to 5 percent N, P, and K. Dried manure compost is commonly used as both a bulking agent and low-grade source of nutrients in these products, which are normally bagged. Many different plant and animal byproducts are blended with the compost to increase the nutrient content. Nearly all products of this class are expensive, but they may be quite effective in some farm situations (typically for high-value specialty crops). Farmers with access to bulk sources of nutrients, such as poultry litter or farm-produced compost, can recognize substantial savings by relying on those resources instead of packaged products.

Manure-based blended fertilizers that contain either synthetic or nonsynthetic ingredients prohibited by the National Organic Rule National List may not be used in certified production.

Applying Compost

Compost is a well-decomposed, humified material with an optimal carbon to nitrogen concentration (C:N) ratio of about 10. The carbon in mature compost is resistant to further degradation. The available nitrogen in compost is low when compared to the available nitrogen in raw, uncomposted manures. In technical terms, this is the result of nitrogen immobilization in microbial biomass and losses from volatilization and denitrification during the composting process and curing. If the finished compost is exposed to precipitation, further losses of nitrogen take place.

Calculating a Compost Application Rate. It is important to calculate a compost application rate based on the concentration of nutrients in the material and crop needs. Applications made on a volume basis to improve a soil's physical properties, such as 4 to 6 inches of compost to production beds, may result in application of excess nitrogen, phosphorous, and potassium. As noted earlier in this publication, excess nutrients can present an environ-mental problem if they leach from or run off the soil into water sources.

Nitrogen availability coefficients. The primary concern with using compost is the amount of organic nitrogen it contains and its mineralization rate. Like the manure application rate, the compost application rate is usually based on the plant-available nitrogen in the material. Based on research tests, a nitrogen availability coefficient can be assigned to the compost that describes the fraction of total nitrogen it will make available to a crop over the first growing season.

The availability coefficient can vary widely, depending on the nature of the compost feedstocks. The nitrogen mineralization rates of composts made from feedstocks high in cellulose and lignin tend to be slower than those containing less woody constituents (even where C:N ratios are similar). The C:N ratio of the finished compost is an indicator of the relative availability of N to plants. Table 7 provides estimations of availability coefficients for composts with varying C:N ratios.

Calculating compost application rates to meet crop nutrient requirements is similar to estimating manure application rates. The process is described in the publication entitled "Composting on Organic Farms." Also refer to that publication for more information on using compost in organic production systems.

Table 7. Proposed N availability coefficients for compost		
C:N	Incorporated	Broadcast
Less than 10	0.50	0.38
10 to 15	0.25	0.19
16 to 20	0.10	0.08
21 to 25	0.05	0.03
More than 25	0.00	0.00

Using Legumes as Nitrogen Sources

Increasingly, organic growers are using legume cover crops as green manures in rotations to meet the N needs of cash crops. As we have discussed in other publications in the *Organic Production* series, legume cover crops fix signifi-cant amounts of N for use by subsequent crops. Through a symbiotic association with the legumes, rhizobia bacteria convert atmospheric N_2 into an organic form that the legume uses for growth. The accumula-tion of N via cover crops depends on the length of the growing season, climate, and soil conditions.

Sometimes a legume that is grown as a green manure crop can supply enough biomass N to meet the entire N requirement of the next crop. This depends on the climate, species of legume, soil conditions, and the length of time the legume is allowed to grow before it is killed.

Table 8 lists cool season legumes commonly planted on organic farms, along with their approximate biomass and biomass N yields. Table 9 lists summer annual legumes that can supply biologically fixed N for fall crops like broccoli, lettuce, or small grains. Tables 8 and 9 each represent North Carolina statewide averages in normal crop years.

Contact a local Extension center to determine appropriate biomass and N averages for a particular location. Remember, soil test recommendations do not generally take into account the N that is fixed by legume cover crops. Methods for determining plant-available N from green manure crops are described below.

Sown shortly after harvest of a cash crop, winter and summer legume covers serve as trap crops for leftover nutrients that might otherwise be lost from the cropping system. These trap crops prevent excess N and inorganic phosphorous from leaching into ground and surface water.

Legume residues contain phosphorous, potassium, and other nutrients that are recycled in relatively available forms for subsequent crop use. Where soil P and K sufficiency index values are high and soil pH is appropriate, legume cover crops can provide nitrogen for subsequent crops without contributing to problematic increases in soil P, K, and trace metal concentrations. Removing legume or other trap crop biomass from the field provides a means of reducing soil concentrations of these and other nutrients. For more information about cover crops and their management in organic production systems, please refer to the publication in the *Organic Production* series entitled “Cover Crops for Organic Farms.

Table 8. Cool-season legumes commonly planted on organic farms (Source: Clark, 1998)		
Legume	**Aboveground Biomass (lb/acre)**	**Aboveground Biomass N (lb/acre)**
Hairy vetch	6,000 –9,000	80 – 200
Crimson clover	5,000 – 8,000	50 – 140
Subterranean clover	5,000 – 8,000	60 – 150
Austrian winter pea	4,000 – 6,000	60 – 180
Common vetch	5,000 – 7,000	60 – 150
Hairy vetch/rye mixture	8,000 – 1,0000	80 – 180
Crimson clover/rye mixture	7,000 – 9,000	80 – 140

Table 9. Potential summer legumes for organic farms (Source: Creamer and Baldwin, 1999)		
Legume	**Aboveground Biomass (lb/acre)**	**Aboveground Biomass N (lb/acre)**
Soybean	3,000 – 7,000	50 – 100
Cowpea	3,000 – 7,000	60 – 90
Velvetbean	4,000 – 7,000	20 – 70
Sunnhemp	5,000 –7,000	80 – 160
Indigo	3,000 – 9,000	60 – 90
Lablab	3,000 – 5,000	20 – 45

USING COMMERCIAL NUTRIENT SOURCES ON ORGANIC FARMS

For information on particular brand-name products that are permitted on USDA-certified organic farms, growers can visit the Web site maintained by the Organic Materials Review Institute (OMRI). OMRI's role in the growing organic marketplace includes maintaining and distributing brand-name product lists. The OMRI Web site also describes essential tools for organic certifiers who audit farms and processing practices under the provisions of the new organic rule.

The National Organic Program requires farmers to manage crop nutrients and soil fertility to maintain or improve soil organic matter content. This must be done in a manner that does not contribute to contamination of crops, soil or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances. The following materials *can* be used:

- a crop nutrient or soil amendment included on the National List of synthetic substances allowed for use in organic crop production;
- a mined substance of low solubility;
- a mined substance of high solubility, provided that the substance is used in compliance with the conditions established on the national list of nonsynthetic materials prohibited for crop production);
- ash obtained from the burning of a plant or animal material, except under the conditions listed below (provided that the material burned has not been treated or combined with a prohibited substance or the ash is not included on the National List of nonsynthetic substances prohibited for use in organic crop production; and
- a plant or animal material that has been chemically altered by a manufacturing process (provided that, the material is included on the National List of synthetic substances allowed for use in organic crop production.

NOP also states that the following materials *cannot* be used:

- any fertilizer or composted plant and animal material that contains a synthetic substance not included on the national list of synthetic substances allowed for use in organic crop production;
- sewage sludge (biosolids) as defined in 40 CFR Part 503 (USEPA, 1994); and
- burning as a means of disposal for crop residues produced on the operation. Burning may be used, however, to suppress the spread of disease or to stimulate seed germination.

NOP & OMRI Web sites

The National Organic Program Web site is **www.ams.usda.gov/nop**

The Organic Materials Research Institute Web site is **www.omri.org**

Lime

Because of thousands of years of weathering and leaching, nearly all soils of the southeastern U.S. are naturally acidic. Weathering of minerals releases aluminum, iron, and manganese. These acidic cations replace calcium, magnesium, and potassium on cation exchange sites in the soil. Generally, acidic conditions are not favorable for vigorous plant growth and microbial activity.

Plant nutrient availability is strongly tied to the pH (acidity) of the soil solution. Decreasing soil pH directly increases the solubility of manganese (Mn), zinc (Zn), copper (Cu), and iron (Fe). At pH values less than approximately 5.5, phytotoxic levels of Mn, Zn, or aluminum (Al) can be present. Liming increases soil pH, which decreases the solubility of these elements and facilitates their precipitation as solids. It also supplies significant amounts of calcium (Ca) and magnesium (Mg), depending on the source of the lime. Indirect effects of liming include increased availability of P, molybdenum (Mo), and boron (B). Liming also produces more favorable conditions for microbially mediated processes such as nitrogen fixation and nitrification, and, in some cases, improved soil structure.

Because liming materials are relatively insoluble to water and immobile in soils, surface applications affect only the top 2 or

3 inches and are an inefficient way of changing pH throughout the root zone. Thoroughly incorporating lime in the soil increases the rate of pH change and impacts a larger volume of the soil. For this reason, farmers must incorporate lime into the soil before beginning no-till plantings or planting perennial crops.

While a good liming program usually provides adequate levels of calcium and magnesium for crop production, there are times when lime is not recommended but additional amounts of these two minerals are required. Gypsum ($CaSO_4$) is a soluble source of calcium, while epsom salt ($MgSO_4$) is a soluble form of magnesium. Magnesium sulfate is only allowed on organic farms that have a documented soil deficiency of this mineral.

Phosphorus Sources

A number of phosphorus fertilizers are available in the marketplace. Organic growers may have a difficult time determining which materials to use and how much to apply. Much of the difficulty stems from confusion about the difference between *total* and *available* P in fertilizers that are derived from mined phosphorus deposits. By law, P fertilizer is sold on the basis of available phosphate (P_20_5). Available P_20_5 is often determined by measuring the amount of P_20_5 that dissolves in a weak citric acid solution. This process is believed to imitate conditions near plant roots. This test provides a standard means of comparing different P_20_5 sources. An organic farmer must be aware that mineral sources of P, because of their generally low P_20_5 availability, are often promoted on the basis of *total* P_20_5 content and not on P_20_5 *availability*.

Rock Phosphate. In the case of rock phosphate, for example, the available P_20_5 is that proportion of the total P_20_5 in the processed (generally ground) rock that is available for crop uptake. While rock phosphate is approximately 25 to 40 percent P_20_5, it commonly contains only 2 percent available P_20_5. Thus, its fertilizer analysis is a relatively low 0-2-0. The fertilizer analysis represents the available nitrogen, P_2O_5, and K_2O, respectively, in the fertilizer. If it contains 2 percent available P_20_5 by weight, then 100 pounds of fertilizer contains 2 pounds of available P_20_5. For a sweet corn crop requiring 50 pounds of phosphate fertilizer, the grower would need to apply 2,500 pounds of rock phosphate (50 divided by.02 equals 2,500). Rock phosphate is derived from ancient marine deposits that vary in P_2O_5 content. It should be noted that rock phosphates with higher concentrations of available P_2O_5 are available in the marketplace.

Mineral Effectiveness Varies

The availability of nutrients derived from mineral deposits varies depending on the source of the materials, the inherent soil conditions where they are applied, and particular soil management strategies at the farm.

By observing crop performance at different application rates, farmers can make adjustments that reflect this variability.

Generally, transportation costs may prove prohibitive for the use of low-analysis mineral fertilizers, such as phosphate rock.

Colloidal Phosphate. Colloidal phosphate is a mined material consisting of clay particles surrounded by natural P_20_5. By weight, it is approximately 20 percent total P_20_5, but contains only 2 to 3 percent available P_20_5. It is a relatively expensive P source.

Bone Meal. This byproduct of the livestock industry is well known to organic growers. Typically it contains approximately 27 percent total P_20_5, most of which is available for plant use. There is a great deal of confusion about the P_20_5 content of bone meal because it is also sold as a feed additive. In the feed industry, phosphorus is expressed on the label as elemental P, while in the fertilizer industry it is expressed as P_2O_5 (P times 2.29 equals P_2O_5). Growers should be aware of this difference when comparing costs of P sources.

Potash Sources

Organic potash (K_2O) sources are similar to organic phosphates in that there are a variety of sources with differing degrees of nutrient availability and agronomic value. As with P_2O_5, there is a difference between *available* K_2O and *total* K_2O. Similarly, there is a difference between K and K_2O, with K_2O being 1.2 times higher in nutrients than K.

Potassium Sulfate and Potassium Magnesium Sulfate (Langbeinite). These two sources of K_2O are commonly used in both organic and conventional agriculture. Both products are available in natural deposits, although most potassium sulfate fertilizer is manufactured by causing a reaction between sulfuric acid and potassium chloride with a high electrical current. Langbeinite (K-Mag®), on the other hand, goes from mine to farm field with minimal processing. The Organic Materials Research Institute (OMRI) lists langbeinite and nonsynthetic potassium sulfate as allowable in certified organic production. It is advisable to check the National Organic Program and OMRI lists before using any mined potassium or other mineral materials.

Farmers should be extra careful and prudent when using potassium-bearing sulfates because of their high salinity and solubility. Although these substances are soluble salts, they are considerably less saline (and less soluble) than muriate of potash (KCl), which is the most common conventional potassium fertilizer. The highly available K_2O content (22% for langbeinite and 50% for potassium sulfate) of these materials allows for relatively modest application rates.

Beware of Rock Dust Claims
Any rock, of course, can be ground into powder, if the price is right. Various people have, at one time or another, proposed additions to the soil of assorted rock dusts, or even powdered gravel. Farmers considering such possibilities should rely on their own testing and powers of observation rather than on unsubstantiated testimonials.

Granite Dust and Greensand. These two *very slow-release* K_2O sources have little fertilizer value. Total K_2O content in granite dust typically varies from 1 to 5 percent, depending on the overall mineral composition of the rock. Granite is mostly feldspar, a mineral so slowly soluble that the K_2O is relatively unavailable to plants. Greensand is a clay-type mineral, glauconite, which is listed by OMRI as allowed for organic production. Total K_2O content of greensand is around 7 percent, but most of the potash is highly unavailable. Consequently, it has little agronomic value in the mineral form, despite vendor claims to the contrary. Growers that use either of these materials are advised that only the finely ground formulations are effective in releasing nutrients at all, and that only a very small fraction of total K_2O will be available in the year of application.

Feldspar. One of the major potassium-bearing minerals of granite, feldspar powder is fairly easily obtained through the ceramics trade. However, most feldspar K_2O is as tightly bound within its mineral structure as is the K_2O in greensand. Other sources of K_2O are preferable for meeting crop K needs.

Biotite (Black Mica). This and certain other micas contain several percent total K_2O. Because of mica's physical structure (quite different from feldspar or glauconite), the K_2O is relatively available in microbially active environments. If pure biotite can be obtained at a reasonable price, it may be cost effective and agronomically useful.

Kiln Dust. A byproduct of the cement industry, kiln dust can be an affordable limestone substitute and K_2O source (availability is approximately 6 percent) in areas where it is available. Some cement kilns are fired using assorted industrial wastes, including hazardous wastes. Dust from these kilns may be a hazardous product, and in several states it is legally treated as such. Check the National Organic Program and OMRI lists before using this material.

Secondary and Minor Nutrient Sources

A number of other rock dusts and powders are occasionally available in various parts of the country. Results of trials of these substances are occasionally reported in national or international publications. However, it is important to remember that results from one region may not apply to another. Additionally, when dealing with natural materials like rock, there is very little product consistency from one batch to another. Results from one trial may not be reproducible with other batches or sources of the same material.

Basalt Dust Amendments. If made available at a reasonable cost, these amendments can provide a wide range of trace minerals to crops over a period of several years. As with most rock powders, transportation costs are a major factor in determining cost effectiveness. Most of the rich volcanic soils of the world are derived from basalt, which gives some indication of basalt's agronomic value. Even when too expensive for land application, basalt dust can provide benefits when mixed with manure in the composting process.

Coal-type Products

Humates are commercial products usually prepared from leonardite, an oxidized form of lignite (soft coal) and clay. Leonardite sometimes contains up to 60 percent organic acids. These mimic the active part of the soil organic fraction. Soil scientists use very broad definitions to describe soil organic matter components. *Fulvic acids* and *humic acids* are terms that lump complex families of organic compounds together based on how they can be most easily extracted from soil. The organic components of leonardite are extractable by the same methods used for soil extraction and are often referred to as *humic acid* or *fulvic acid*. They should not be confused with the humic or fulvic acids common in agricultural soils.

Although extremely useful and cost-efficient in certain situations, such as nutrient substrates in soil-less greenhouse production, the usefulness of humates and similar products in most field situations is less clear (except under alkaline soil conditions). Using leonardite and similar products appears to be entirely consistent with the norms of organic production practices, given that they are natural products and proven growth stimulators.

To get an idea of the effectiveness of using humates to increase organic matter in the field, a farmer must consider the sheer volume of total organic matter in most agricultural soils. The top 6 inches of soil weighs approximately 2 million pounds per acre. Each percent of organic matter, therefore, weighs 20,000 pounds. Assuming for a moment that the organic matter in humate products actually is similar to that in soil, it requires 4,000 pounds of humates per acre to increase soil organic matter by 0.1 percent. It is unlikely that this much humate can be applied economically to increase organic matter content of agricultural soils.

Many humate products are listed as allowed by OMRI. Before using any humate (or fulvate), check the list to ensure that the brand name is on the OMRI list.

Plant Byproducts

Many plant byproducts are used by organic farmers as nitrogen sources for crops, including bagged alfalfa, cottonseed and soybean meals. These products are available as registered fertilizers with a guaranteed analysis of soluble N, P_2O_5, and K_2O. Just like any commercial, inorganic fertilizer, these materials can be applied to crops at agronomic rates based on the guaranteed analysis (printed on the label). Moreover, these materials usually contain additional nutrients in slowly available organic forms. They are often applied by organic farmers as preplant, starter fertilizers to provide nutrients for crops in early spring. After the soil warms, microbial mineralization of green manures, animal manures, composts, and other organic amendments can supply the remainder of the nutrients required by the crop.

Alfalfa Meal (or Pelletized Alfalfa). Dried alfalfa contains around 4 percent nitrogen and is commonly used as an animal feed. It is an excellent horticultural fertilizer and is said to contain “unknown growth factors” that make its mineral content more effective as a plant nutrient source.

Cottonseed Meal. After most of the oil is extracted from cottonseed for food-grade products, the hulls are finely ground to create this product. It is a rich source of nitrogen (7 percent).

A Note about Seed Meals
Seed meals and other plant-based fertilizers are permitted in organic production. Individual certifiers, however, may require that a fertilizer material be tested for excessive pesticide contamination before it is used. This might well apply to conventional cottonseed meal, because the crop is, in most cases, heavily sprayed. While genetically modified organisms are not permitted in organic production, there is currently no restriction on the fertilizer use of seed meals or other plant parts that may derive from genetically engineered crops.

Soybean Meal. Like alfalfa, this product is most commonly used as a protein supplement in animal feeds. With about 7 percent plant-available nitrogen, it can be a useful, although somewhat expensive, fertilizer.

Wood Ash contains about 2 percent P_2O_5 and 6 percent K_2O, but may be contaminated with heavy metals, plastic, or other prohibited materials. Use of ash is allowed with the restrictions described previously. Some state agriculture departments will test wood ash (and other materials) to determine its value as a liming agent and nutrient source.

Animal Byproducts

Blood Meal. This product consists of dried slaughterhouse waste containing about 12 percent nitrogen. Generally, blood meal products are relatively high in ammonia and must be used carefully to avoid damaging plant roots. If the material is applied to the surface and not incorporated into the soil, significant amounts of ammonia content will simply vaporize into the atmosphere. Blood meal is costly, and farmers should carefully evaluate the benefits that will be derived from its use relative to other organic nitrogen sources. The OMRI Web site lists products derived from blood.

Feather Meal. This is a common byproduct of the poultry slaughter industry. Although total nitrogen levels are fairly high (7 to 12 percent), feathers decompose slowly and, therefore, contain much less immediately available nitrogen than many other products of similar price.

Fish Meal and Fish Emulsion. Like most animal byproducts, these are rich in nitrogen. Fish meal contains approximately 10 percent N and 6 percent P_2O_5. Fish meal is most commonly used as a feed additive in livestock operations, but can be used as a fertilizer on organic farms. The National Organic Program allows fish products as plant or soil amendments. It is permissible to adjust the product's pH (acidity) with additions of sulfuric, citric, or phosphoric acid.

Fish emulsion is a fertilizer commonly used in organic greenhouse operations, such as organic transplant production. The fertilizer analysis of fish emulsion varies with the processing method. Either phosphoric acid or enzymes are added for a digestion of whole fish and fish parts to form a slurry. Acid-digested fish emulsion has an analysis of approximately 4-4-1, while enzyme-digested fish emulsion is usually labeled as 4-1-1. Fish emulsion is often fortified with chemical fertilizer, so organic farmers should be wary of any product that contains more than 5 percent nitrogen. If prohibited materials are used on certified fields, claims of ignorance about product constituents will not protect growers from loss of certification.

Seaweed Products

Seaweed fertilizers, soil amendments, and growth promoters are usually derived from kelp (*Ascophylluni* spp.) and other species of seaweed harvested primarily in the North Atlantic. Dried seaweed contains about 1 percent nitrogen, a trace of P_2O_5, 2 percent K_2O, varying amounts of magnesium and sulfur, and numerous trace elements.

Kelp Meal. Ground kelp meal is most often used for production of high-value horticultural crops in situations when the high product cost is most likely recoverable.

Raw Seaweed Products. Raw seaweed products are prepared by various methods and sold under a variety of brand names. Check the OMRI list to ensure that a particular product is allowed.

Seaweed Extracts. More often, compounds from kelp and other seaweed are extracted by various methods to concentrate both micronutrients and naturally occurring plant hormones in a soluble, easily transportable form. Kelp extracts are usually foliar-applied by farmers seeking a natural, supplemental source of micronutrients. Generally, the micronutrient concentrations of kelp extracts are low and may not correct deficiencies of nutrients in the soil.

Seaweed extracts have been promoted as a potent natural source of plant hormones and growth regulators. A class of plant growth regulators present in seaweed, the *cytokinins*, has attracted considerable attention in horticulture. It has been reported that foliar applications of cytokinins can have beneficial effects on crops: for example, increased numbers or size of fruits or seed heads, synchronization of flowering within a field, and delayed senescence (dying or dormancy). Cytokinins are also said to significantly reduce transplant stress when used as a root dip (Hall, 1997).

Most other plant hormones present in seaweed extracts are present at concen-trations insufficient to have noticeable effects on crops. In almost all cases, hormonal concentrations in seaweed preparations are rarely measured, and even more rarely guaranteed in commercially available plant hormone products. A number of manufacturers add synthetic hormones to their products to ensure performance in the field. This may pose problems if the product is to be used in certified organic production. Check the National and OMRI lists before using any plant hormone products, regardless of derivation.

ENVIRONMENTAL AND REGULATORY CONSIDERATIONS

Applications of manure, compost, and other organic amendments should be limited on fields where significant environmental hazards or concerns are present, for example on highly erodible land (HEL). Uniform application of organic materials on highly erodible land is often physically difficult. Surface-applied materials on HEL are subject to runoff. Nutrient rates should be based on realistic yield expectations (RYE) for the crop and on plant-available nitrogen or phosphor-ous, as described previously in this publication. For amendments with significant nitrogen content, applications should not be made to HEL fields more than 30 days before planting.

Complying with this last recommendation can complicate manure management for certified organic growers. Manure cannot be applied within 120 days of harvesting a crop that will come into contact with soil or soil particles. If a leaf lettuce crop (fertilized with manure) requires 45 days from planting to harvest, manure would have to be applied at least 75 days before planting. This is in obvious conflict with the recommendation not to apply manure more than 30 days before planting.

Best Management Practices

In addition to the rules for manure management mentioned previously in this publication, the National Organic Program Rule requires the use of best management prac-tices (BMPs) in organic operations. The objectives are to use “plant and animal materials to maintain or improve soil organic matter content in a manner that does not contribute to contamination of crops, soil or water by plant nutrients, pathogenic organisms, heavy metals or residues of prohibited substances." Some best management practices are listed below.

Animal waste should not reach surface waters by runoff, drift, manmade conveyances, direct application, or direct discharge during land application. Proper application rates and methods should be used to ensure that animal waste does not impact surface waters.

1. Animal waste should be applied to meet, but not exceed, the nitrogen needs for realistic crop yields based on soil type, available moisture, historical data, climatic conditions and level of management, unless there are regulations that restrict the rate of application for other nutrients.

2. Liquid waste should be applied at rates not to exceed the soil infiltration rate. In order to control conditions conducive to odor or flies, no ponding should occur.

3. Manure should not be applied to saturated soils, during rainfall, or when the surface is frozen. When manure is to be applied on acres subject to flooding, it 4. should be incorporated to the soil on conventionally tilled cropland. When applied to conservation-tilled crops or grassland, the waste may be broadcast, provided the application does not occur during a season prone to flooding.

5. Manure should not be applied closer than 100 feet to wells or within 200 feet of dwellings other than those owned by the landowner. Manure should be applied in a manner not to reach other property and public rights-of-way.

6. Manure should not be applied on grassed waterways that discharge directly into watercourses. If used in this situation, manure should be applied at agronomic rates and in a manner that causes no runoff or drift from the site.

7. Records of waste application should be maintained to establish actual application rates. The records should include date of application, amount of waste applied per acre by tract number and field number, most recent waste analysis and soil test report, and the realistic yield expectation (RYE) nitrogen rate.

8. Proper calibration of application equipment is important to ensure uniformity and accuracy of spreading rates.

9. Maintaining good crop growing conditions will reduce both runoff losses and leaching losses of plant nutrients. Preventing pest damage to the crop, adjusting soil pH for optimum growth, providing good soil tilth for root development, planting suitable crop varieties, and improving water management practices will increase crop efficiency in nutrient uptake.

10. Crop sequences, cover crops, and surface crop residues are useful tools for reducing runoff and leaching losses of soluble nutrients. Winter cover crops can capture residual nutrients after harvest of the summer crop. Nutrients from green manures and cover crops must be credited to determine the appropriate nutrient additions.

11. Where possible, develop field borders that can serve as a nutrient trap if field runoff occurs.

ACKNOWLEDGEMENTS

Many thanks to Dr. Steve Hodges and the North Carolina State University Soil Science Extension staff for making this publication possible.

Thanks also to ATTRA (the national sustainable agriculture information service) for providing the information included in the section on "Using Commerical Nutrient Sources." The ATTRA Project is operated by the National Center for Appropriate Technology under a grant from the Rural Business-Cooperative Service, U.S. Department of Agriculture. ATTRA is located in the Ozark Mountains on the University of Arkansas campus in Fayetteville, at P.0. Box 3657, Fayetteville, Arkansas, 72702. ATTRA staff prefers to receive requests for information about sustainable agriculture via the toll-free number 1-800-346-9140, or on the Web at http://www.ncat.attra.org.

RECOMMENDED READING

Sources Cited

Clark, A. (Ed.). 1998. *Managing Cover Crops Profitably,* 2nd Ed. Sustainable Agriculture Network, Handbook Series 3. Beltsville, MD.

Creamer, N.G., and K.R. Baldwin. 1999. *Summer Cover Crops*. HIL-37. North Carolina Cooperative Extension Service, NC State University. Raleigh, NC. Online: www.ces.ncsu.edu/depts/hort/hil/pdf/hil-37.pdf.

Hall, B. 1997. *Nonconventional Soil Amendments*. Appropriate Technology Transfer for Rural Areas. Fayetteville, AR.

Hodges, S.C. 1998. *North Carolina Nutrient Management Planning Manual*. North Carolina Cooperative Extension Service. NC State University, Raleigh, NC.

Organic Materials Research Institute. 2001. Online: www.omri.org/brand_list.html

Sanders, D.C. (Ed.). 1999. *1999 North Carolina Commercial Vegetable Recommendations.* pp. 5-8. North Carolina Cooperative Extension Service. NC State University, Raleigh, NC.

Tucker, M.R. and R. Rhodes. 1987. *Crop Fertilization Based on N.C. Soil Tests*. Circular no. 1. N.C. Department of Agriculture, Agronomic Division. Raleigh, NC.

U.S. Department of Agriculture (USDA). 2000. 7 CFR Part 205. RIN 0581-AA40. National Organic Program. Final Rule. Agricultural Marketing Service. United States Department of Agriculture. Washington, DC. Online: http://www.ams.usda.gov/nop/

U.S. Environmental Protection Agency (EPA). 1994. *A Plain English Guide to the EPA Part 503 Biosolids Rule*. Washington, DC. Publication no. EPA/832/R-93/003.

Weber J.B., M.R. Tucker and R.R. Isaac. 1987. Making herbicide rate recommendations based on soil tests. Weed Technology. 1:41-45.

Additional Reading

Baird, J.V., S.C. Hodges, J.P.Lilly, J.P. Zublena, and M.R. Tucker. 1997. *Careful Soil Sampling—The Key to Reliable Soil Test Information*. Publication no. AG-439-30. North Carolina Cooperative Extension Service, NC State University. Raleigh, NC.

Coleman, E. 1995. *The New Organic Grower : A Master's Manual of Tools and Techniques for the Home and Market Gardener*. 304p. Chelsea Green Publishing. White River Junction, VT.

Cramer, C., G. DeVault, M. Brusko, F. Zahradnik, and L Ayers (Eds.). 1985. *The Farmer's Fertilizer Handbook: How to Make Your Own NPK Recommendations…and*

Make Them Pay. Regenerative Agriculture Association. Emmaus, PA.

Diver, S. 1998. *Alternative Soil Testing Laboratories*. Appropriate Technology Transfer for Rural Areas. Fayetteville, AR.

Gershuny, G., and J. Smillie. 1986. *The Soul of Soil: A Guide to Ecological Soil Management*, 2nd Ed. Gaia Services. Quebec, Canada.

Kuepper, G., and S. Diver. 1997. *Sources for Organic Fertilizers & Amendments*. Appropriate Technology Transfer for Rural Areas. Fayetteville, AR.

Lilly, J. P., and J.V. Baird. 1993. *Soil Acidity and Proper Lime Use*. Publication no. AG-439-17. North Carolina Cooperative Extension Service, NC State University. Raleigh, NC.

Lilly, J. P. 1991. *Best Management Practices for Agricultural Nutrients*. Publication no. AG-439-20. North Carolina Cooperative Extension Service, NC State University. Raleigh, NC.

Magdoff, F. 1992 *Building Soils for Better Crops: Organic Matter Management*. University of Nebraska Press. Lincoln, NE.

Maynard, D.M., and G.J. Hochmuth. 1997. *Knott's Handbook for Vegetable Growers,* Fourth Edition. John Wiley & Sons, Inc. New York, NY.

Parnes, R. 1990. *Fertile Soil: A Grower's Guide to Organic & Inorganic Fertilizers*. agAccess. Davis, CA.

Peet, M.M. 1996. *Sustainable Practices for Vegetable Production in the South.*. Focus Publishing. Newburyport, MA.

Rynk, R., M. van de Kamp, G.G. Willson, M.E. Singley, T.L. Richard, J.J. Kolega, F.R. Gouin, L. Laliberty Jr., D. Kay, D. Murphy, H.A.J. Hoitink, and W.F. Brinton. 1992. *On-Farm Composting Handbook*. R. Rynk (Ed.) NRAES-54. 186p. Natural Resource, Agriculture, and Engineering Service. Ithaca NY.

Sarrantonio, M. 1998. Building soil fertility and tilth with cover crops. In A. Clark (Ed.) *Managing Cover Crops Profitably*, 2nd Ed. pp.22-23. Sustainable Agriculture Network, Handbook Series 3. Beltsville, MD.

Sarrantonio, M. 1994. *Northeast Cover Crop Handbook*. Soil Health Series. Rodale Institute. Kutztown, PA.

Sullivan, P. 1998. *Overview of Cover Crops and Green Manures*. Appropriate Technology Transfer for Rural Areas. Fayetteville, AR.

Zublena, J.P., J.C. Barker, and D. P. Wessen. 1996. *Dairy Manure as a Fertilizer Source.* Publication no. AG-439-28. North Carolina Cooperative Extension Service, NC State University. Raleigh, NC.

Zublena, J.P., J.C. Barker, and T.A. Carter. 1993. *Poultry Manure as a Fertilizer Source.* Publication no. AG-439-5. North Carolina Cooperative Extension Service, NC State University. Raleigh, NC.

Zublena, J.P., J.C. Barker, J.W. Parker, and C.M. Stanislaw. 1993. *Swine Manure as a Fertilizer Source*. Publication no. AG-439-4. North Carolina Cooperative Extension Service, NC State University. Raleigh, NC.

Zublena, J.P., and C.R. Campbell. 1993. Poultry Waste Analysis. Publication no. AG-439-33. North Carolina Cooperative Extension Service, NC State University. Raleigh, NC.

Zublena, J.P., and J. P. Lilly. 1991. *Nutrient Content of Fertilizer and Organic Materials.* Publication no. AG-439-18. North Carolina Cooperative Extension Service, NC State University. Raleigh, NC.

Zublena, J.P. 1991. *Nutrient Removal by Crops in North Carolina.* Publication no. AG-439-16. North Carolina Cooperative Extension Service, NC State University. Raleigh, NC.

The *Organic Production* publication series was developed
by the Center for Environmental Farming Systems,

a cooperative effort between
North Carolina State University,
North Carolina A&T State University, and the
North Carolina Department of Agriculture and Consumer Services.

The USDA Southern Region Sustainable Agriculture Research and Education Program
and the USDA Initiative for Future Agriculture and Food Systems Program
provided funding in support of the *Organic Production* publication series.
David Zodrow and Karen Van Epen of ATTRA
contributed to the technical writing, editing, and formatting of these publications.

Prepared by

Keith R. Baldwin. Program Leader, ANR/CRD
Extension Specialist—Horticulture
North Carolina A&T State University

Published by
NORTH CAROLINA COOPERATIVE EXTENSION SERVICE

AG-659W-06

07/2006—BS
E06-45788