Chapter 5

Soil Fertility and Cover Crops

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Soil health is the basis of a successful organic farming system. Fertile soil provides essential nutrients to plants, while supporting a diverse and active biotic community that helps the soil defend against environmental degradation. More emphasis is placed on biological processes within the soil system to recycle and release nutrients rather than provide high amounts of soluble nutrients from manufactured fertilizers. This chapter focuses on the various approaches to managing and maintaining soil fertility for organic vegetable production (also see Chapter 4 Soil Health for more information about how cover crops influence soil health).

Organic producers face unique challenges with managing soil productivity. For organic farmers, guidelines regarding nutrient management are fairly general. There is great variability in the quantities of nutrients applied and the soil fertility status of organically managed farms. Organic farmers seek to "build the soil" or enhance its fertility by using crop rotations, animal and green manures, and cover crops. Nutrient levels are maintained through the use of natural substances and approved synthetic substances as listed in Chapter 1 Organic Certification and the *National List of Allowed and Prohibited Substances*. This list includes a few synthetic fertility inputs, such as aquatic plant extracts, liquid fish products, etc. Growers are advised to consult with their certifying agent prior to purchasing or applying any synthetic inputs.

Managing and Maintaining Soil Fertility for Organic Vegetable Production

Organic Fertilizers

Organic fertilizers that are acceptable for organic production usually have a low nutrient analysis. Typically, organic fertilizers must be applied in larger quantities than synthetic fertilizers to attain the same nutrient value. Organic fertilizers consist of larger insoluble molecules that gradually break down into forms that are available for plant use. Nearly all nutrients must be dissolved in the soil solution before plant roots can absorb them. Fertilizers for organic production are available to the plant very gradually rather than quickly. These types of fertilizers are ideal because they do not drastically alter the soil's chemical properties during the short term. In addition, they promote a buildup of organic matter thus improving the soil's physical properties. Generally, fertilizers used for organic production have a low salt index; therefore, larger amounts can be applied using a single application without causing injury to plant roots. An added benefit of organic nutrient sources is that a single application can be completed without losing most of the nutrients (especially nitrogen) due to leaching after a large rainfall. However, it must be noted that excessive applications and misuse of organic fertilizers *will* cause environmental problems, such as nitrate leaching and phosphate enrichment of surface waters.

Soil Testing

Soil testing plays an important role in organic as well as conventional crop production. Typically, a soil test evaluates the soil's pH level, Cation Exchange Capacity, and the amount of macronutrients (e.g. phosphorus, potassium, calcium, magnesium, and sulfur). Testing the soil's organic matter content also is recommended. Soils also can be tested for micronutrients (i.e. nutrients required by plants in relatively small quantities). It is advisable to utilize the same laboratory for all testing; this practice will allow the grower to compare results from year to year. It is essential to use reliable soil testing procedures to obtain accurate results -- collect a representative sample of the field and include the soil volume where the crop plant roots will grow. Based upon the crops grown and soil test results, general recommendations specify the quantity of nutrients that must be applied. Refer to the University of Maryland Extension bulletin EB-236 available at http://mdvegetables.umd.edu/ for additional information regarding soil sampling, soil testing, and lime and fertilizer recommendations based on soil test results.

pH Management

The simplest and most important factor in all growing systems is to maintain optimal soil pH levels. The optimum pH for the growth of most vegetable crops is between 6 and 7. The pH level of soil influences nutrient solubility, microbial activity, and root growth. High pH favors weathering of minerals, bacterial populations, and an increase in the release of cations; however, it reduces the solubility of salts including carbonates and phosphates. Typically, pH levels less than 5.5 reduce the availability of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and molybdenum (Mo). However, the availability of aluminum and manganese can increase to toxic levels. Low pH levels reduce the activity of important microbial decomposers, which can greatly depress the biological conversion of organic material to useable nutrients for plant growth. Nitrogen fixation by legumes is also reduced at low pH. Over time soils become acidic due to manure applications; therefore, it is important to monitor the pH level and apply agricultural limestone according to soil test recommendations if the pH falls below 6.0. Soils with pH levels ranging from 7 to 8.3 promote microbial activity, but may limit phosphorus, iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) availability. Utilizing organic matter amendments and organic foliar products help increase the availability of these nutrients under alkaline conditions.

Nitrogen Management

Many organic farms supply nitrogen for crops through nitrogen fixation using legume cover crops. Legume cover crops and green manures can be excellent sources of nitrogen. Vigorous stands of clovers or hairy vetch as well as other legume cover crops can provide between 100-200 pounds of nitrogen—the amount of nitrogen necessary for subsequent vegetable crops. Approximately half the nitrogen in a green manure cover crop is released during decomposition following incorporation. However, nitrogen requirements also can be supplemented through the addition of animal manures—either composted or raw, or other more concentrated sources of nitrogen (e.g. blood meal, fish emulsion, seaweed, and vegetable meals).

Manure

Growers should recognize that it is not possible to rely solely on animal manure or compost to supply all the nitrogen needed for vegetable crops. Phosphorus is immobile and has the tendency to accumulate in soil due to the fact that growers add manure to achieve the necessary level of nitrogen. After a few years, phosphorus levels build to detrimental levels. As a result, cover crops must be used to aid the supply of nitrogen without increasing phosphorus levels (see the cover crop section). The precise nutrient content of any manure is dependent upon the livestock species, the rations fed, the kind of bedding used, and the amount of liquid added. It is advisable to test manure in order to assess its fertilizer value. Fresh manure that has not been composted will have greater nitrogen content than composted manure; however, the use of composted manure will contribute more to the organic matter content of the soil. Fresh manure is high in soluble forms of nitrogen, which can lead to leaching losses when over-applied. Fresh manure may contain high amounts of viable weed seeds; this can lead to weed problems. Heavy metals also can be problematic with regards to manure—especially when industrial-scale production systems are used. Heavy-metal contamination also is a concern for composted sewage sludge, which is the reason that it is prohibited from most certified organic production systems. The improper use of raw manure can adversely affect the quality of vegetable crops. When manure breaks down in the soil it releases phenols that are absorbed by plants, these compounds can cause off-flavors and odors for vegetables such as potatoes, cucumbers, squash, and many of the brassicas.

In addition to these concerns, a recent phenomenon has been observed when Maryland growers used fresh manure or compost from animals that were fed hay or grass from a field that was treated with an herbicide containing the active ingredient aminopyralid. This herbicide does not break-down easily and can pass through the digestive system of a horse or ruminant and appear in its manure. If the manure (or compost made from this manure) is spread onto a field, the active ingredient can adversely affect vegetables (especially tomatoes) by causing new growth to become twisted and reduced in size. Often affected plants are unable to produce fruit. Growers must exercise caution when purchasing manure or compost.

Raw animal manure must either be composted or incorporated into the soil at least 90 days prior to harvesting an edible product that *does not* come in contact with the soil (e.g. staked tomatoes, peppers, sweet corn, etc.). A minimum of 120 days are required prior to harvesting an edible product that *does* come into contact with the soil (e.g. radish, spinach, bean sprouts, potatoes, etc.).

Composting

Figure 1. Composted manure

According to organic standards, composted plant or animal materials must be produced through a process that establishes an initial carbon-to-nitrogen (C:N) ratio between 25:1 and 40:1 and achieves a temperature between 130°F and 168°F. The C:N ratio is an important consideration when using various composts; it also is a controlling factor in the composting process itself. Composting operations that utilize windrow composting systems must maintain a temperature within that range for a minimum of 15 days. During this time materials must be turned 4-5 times. Heat generated during the composting process kills most weed seeds and pathogens. The microbial-mediated composting process lowers the amount of soluble nitrogen forms by stabilizing the nitrogen in larger organic, humus-like compounds. Composting converts animal wastes, bedding, and other raw products into humus—the relatively stable, nutrient-rich, and chemically active organic fraction found in fertile soil. In stable humus, there is little free ammonia or soluble nitrate; however, a large amount of nitrogen is bound as proteins, amino acids, and other biological components. Other nutrients are stabilized in compost as well. A disadvantage of composting is that some of the ammonia-nitrogen will be lost as a gas. Single-handedly, compost may not adequately supply the available nutrients—particularly nitrogen during rapid growth phases of crops with high nutrient demands (e.g. watermelon, tomato, and pepper at fruiting).In addition, composted manure typically is more expensive than fresh or partially aged manure.

Rapid-dried Manure

Manure or compost that has been heated to rapidly dry out can be easier to handle and applies more uniformly to fields—especially those that have been processed into pellets (Perdue AgriRecycle OMRI approved pelleted poultry manure 4:2:3). Heat drying of manure and immature compost may increase volatilization of ammonia-nitrogen and reduce the total nitrogen content of the finished product. Partially composted material that has been dried rapidly at high temperatures rather than cured at normal temperatures will not be as biologically active as mature compost. Prior to using rapidly-dried manure/compost, growers must verify that the manure/compost has been certified for organic crop production.

Figure 2. Perdue's AgriRecycle Microstart 60

Applying Manure

One of the most challenging aspects of using manure as a fertilizer is the accurate application of the material. For some growers, the box spreader is an obsolete piece of equipment designed to dispose of a waste product, and not manage a nutrient resource. Growers should attempt to calibrate their spreaders to determine the rate of manure application. When attempting to accurately distribute manure based upon the needs of the crops, it is sometimes difficult for growers to calibrate many of the machines. To calibrate a spreader, growers will need the following: scale (capable of accurate measurement in 1-2 pound units), 10 ft x 10 ft plastic sheet, 5-gallon bucket, and a spreader-load of manure or compost. First weigh the plastic sheet and bucket. Next, spread the sheet over the ground in the path of the spreader and drive at normal speed over the sheet. Take the sheet and transfer it and the manure to the bucket and then weigh all three. Subtract the weight of the bucket and sheet to determine how much manure was acquired. The amount of manure or compost applied per acre can be estimated using the following figures:

Pounds of manure on sheet	Tons of manure per acre
4	1.1
6	1.4
8	1.8
10	2.2
12	2.6
14	3.0
16	3.5
18	3.9
20	4.4

Available Nitrogen from Manure

Bedding or litter usually decreases the nutrient content of manure due to dilution. If materials high in carbon (e.g. straw) are present in the manure, nitrogen availability may be reduced by the larger C:N ratio of the product. High C:N ratio will tie-up the nitrogen and has the potential to cause a deficiency in the crop. A C:N ratio of 25:1 or greater leads to nitrogen tie-up in the soil; whereas, a C:N ratio of less than 25:1 releases nitrogen to crops.

All of the nitrogen in manure or compost will not be available to the crop during the first year. In non-composted manure, some of the nitrogen will be lost to the atmosphere during application in the form of ammonia gas. Manure applied to land should be incorporated as soon as possible after application to avoid ammonia losses. Nitrogen, in the organic form, must be broken down by microorganisms before plants can use it. Anywhere from 5-90% of the organic nitrogen may be available as useable forms the first year. For dairy manure, 40-60% of the nitrogen is generally considered to be available the first year, and 30-40% of the nitrogen is available during the second and third years. For poultry manure, 50-75% of the nitrogen is available the first year and 20-25% is available during the second and third years. For composted dairy manure, 5-20% of the nitrogen is available the first year. Composting manure reduces many of the negative aspects associated with raw manure use. Good compost is a "safe" fertilizer that will not burn plants and can be applied directly to growing vegetable crops safely.

Some commercial organic fertilizers consist of composted manures supplemented with rock powders, plant by-products, and animal by-products such as blood.

The residual effects of manure and compost are important. Some benefits are gained during the second and third years following application. When manure and compost are used to fertilize crops, soil organic matter increases over time and subsequent application rates can be reduced because of increased nutrient cycling. Continuous use of high amounts of manure or compost (>15 tons per acre per year) is not recommended as this often leads to high levels of nitrogen and other nutrients—especially phosphorus, which can potentially run off or leach to pollute groundwater. Composting also can concentrate several metals; therefore, making the contaminated compost more hazardous than the manure from which it was created. Calculating the residual release of nitrogen in subsequent years should help avoid excessive applications. Crop rotations that feature non-manured crops following manured crops are best as they avoid excess phosphorus and heavy metals, but supply micronutrients.

Cover Crops

Green Manure Cover Crops

Green manure cover crops are used to supply nitrogen and increase soil organic matter and can be incorporated into the soil while still green, thus, are referred to as green manures. Cover crops have the added advantage of protecting soil from erosion during the non-growing season, which also is an important method for conserving soil nutrients. Another major benefit obtained from green manure cover crops is the addition of organic matter to the soil. A rapid increase in soil microorganisms occurs after a young, relatively lush green manure crop is incorporated into the soil. The soil microbes multiply in order to attack the freshly incorporated plant material. During microbial breakdown, nutrients held within the plant tissues are released and made available to the following crop. The contribution of organic matter to the soil from a good stand of a green manure cover crop is comparable to the addition of 9-13 tons per acre of poultry manure.

Figure 3. Green manure legume and grass cover crops

During the breakdown of organic matter by microorganisms, compounds are formed that are resistant to decomposition. These compounds and the biological products produced by microorganisms help bind soil particles as aggregates. A soil that is well-aggregated tills easily, is well aerated, and has a high water infiltration rate. Increased levels of organic matter also influence soil humus (the substance that results as the end product of the decay of plant and animal materials in the soil). Humus provides a wide range of benefits to crop production. Grass-legume green manure cover crops are important for crop rotations due to the fact that they help replenish organic matter lost during annual cultivation. Table 1 has planting rates, time, and depth for most of the common cover crops for our area.

Factors that influence the ability of microorganisms to break down green plant material include soil temperature, soil moisture, and the C:N ratio of the plant material. As plants mature, fibrous (carbon) plant material increases and protein (nitrogen) content decreases. The optimum C:N ratio for rapid decomposition of organic matter is between 15:1 and 25:1. With high carbon residues, it is advisable to add some nitrogen fertilizer (manure, blood meal, compost, etc.) to aid the decomposition process. The lower the C:N ratio, the more nitrogen will be released into the soil for immediate crop use.

Legumes such as clover or hairy vetch can fix between 100 and 200 pounds of nitrogen per acre in a single growing period. The use of grasses such as rye or triticale without a legume somewhat increases the nitrogen content of a soil; however, grasses are typically used to increase soil organic matter. They also can scavenge residual nitrogen from the previous crop and keep it from being lost by leaching. A mixture of both grasses and legumes can be used to obtain the advantages of each. Improved soil tilth (or physical condition of soil includes such factors as the formation and stability of aggregated soil particles, moisture content, degree of aeration, rate of water infiltration, and drainage) from added organic matter improves root growth, which increases the capacity of a crop to take up available soil nutrients. A reliable website that will enable growers to learn about many different cover crops is: http://www.sarep.ucdavis.edu/cgi-bin/ccrop.exe.

Table 1. Seeding rates, time and depth of commonly grown cover crops in Maryland

Cover Crop	**Seeding Rate (lbs/ac)**	**Time to Seed**	**Seeding Depth (Inches)**	**Potential problems**
Rye (winter)	100-150	Sept. - Early Nov.	3/4 - 1 1/2	Regrowth may occur if not completely killed
Perennial Rye Grass	20-35	Aug. - Sept.	1/2 - 3/4	Low heat tolerance
Italian or Annual Rye	20-40	Aug. - Sept.	1/4 - 1/2	Slow establishment
Winter Wheat/Triticale	100-120	Sept. - Mid Oct.	1/2 - 1 1/2	Roll/crimp at soft-dough stage
Oats	70-100	May - June and Aug.- Sept.	3/4 - 1	Winter kills, can lodge easily
Red Clover	8-15	Aug. - Mid Sept.	1/2 - 1	Slow initial growth, pest susceptible
White clover	5-15	Aug. - Mid Sept.	1/4 - 1/2	Poor yield when hot and humid
Sweet white/yellow clover	15-20	Aug. - Mid Sept.	1/2	Seeds need scarified to germinate
Crimson clover	15-25	Aug – Sept.	1/2	Poor heat and no drought tolerance
Hairy Vetch	20-40	Aug. - Sept.	1/2 - 1 1/2	Slow establishment, weeds possible
Purple & Common Vetch	50-75	Aug. - Sept.	1 1/2 - 2 1/2	Weed may present a problem if sets seed
Buckwheat	50-70	May - July	1/2	Limited growing season
Millet	20-50	May - June	1/2 - 1	Summer cover crop
Hairy Vetch & Rye	25 and 75 100	Early to late Sept.	1/2 - 1 1/2	Rye may over grow vetch

Rape or Canola	5-10	April - May or early to mid Sept.	1/2 - 1	Potential pest carry over
Sudangrass/Sorghum (Sudex)	35-45	May - June	1	Can be difficult to incorporate
Forage or Oil Seed Radish	8-15	Aug. - mid Sept.	1/4 - 1/2	Winter kills, poor in wet soils
Austrian Winter Pea	50-70	Sept. - Oct.	1	Shallow root system

Grass Cover Crops

In Maryland, winter rye is a popular choice for winter cover crops are planted after the vegetable crops because it can generate vegetative growth through most of the fall and early winter. Fairly late in the season, oats or other small grains (e.g. wheat, triticale) also can be sown; however, they do not grow as well as rye. These grasses are effective scavengers of any residual nitrogen that is available from the summer vegetable crop. Rye produces a lot of biomass in the spring, which helps maintain soil organic matter levels. It also produces an extensive root system early in its growth cycle that effectively captures any late season nitrogen present after vegetable crops have been harvested. However, a potential concern regarding the use of rye is the occasional rank amount of residue that must be handled during the spring. Growers who desire to plant an early spring crop may not wish to plant a cover crop of rye, because when the spring is very wet the rye becomes more difficult to manage. In such instances, growers usually plant wheat or oats in fields that must be turned under in early spring—these cover crops are less likely to become very tall or unmanageable in wet seasons.

Figure 4. Rye cover crop

Annual or Italian ryegrass is less expensive than perennial ryegrass, and is more likely to winter-kill; however, it may overwinter in southern and central Maryland. These crops form a dense sod that reduces erosion. Oat as a winter cover crop can protect the soil without requiring intensive management in the spring, because it is frost-killed. To protect the soil, it is recommended that growers plant by late August to ensure that an adequate amount of growth is present before the first frost. Oat residues remaining on the soil surface may chemically suppress weed growth and act as a physical barrier. Also, oat may be used as a spring cover when mixed with hairy vetch. In Maryland, other small grains such as winter wheat, barley, and triticale have been used successfully as winter and early spring cover crops. Small grains provide an effective rotation crop when coupled with vegetables due to the fact that they generally do not host most vegetable diseases.

Summer Cover Crops

Summer cover crops such as buckwheat, sunn hemp, and sorghum grow quickly in warm weather and effectively smother weeds. These summer cover crops are drought tolerant, decompose rapidly, and are easy to incorporate in the soil; although they do not significantly contribute to the organic matter of the soil. Buckwheat flowers serve as a favorite nectar source for bees; however, if allowed to flower and set seed, hundreds of these plants will sprout the following year. To smother weedy fields, some growers plant a fallow cycle of two successive crops of buckwheat followed by winter rye. In general, buckwheat does not have frost tolerance. Other summer cover crops such as Sudangrass and sorghum-Sudangrass are fast-growing crops that require superior fertility and moisture in order to perform well. Under these conditions, the rank growth of

Figure 5. Buckwheat in flower (left) and Sunn Hemp summer cover crops

these crops provides exceptional weed suppression; although, it should be noted that this type of heavy growth can be difficult to incorporate. Mid-season mowing provides the opportunity for regrowth before the crop winter-kills. Pearl or Japanese millet also is a warm season crop that generates rapid growth provided that it has been planted during early June. Pearl or Japanese millet is not as tall or rank as sorghum-Sudangrass; however, it can be easily incorporated in the fall or spring.

Legume Cover Crops

Generally, legume cover crops are sown after the vegetable crop has been harvested and their residues have been plowed or disked in. Often, these cover crops supply the majority of the vegetables' nitrogen needs. Research conducted by the author (Brust 2010) concerning organic vegetable systems has shown that an effective cover crop of hairy vetch (2,500-3,200 pounds of dry matter per acre) will supply the necessary nitrogen for most vegetables, with the exception of sweet corn and possibly peppers. These crops would benefit from a 2,000-3,000 pound application of manure or compost during the spring. Legumes usually require proper drainage and fertility to establish and grow. At first, most legumes grow slowly; therefore, they do not compete well with weeds until they become well-established. An excellent practice is to sow the legumes with a companion crop such as oats, rye, or in mixes with perennial grasses.

There are many types of clovers, and selection should be based on soil type, climatic conditions, light, and water availability. Clovers do not compete well with weeds unless they have been mowed, when their ability to grow laterally and low to the ground provides an advantage.

- Red clover is a short-lived perennial that is mildly tolerant of soil acidity and poor drainage (a good stand can add 90 pounds of nitrogen to soil).
- Crimson clover grows rapidly, but has poor drought tolerance (a good stand can add 100 pounds of nitrogen to soil).
- White clover is a low-growing perennial that is tolerant of shade and slightly acidic soil (a good stand can add 110 pounds of nitrogen to soil).
- Ladino types are taller than the white or Dutch varieties, which are the low-growing strains (a good stand of these types can add 90-120 pounds of nitrogen to soil).
- Sweet clover is a biennial crop that is deep-rooted and adapts to a wide range of soils; also it is an excellent soil-improving cover crop.
- Yellow sweet clover matures earlier and is somewhat less productive than white sweet clover (a good stand of a sweet clover can add 80-130 pounds of nitrogen to soil).
- Austrian winter peas establish more effectively in cool weather and do not tolerate hot humid conditions. Austrian winter peas have shallow root systems and do not overwinter north of Maryland (a good stand of Austrian winter peas can add an average of 100 pounds of nitrogen to soil). Deep rooted cover crops may deplete soil of moisture in the spring, which may present a problem for subsequent crops during dry years.

Hairy vetch is a hardy, winter annual cover crop that performs well throughout Maryland (a good stand adds 100-180 pounds of nitrogen to soil). Vetch produces little growth during the fall; therefore, it is advisable to grow it with a grass companion during late August to mid-September to ensure adequate soil coverage during the winter. Utilizing rye allows the vetch to climb during the spring; this can reduce matting and increase its incorporation into the soil or its rolling. Rolling/crimping (see no-till section in this chapter) at flowering will kill the vetch and rye as well as leave a weed-smothering residue. Vetch can be spring-planted and used as a fallow because it provides a valuable cover through late the summer. Vetch has strong drought tolerance and is the most cold tolerant of the winter annual legumes.

Figure 6. Hairy vetch cover crop

Forage Brassicas

Forage brassicas include the varieties of several species of mustard-family crops such as rape, turnip, and forage radish. These cool-season crops (especially forage radish) help break-up compacted soils or pans with their tap roots. Research (Heckman et al 2009) has shown that other potential benefits of using forage radish includes suppressing weeds, building soil organic matter, releasing nitrogen early in the season, and reducing both nitrate leaching and soil erosion.

Figure 7. Forage radish cover crop early fall (left) and winter killed by March (right)

Other Methods of Establishing Cover Crops

Interseeding or undersowing a cover crop into a standing vegetable crop allows an earlier establishment of a winter cover crop. Earlier establishment increases the selection of cover crops, compared with waiting to sow a cover crop after the full-season vegetable crop is done. Cover crop sowing must be delayed long enough to minimize competition with the vegetable crop, yet early enough to ensure that the cover crop can survive competition with the vegetable and withstand the harvest traffic. Vigorous vegetables, such as winter squash and sweet corn are suitable for interseeding. This method requires effective soil-seed contact, sufficient rainfall, and adequate weed control early during the season to guarantee that the cover crop has the opportunity become well established. Interseeding immediately after the last cultivation is the most effective method.

Cover Crop, Manure and Nitrogen Content of Vegetables

Research by the author (Brust 2010) organic vegetable site in Upper Marlboro demonstrated that a vetch, vetch/rye, or rye stand of 2,600, 3,200, and 3,500 pounds of dry matter per acre, respectively, produced SPAD readings (i.e. chlorophyll levels, which are equivalent to overall nitrogen content of a plant) in vegetable crops that range between 85 and 160 pounds of a synthetic nitrogen application (Table 2). Treatments that did not use cover crops or manure (essentially the plots were covered with weeds), and had dry weight plants with a biomass of 1,200 pounds produced chlorophyll readings for the vegetable crops equivalent to 35 pounds of synthetic nitrogen. Typically, it would be necessary to apply a minimum of 12 tons/a of chicken manure to these "weedy" plots in order to obtain chlorophyll readings equaling 150 pounds of synthetic nitrogen. Adding extra manure to singular vetch treatments or vetch/rye treatments did not change the overall chlorophyll readings (Table 2). However, the addition of manure to the rye or no-cover plots increased chlorophyll readings on average by 25%. This occurrence demonstrated that plants in vetch treatments or vetch/rye treatments received an adequate supply of nitrogen from the cover crop, and the addition of the manure proved unnecessary and constituted an excess of nitrogen. It should be noted that the rye cover crop benefited from the additional nitrogen supplied by the manure due to the fact that the rye cover crop was unable to supply the necessary level of nitrogen for the vegetable crops.

Table 2. Cover Crop and Manure Contribution to Nitrogen Levels in Vegetables[1]

Treatment (cover crop)	Manure applied (2 tons of poultry manure)	Mean SPAD (chlorophyll) reading of vegetables	Equivalent value to a synthetic nitrogen application
Rye	No	39.2	85
Rye	Yes	49.4	135
Rye + Hairy Vetch	No	56.4	150
Rye + Hairy Vetch	Yes	58.2	160
Hairy Vetch	No	57.6	155
Hairy Vetch	Yes	58.9	160
No Cover	No	27.2	35
No Cover	Yes	34.7	75

[1]Vegetables included tomato, pepper, cantaloupe, eggplant and broccoli

Phosphorus and Potassium Management

An average of 75% of the phosphorus and potassium in manure will become available to crops during the first year of application. The phosphorus and potassium content of manure varies according to the type of manure and storage. Poor storage of manure or compost will lead to losses of potassium through leaching. Manure or compost products should be tested for phosphorus and potassium content prior to application. Other than manure, other sources of phosphorus for organic production include: bone meal, fish and poultry meal, and rock phosphate. Sources of potassium for organic production other than manure include: alfalfa meal, kelp meal, greens, and wood ash. Both phosphorus and potassium are relatively immobile within the soil; therefore, it is advisable to incorporate phosphorus and potassium fertilizers or amendments into the soil at a depth of six to eight inches.

Secondary Nutrients and Micronutrients

Secondary nutrients such as calcium, magnesium, and sulfur, and the micronutrients iron, manganese, copper, zinc, boron, and molybdenum should be supplied through manure, compost, and liming amendments. A significant advantage of organic nutrient sources is that they usually contain a small amount of all essential plant nutrients.

Growers should use soil tests and foliar tissue analysis to determine whether supplemental applications of these nutrients are needed.

Tillage

Tillage is an integral part of successful organic farming systems; thus, it is crucial to manage soil tilth, organic matter, and fertility. In order to control weeds, new organic systems usually require tillage prior to planting as well as cultivation after planting. Unfortunately, tillage destroys the organic matter that's critical for improving soil fertility and soil water-holding capacity. Tillage should be performed when soil moisture is low enough to prevent compaction. Because primary tillage operations are usually performed at least a month prior to crop planting, tillage operations require careful planning and the ability to capitalize on periods of dry weather. In recent years, no-till agriculture has been used more widely in organic farming systems. For more information regarding no-till vegetable production in Maryland, growers should visit the following links: http://newfarm.rodaleinstitute.org/features/0104/no-till/index.shtml or http://newfarm.rodaleinstitute.org/features/0104/no-till/chart.shtml.

No-till Vegetable Systems

No-till vegetable systems have the potential for wider adoption by commercial organic growers. Cover crops are vital for no-till production; it is imperative to select cover crops that have adapted to the specific region and specific cropping system. For example, hairy vetch has been successfully utilized as a no-till mulch for tomatoes at the USDA Beltsville and University of Maryland research sites. Non-chemical weed control is an available option for managing cover crops; however, success is often dependent on specialized equipment, cultural practices, and fortuitous timing. Several types of equipment are described below.

Figure 8. Rye-hairy vetch rolled cover crop

Flail Mowers

Flail mowers can chop cover crops until they remain only an inch above the ground, while shredding the cover crop material and leaving the mulch in place. Rotary mowers (brush-hogs) clip higher and usually distribute vegetative residue throughout a wider area. It is very important to determine the optimum time to mow cover crops because the root system senesces and dies once the cover crops have been mowed. Optimum timing is crucial because cover crops that have been mowed too early will re-sprout and compete with the vegetable crop—like a weed. Hairy vetch must be mowed when it begins to flower; whereas, rye should be mowed when the anthers shed pollen. Often, vetch will re-sprout when it is mowed too early.

Rolling/Crimping

Rolling/crimping was specifically developed for cover crop management in no-till production systems. They roll down and crimp cover crop—a technique known as rolling/crimping. Rolling/crimping uses heavy-duty drum rollers with horizontal-welded blunt-steel strips. When the drum rollers are pulled through the field they crush and crimp the cover crop, which leaves residue lying flat on the soil surface and discourages regrowth. Research at the University of Maryland Upper Marlboro station (Brust 2010) has shown that rolling/crimping cereal grains such as winter rye, wheat, hairy vetch, or a combination of rye and vetch is the most effective during the pollen-shed stage. Rolling/crimping at that stage kills cover crops just as effectively as herbicides.

Figure 9. Roller/crimper used to create dead-mulch layer

Undercutter-roller

The undercutter-roller is a specialized implement developed at Ohio State University; it was designed to slice through the soil and sever cover crop roots underground. It consists of a V-shaped sweep blade mounted on a toolbar, followed by a rolling harrow to crimp and roll the cover crop residue as it falls on the ground. Undercutting suppresses weeds more effectively than a flail mower or sicklebar mower. The undercut mulch is thicker and better equipped to prevent light penetration to the soil surface, which results in fewer weeds. Also, residue remains on the soil surface for a longer period of time.

Problems Associated with Over-application of Organic Nutrients

The problems associated with the over-application of organic nutrients can vary. In Maryland, the most widespread problem appears to be phosphorus over-additions when manure is utilized. This occurs because the ratio of phosphorus to nitrogen in manure exceeds what is required by a plant. In addition to the buildup of excess phosphorus, growers must remain aware of the concentration of copper and zinc that may accumulate in the soil. Growers should avoid becoming dependent upon animal manures. It has been demonstrated that a nitrogen surplus increases microbial activity which then decreases organic matter and reduces plant-microbe interactions. Excess nutrients also can increase plant susceptibility to pathogens and arthropod pests and can lead to increased weed competition.

Bioremediation of Soils

Growers who aspire to plant long-lived organic crops such as small fruit (e.g. blueberries, raspberries, strawberries (matted row)) will sometimes discover the presence of plant parasitic nematodes which can greatly reduce yield. Nematodes that can impact yield include lesion (*Pratylenchus penetrans)*, dagger (*Xiphinema americana*) and root knot nematodes (*Meloidogyne* spp.). Currently, there are accepted methods used to reduce these nematode pests and increase organic matter, including the establishment of a cover crop regime. The cover crop regime should be initiated two years prior to planting the main crop. The planting regime includes utilizing Sudex (sorghum x Sudan grass) in the spring, followed by mowing once or twice during the summer months to reduce fibrous plant material. In August, Sudex should be incorporated and the rape (Dwarf Essex) is planted and allowed to overwinter. In the spring of the second year, the rape is mowed and plowed under to release chemicals that are toxic to nematodes. A second rape crop is planted two weeks after the first has been plowed under; it is then allowed to grow until the end of the summer. The next steps are largely contingent upon the particular crop that will be planted. Growers should note that this description is merely a general summary of the process. Details regarding the entire process can be located in the *Pre-Plant Renovation and Soil Conditioning for New Vineyards and Small Fruit Plantings* by John Halbrendt, Penn State University Fruit Laboratory.

REFERENCES

Brust, G. 2010. Supplying nitrogen to vegetables in organic production systems. Found at: http://mdvegetables.umd.edu/Horticultural/index.cfm

Heckman, J.R., R.R. Weil, and F. Magdoff. 2009. Practical steps to soil fertility for organic agriculture, p. 139-173, In C. A. Francis, ed. Organic farming: The ecological system. American Society of Agronomy/ Crop Science Society of America, and Soil Science Society of America, Madison, WI