Crop Rotations, Composting and Cover Crops

FOR ORGANIC VEGETABLE PRODUCTION

Introduction

Organic production and consumption has increased to a $39.5 billion industry in the United States with over 22,000 organic farmers. Over 5.4 million acres are in organic production in the U.S., including 164,403 acres of organic vegetables, valued at $1.3 billion. Consumers purchase organic foods for several reasons including a reduction in pesticide residues (organic production prohibits the use of synthetic pesticides) and perceived health benefits in terms of phytonutrients and certain vitamins. Organic consumers support local farmers who rely on environmentally-friendly methods of production that help protect groundwater and waterways. The majority of organic vegetable growers incorporate crop rotations, composting, and cover crops in their operations. The following information offers a guide for including these practices to meet certified organic rules and increase the long-term sustainability of an organic farm.

Crop Rotation

Crop rotations involve a systematic farm plan, where the crop planted in one field on the farm changes every year or every season. The history of crop rotations in farming systems dates back to ancient Greece and Rome, where Pliny described the benefits of incorporating legume crops to enhance soil and crop quality in grain crop systems that included wheat, barley, and emmer. In the U.S., George Washington established a seven-year crop rotation of grain and legume crops in the 1700s, along with carrots, cabbage, peas, potatoes, pumpkins, and turnips, to enhance soil quality on his Mount Vernon farm. While soil quality derives from inherent parent material, climate, and topography, human-mitigated operations, including tillage and crop rotation, can also affect soil fertility. More diverse crop rotations include more crops in the rotation and tend to have better soil quality. Longer crop rotations have been shown to improve the soil's physical properties, decrease erosion, reduce nitrogen (N) leaching potential, improve soil organic matter, and provide competitive crop yields.

Certified organic farmers are required by law to practice crop rotation under the USDA-National Organic Program (NOP). This standard dictates that the producer must implement a crop rotation, including, but not limited to, sod, cover crops, green manure crops, and catch crops that aid in soil quality and pest management. Among the many benefits of crop rotations, the USDA-NOP recognizes that crop rotations

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can improve soil organic matter, supply necessary plant nutrients, and provide erosion control. In the NOP standard on pest, weed, and disease management (§205.206), crop rotation is specifically stated as the first method used in managing pests and expressing the linkage between healthy soils and healthy plants. Because organic certification verifies that only organic practices were used for a minimum of 36 months prior to certification, farmers must complete an Organic System Plan (OSP), which provides information on the history of crop rotations planted in the last three years for every organic field. Thus, determining crop rotations for the next few years will greatly assist the certification process and lead to better farm management.

CROP ROTATIONS TO ENHANCE SOIL FERTILITY

Many organic farmers are striving for a closed, integrated farm, relying on on-farm or locally produced inputs and techniques, such as crop rotations, to meet crop nutritional needs. Building or maintaining soil carbon (C) and nitrogen (N) pools for subsequent crop use is an important consideration in developing sustainable organic farming systems. Incorporating crop residues from crop rotations and manure has led to greater soil carbon sequestration, improvements in soil function, nutrient cycling, and pest control. This has led to greater water holding capacity, higher microbial biomass of C and N, enhanced soil respiration, and greater potentially mineralizable N relative to nitrate-N; these results were attributed to the use of diverse crop rotations that included cover crops and applications of organic-based amendments.

In organic production systems, high N-demanding crops, such as sweet corn, are usually planted in a field following a soil-building crop such as oats, barley, rye, wheat, hairy vetch, and red or white clover, due to their quick establishment, ability to over-winter, weed competitiveness, and ease of mechanical termination. Because of their ability to fix N, leguminous cover crops provide the greatest potential for improving yields. Cereal crops generally result in higher levels of soil organic matter helping suppress weeds, immobilize soil nitrogen, and reduce nitrate leaching during winter months. Planting small grains and N-fixing cover crops together may be an effective management strategy to increase soil C and improve the N cycling processes, thereby reducing N leaching while maintaining robust yields. An example of a crop rotation plan from an organic farm in the northeast United State is shown in Figure 1.

Figure 1.

Typical organic vegetable crop rotation on Northeast U.S. farm (from C. Mohler and S.E. Johnson, 2009: Crop Rotation on Organic Farms: A Planning Manual, NRAES 177).

While legumes may provide a significant amount of N (20-120 pounds/acre depending on the species mixture), the contribution may not meet the complete needs of the cash crop. Soil testing in the fall following crop harvest can help determine the need for further amendments. Before planting in the spring, producers can apply well-decomposed animal manure, or preferably, a manure-based compost in an amount that will provide the full complement of N necessary for vigorous plant growth. Many NOP-compliant fertilizers, such as fish emulsion, humates, humic acids, surfactants, bioactivators, or Biodynamic™ preparations can also be used. However, these amendments may be viewed as cost-prohibitive on a large scale and must be compatible with marketing requirements in order not to limit marketing options.

Maintaining a soil pH of 6.0-7.0 is also critical for optimal crop production. Various agricultural liming materials can be used to neutralize the acidity of soils and to provide calcium and magnesium, but concern over soil magnesium buildup from dolomitic lime applications has led to the popularity of naturally mined calcium carbonate (limestone) in organic systems. Soil testing will help determine the need for lime and other rock mineral powders, such as rock phosphate. Hard-rock phosphate varies considerably in soil reactivity while soft-rock or colloidal phosphate has greater applicability. Gypsum is used on many organic farms to supply calcium and sulfur, especially on high-pH and sodic soils. Elemental sulfur can be used to lower pH so growers should test for this, especially when using compost every year. There are several organic-compliant commercial fertilizers and soil amendments that can be used for supplemental potassium, including sulfate of potash-magnesia (e.g., Sul-Po-Mag®) and naturally mined potassium sulfate, but all must be approved by a certification agency before application.

Research conducted through the Iowa State University Long-Term Agroecological Research (LTAR) experiment (Figure 2) has demonstrated excellent organic corn yields in the range of 120-209 bushels/acre when rotations with soil-building legumes preceded corn crops. Soil quality has remained high in these systems even with multiple tillage operations. High yields have been achieved by preceding organic corn crops with legumes, such as alfalfa, and composted manure applications. Many organic farmers seek optimal yields, based on the limits of their farm's internal resources, as opposed to maximum yields which are achieved through external inputs. Vegetable crops strictly relying on crop rotations, or cover crop residues, usually require additional compost applications to equal conventional yields. A systems experiment from 1998-2003 comparing organic and conventional bell pepper production demonstrated similar growth and yield of conventional and organic crops, when 100 pounds/acre N was applied as compost. Using a rotation of hairy vetch/rye preceding the pepper crop, without compost additions, resulted in reduced pepper yields compared to conventional yields 50 percent of the time. Soil analysis revealed higher N in plots where cover crops were tilled compared to strip-tilled plots, leading to recommendations for side-dressing N in strip-tilled fields. Thus, most organic growers use a combination of crop rotations, cover crops, and compost to achieve the highest yields.

Figure 2. Overview of the 44 fields of the Long-Term Agroecological Research (LTAR) experiment, which examines biological and economic outcomes from five crops in four crop rotations over time, at the ISU Neely-Kinyon Farm, Greenfield, Iowa.

EFFECTS OF CROP ROTATIONS ON WATER QUALITY

The issue of water contamination from excess N applications has become increasingly critical for the future of farming. A significant proportion of the NO_3-N in the Mississippi River comes from agricultural land in the Midwest, and high nitrate levels in waters from agricultural lands flowing into a municipal water plant is the subject of a 2015 lawsuit in Iowa. Relying primarily on crop rotations (legumes) to supply N to the vegetable crop can assist with alleviating potential leaching problems associated with excess N applications, even those from manure sources. Using composted manure, which is in a more stable organic form, will help reduce leaching loss compared with fresh manure or synthetic nitrogen. A study in Ames, Iowa, has shown that using longer rotations of corn-soybean-oats/alfalfa-alfalfa can help reduce nitrate leaching by 50 percent compared to a conventional corn-soybean rotation. Another study evaluating nitrate-N leaching in an organic vegetable system amended with composted poultry litter demonstrated that nitrate-N concentrations in lysimeter leachates were generally below 10 ppm during 52 months of monitoring. Thus, an ongoing challenge for organic growers is to synchronize nutrient release from various crop residues and amendments with crop needs, which in turn will help reduce both N_2O emissions and NO_3-N leaching.

CROP ROTATIONS FOR DISEASE PEST MANAGEMENT

Vegetable growers around the world are cognizant of the need for separating or rotating fields of vegetable crops of the same family in order to avoid soil born diseases prevalent in one particular family (e.g., a 3-year rotation to avoid Verticillium wilt in Solanaceae crops). In organic systems, this separation is even more critical, as synthetic fungicides are not allowed and prevention is the main tool utilized for disease management. Typically, organic farms maintain greater spatial and temporal diversity of crops than conventional counterparts, as green manure and perennial legume crops, in addition to vegetable crops, are often part of the OSP.

Other recommendations include a 3-4 year rotation to avoid blackleg in brassicas, and up to 20 years for white rot in allium crops. Variety selection should include cultivars designated as V, F, and N, which signifies resistance to Verticillium wilt, Fusarium wilt, and pathogenic nematodes. In a properly rotated organic field of the most resistant or tolerant vegetable cultivars available, planting at the proper time to permit quick germination and growth will generally keep disease and insect pests below economic injury levels. Because disease inocula can survive on infected crop residue, crop rotation can break the disease triangle (pathogen–host–environment) by changing to a non-host that does not support the growth of that particular pathogen. As with fertility regimes, a systems approach, including crop rotation and tillage, can limit continued spread of pathogenic organisms. Seed-corn maggots, the legless fly larvae that attack corn seeds particularly in cool, wet fields, can be avoided through the use of quality seed, crop rotation (especially away from previously infected fields) and planting when soils are warm (above 50° F) to ensure quick germination.

CROP ROTATIONS FOR INSECT PEST MANAGEMENT

Habitat diversification, which includes rotations of crop types across space and time, has been recommended as a strategy to enhance biological control and subsequent insect pest reduction, either through resource provisioning for natural enemies or spatial interference from a mixture of host-crop and non-host-crop species. As an example, corn rootworms (Northern and Western types of *Diabrotica* spp.) are not generally problematic on organic farms where 3-4 year crop rotations are practiced. There are also many natural enemies of prominent lepidopteran pests in vegetable systems, including predators that feed on eggs and larvae, such as lady beetles, lacewings, bigeyed bugs (*Geocorus* spp.), damsel bugs (*Nabis* spp.), minute pirate bugs, and others. The most significant parasitic wasps against European corn borer are *Macrocentris grandii*, a braconid larval parasite, and *Trichogramma ostriniae*, an egg parasite. Pathogens of corn borer include *Nosema pyrausta* and *Beauveria bassiana*. A diverse habitat has been found to support natural enemies through provisioning of nectar, pollen, and insect pest (host) sources, as some host must be maintained for natural enemy survival.

CROP ROTATIONS FOR WEED MANAGEMENT

In areas where soil fertility is adequate, weeds are considered the greatest constraint in organic vegetable production. Weeds generally occupy the same ecological niche as the annual or perennial crop plants where they grow and thus can be reduced through crop rotations utilizing crops with different life cycles and management requirements, such as deep-rooted, perennial legumes with annual, shallow-rooted vegetable crops. Cultivar selection can also impact crop competitiveness over weed species, as quick-germinating, taller, and leafier plants tend to be more competitive in their resource utilization. Longer crop rotations (three years or more) have been found to be instrumental in disrupting weed establishment and growth. In a study in Greenfield, Iowa, the shorter two-year organic rotation of soybean-wheat had, on average, two to three times the weed population of the three and four-year rotations of grain crops with oats/alfalfa.


RYE COVER CROP


CHECK FOR PRESENCE OF N-FIXING NODULES IN LEGUME COVER CROPS

With the focus in organic crop production on weed prevention, establishment and growth of weed seeds can be greatly managed through both crop rotations and allelopathic cover crops. Rye is particularly important in crop rotations in helping prevent weed proliferation through its allelopathic properties. Weed reductions of as high as 99 percent were observed for lambsquarter when soybeans and sunflowers were planted into killed rye compared to tilled plots with no mulch. In Iowa, weed populations in organic tomato plots with a rolled or crimped hairy vetch/rye mulch were lower or statistically equivalent to tilled plots with no mulch. Other fast-growing, high-biomass cover crops, like sorghum-sudangrass and sunnhemp (warmer climates) can provide excellent weed control when used in rotation with vegetable crops, and are particularly useful when rotating out of sod crops like bermudagrass or bahia grass.

ECONOMIC CONSIDERATIONS OF CROP ROTATIONS

Both farm and field considerations are involved in determining the economic viability of specific crop rotations. The balance between financial and biological considerations should be considered before long-range crop rotation plans are established. This includes both short-term (annual) and long-term (multi-year) farm management decisions. Several factors can often override rotation plans, including weather, market opportunities, and crop failure. Organic certification agencies have the authority to grant variances in crop rotation plans when unforeseeable events, such as an extended cold and rainy season cause germination to fail in spring vegetable crops, leading to a summer crop planting instead. Economic decisions are often based on growing the most profitable crop for the area, such as heirloom tomatoes, which can return $547.21 over all costs for a 4 x 100-foot bed. Not rotating tomato crops, however, can be detrimental to the long-term viability of the farm if diseases, such as late blight, severely affect yields and profits. Growing 3-6 signature vegetables which provide the main income for the farm is recommended while also rotating other less-profitable vegetable crops and non-vegetable crops which are useful for the ecosystem services they provide like N fertilization and other nutrients, beneficial insect habitat, weed management, and potential mitigation of greenhouse gases. Economic analysis shows higher returns in longer crop rotations that include grain crops and legumes compared to a two-crop rotation, and a general equivalency between vegetable crops grown with cover crops in rotation and those without cover crops. When crops like hairy vetch/rye are grown strictly for soil-building purposes and nothing from this crop is marketed off the farm, the cost of cover crop seed must be off-set by the additional gain in yield or, ideally, “green payments” for their carbon sequestration benefits. The soil-building properties of these cover crops and other benefits they provide to the whole farm, however, can be considered a type of bank to support long-term farm viability.

Organic Fertility Sources Manure and Composted Manure

In addition to crop rotations, organic farmers rely on animal manure or compost to provide additional soil fertility. Proper use of manure and compost in cropping systems is essential from both a crop production and environmental standpoint. According to USDA–NOP rules, raw manure cannot be put on vegetable crop fields unless it is properly composted or applied at least four months before vegetable harvest. Raw manure and compost should be applied after the soil has warmed in the spring so microbial activity can immediately commence, as opposed to applying to frozen or cold ground where manure can run off more easily, potentially causing water pollution. Incorporation is always the best strategy for the most effective use of these amendments, but if time or resources permit only a broadcast application, it is even more essential to wait at least four weeks before planting. Manure that is applied too soon before planting (at least two weeks with incorporation) can burn plant tissue and increase problems with insect pests, like seed-corn maggots. Compost that is not properly cured can detrimentally affect plant growth by tying up nitrogen and producing harmful compounds that can stunt plant growth or even kill sensitive plant species. Applying very low rates can lead to nutrient deficiency and reduced yields. On the other hand, excessive applications can lead to nitrate leaching, phosphorus runoff, and excessive vegetative growth of some crops. Thus, understanding the process of composting, compost nutrient composition and availability, and proper handling techniques is important when utilizing compost or manure as a major source of nutrients.

COMPOST USE IN ORGANIC VEGETABLE PRODUCTION

Organic systems heavily rely on organic matter based amendments such as manure and compost to meet crop nutrient demand. Composts and manures are applied to agricultural lands as a source of essential microbial populations, as plant nutrients, and as a source of organic matter. Composts have also been successfully used in organic vegetable transplant production. Organic fertility amendments such as compost and manure have been known to improve the physical, chemical, and biological properties of soil and produce yields equivalent to conventional cropping systems. A 2012 study proved that compost amendments in organic vegetable production systems can result in increased soil microbial biomass and enhanced microbial diversity. Soil fertility and crop nutrient management standards are set forth by the USDA-NOP and regulate practices required for management and application of plant and animal materials in organic production. Compost made in accordance with NOP rules may be applied in organic production systems without restriction on the time interval between application and crop harvest. Because many producers do not have the equipment, time, or resources to follow the rigorous NOP rules, they opt to follow the raw manure rule and apply their compost at least four months ahead of vegetable harvest.


COMPOST PILES

Numerous studies have shown benefits of using compost in organic vegetable production systems. Studies conducted on organic pepper production have shown better growth and yields in compost-based organic fertilizer treatments than their conventional counterparts. Similarly, a study conducted in organic cucumber production showed enhanced crop growth and higher marketable yields in compost amended soils. In another study, yields of peppers grown with dairy leaf compost produced similar yields as conventionally grown peppers. After three years of compost additions, yields of three Spanish onion cultivars from the compost plots were significantly greater than un-amended plots. Compost application rates in organic vegetable production systems vary depending upon the N content of the compost, N demands for the crop, and soil test results. Although some research has shown certain composts deliver only 10-25 percent of compost N as plant-available during the first year of application, because estimates for P and K availability in the first year are 40 percent and 60 percent, respectively, most growers apply based on total N rates in the compost to avoid problems of excess phosphorus pollution.

LAB TEST TO GET ACCURATE RATES

Obtaining an accurate soil, compost, or manure nutrient test from a reputable lab is essential in determining application rates for crops (Table 1). An example analysis with rates used for organic vegetable crops is a compost composed of poultry manure and organic straw that had an analysis of 3 percent nitrogen (3-2-3 N-P-K). In order to achieve a rate of 100 pounds of nitrogen per acre (100 pounds N/acre), a recommended amount if soil is relatively fertile as most Iowa soils are, would require applying 3,333 pounds/acre of the compost. While this number may seem large, when such an amount is applied, the compost itself on the fields may be imperceptible, often ranging from only a quarter-inch to half-inch in depth.

Table 1. Labs for testing Iowa soils

A & L Labs 111 Linn St, Atlantic, IA 50022 712-243-6933 www.alheartland.com/Html/Contact_us.html
Iowa State University Plant and Soils Lab Department of Agronomy - Kerry Culp 2104 Agronomy Hall, Ames, IA 50011 515-294-1360 http://soiltesting.agron.iastate.edu
Midwest Laboratories 335 4th Ave SW, Plainview, MN 55964 507-273-3339 www.midwestlabs.com
Woods End Research Laboratory PO Box 297, Mt Vernon, ME 04352 207-293-2457 https://woodsend.org

THE COMPOSTING PROCESS

Composting can be defined as the decomposition of organic matter into a humus-like substance and minerals by the action of microorganisms under aerobic conditions, combined with chemical and physical reactions. Composting is predominantly an aerobic or oxygen-requiring process in which microorganisms consume oxygen while feeding on organic matter. In doing so they produce carbon dioxide, water, heat, and miscellaneous gaseous byproducts to create compost (Figure 3). Composting stabilizes the nutrient content of manure and other organic materials and releases nutrients slowly, minimizing nutrient loss and potential environmental contamination. Depending on the raw material used, the time required to produce a mature batch of compost in Iowa could range from 6-8 months. To be successful, the composting process must be carefully managed; from the mixing of the initial ingredients through the high temperature phase to the maturation phase when the compost is deemed ready for use. Preparation of high quality compost requires appropriate raw materials, proper temperature and moisture management, and an understanding of the science behind the composting process.

The composting process begins when the appropriate raw materials and water are mixed and brought together in a pile. In the presence of oxygen, microorganisms begin to decompose the organic matter in the pile. The major group of microorganisms that participate in composting are bacteria, fungi, and actinomycetes. Bacteria tend to flourish during the early stages of composting, with higher populations of mesophilic bacteria active in the 95-115°F range, whose activity and energy raises the temperature of the compost pile. At 115°F the activity of thermophilic bacteria (heat loving bacteria) increases the temperature of the pile to 149-158°F. As oxygen levels are depleted microbial activity and temperature decreases. Compost piles must be turned and mixed to bring in oxygen and restart the decomposition cycle. After successive agitations and depletion of easily degradable compounds, bacterial activity and population decreases. The compost enters a final maturation phase and is inhabited by mesophilic bacteria, fungi and actinomycetes feeding on resistant organic materials that remain in the pile. The final phase of composting is the curing phase where the compost no longer reheats after agitation. During the curing phase, microorganisms, protozoa, worms, insects, and other large organisms that feed on microorganisms and organic matter colonize the pile. The concentration of nitrate N also increases as the compost pile cools down and enters this phase. The curing time for compost varies based on the length of the active composting phase which in turn depends on raw material, composting conditions, and management of the pile. The recommended time for curing is around 30 days; a longer period is necessary if active composting was not completed.

COMPOSTING METHODS

Depending on how the compost pile is handled, composting can be broadly classified into three methods: windrow, passive, and aerated static pile composting. There are other methods used commercially, but these three methods are common on organic vegetable production farms. Windrow composting is the most common of the three and in this method, the mixture of raw material is placed in long narrow piles or windrows that are turned on a regular basis. Typically, windrow height ranges from 12-15 feet for fluffy material such as leaves and from 3-6 feet for dense material such as manure. It is important to maintain the correct height for the windrow as large windrows can develop anaerobic zones near the center and can lose heat quickly and are not able to maintain the high temperatures needed to evaporate moisture and kill harmful pathogens if too small. Windrow width varies from 12-18 feet and should be turned or mixed on a periodic basis to provide oxygen

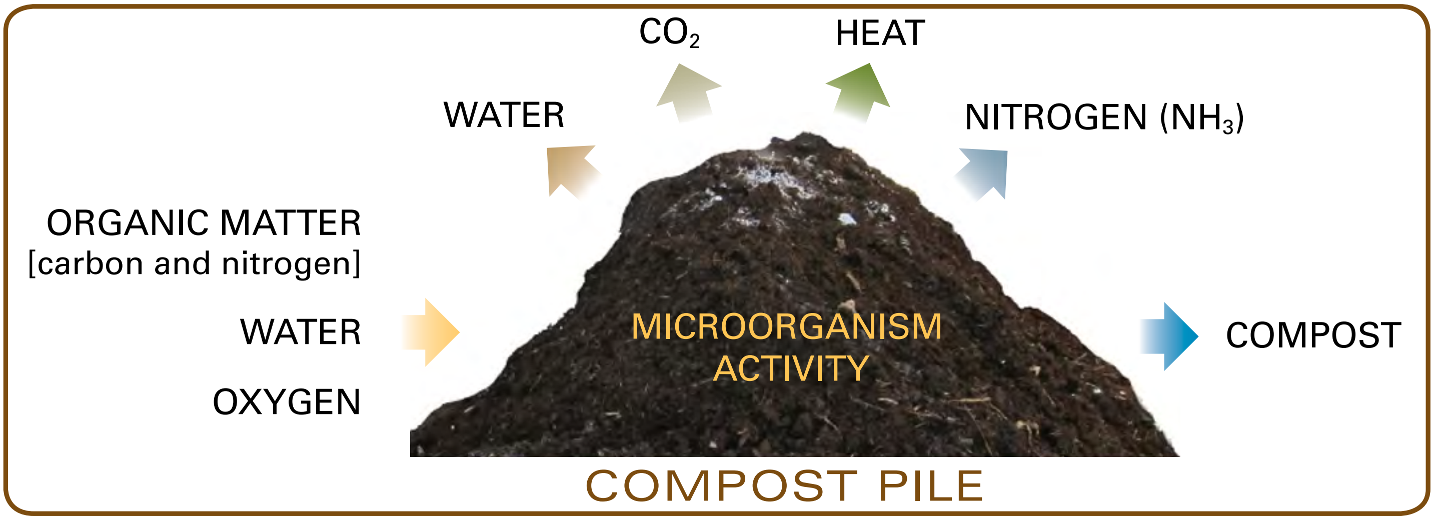

Figure 3. Schematic of composting process

throughout the pile to help rebuild the pore space in the pile that is lost due to decomposition and settling of the organic material, while releasing trapped heat, water vapor, and gases. Turning also distributes water, nutrients, and microorganisms throughout the windrow.

Aeration of the windrow occurs at the time of turning and by diffusion, wind, and convection between turnings. The number of times a windrow pile is turned is determined by many factors, including pile temperature, moisture content, and porosity of the pile. For certified organic production, the NOP stipulates that temperatures must be maintained between 130 and 170°F for 15 days, during which the materials must be turned a minimum of five times. A common strategy is to turn the windrow when the interior temperature falls below 122°F, resulting in turning every 2-3 days for the first 2-3 weeks, followed by weekly turnings for another 6-8 weeks. Growers often use thermometers with a long stem to measure temperatures at 50-75 foot intervals along the windrow. Turning the windrow on small to moderate scale farms usually is done with a front-end loader or a bucket loader. Specialized equipment such as tractor-assisted windrow turners can also be used as they are highly efficient and save time. Many organic farms use the windrow composting method, as it easily accommodates a wide range of feedstock, equipment, farm size, and management strategies.

In passive composting, organic materials are placed in a pile and left for extended periods of time to decompose. Aeration, which is a critical factor for the composting process, occurs passively by diffusion, natural air movement, and thermal convection. Without active aeration, a passive compost pile will take much longer than a windrow pile to mature. As the temperature of the pile rises, gases in the pile also heat and rise, creating a vacuum in the pile that results in the movement of air from the surrounding area. The moisture content of such a pile may exceed levels required to maintain a porous structure in the pile, which may lead to low temperature, slow decomposition, and release of malodorous gases, including hydrogen sulfide, from the pile. Passive composting is not approved for certified organic production. To meet NOP requirements, piles that are passively composted must be aerated to sustain microbial activity and adequate temperatures.

Growers often install perforated pipes at the base of the pile and sometimes will install fans or blowers to force air through the pile. This is the aerated static pile method. The base of the aerated static compost pile is composed of wood chips or chopped straw to provide porosity to the pile. Underneath the base is a perforated aeration pipe that provides oxygen and removes water vapor, carbon dioxide, and other products of decomposition. No turning or agitation of the pile occurs after the pile has been set up. Growers also cover the static pile with a layer of finished compost, straw, wood chips, or a breathable compost cover to insulate the pile and retain heat. The feedstock material for the compost pile needs to be well mixed before being placed on the pile as there is no further turning or agitation of the pile. Aerated static piles range in height from 6-12 feet. The length of the pile depends on the efficiency and uniformity of air distribution of the pipe and ducts. Typically, the length of the pile ranges from 90-200 feet. One of the advantages of this method over the windrow method is that it requires less area and the efficiency of aeration is higher, although uniform distribution of forced air largely depends on the porosity of the pile and how well feedstocks are mixed. This method, if done properly, can produce high quality compost in 6-8 weeks.

RAW MATERIALS

Raw materials or feedstocks used in composting are generally organic byproducts or waste materials. Some commonly used raw materials for composting include animal manure, crop residues, straw bedding, and food wastes. The elemental composition of the final compost largely depends on the chemical composition of the feedstock. Of all the elements, the two most important elements are carbon (C) and nitrogen (N). During the composting process, the N concentration directly influences microbial population growth, while C serves as the energy source. The most important aspect of the feedstock is the carbon to nitrogen ratio. Higher C:N ratios in raw materials (more than 40:1) can immobilize nitrogen and slow the composting process. Lower ratios lead to the loss of N as ammonia, although higher and lower ratios are debatable. The most accepted and agreed upon C:N ratio of the feedstock is between 25 and 35. Table 2 outlines C:N ratios of commonly used feedstocks for composting.

Table 2. C:N ratios of common composting materials

Raw material	C:N Ratio	Raw material	C:N Ratio
Crop residue and fruit/vegetable		Manures	
Coffee grounds	20:1	Broiler litter	14:1
Corn stalks	60-73:1	Dairy manure	19:1
Cull potatoes	18:1	Horse manure	30:1
Fruit wastes	18-49:1	Poultry	6:1
Hay	15-32:1	Sheep	16:1
Straw	48-150:1	Swine	14:1
Vegetable wastes	11-13:1		
Wood and yard waste			
Bark-hardwood	223:1		
Bark-softwood	496:1		
Grass clippings	17:1		
Leaves	54:1		
Wood chips	600:1		

Source: Rynk et al. 1992. On-Farm Composting Handbook, NRAES 54

In addition to considering the C:N ratio of the feedstock, the biodegradability and bioavailability of organic materials in the compost will depend on the form in which carbon exists in the pile. Feedstocks also impact the odor potential of the pile through presence of odorous raw materials, ammonia generated during composting, and anaerobic conditions within the compost pile. Feedstocks that have higher odor potential include fish wastes, swine manure, and other forms of liquid manure. Materials such as crop residue, leaves, and sawdust present little or no odor issues. A good mix of feedstock, appropriate moisture content, and frequent turning or agitation reduce odor problems. In aerated static piles, lining the surface with peat moss or finished compost helps to trap odor-forming gases.

APPLY COMPOST AFTER STABILIZATION

Compost is considered stabilized when the temperature of the pile does not rise, even after turning, and subsides to near ambient levels. Fully mature compost is well decomposed, stable, and has an earthy smell (Table 3). During the curing phase, the C:N ratio decreases, the pH of the pile shifts toward neutral, and conversion of ammonium-N (NH_4-N) to nitrate-N (NO_3-N) occurs. Plants absorb both forms of nitrogen, but higher concentrations of ammonium can cause temporary stunting and burning of foliage in susceptible young plants. Vegetable crops absorb most of their N in the nitrate form although in their younger stages they will absorb the ammonia form as well. Fully mature compost has gone through the curing phase and contains more of the nitrate than ammonia form. Although not a rigorous assessment, growers often test maturity of the compost based on its color and odor. A pile that is not fully composted usually smells foul and is considered immature. Measuring the electrical conductivity (EC), soluble salt concentration, and pH is another tool growers often use to assess compost maturity. The pH range for most finished compost is between 6.0 and 8.0. Similar to pH, EC largely depends on the feedstock used. Compost with high salt concentrations can affect seed germination and stunt root growth. Usually, compost with EC higher than 3 dS/m is considered phytotoxic for seed germination. However, compost EC can be in the 8-10 dS/m range if the intended use of compost is soil incorporation in the field. Additionally, certain vegetable crops such as onions and beans are more susceptible to higher salt concentration than others. Tests that measure oxygen consumed and carbon dioxide released from a finished compost pile can help determine the maturity of the pile. The rate of compost respiration determined over three days by carbon dioxide respiration at 98°F is a standard method of measuring compost stability by the US Composting Council. A rapid semi-quantitative test called the Solvita® test involves the use of colorimetric pads sensitive to carbon dioxide and ammonia placed into a jar that contains a fixed volume of compost sample. The pads are left in the jar for four hours where they absorb carbon dioxide and ammonia and change color. The color change on the pad surface is visually compared to a pre-calibrated coded color chart.

Table 3. Suggested optimum qualities of compost for on-farm use

Compost attribute	Optimum
Organic matter	Should range between 40-60%
C: N ratio	10-15:1
pH	6-8
Electrical conductivity	Below 10 dS/m
Phytotoxicity	Seed germination > 85%
Weeds	No or few seeds

Source: Cooperland 2002

Cover Crops

One practice that has been routinely used on organic farms, and is now gaining traction on conventional farms, is cover crops. Cover crops can have a profound impact on soil health, as they add soil organic matter, enhance soil structure and fertility, improve water-holding capacity, suppress weeds, and reduce soil erosion. Cover crops help support diverse and active soil biotic communities that serve as a foundation for agricultural sustainability.

NITROGEN FIXATION

Legume cover crops, in addition to adding organic matter, add nitrogen to the soil by fixing atmospheric nitrogen through a symbiotic relationship with soil bacteria (*Rhizobium* sp.) The bacteria, living in legume plant roots, absorbs nitrogen from the air and transforms it into plant-available forms. The amount of nitrogen contributed by legumes varies by species. There are specific species of bacteria that form symbiotic relationship with individual legume cover crop species. Growers should inoculate legume seeds with the proper nitrogen-fixing bacteria strain to improve nitrogen fixation. The cost for the inoculum packet is $5-10 and can usually treat 50 pounds of seeds. Research has shown significant increases in cover crop biomass and nitrogen-fixing potential in inoculated legume cover crop systems. Legume-based cover crops, such as hairy vetch and field pea, are best used before high nitrogen-demanding crops, like corn and vegetables, with rye being the best before N-fixers like soybeans. In warmer climates like Florida, sun hemp is used extensively as a cover crop.

WEED SUPPRESSION

Cover crops can be used to manage weeds in vegetable production systems by reducing weed germination and establishment by competing or producing allelochemicals which suppress weed seed germination. Cover crops can influence weeds either in the form of living plants or as plant residue remaining after the cover crop is killed.

Cover crops such as cereal grins and grasses establish quickly in the fall, cover the soil, and grow throughout the winter, thereby suppressing fall and winter weeds. Small-seeded legumes that are seeded alone in the fall are not a good choice for weed suppression as they grow slowly during cold weather and weeds may out-compete them.

SOIL EROSION AND WATER QUALITY

Most vegetable growers use cover crops as a strategy to reduce soil erosion in the fall and early spring. A cover crop provides vegetative cover during periods when a vegetable crop is not present and reduces the impact of falling raindrops, which otherwise would detach soil particles and increase erosion. They also slow the rate of runoff, thus improving moisture infiltration into the soil. No-tillage (commonly called no-till) and other conservation tillage practices combined with cover crops have shown to significantly reduce runoff and soil erosion losses. Cover crops have also shown to improve water quality by suppressing nitrate leaching. Research has found that nitrate leaching was reduced by 50 percent in plots having a rolled cover crop of cereal rye and hairy vetch in organic broccoli and pepper production compared to tilled cover crop plots of the same plants.

ORGANIC NO-TILL

The concept of no-till or reduced tillage has been proven to provide multiple environmental benefits on conventional farms, particularly in the area of soil conservation, while also reducing machinery, labor, and fuel costs. On organic farms, no-till systems had been constrained by the prohibition of herbicides to terminate cover crops. The Rodale Institute (RI) began investigating using a roller/crimper in 2004 to crush cover crops in lieu of herbicide termination to comply with organic rules. The cover crop (typically rye alone, or a rye and hairy vetch combination) is planted in the fall and then terminated with a roller/crimper when the grass crop reaches anthesis (pollen shed).

TRANSPLANTING IN NO-TILL

Weather conditions are extremely important in achieving success with organic no-till. When spring and summer rains fall evenly and adequately organic no-till soybean yields ranged from 37-45 bushels per acre in Iowa, which is an excellent organic tofu-variety soybean yield, especially considering no post-planting tillage was performed to manage weeds. Soil scientists at the USDA-ARS in Ames, Iowa, have documented increases in soil carbon and microbial biomass carbon and nitrogen in the organic no-till system compared to the normal, tilled organic system. The challenge remains to balance improving soil quality while maintaining optimal yields. Some farmers are experimenting with drilling organic no-till soybeans on 7-inch rows, as opposed to normal 30-inch rows. The concern with moving to 7-inch rows was the limited ability to perform any "rescue" cultivating if needed.

The reliance on irrigation in vegetable systems can help ameliorate unfavorable weather conditions during the crucial period when cover crops are decomposing and the cash crop needs additional moisture. Yields in the organic no-till vegetable systems studied in Iowa (broccoli, tomatoes, peppers, and lettuce) have been competitive with conventional yields when sufficient biomass is produced by the cover crop (planting at 1.5-2 bushels/ acre is best) and moisture levels are kept adequate through irrigation. Sweet corn, however, performs best in tilled systems, which was also found for field corn. Ideal results occur when the cover crop can be crushed early in the spring (before May 15) when the rye reaches, or is past

ROLLING HAIRY VETCH AND RYE

anthesis, which has become more difficult in recent years with global climate change creating cooler, wetter springs that slows cover crop growth.

Cambardella has also found interesting results with the no-till organic systems sequestering more soil carbon than tilled plots. Nitrate leaching is also reduced in the cover crop-based systems compared to completely tilled plots. In Florida's sandy soils, no-till summer squash yields were equal or greater than tilled yields, with no significant difference between no-till and plastic mulch. In warmer climates, organic no-till holds the most promise, because of the potential for early cover crop planting, continuous cover crop growth over the winter months, and earlier termination dates in the spring. Sandier soils also seem to be more amenable to organic no-till, as has been demonstrated in both Florida and Pennsylvania where even no-till corn yields were high. A mechanical issue (e.g., the ability of the roller/crimper to sink deeper into the soil and crush the cover crop) may be the mechanism here.

Conclusion

Crop rotations, composting, and cover crops can provide numerous horticultural and ecological benefits in vegetable production systems. A system's approach to production is necessary to identify and understand the significance of the linkages between grower practices and their implications for crop growth, productivity, and the environment. Examples provided here are a starting point and can be modified to fit grower needs, resources, and Organic System Plans.

Prepared by Kathleen Delate, professor and extension organic specialist in horticulture and agronomy with Iowa State University; and Ajay Nair, assistant professor of horticulture and extension vegetable production specialist with Iowa State University.

Photo credits: Kathleen Delate and Ajay Nair.

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References

Cooperband, L. 2002. The art and science of composting. Center for Integrated Agricultural Systems, University of Wisconsin, Madison, Wisconsin.

Delate, K. and C. Cambardella. 2004. Agroecosystem performance during transition to certified organic grain production. Agronomy Journal 96: 1288–1298.

Delate, K. H. Friedrich and V. Lawson. 2003. Organic pepper production systems using compost and cover crops. Biol. Ag. and Horticulture 21(1):131–150.

Delate, K., C. Cambardella, and A. McKern. 2008. Effects of organic fertilization and cover crops on an organic pepper system. HortTechnology 18: 215–226.

Delate, K., C. Cambardella, C. Chase, A. Johanns, and R. Turnbull. 2013. The Long-Term Agroecological Research (LTAR) experiment supports organic yields, soil quality, and economic performance in Iowa. Crop Management doi: 10.1094/CM-2013-0429-02-RS.

Delate, K., D. Cwach, and C. Chase. 2012. Organic no–till system effects on soybean, corn and irrigated tomato production and economic performance in Iowa, USA. Renewable Agriculture and Food Systems 27(1):49–59. doi: 10.1017/S1742170511000524.

Jokela, D. and A. Nair. 2014. Effects of reduced tillage and split fertilizer application in organic broccoli and pepper production systems. ISRF 14-36. http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1036&context=farmprogressreports

Moyer, J. 2011. *Organic No-Till Farming*. Rodale Institute.

Nair A., B. Carpenter, J. Tillman, D. Jokela, and K. Tester. 2013. Integrating cover crops in high tunnel crop production. ISRF 13-36. http://farms.ag.iastate.edu/sites/default/files/IntegratingCoverCrops.pdf.

Nair A. and M. Ngouajio. 2010. Integrating rowcovers and soil amendments for organic cucumber production: implications on crop growth, yield, and microclimate. HortScience 45:1–9.

Nair A. and M. Ngouajio. 2012. Soil microbial biomass, functional microbial diversity, and nematode community structure as affected by cover crops and compost in an organic vegetable production system. Applied Soil Ecol. 58:45–55.

Nair A., M. Ngouajio, and J. Biernbaum. 2011. Alfalfa-based organic amendment in peat-compost growing medium for organic tomato transplant production. HortScience 46:253–259.

Nair, A., T. Kaspar, and G. Nonnecke. 2015a. Cover crops in vegetable production systems. Iowa State University Extension and Outreach HORT3026. https://store.extension.iastate.edu/Product/Cover-Crops-in-Vegetable-Production-Systems

Nair A., K. Delate, G. Artz, and C. Bregendahl. 2015b. Assessing nitrogen credits from clover cover crops and effects of seed inoculation. http://farms.ag.iastate.edu/sites/default/files/AssessingNitrogenCredits_0.pdf.

Rynk R., M. Van de Kamp, G.B. Wilson, M.E. Singley, T.L. Richard, J.J. Kolega, F.R. Gouin, L. Jr. Laliberty, D. Kay, D.W. Murphy, H.A.J. Hoitink, and W.F. Brinton. 1992. On-Farm composting handbook. Rynk, R. (ed.) Northeast Regional Agricultural Engineering Service, Ithaca, New York, p. 6-13, 106-113.

Woods End Research Laboratory. 1999. Guide to Solvita® testing for compost maturity index. Woods End Research Laboratory Inc. Mt. Vernon, Maine. https://solvita.com/compost. Accessed 25 July 2015.

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