Crop Rotations on Organic Farms

by Keith R. Baldwin

Farmers in ancient cultures as diverse as those of China, Greece, and Rome shared a common understanding about crop rotations. They learned from experience that growing the same crop year after year on the same piece of land resulted in low yields, and that they could dramatically increase productivity on the land by cultivating a sequence of crops over several seasons. They came to understand how crop rotations, combined with such practices as cover crops and green manures, enhanced soil organic matter, fertility, and tilth.

For a variety of other reasons that we will explore in this publication, crops can and should be managed in rotations. No one disputes the fact that rotations are beneficial. The use of two- and three-year rotations by the majority of the grain farmers in this country shows they agree that yields are generally higher when crops are grown sequentially in rotations.

Figure 1. Soybeans are often part of an organic rotation schedule in the South. *Photo courtesy of USDA.*

In this publication, we will discuss crop rotations as key strategies that farmers can use to build the soil, manage pests, and increase yields. Our discussion will be organized around the following topics:

Contents

- **A historical perspective.** We will describe how crop rotations fit into the history of farming in America, particularly in the South, and how modern conventional farming methods have altered the way some farmers practice crop rotations.
- **Crop rotations versus continuous cropping**. We will summarize the results of several scientific studies that have compared the impacts of long- and short-term rotations and continuous cropping, or *monoculture*, on soil properties. These studies indicate that using crop rotations can lead to dramatic increases in soil fertility, help to optimize nutrient and water use by crops, and improve our soil resources.
- **Crop rotations and soil fertility.** We will describe the use of crop rotations to improve fertility.
- **Crop rotations and pest management.** We will describe the use of crop rotations to manage pests, including diseases, weeds, and insects.

Continuous Cropping

In the South, continuous cropping that incorporates organic matter is better than fallow periods for the soil. During fallow periods, biomass additions are not made to the soil. However, mineralization of organic matter in the soil continues during fallow periods, thus leading to reductions in organic matter.

A HISTORICAL PERSPECTIVE

There was a time in America when the use of long-term crop rotations figured prominently in every farmer's plans to boost soil fertility and control crop pests and diseases. But since the 1950s, farmers increasingly have replaced crop rotations with modern practices, such as using synthetic fertilizers to supply annual crop nutrients, applying agri-chemicals to control pests and diseases, and selecting improved crop varieties for increased yields.

Many farmers still use crop rotations, but in much shorter cycles. For instance, approximately 80 percent of the U.S. corn crop is now grown in two-year rotations with soybeans or three-year rotations with soybeans and wheat. These short, two- to three-year rotations rarely include pastures, cover crops, or green manures. These modern cropping systems have allowed American farmers to benefit from economies of scale by specializing their operations and marketing crops in volume. And these systems require fewer pieces of equipment because the crops grown are less diverse.

Such modern farming practices have helped U.S. farmers to produce remarkable crop yields. Nevertheless, the use of intensive cropping for the past 50 years has caused some negative impacts on our environment, especially on our farm soils. Today, the biggest risks for farmers are declining soil quality and increasing environmental degradation. As a result, researchers are once again focusing on crop rotations as a primary way to attain sustainable crop production, improved yields, and the economic returns that support a diversified rural economy.

In the South, farmers historically have used crop rotations in the production of cotton, tobacco, and peanuts. For example, these were traditional rotations for tobacco in the early 20th century:

- *tobacco—wheat—clover,*
- *tobacco—wheat—cowpea, or*

- *tobacco—wheat—red clover—mixed forages—corn.*

The cowpea was generally included when legumes were used as a green manure to maintain soil humus.

Cotton rotations were similar to those for tobacco. Other crops in the rotation were selected to maintain soil humus content, for their potential as livestock feed, or both. On livestock farms, a rotation of *corn—oats—wheat—clover—pasture* was often employed to produce livestock feed.

Crop Rotations: The Benefits

- Build soil fertility.
- Preserve the environment.
- Boost economic returns.
- Aid control of weeds, diseases, and harmful insects.
- Add to crop and market diversity.

CROP ROTATIONS VERSUS CONTINUOUS CROPPING

As discussed in other publications within this series, organic farmers work toward a key goal: to improve soil quality and structure. This goal isn't accomplished overnight. It takes years of concerted effort to feed the soil and build a friable soil structure with these characteristics:

- Nutrients and water reside in a soil nutrient reservoir or pool and become available to plants over both the short and long term.
- A healthy microbial pool of living microorganisms exists to facilitate nutrient cycling from the nutrient reservoir to plant roots.
- A natural ecosystem is established that serves as an environmental filter. This filter helps to protect the agro-ecosystem from potentially adverse farming practices and environmental calamities.

Soil Organic Matter

Organic farmers often judge and monitor soil health based on the amount of organic matter in each farm field. Active soil organic matter refers to a diverse mix of living and dead organic materials near the soil surface that *turn over* or *recycle* every one to two years. Active organic matter serves as a *biological pool* of the major plant nutrients. The balance between the decay and renewal processes in this biological pool is very complex and sensitive. The populations of microorganisms that make up the biological pool are the driving forces in soil nutrient dynamics. Together they also play a key role in building a soil structure that both retains *and* freely exchanges nutrients and water—a soil where plant roots thrive.

Crop Rotations and Soil Organic Matter

Which crop rotation factors affect soil organic matter?

- Rotation length
- Loss of organic matter from tillage operations
- Interactions with fertilization practices

Source: Karlen et al., 1994

Conventional Tillage

It's easy to see how this delicate world beneath the soil surface can be affected so readily one way or the other by various cropping systems. Imagine the impact on soil fertility, structure, and nutrient processes when the soil is turned up and mixed regularly. Many studies have shown that in most conventionally tilled agricultural soils, both soil organic matter and microbial activity *decrease*. Although bulk organic matter may still exist under some high-tillage systems, *active* soil organic matter is lost.

Extensive tillage stimulates microbial activity by providing soil microorganisms with the oxygen they need to break down or *consume* organic matter. Populations of microorganisms build quickly under these circumstances and actively decompose any amendments, green manures, or crop residues that are turned in with tillage. Organic matter doesn't normally accumulate in the soil under these conditions.

Because they do not generally include green manure or forage crops, continuous cropping and short-term rotational systems (systems that use two- or three-year rotations) deplete soil organic matter levels. As a result, soil structure—as measured by soil aggregate stability, soil bulk density, water infiltration, and soil erosion—can degrade.

Effective Crop Rotations

Rotations are most effective when combined with such practices as manuring, composting, cover cropping, green manuring, and short pasturing cycles. Together, these practices create soil quality improvements such as increased soil aggregate stability, decreased crusting of soil surfaces, and increased granular structure and friable consistence. Rotations that include sod, pasture, or hay crops also help to decrease bulk soil density, which can greatly impede root growth and nutrient flow. Simply put, management systems that maintain or increase soil organic matter have the potential for increasing soil productivity for all cropping systems, including organic systems.

Crop Rotations and Soil Erosion

Farmers who practice long-term crop rotation can reduce soil erosion on their land. A study conducted in 1988 found 6 inches more topsoil on an organic farm than on an adjacent conventional farm in the Palouse region of Washington state.

The 7,700-acre organic farm had been managed without the use of commercial fertilizers and with limited use of approved pesticides since its soil was first plowed in 1909. Researchers compared the organic farm's topsoil to that of a nearby conventional farm. The 1,400-acre conventional farm, first cultivated in 1908, began receiving recommended rates of commercial fertilizers in 1948 and pesticides in the early 1950s.

The difference in topsoil depth between the two farms was attributed to significantly greater erosion on the conventional farm between 1948 and 1985. Researchers attributed the difference in erosion rates to crop rotation because the organic farmer included green manure crops within the rotation plan while the conventional farmer did not.

Source: Reganold et al, 1988

CROP ROTATIONS AND SOIL FERTILITY

U.S. farmers soon may have no choice as to adopting such practices as crop rotations. Alarming increases in nitrogen concentrations in surface and groundwater have been attributed to the use of nitrogen and phosphorous fertilizers on farms. Such problems may result in laws mandating *best nutrient management practices* on farms.

Crop Rotations:
Match Profits with Practices

The challenge for farmers practicing crop rotation is this: to define systems that maintain farm profits with practices that improve soil quality and prevent environmental degradation.

Farmers may want to consider such options as alternative crops, double and triple cropping, value-added enterprises (such as producing cover crop seed or forages and green manures for composting), or a combination of all of these.

Nitrogen

Farmers use a best nutrient management practice when they use legumes in crop rotations to supply biologically fixed, atmospheric nitrogen as a replacement or supplement for inorganic nitrogen fertilizer. The amount of nitrogen in legume cover crops varies among species, but legumes generally contribute 50 to 200 pounds of nitrogen per acre. This nitrogen is mineralized over an extended period of time, so that any surpluses of it do not readily run off into streams and underground water supplies. The nitrogen in conventional fertilizers, however, is available immediately and surpluses can runoff or leach. Researchers estimate that from 40 to 75 percent of the total nitrogen contained in a legume cover crop is available in the soil for subsequent crops, depending on environmental conditions.

In addition, *trap crops* like small grains can be used to capture leftover nitrogen from farm fields after a harvest of cash crops. Small grains have extensive, fibrous root systems that can effectively mine the soil for available nitrogen. By capturing and storing residual soil nitrogen, these trap crops prevent this nitrogen from leaching or running off farm fields.

Phosphorus and Potassium

The effect of crop rotations on soil nitrogen (N), phosphorous (P), potassium (K) and carbon (C) is very complex. Southeastern organic farmers report that including deep-rooted cover crops in rotations helps to better distribute phosphorous and potassium from deep within the soil profile to the soil surface, where plant roots have better access to them.

Soil Organic Carbon Reflects Soil Quality

Soil organic carbon (SOC) is an important indicator of soil quality because it influences soil structure. Soil structure affects soil stability, as well as its capacity to hold water, and it is a driving force in nutrient cycling. Equilibrium concentrations of SOC in agro-ecosystems are the direct result of the farming practices implemented on the land. Organic farmers can attempt to build higher SOC with sustainable farming practices. However, they should realize that following a change in land management, SOC changes slowly.

Organic farmers have reported many beneficial effects from crop rotations on phosphorous relationships in the soil. According to these farmers, crop plants raised in rotations generally have better root function, and so are better able to take up phosphorous from the soil. The farmers point out that rotations employing green manures have a tendency to increase soil microbial activity, as well as plant-available phosphorous. Finally, the enhanced nutrient cycling that results from crop rotations increases the amount of two plant-available forms of phosphorous in the soil: biomass phosphorous and labile organic phosphorous.

Crop Rotations Boost N, C, P, and K in Soils

A team of researchers reported in a 1998 issue of *Agronomy Journal* that the use of rotational organic farming practices over an eight-year period increased soil organic carbon, soluble phosphorous, exchangeable potassium, and soil pH (acidity measurements).

At the conclusion of the eight-year trial, soil organic carbon was 2 percent higher in a field where organic rotational practices were used than in a baseline field where conventional practices and a two-year rotation scheme was used. Likewise, total soil nitrogen was 22 percent higher in the organic field than in the baseline conventional field. *Source:* Clark et al. (1998)

Light and Heavy Feeders

Organic farmers often base their crop rotations on whether various plants in the rotational lineup are light or heavy feeders. Crops differ in their ability to extract water and nutrients from the soil. Some plants with shallow roots feed near the surface; others have root systems that explore the soil at lower depths (Table 1). Following a shallow-rooted crop like onions or carrots, organic farmers may plant deeper-rooted crops like corn to recover nutrients that were unused by the shallow feeders and may have leached by irrigation or rainfall to lower depths in the soil profile.

Conversely, these farmers sometimes follow deep-rooted heavy feeders with shallow-rooted light feeders to scavenge nutrients that may remain after heavy applications of nutrients.

Examples of Light and Heavy Feeders

Some crops are *heavy feeders* that *deplete* soils, while other crops are *light feeders* that *build* soils.

Soil Depleting Crops
Row crops — corn, soybeans, vegetables, potatoes

Soil Neutral or Soil Conserving Crops
Cereal crops — wheat, barley, oats

Soil Building Crops
Legume sods — alfalfa, clover
Grass sods — prairie grass, meadows, pastures

Cover Crops

Warm-season legumes, grown as cover crops, figure prominently in every rotation on an organic farm. This is because they are a primary source of nitrogen for other crops in the organic rotation. In most years, growing a winter legume like hairy vetch or crimson clover will provide all the biological nitrogen necessary for a summer cash crop. Warm-season legumes like cowpeas, sunnhemp or soybeans also offer opportunities for biological nitrogen fixation during the summer season. Legumes often follow spring crops or precede fall vegetable crops in organic rotations.

Based on calculations of how quickly a particular cover crop will decompose when incorporated into the soil, organic farmers may choose to follow the crop with either a light or heavy feeding crop. If the expected rate of decomposition of cover crop biomass is rapid and biomass-nitrogen yield is expected to be high (such as a succulent winter legume killed in mid-May), a farmer may want to plant a heavy feeder. If the expected rate of decomposition is slow (such as a mature cereal grain) or biomass production may be low (such as a legume killed in late March), a farmer may want to follow with a light feeder.

EXAMPLE

How Cover Crops Are Included in Crop Rotations

A farmer decides to plant tomatoes, which are relatively *heavy* feeders, in late spring after all danger of frost has passed. In the late spring, in preparation for planting tomatoes, the farmer incorporates a hairy vetch cover crop into the soil to add organic matter and nitrogen to the soil.

The farmer chose hairy vetch as a cover crop because he/she knew that tomato plants need an early-season shot of nitrogen. Hairy vetch, with its low *carbon to nitrogen* (C:N) ratio and rapid decomposition rate, can fulfill that need.

What f the farmer had planted lettuce instead? Lettuce must be planted much earlier in the season than tomatoes. And legumes like hairy vetch make most of their biomass in the spring *after* lettuce would normally be planted.

In this case, the farmer might want to plant a small grain cover crop, such as cereal rye, during the preceding fall. Cereal rye will actively recover any leftover nitrogen from the past summer crop. That nitrogen will be available to the lettuce as the rye, still relatively green, breaks down quickly in the early spring.

Versatility is a Plus for Organic Farmers

- Organic vegetable farmers have ample opportunities to change their rotation plans even in mid-season, for example, as a response to insufficient nitrogen from green manures. They can choose from a diversity of vegetable crops that have widely ranging nutrient requirements. So, rotations can be quickly altered to fit the situation.
- Many vegetable crops, such as lettuce, remain in the field for a relatively short period, thus allowing for multiple croppings.
- Producing two or three crops in one season may offset the costs associated with leaving a field out of production every third or fourth year for "rebuilding."
- The patchwork nature of many small- to medium-sized market vegetable farms, containing many small fields, allows farmers to give individual attention to the particular fertility or physical needs of each field.

Source: Sarrantonio, 1992

Table 1. Effective root zone depth of key crops calculated in inches

Field Crops Barley, 24 Corn (Field), 24 Cotton, 24 Flax, 24 Oats, 24 Peanuts, 24 Rye, 24 Sorghum, 24 Soybeans, 24 Sunflower, 24 Tobacco, 18 Wheat, 24 **Forage Crops** Alfalfa, 24 Bluegrass, 18 Bromegrass, 24 Ladino Clover, 18 Orchardgrass, 24 Red & Sweet Clovers, 24 Sudan Grass, 24 Ryegrass, 24 Bermuda Grass, 18 Tall Fescue, 18	**Vegetable Crops** Asparagus, 24 Beets, 12 Broccoli, 12 Cabbage, 12 Cantaloupes, 18 Carrots, 12 Cauliflower, 12 Celery, 12 Corn (sweet), 24 Cucumbers, 18 Kale, 18 Lettuce, 6 Lima Beans, 18 Onions (bunch), 6 Onions (dry),12 Peas, 18 Peppers, 18 Potatoes, 18 Radish, 6 Snap Beans, 18 Spinach, 6 Squash, 18 Tomatoes, 18 Watermelons, 24	**Fruit Crops** Apples, 24 Blueberries, 18 Cane Fruits & Grapes, 18 Peaches, 18 Pears, 18 Strawberries, 6 **Turf** Athletic Fields (in active use), 6 Athletic Field (not in active use), 12 Golf Greens/Fairways, 6 Grass Sod (being established or prepared for immediate sale), 6 Grass Sod (lawn and sod being held for sale), 12	**Flowers** Annual Flowers, 6 Ericaceous Ornamental Plants (Azalea, etc.), 12 Gladioli/Peonies/Irises, 12 Other Bulb or Corm Plants, 12 **Nursery Plants** Bedded Plants (after propagation). 6 Finished Landscape Plants,(ready for sale), 18 to 24 Ground Cover Plants (vinca, ivy, etc.), 6 Lining-out Plants, 12 Perennial Ornamentals, 24 Trees, Shrubs (conifers and flowering shrubs), 24

Root depth was based on these factors:

1. The depth of soil to which most of the total root system has developed when the marketable part of the crop is being produced or when the loss of water from turf and ornamental plants is greatest.
2. Research and experience regarding the overall water needs of each crop for maximum quality as well as yield or growth.
3. The kind of soil in which some crops are grown. The depth of irrigation while the crop is developing its root system should be determined by the actual root depth at the time of irrigation.

Data adapted from: *Soil Moisture Sensors for Irrigation Management*, Bulletin 312, University of Maryland Cooperative Extension Service, 1984; *Evapotranspiration and Irrigation Water Requirements*, ASCE Manual on Engineering Practice, No. 70. Disclaimer: Commercial products are named in this publication for informational purposes only. The authors, Virginia Cooperative Extension, and Virginia Polytechnic Institute and State University do not endorse these products specifically and do not intend discrimination against other products that are not mentioned but which might also be suitable.

CROP ROTATIONS AND PEST MANAGEMENT

Consider the sheer abundance of insects, pathogens, weeds, and plant diseases, and you will realize the critical role of crop rotations in reducing damage by these pests on organic farms. Farmers who implement a good crop sequence must consider two things at once:

- How one crop can benefit from the crop that precedes it.
- How any pest problems these crops share can be addressed.

Because organic farmers cannot use conventional agricultural chemicals to manage crop pests and must rely largely on cultural strategies, they must have a better understanding than most farmers about how crop pests live and function. Basically, they must outwit these pests as they employ many kinds of strategies to complement crop rotations.

Learning Pest Histories

Understanding the natural history of a pest is extremely important for determining the sequence of crops in a rotation. Many insects and diseases attack more than one family of plants, and rotating into a different family may do little to reduce pathogen potential or insect pressure if the subsequent crop is also a host plant. For example, southern blight, *Sclerotium rolfsii*, is a pathogen that attacks most vegetable crops, regardless of family, genus, or species. If a field has a history of problems with this pathogen, managers may have to include a row crop in the rotation—for example, corn or some other grass, hay, or a pasture crop for two or three years.

Controlling Soilborne Diseases

Organic farmers also must know about the soilborne pathogens that build up when a soil is sown with the same crop or family of crops every year.

Crop Families. Generally, crops in the same family should not follow one another in the field. For instance, cantaloupes should not follow cucumbers. A *cucumber-melon-squash* rotation obviously invites disease problems. At a minimum, crops from a particular family should be separated by *at least* two years of crops from other families. For example, a rotation of families might include Brassicaceae (cole crops), followed by Asteraceae (lettuce, cut flowers), followed by Solanaceae (tomatoes, potatoes, peppers, eggplants), followed by Curbitaceae (squashes, cucumbers, melons).

Length of Rotation. The length of time soilborne pathogens remain viable in the field is critical to any decision about the length of the rotation before replanting the same vegetable crop. Although there are some exceptions, a four-year rotation that includes a succession of crops *not susceptible* to the same pathogens will generally minimize problems from soilborne diseases. For this strategy to be effective, however, it is important that pathogen-susceptible weeds and volunteer plants be excluded from the field, too.

Some exceptions to this rule include club root of crucifers, sclerotinia white mold on lettuce, and fusarium wilt (a disease affecting many vegetables). Long rotations of four years and more are desirable for avoiding these diseases. Where there is a history of problems with long-lived pathogens, these practices have proven beneficial:

- soil solarization (covering a field area with clear plastic so the sun can raise soil temperatures enough to destroy pathogens),
- compost additions,
- use of resistant varieties, and
- long rotations.

As a general rule, a two-year rotation will reduce the incidence of foliar (leaf) diseases because a primary source of inoculum for infection is often the infected tissue from previous crops. Generally, that tissue will be well-decomposed in two years, and any inoculum will disappear along with crop residues. For example, most of the inoculum for early blight in tomatoes, cercospora of cucurbits, and most foliar bacterial diseases can be eliminated by destruction and incorporation of residues and a one-year waiting period before replanting.

Table 2. Rotation periods to reduce soilborne diseases

Vegetable	Disease	Years without a Susceptible Crop
Asparagus	Fusarium rot	8
Cabbage	Clubroot	7
Cabbage	Blackleg	3 - 4
Cabbage	Black rot	2 - 3
Muskmelon	Fusarium wilt	5
Parsnip	Root canker	2
Peas	Root rots	3 - 4
Peas	Fusarium wilt	5
Pumpkin	Black rot	2
Radish	Clubroot	7

Source: S.A. Johnson & P.J. Nitzche, USDA

Tillage Practices. Various tillage practices can make an impact on disease control or crop rotations. For instance, southern blight pathogen survival from one year to the next is generally restricted to the upper 2 or 3 inches of soil, and burial below these depths is an effective disease control strategy. Farmers must also consider how different types of tillage systems can influence a rotation. For example, if management plans call for a period of no-till, incorporation of crop residues will be delayed and the selection of crops for a rotation in this instance may be more limited. Tillage practices that enhance soil drainage generally reduce the incidence of seedling diseases. Including rotational crops that are planted on high ridges or in plant beds in the rotation often reduces the incidence of damping-off disease.

Hard-case Pathogens. Some particularly troublesome pathogens in the soil can be controlled by relatively short rotations of specific plants that are unsuitable hosts for the disease. Other pathogens require longer rotations to control.

An example of a disease that requires a long rotation is Granville wilt or southern bacterial wilt. In fact, it is not possible to manage this pathogen successfully where the infestation level is moderate to high without an appropriate crop rotation. Rotations are effective against southern bacterial wilt because these bacteria do not multiply in the soil without susceptible plant tissue. Thus, populations decline if a suitable plant, such as the tomato, is absent for even one year. Planting a nonhost crop, such as soybeans, fescue, corn, cotton, and sorghum, for just one year will significantly reduce the losses to this disease in the following tomato crop.

As is true with any other soilborne pathogen, the longer the rotation, the more efficient the control. Other management practices also help to control this pathogen, such as drainage improvements, avoidance of late or deep cultivation (or both), stalk and root destruction, and soil solarization (Melton and Shew, 1998).

Some Pathogens Require Long-term Crop Rotations

An example of a pathogen that requires longer crop rotations for control is *Streptomyces* soil rot or pox of sweet potato. A typical rotation plan to control this pathogen might look like this:

- **Year 1.** Check soil pH, apply lime if needed, and plant beans.
- **Years 2 and 3.** Plant corn and small grain.
- **Year 4.** Plant tobacco.
- **Year 5.** Check soil pH. If at pH 5.2 or under, solarize soil and plant sweet potatoes. When developing a rotation program, sweet potatoes should not follow a crop requiring a high soil pH.

Source: Averre and Ristaino, 1991

Nematode Management

Susceptibility to parasitic nematodes, which are common plant pests, is another consideration in planning a crop rotation. This is a complex issue because many different pest nematode species occur, and their ability to infect vegetable crops varies with the nematode species and the crop.

Generally, rotations should separate a crop sensitive to a particular nematode, say root knot nematode, with crops that are not sensitive or easily infected by that nematode. Nematode populations then decline in intervening years to levels below thresholds for economic injury to susceptible crops. When nematode populations become lower than these thresholds, sensitive crops can be replanted.

Major Plant Parasitic Nematode Genera in the U.S. and How They Damage Plants

- **Root-knot nematodes** form galls on injured plant tissue. The galls block water and nutrient flow to the plant, stunting growth, impairing fruit production, and causing foliage to yellow and wilt. Roots become rough and pimpled and susceptible to cracking.
- **Cyst nematodes** give plants an unthrifty or malnourished appearance, and cause them to produce smaller-than-normal tops. Foliage is liable to wilt and curl, while roots become thick and tough and take on a red or brown coloring.
- **Sting nematodes** are found mainly in the South, especially in sandy soils with meager organic matter content. Areas of stunted plants are an early indicator. As these areas grow larger and finally meet, the plants that were first affected will start to die at the margins of older leaves.
- **Root-lesion or meadow nematodes** cause internal browning in potato tubers and in the roots of corn, lettuce, peas, carrots, tomatoes, and brassicas.

Source: Roger B. Yepsen, 1984

Green manure crops that do not serve as hosts to problem nematodes are sometimes used as intervention crops. There is a great deal of ongoing research in matching vegetable crops and green manures to suppress adversarial nematodes. Rapeseed and mustard have shown insensitivity to infection by a wide range of parasitic nematodes and are commonly planted by organic farmers to "clean up" soil during winter months. Some cover crops have also been shown to suppress nematode populations, such as velvetbean, sorghum-sudangrass, and sunnhemp.

Weed Management

Crop rotations should be designed that make it difficult for weeds to grow and reproduce. Disturbing the soil with some sort of timed tillage is a good way to create an inhospitable or unstable setting for weed growth. Certain crops can suppress weeds by out-competing them for water and nutrients, or by shading them so they cannot receive adequate sunshine.

EXAMPLE
A Rotation To Suppress Weeds

In a field planted to continuous spring lettuce, a farmer could follow the crop with a fast growing, vigorous summer cover crop, such as soybean or cowpea and Japanese millet, and then plant fall broccoli. Little or no weed seed will be spilled, and subsequent lettuce crops will have less weed competition.

Allelopathic Properties. Many crop plants can also create what is called *allelopathic interference*. These plants release chemicals either while they are growing or decomposing that prevent the germination and growth of other plants. Plants differ in their allelopathic properties and in their susceptibility to allelopathic chemicals produced by other crops. Thus, broadleaf weed germination may be inhibited in the spring following plowdown of a winter cereal-rye cover crop, but sweet corn sown into that stubble may not be influenced in the least. Researchers have effectively used cover crops of wheat, barley, oats, rye, sorghum, and sudangrass to suppress weeds through allelopathy, competition, and shading. Weed suppression has also been reported from residues and leachates of crimson clover, hairy vetch, and other legumes. When killed and left on the surface as mulch, cover crops continue to suppress weeds, primarily by blocking out light.

Insect Management

Managing insect pests in crops without using pesticides is no easy task for organic farmers. Organic farmers rely largely on good management practices, such as crop rotations, to keep pests in check. They must have a good working knowledge of insect, disease, and weed life cycles, along with cultural controls that affect pest populations. A farmer must also know a pest's feeding habits and preferences, as well as plant crops that are unappetizing to pests prevalent in the region.

Needless to say, rotations will not control all insect pests. Rotations have little impact on highly mobile insects because these insects have the ability to invade from adjacent fields or other areas. A good rule of thumb is to sequence crops in a rotation that are hosts to entirely different sets of pests, have different growth habits, and are dissimilar in other respects.

All of this helps to interfere with the normal needs of a pest during its life cycle, such as an insect's need to find food, a pathogen's need for a suitable host to infect, or, in the case of weeds, the need for a crop *architecture* or tillage regime to exploit.

In a California study conducted in 1988, researchers M.L. Flint and P.A. Roberts found that crop pests that can be controlled by rotations had some common characteristics:

- The host range of the pest needs to be fairly narrow or at least must not include plants that are reasonably common in a given area.
- The pest source should be the field itself.
- The pest must be incapable of surviving long periods without a living host. That is, pest populations must decrease substantially within a year or two of removing a living host plant. The pest should be as immobile as possible, such as soil and root-dwelling nematodes and soilborne pathogens (if they do not produce airborne spores, such as *Ralstonia solanacearum*).

Carefully Plot Your Tactics in the War on Insect Pests

Insect pests that are less mobile and that feed on specific plants in limited areas are the easiest to control. Employing rotations in the bug battle boils down to making it as hard as possible for insects to find the host plants they love.

Farmers try to disrupt insect growth and breeding schedules by including non-susceptible crops in the rotation. When farmers expect problems from particular insects, they may want to physically separate susceptible species with non-susceptible species and thus make it harder for insects to *cross over* to crops they favor.

Another tactic is to include cash or cover crops in the rotation that will attract the beneficial insects that help keep pest populations in check. Researchers in Georgia reported high densities of big-eyed bugs, ladybugs, and other beneficial insects in vetches and clovers planted as cover crops (Bugg and Waddington, 1994). There is anecdotal evidence that beneficial insects have destroyed Colorado potato beetles feeding on eggplant planted into strip-tilled crimson clover.

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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 Ven Epen of ATTRA
contributed to the technical writing, editing, and formatting of these publications.

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Published by
NORTH CAROLINA COOPERATIVE EXTENSION SERVICE

NC STATE UNIVERSITY

AG-659W-05

06/2006—BS
E06-45788