CENTER FOR ENVIRONMENTAL FARMING SYSTEMS

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Cover Crops for Organic Farms

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Figure 1. Millet is planted in fields where cover crops are incorporated into the soil. (Photo courtesy of USDA)

Cover crops are pivotal parts of every organic farmer's management scheme. They are crucial to the main goals of building soil health and preventing soil erosion. Cover crops are also important tools for increasing fertility and controlling weeds, pathogens, and insects in organic crops.

In this publication, we will discuss planting, growing, and incorporating cover crops as amendments into the soil. Our discussion will include the following topics:

- **How cover crops affect the soil**, including how they impart nitrogen for cash crops and how they can be used to control crop pests and diseases. We will also point out some concerns of growing cover crops, such as the potential for them to rob soil of moisture needed for cash crops and to harbor damaging insects and pathogens.
- **Establishing cover crops** involves using a drill and cultipacking the field.
- **Managing cover crop residue.** The residue can be incorporated or left on the surface after using a kill method.
- **The economics of planting cover crops.** Each farmer must consider the cost of establishing the cover crop and its benefits.

Contents

- **Cover crops for the Southeast.** We review recommended winter and summer cover crops and how they fit specific cropping schemes.
- **Recommended resources** for further study.

HOW COVER CROPS AFFECT THE SOIL

Soil Erosion

The best place to begin our discussion of cover crops is to focus on how they help to reduce one of the most serious, persistent threats to long-term farm productivity and the environment—soil erosion. Cover crops do this partially by keeping the soil covered during rainy periods when it might normally be bare and subject to erosion by rainfall. Langdale et al. (1991) concluded that cover crops reduced soil erosion by 62 percent based on a comparison of bare soil and soil planted with a cover crop in the southeastern United States.

Erosion decreases topsoil, and it also causes *sedimentation* of our rivers, reservoirs, and estuaries. Sedimentation occurs when runoff from rainfall carries eroded soil and deposits it into waterways. In time, sediment deposits produce losses of aquatic habitat that are extremely difficult to reverse. The short-term costs of soil erosion include nutrient losses in runoff from farm fields and negative impacts to the soil's physical structure.

> Soil scientists have estimated that the United States has lost 30 percent of its topsoil in the past 200 years due to agricultural practices that leave bare, fallow soils for a significant portion of the year.
>
> (Tyler et al., 1994)

How well do cover crops help to prevent soil erosion? During the fall, winter, and early spring, this depends largely on when the cover crop is established. Timing is particularly important in the fall because late planting of legume crops, such as hairy vetch, can result in poor stands and small plants with limited root systems. If the cover crop is established early, however, its vigorous fall growth protects soil and reduces erosion. Because of its rapid growth in fall and its continued growth during winter, cereal rye (*Secale cereale*) provides excellent protection from erosion during the winter. The use of cover crops in no-till systems provides extended erosion control because residue is left on the surface after the cover crop is killed and the subsequent cash crop is planted.

> **How Cover Crops Improve the Soil**
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> - Increase soil organic matter through additions of plant biomass.
> - Form soil aggregates, which stabilize soil and reduce runoff and erosion.
> - Increase soil porosity and decrease soil bulk density to promote root growth.
> - Improve soil tilth, which reduces crusting and increases the rate of water infiltration.
> - Encourage populations of soil microbes, micro- and macro-arthropods and earthworms, all of which contribute to efficient nutrient cycling and improvements in soil structure.

Soil Moisture

One of the most important considerations in growing cover crops is their impact on soil moisture. During the summer months, cover crops left on the surface can help to conserve soil moisture by reducing evaporation from the surface and by increasing water infiltration. However, grown too late in the spring, cover crops can draw moisture down from the soil's upper layer, where it will be needed for seed germination and stand establishment of subsequent cash crops.

Thus, knowing when to kill and incorporate cover crops in the spring is a balancing act. The goal is to produce the greatest possible amount of *biomass,* or living matter, with the cover crop, which maximizes fertilizer values, while not depleting soil moisture. Timing is everything.

In early spring, while cover crops are still actively growing, farmers should begin monitoring soil moisture. During years with normal to dry weather patterns, the best time to kill cover crops is usually two weeks before planting cash crops (depending on weather forecasts). Biomass yield and nitrogen (N) production by legume cover crops may not be at their maximum levels at this point. However, in most seasons, sufficient rainfall for adequate crop emergence will occur during the two-week preplant period or within the week immediately following planting. In wet years or when a rainy period is forecast, the cover crop can be killed immediately before soil preparation and planting of spring crops.

With these weather windows in mind, a farmer can create a plan to produce the highest possible cover crop biomass and biomass N yields. Studies show that when cover crop kill is delayed from early April to early May, the yields of hairy vetch, cereal rye, and mixtures of both increase by an average of 160 percent in the Maryland piedmont and by 83 percent in the coastal plain (Clark et al., 1994). In Clark's study, the N contents of hairy vetch and hairy vetch-rye mixtures were 1.6 to 2 times greater at the late kill date: They ranged from 65 to 100 pounds N per acre for early kill, and from 135 to 200 pounds N per acre for late kill. Based on those considerations and by monitoring soil moisture and obtaining rainfall predictions, a farmer can decide on the best possible times for killing and incorporating a cover crop.

Weed Management

Cover crops and surface crop residues can be used to control or inhibit weeds in subsequent cash crops in three basic ways:

- By smothering and shading them so they don't receive adequate air and light.
- By outcompeting them for nutrients.
- By producing an effect known as *allelopathy*, the toxic effect on weed seed germination and seedling growth that occurs as residues of some cover crops decompose.

The primary way to suppress weed seed germination and growth is to have a vigorous cover crop stand. Such a stand will simply out-compete weed seeds for light and nutrients (Teasdale and Daughtry, 1993). When the cover crop is killed, its thick residues remain on the surface and hinder weed growth by physically modifying the amount of natural light, soil temperature, and soil moisture that is necessary for weed seed germination.

It's important to note that suppressing weeds by smothering them becomes less effective as cover crop residues decompose. How fast residues decompose depends on several variables. For instance, warm temperatures, rainfall, and field tillage can speed up the decomposition rate. Another important factor is the *C:N ratio,* the carbon-to-nitrogen ratio of different kinds of crop residues. Residues with a high C:N ratio, such as mature small grain cover crops like rye (which has a C:N ratio of around 50), have a much slower decomposition rate than legumes like hairy vetch (which has a C:N ratio of around 12). Mixtures of legumes and small grains have an intermediate rate of decomposition (a C:N ratio of around 25).

Cover crop residues also interfere with weed emergence through the allelopathic effect (Creamer at al., 1996a). Scientists are still researching the many (and sometimes mysterious) allelopathic effects that one plant has on another through its *allelochemicals*, the chemicals a plant releases into the environment that can be toxic to other plants. Some scientists believe that the specific allelopathic effects of certain plants are enhanced by chemicals produced by actinomycetes, algae, fungi, or other microbes associated with particular plant root systems in the upper soil layers (Putnam, 1988). Where and how these allelochemicals originate is often hard to discern. Each chemical's biological activity may be reduced or enhanced by other factors, such as microbe action in the soil and oxidation. Other factors, such as environmental conditions, insects, or disease pressure, can speed up the detrimental effects of allelochemicals on weeds.

In one study, researchers found that cereal rye residues on the soil surface suppressed most common annual broadleaf and grassy weeds for four to eight weeks (Smeda and Weller, 1996). Thus, using a rye cover crop could eliminate the need for a soil-applied herbicide at transplanting without depressing yield. The authors indicated, however, that post-emergence weed control of escaped weeds might be necessary in some years.

Researchers have reported that the cover crops listed in Table 1 have shown allelopathic effects on certain weeds. We should note that the allelopathic effects of crimson clover and hairy vetch are more apparent if the cover crop is incorporated rather than left on the surface in no-till management (Teasdale and Daughtry, 1993).

Table 1. A summary of research on the allelopathic effects of cover crops

Cover Crop	Weeds Suppressed	Investigator and Publication Date
Hairy vetch	Lambsquarters, yellow foxtail, yellow nutsedge, pitted morningglory	Teasdale et al., 1993 White et al., 1989
Crimson clover	Pitted morningglory, wild mustard, Italian ryegrass	Teasdale et al., 1993 White et al., 1989
Cereal rye	Lambsquarters, redroot pigweed, common ragweed	Barnes and Putnam, 1986 Schilling et al., 1985 Masiunas, 1995
Wheat	Morningglory, prickly sida	Liebl and Worsham, 1983
Velvetbean	Yellow nutsedge, chickweed	Hepperly et al., 1992 Fujii et al., 1992
Sorghum sudangrass	Annual ryegrass	Forney and Foy, 1985

Disease Management

The impact of cover crops on *pathogens*—agents in the soil, such as bacteria or viruses, that cause disease—can be good, bad, or nonexistent. This impact varies broadly depending on individual circumstances and situations. A cover crop can act as a host for soilborne pathogens, or it can serve as an effective form of biological control for other plant pathogens. Incorporating cover crop residues can, in some cases, provide an organic food base that encourages pathogen growth (Phillips et al., 1971). On the other hand, some cover crops, such as brassicas (cabbage and mustard), can actually decrease soil pathogen populations (Lewis and Papavizas, 1971; Subbarao and Hubbard, 1996).

The impact of a cover crop on a pathogen involves many variables. Principally, it depends upon the pathogen's nature and life cycle requirements. For example, if the pathogen survives best on surface residue and the cover crop residue is left on the soil surface as mulch, then the pathogen may survive until the next crop is planted and the level of disease may increase (Fawcett, 1987). Many plant diseases are associated with surface residue, for example, fungal and bacterial leaf blights (Boosalis and Cook, 1973).

At the same time, the increases in soil organic matter provided by cover crops can enhance biological control of soilborne plant pathogens. This comes about both through direct antagonism and by competition for available energy, water, and nutrients (Sumner et al., 1986). Organisms that cause disease can also be affected by changes in temperature, moisture, soil compaction, and bulk density, as well as nutrient dynamics. Whether or not the cover crop is in the same family of plants (taxonomically related) to the subsequent cash crop can also influence whether or not disease cycles are interrupted or prolonged.

Nematode Management

Nematodes are enough of a concern in the sandy soils of the southeastern U. S. to give them individual attention when considering disease management. The root-knot nematode (*Meloidogyne* spp.) is particularly troublesome in the Southeast. Agricultural scientists have more questions than answers concerning how to reduce populations of nematodes with cover crops. They are struggling to find a selection of crop rotations with cover crops that can address a wide variety of nematodes that have a very diverse host range (Reddy et al., 1986). They are also unclear, at this point, as to how some cover crops reduce the population levels of certain nematode species.

Examples of Nematode-Control Success with Warm-Season Legumes

Warm season legume cover crops are effective in reducing populations of *some* plant-parasitic nematodes:

- Rhoades and Forbes (1986) reported that hairy indigo and joint vetch cover crops (coupled by mulching with clippings of cowpea) were highly effective for maintaining low populations of *B. longicaudatus* and *M. incognita* nematodes.
- Rodriguez-Kabana et al. (1992) reported that velvetbean was effective in lowering population densities of several root-knot species (present simultaneously) in greenhouse and field tests. Unfortunately, this is not always the case in field tests.

For instance, some green manure or cover crops placed in a rotation can reduce damage by one nematode species but not others. In a study in Florida, the warm-season legumes, which included pigeonpea, crotalaria, hairy indigo, velvetbean, and joint vetch, reduced root-knot nematode damage in a subsequent snapbean crop when the crop was compared to one produced in fallow. These same cover crops, however, were no more effective than fallow in reducing damage from sting (*Belonolaimus longicaudatus*) and lesion (*Pratylenchus brachyurus*) nematodes.

In some cases, a cover crop can reduce populations of one parasitic nematode but serve as a host that increases populations of other nematodes. While two researchers (McSorley and Gallaher) reported in 1991 that sorghum-sudangrass cover crops reduced levels of root- knot nematodes, Rhoades and Forbes (1986) found that a sorghum-sudangrass cover crop increased populations of *B. longicaudatus* and *M. incognita* nematodes. Farmers attempting to use crop rotations for controlling one nematode species must be aware that these rotations could benefit other damaging nematodes present in the field (McSorley and Dickson, 1995). Potential rotation crops should be evaluated for their effects on as many different damaging nematodes as possible.

Cover Crop Tip

Organic growers commonly plant rapeseed, mustard, and other brassicas as rotation crops to "clean-up" soil during winter months. These plants have been shown to suppress a wide range of parasitic nematodes.

(Bending and Lincoln, 1999)

Insect Management

Cover crops can be both a blessing and a drawback because they attract both beneficial and harmful insects to farm fields (Altieri and Letourneau, 1982; Andow, 1988). When a cover crop matures or dies, both the beneficial and pest insects may move to cash crops. The resulting effect on insect pest populations on the farm (an effect that also depends on several environmental factors) can present frustrating dilemmas for a farmer. For example, in a study in 1991, researchers found that a rye cover crop helped to reduce fruitworm populations in the tomato crop that followed it. But the rye cover also led to increased stinkbug damage (Roberts and Cartwright, 1991).

To create the best situation, a farmer grows a cover crop to attract beneficial insects before the damaging insects arrive. The beneficial insects are attracted by the moisture, shelter, pollen, honeydew, nectar, and potential insect prey associated with the cover crop. These beneficial insects subsist in the cover crop and then move into the vegetable crop to attack arriving pest insects. Several studies show that this approach is often successful. Researchers in Georgia reported high densities of big-eyed bugs, lady beetles, and other beneficial insects in vetches and clovers that moved into ensuing tomato crops (Bugg et al., 1990). In a more recent study, a researcher reported that assassin bugs destroyed Colorado potato beetles feeding on eggplant that had been planted into strip-tilled crimson clover (Phatak, 1998).

Nitrogen Fixation

One of the most significant contributions that legume cover crops make to the soil is the nitrogen (N) they contain. Legume cover crops fix atmospheric N in their plant tissues in a *symbiotic* or mutually beneficial relationship with rhizobium bacteria. In association with legume roots, the bacteria convert atmospheric N into a form that plants can use. As cover crop biomass decomposes, these nutrients are released for use by cash crops. Farmers should make an effort to understand this complex process because it will help them to select the proper legumes for their cropping plan, calculate when to incorporate cover crops and plant cash crops that follow, and plan fertilizer rates and schedules for those cash crops. Above all, they need to inoculate legume seed before planting with the appropriate *Rhizobium* species.

Cover Crop Tip

Nonleguminous cover crops, typically grasses or small grains, do not fix nitrogen. Nonetheless, they can be effective in recovering mineralized nitrogen from soil after crops are harvested.

The N associated with cover crop biomass undergoes many processes before it is ready to be taken up for use by cash crops. The process begins with *biomass N*, which is the nitrogen contained in mature cover crops. From 75 to 90 percent of the nitrogen content in legume cover crops is contained in the aboveground portions of the plant, with the remaining N in its roots and nodules (Shipley et al., 1992).

When legume or grass cover crops are killed and incorporated into the soil, living microorganisms in the soil go to work to decompose plant residues. The biomass nitrogen is *mineralized* and converted first to ammonium (NH_4) and then to nitrate compounds (NO_3) that plant roots can take up and use. The rate of this mineralization process depends largely on the chemical composition of the plant residues that are involved (Clement et al., 1995), and on climatic conditions.

Determining the ratio of carbon to nitrogen (C:N) in the cover crop biomass is the most common way to estimate how quickly biomass N will be mineralized and released for use by cash crops. As a general rule, cover crop residues with C:N ratios lower than 25:1 will release N quickly. In the southeastern U. S., legume cover crops, such as hairy vetch and crimson clover, killed immediately before corn planting generally have C:N ratios of 10:1 to 20:1 (Ranells and Wagger, 1997). Residues with C:N ratios greater than 25:1, such as cereal rye and wheat, decompose more slowly and their N is more slowly released.

A study conducted in 1989 reported that 75 to 80 percent of the biomass N produced by hairy vetch and crimson clover residues was released eight weeks after the cover crops were incorporated into the soil (Wagger, 1989a). This amounted to 71 to 85 pounds of N per acre. However, not all of the released N was taken up by the subsequent corn crop. The corn utilized approximately 50 percent of the N released by both residues. (This value may be con-sidered the *N uptake efficiency* of corn from legume residues. This value is similar to the N uptake efficiency of corn from inorganic fertilizer sources, such as ammonium nitrate.) The N not taken up by the following crops may still contribute to soil health. Living microbes in the soil may use the nitrogen to support population growth and microbial activity in the soil.

As with just about everything else when it comes to farming, the practice of growing cover crops to produce nitrogen in the soil is complicated by many variables. Weather, differences in growing seasons, the types of cover crops involved, and the timing of cover crop desiccation to produce the optimum benefit all come into play. Amassing experience in cover crop production is simply the best way for a farmer to learn how to deal with the interplay of all these variables.

Legumes Versus Grasses. As we've seen above, legume cover crops play a vital role in producing N for subsequent cash crops. What part do nonleguminous cover crops, which do not produce nitrogen, have in the cropping scheme?

Organic farmers often plant nonleguminous winter cover crops to trap the soil N that is left over from summer cash crops and to prevent this N from leaching out of the root zone or running off the field. Generally, grass cover crops are very effective—much more so than legumes—in trapping and recovering N from the soil. Grass and legume cover crop mixtures are more efficient than legumes alone in trapping leftover N in the soil, but don't do as effective a job as straight grass cover crops.

There are many advantages, however, to planting cover crops that are grass and legume mixtures called *bicultures*. Researchers (Clark et al., 1994) reported that a cereal rye-hairy vetch biculture successfully scavenged potentially leachable N from the soil, and also added fixed N for use by an ensuing corn crop. Additionally, the cover crop used excess water in the soil, which also helped limit N leaching losses.

Grass species establish ground cover more quickly than legume monocultures, and their root growth remains active in the cooler temperatures of autumn (Ranells and Wagger, 1997). Cover crop mixtures that include grasses can, therefore, prevent soil erosion more effectively. Growing deep-rooted and shallow-rooted cover crops together will also help a farmer to make better use of water and other resources throughout the soil profile.

Legumes or Grasses? How To Choose a Cover Crop

Generally, cover crop selection is based on each farmer's situation and production goals. For example, if the purpose of a cover is to provide readily available, biologically fixed nitrogen for cash crops, then the farmer should choose a legume, such as hairy vetch or cowpea.

If the cover crop will be managed as a surface mulch for weed suppression or incorporated to improve soil quality, then the farmer should choose a grass cover crop, such as cereal rye or a sorghum-sudangrass mix. Both of these grass cover crops can produce large amounts of biomass with high C:N ratios at maturity, and both are reported to suppress some weeds.

Farmers can also more effectively manipulate nitrogen cycling with mixed cover crop species. Combining mature cereals, which have high carbon to nitrogen (C:N) ratios and break down slowly, with legumes, which have low C:N ratios and break down more quickly, can influence decomposition of cover crop residues. The decomposition of such cover crop mixtures will occur more quickly than that of cereal alone, releasing N more quickly for uptake by cash crops.

Planting mixtures of cover crops can help a farmer to use the allelopathic potential of the cover crops to suppress weeds. Allelopathic suppression of weeds depends on both the cover crop and the weed. Therefore, a broader spectrum of weed control may be possible by growing a mixture of cover crops, with each species contributing allelopathic activity towards specific weed species (Creamer and Bennett, 1997).

Mixtures of cover crops can also be planted to influence insect populations. Species that may not produce much biomass or biomass N may be included in mixtures to attract beneficial insects into the cropping system.

Measuring Cover Crop Nitrogen. To ensure that cash crops receive enough nutrients, farmers must accomplish these calculations in this sequence:

1. Determine the biomass produced.
2. Determine the nutrient levels in that biomass.
3. Predict how quickly the biomass will decompose, releasing nutrients for cash crops.
4. Calculate whether additional nutrients are required for the desired crop yields.

Cover Crop Tip

Calculating the nutrient levels released by green manures for a subsequent cash crop normally requires three measurements:

- The amount of biomass (dry weight).
- The nutrient composition of the cover crop.
- The decomposition rate of the cover crop during the cash cropping season.

To estimate yield, take cuttings from several areas in the field. Dry and weigh the samples. Use a yardstick or metal frame of known dimensions and clip the plants at ground level within the known area. Dry the samples in an oven at about 140°F for 24 to 48 hours until they are crunchy dry. Use the following equation to determine per acre yield of dry matter:

Yield (lb/acre) =

$$\frac{\text{Total weight of dried samples (lb)}}{\text{Area (sq ft) sampled}} \times \frac{\text{43,560 sq ft}}{\text{1 acre}}$$

For example, two 3 feet by 3 feet (9 sq ft or 1 sq yd) samples weigh 2.5 pounds. The dried biomass yield equals:

Yield (lb/acre) =

$$\frac{\text{2.5 lb}}{\text{18 sq ft}} \times \frac{\text{43,560 sq ft}}{\text{1 acre}} = \text{6,050 lb/acre.}$$

Though not as accurate, yield can be estimated from the height of the cover crop and the percentage of ground it covers. At 100 percent ground coverage and a 6-inch height, most nonwoody legumes contain roughly 2,000 pounds per acre of dry matter. For each additional inch, add 150 pounds.

For example, a hairy vetch cover crop is 18 inches tall and has 100 percent ground coverage. The first 6 inches of dry biomass weighs roughly 2,000 pounds. The 12 additional inches of growth weighs 150 pounds per inch. The additional weight is:

12 X 150 = 1,800 lb,

and the total weight of the cover crop dry matter is:

2,000 + 1,800 = 3,800 lb

If the stand has less than 100 percent ground coverage, multiply the total weight by the percentage of ground covered, represented as a decimal number (the percentage divided by 100). If the percentage of ground covered in the example above is 60 percent, then the weight of the dry matter is:

3,800 X 0.60 (60/100) = 2,280 pounds of dry biomass (Adapted from Sarrantonio, 1998)

These calculations normally require three measurements: the amount of biomass (dry weight), the nutrient composition of the cover crop, and the decomposition rate of the cover crop during the cash cropping season.

Farmers can estimate the amount of nitrogen in a cover crop by estimating the total biomass yield of the cover crop and the percentage of nitrogen in the plants when they're killed. A simple process for the assessment is explained in *Managing Cover Crops Profitably* (Sarrantonio, 1998:

For cereal rye, the height relationship is a bit different. Cereal rye produces approximately 2,000 pounds per acre of dry matter at an 8-inch height and 100 percent ground coverage. For each additional inch, add 150 pounds, as before, and multiply by the percentage of ground covered, represented as a decimal (the percentage divided by100). For most small grains and other annual grasses, start with 2,000 pounds per acre at a 6-inch height and 100 percent of ground covered. Add 300 pounds for each additional inch, and multiply by the percentage of ground covered, represented as a decimal (the percentage divided by 100).

To calculate the amount of nitrogen in the dried cover crop biomass, multiply the dry biomass yield times the percentage of nitrogen expressed as a decimal (percentage of N divided by 100). For the hairy vetch cover crop example above with 100 percent cover and an estimated 4 percent nitrogen at flowering:

Total N (lb/acre) = 3,800 lb/acre X .04 (4 ÷ 100) = 152 lb N per acre

Annual legumes typically have between 3.5 and 4.0 percent nitrogen in the above-ground biomass prior to flowering, and 3.0 to 3.5 percent at flowering. After flowering, nitrogen in the leaves decreases quickly as it accumulates in the growing seeds. Most cover crop grasses contain 2.0 to 3.0 percent nitrogen before flowering and 1.5 to 2.5 percent after flowering. Other cover crops, such as *Brassica* species and buckwheat, will generally be similar to, or slightly below, grasses in their N concentration. To precisely determine the percentage of nitrogen in the cover crop, send a plant sample to a laboratory for a chemical analysis. The N.C. Department of Agriculture Plant Analysis Lab provides that service for $4 per sample.

As discussed previously, not all of the nitrogen contained in the cover crop residue will be available to the cash crop. To conservatively estimate the amount that will be available to the following crop, multiply legume biomass nitrogen, as calculated above, by 0.50 if the cover crop residue will be incorporated and by 0.40 if the residue will be left on the soil surface.

From the example above, if the hairy vetch is incorporated in the soil in early May in a normal spring, then the nitrogen available from the hairy vetch to the cash crop will be:

Available N (lb/acre) =
152 lb N per acre X .50 = 76 lb N per acre.

If the hairy vetch is left on the soil surface in early May in a normal spring, then the nitrogen available from the hairy vetch to the next crop will be:

Available N (lb/acre) =
152 lb N per acre X .40 = 61 lb N per acre

These *availability coefficients* will change, depending on the weather. In dry or cold and wet springs, the soil microorganisms responsible for mineralization of the organic nitrogen in the cover crop residue will be less active. The mineralization rate will be reduced, and a lesser fraction of the nitrogen will be available to the following cash crop. In almost all cases, the availability coefficient of a small grain cover crop, such as cereal rye, will be very low. Very little N in the residue will be released for use by the cash crop.

ESTABLISHING COVER CROPS

Using a drill to sow cover crops into a conventionally prepared seedbed is the most reliable way to obtain a uniform stand. However, in a no-till situation, a no-till grain drill can also be used successfully, provided that the residue from the previous crop is not excessive and the soil is moist enough to allow the drill to penetrate to the desired planting depth. Seeds may be broadcast if the soil has been disked and partially smoothed, but seeding rates should be increased by 20 percent.

It is best to cultipack the field after broadcasting to firm the soil around the seeds. Crimson clover, in particular, can be established quite easily with this method. In a limited number of trials, aerial seeding of crimson clover into a standing crop, such as soybeans, has proven successful. An innovative system that has shown promise in North Carolina and other southeastern states is to allow crimson clover to reseed itself naturally.

MANAGING COVER CROP RESIDUE

In organic systems, cover crops may be killed and incorporated into the soil by tillage, mowing, undercutting, or rolling. Details about these methods are included in another publication within this series: "Conservation Tillage on Organic Farms."

Should Farmers Leave Cover Crops on the Surface Or Incorporate Them?

In a wet growing season, incorporating legumes into the soil may produce the highest yields in cash crops that follow. However, under relatively dry growing conditions, cover crop residue left on the surface will help to conserve soil moisture.

In no-till organic production systems, cover crops are usually killed mechanically and left on the surface as a mulch. Each kill method has its benefits and drawbacks:

Undercutting utilizes a steel bar that is drawn several inches underneath the soil surface (usually beneath a plant bed), severing the top growth and crown of the plant from the roots and leaving the surface and aboveground biomass undisturbed. The main advantage of undercutting is that it leaves the cover crop intact and the large pieces break down more slowly, enhancing weed suppression.

Mowing with a flail mower leaves the finely chopped residue evenly distributed over the bed. The residue tends to decompose quickly, so high biomass is desirable.

Rolling the cover crop often includes crimping the cover crop stems, which damages each plant's vascular system and causes it to die. Rolling keeps the aboveground part of the plant attached to the root system. As with undercutting, rolled plants decompose more slowly than those killed by mowing and, consequently, control weeds for a longer period of time (Lu et al., 2000). To facilitate seeding into rolled or undercut cover crops, farmers should plant in the same direction as they rolled the cover crop.

THE ECONOMICS OF PLANTING COVER CROPS

Researchers are just beginning to investigate the long-term profitability of using cover crops in horticultural systems. Farmers using cover crops have additional expenses due to seed, seeding, and management. However, cover crops allow a farmer to reduce costs for fertilizers, pest and disease control, and extensive tillage. They also represent a long-term investment in soil resources. Relative to these benefits and to the potential returns from high-value horticultural crops, the cost of cover cropping is comparatively minor.

Legume cover crops are generally reported to have more profitability potential than grass cover crops because they contribute nitrogen to the subsequent cash crop, reducing input costs (Roberts et al., 1998). Grass cover crops may, in fact, consume soil N that could be used by the cash crop. Hairy vetch may be among the more promising cover crops. It contributes N to the soil, and it also improves the soil's structure and water-holding capacity. In doing so, it also increases the effectiveness of fertilizer-applied N (Lichtenberg et al., 1994; Hanson et al., 1993).

We would like to emphasize that all of these benefits may not always lead to increased profits for farmers. Allison and Ott (1987) reviewed studies investigating the economics of using legume cover crops in conservation tillage systems. They concluded that legume cover crops increase profitability *if* they enhance the yield of the succeeding crop. But they decrease profitability when used as the sole source of nitrogen in a corn cropping system. If nitrogen prices, which increase with energy prices, continue to rise, legume cover crops may become cost-effective N sources.

In studies where cover crop systems are reported to be less profitable than conventional systems, the lower profitability is attributed to the establishment cost of the cover crop. In these studies, the benefits of using the cover crop (increased yields and reduced amounts of applied N) do not outweigh the establishment cost of the cover crop (Bollero and Bullock, 1994; Hanson et al., 1993).

Each farmer must determine how to account for the less apparent, long-term benefits—such as reduced soil erosion, increased organic matter content, improved soil physical properties, reduced nitrate leaching, and enhanced nutrient cycling.

COVER CROPS FOR THE SOUTHEAST

Which winter and summer legume and grass cover crops perform well in the southeastern United States? Our descriptions of recommended cover crops are drawn primarily from three sources: Duke (1981), Sarrantonio (1994), and Bowman et al. (1998). An electronic source we found very useful was the University of California at Davis (UCD) Sustainable Agriculture Cover Crop Resource Page at http://www.sarep.ucdavis.edu/ccrop/ (UCD, 2001). For more information on the cover crops listed, or to find information about other potential cover crops, refer to these references, which are listed in the "Recommended Reading" section of this publication.

Recommended Winter Species

Examples of winter legume cover crops include crimson clover, hairy vetch, Austrian winter pea (*Pisum sativum arvense*), and subterranean clover (*Trifolium subterraneum*). Cereal rye, wheat, and oats are also commonly used as small grain cover crops and in mixtures with the legumes mentioned above. Generally, winter cover crops are planted in early fall and allowed to grow until mid-spring, at which time the crop is incorporated by tillage, or killed and left as a surface mulch into which another crop is planted.

Winter Legumes

> **Clover, Vetch & Winter Peas—What Are Their Limitations?**
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> Hairy vetch tends to be more winter hardy than the other winter legumes and can generally be planted later in the season. Hairy vetch also adapts better to sandy soils than crimson clover, although crimson clover will provide adequate dry matter production on most well-drained, sandy loams.
>
> In contrast, crimson clover grows faster in the spring, thereby maturing and obtaining peak dry matter production approximately three to four weeks before hairy vetch. Adequate dry matter and nitrogen production will be obtained with a soil pH from 5.8 to 6.0. Soil testing will help determine P and K fertilizer requirements. It is important to inoculate legumes with the proper strain of N-fixing bacteria.

Hairy vetch (*Vicia villosa*). Hairy vetch forms a very dense cover and, if planted with a tall growing species like rye, will climb and produce a great deal of biomass. Hairy vetch is probably the most commonly used cover crop in the United States, in part because it is so widely adapted. Hairy vetch is seeded at 20 to 30 pounds per acre, with the lower rate used if the vetch is drilled or planted in mixtures. At mid-bloom, hairy vetch can be easily killed by undercutting or mowing. Be aware that hairy vetch can harbor root-knot nematodes (*Meloidogyne* spp.), soybean cyst (*Heterodera glycines*), and various cutworms. Susceptible vegetable crops should be temporarily separated in a rotation. If allowed to produce mature seed, vetch can also be viewed as a weed in subsequent small grain crops.

Crimson clover (*Trifolium incarnatum*). Crimson clover stands upright and blooms about three to four weeks earlier than hairy vetch. It grows vigorously in fall and winter and has good reseeding ability. It is not widely adapted, however, and is more appropriate in warmer climates. Crimson clover has good shade tolerance and can be overseeded into fall vegetable crops in September. Seeding rates vary from 15 to 25 pounds per acre, with the lower rate being used when the seed is drilled.

Subterranean clover (*Trifolium subterraneum*). Subterranean clover is a relatively low growing winter annual with prostrate stems. In late spring, subterranean clover develops seeds below ground (much like peanuts), which gives it an excellent reseeding ability. Subterranean clover forms a thick mat when left on the surface as a mulch and has been shown to suppress weeds in vegetable crops planted into the mulch. Subterranean clover does not produce as much biomass as other cool-season legumes grown in the South, but biomass yield can reach 5,500 pounds per acre with a nitrogen concentration of between 2 and 3 percent. Subterranean clover is seeded at 8 to 15 pounds per acre between mid-September and mid-October.

Austrian winter pea (*Pisum sativum arvense*). Austrian winter pea is succulent and viney and can climb when planted with small grain crops. It grows vigorously and will suppress weeds while growing, but it decomposes rapidly and is not a good choice for a surface mulch and weed control. Austrian winter pea does well in a mixture with oats, barley, rye, or wheat. Seed is drilled at 60 to 90 pounds per acre and can be sown through October.

Winter Nonlegumes

Cereal rye (*Secale cereale*). Rye is one of the most commonly used winter cover crops. It grows 3 to 6 feet tall and has an extensive, fibrous root system. It performs well when mixed with hairy vetch, which will use it for climbing support. Rye can tolerate a wide variety of soil types and climatic conditions and is considered to be weed suppressive when managed as a mulch. Of all the small grains, rye is the best scavenger of excess soil nitrogen in the fall. The seeding rate is 100 pounds per acre.

Annual ryegrass (*Lolium multiflorum*). Annual ryegrass is a noncreeping bunchgrass. In the spring it can grow 2 to 4 feet tall. Annual ryegrass can be difficult to control and can become a serious weed if it produces seed. Ryegrass requires considerable nitrogen and water. If these are limited, it may not be a good choice. Ryegrass has a very fibrous, dense root system that protects against soil erosion while improving water infiltration and soil tilth. Dry matter yield can average between 1,300 and 2,000 pounds per acre, with an average nitrogen content of 1.5 percent. Normally seeded in the fall, seeding rates are between 20 and 30 pounds per acre.

Other cereal grasses. All of the cereal grasses will produce biomass ranging from 2,000 to 6,000 pounds per acre with nitrogen concentrations between 1 and 2 percent. Biomass accumulation depends, in part, on how early in the spring the cover crop is killed. The high end of the range represents a kill date in mid- to late May. At this late date, however, the biomass carbon to nitrogen (C:N) ratio will normally be greater than 50:1, a ratio at which soil microbes would immobilize any mineralized nitrogen. Small grains are normally drilled at 100 pounds of seed per acre.

- **Wheat** (*Triticum aestivum*) provides a good overwintering ground cover and also provides the option of harvesting the grain.
- **Barley** (*Hordeum vulgare*) biomass production peaks about two weeks earlier than wheat, and about the same time as crimson clover. Barley, grown as a smother crop, has been shown to suppress winter annual weeds in cropping systems, but must be planted in September or early October to reduce winter kill.
- **Oats** (*Avena sativa*) grow well in cool weather and provide rapid ground cover in the fall. Some growers plant spring oats in the fall to produce a winter-killed mulch for early spring no-till vegetable plantings. However, spring oats may not always winter-kill in mild winters.

Recommended Summer Species

There is growing interest in the use of short-season summer annual legumes or grasses as cover crops and green manures in cropping systems. Summer annual legumes and grasses can provide benefits between the harvest of spring vegetable crops and the planting of fall vegetables or small grains. While additional legumes and grasses are being evaluated for use, the following species are currently the best options.

Summer Legumes

Cowpea (*Vigna unguiculata*). Other common names for this species are blackeyed, crowder, and southern pea. Cowpea is a fast growing, summer cover crop that adapts to a wide range of soil conditions. Cowpeas have a deep taproot, tolerate drought, and compete well against weeds. Cowpeas produce 3,000 to 4,000 pounds of dry biomass per acre, which contains 3 to 4 percent nitrogen. Maximum biomass is achieved in 60 to 90 days. Residues are succulent and decompose readily when incorporated into the soil. Cowpeas can be planted in the spring (after all danger of frost) through late summer. Cowpea seeds can be drilled in rows 6 to 8 inches apart at 40 pounds per acre or broadcast at approximately 75 pounds per acre. Higher seeding rates are necessary in late summer when soil moisture is likely to be limited. Recommended cultivars include Iron Clay and Red Ripper. Plants normally grow up to 24 inches tall, but some cultivars can climb when planted in mixtures with other species. Good mixture options are sorghum-sudangrass and German foxtail millet. When mowed or undercut, cowpeas have the potential for considerable regrowth in some years.

Soybean (*Glycine max*). Soybean is one of the most economical choices for a summer legume cover crop. It is an erect, bushy plant that grows 2 to 4 feet tall, establishes quickly, and competes well with weeds. When grown as a green manure crop, late maturing cultivars usually give the highest biomass yield and fix the most nitrogen. If well established, soybean will withstand short periods of drought. The viney, forage types (for example, the cultivars Quailhaven and Laredo) have the potential to produce more biomass than traditional soybean cultivars.

Velvetbean (*Mucuna deeringiana*). Velvetbean is a vigorously growing, warm-season annual legume native to the tropics and well adapted to southern U. S. conditions. It performs well in sandy and infertile soils. Most cultivars are viney, and stems can grow as much as 10 meters. Velvetbean is an excellent green manure crop, producing high amounts of biomass that decompose readily to provide nitrogen for a cash crop. Velvetbean does best when direct-seeded into warm soils in 38-inch rows. Velvetbean seed should not be drilled, because the very large seed can be damaged in conventional drills.

Sunnhemp (*Crotalaria juncea*). Sunnhemp is a tall, herbaceous, warm-season annual legume with erect fibrous stems. It has been used extensively for soil improvement and green manuring in the tropics. It competes with weeds, grows rapidly, and can reach a height of 8 feet in 60 days. It can tolerate poor, sandy soils and drought, but requires good drainage. Sunnhemp tolerates moderate acidity, but a soil pH below 5 can limit growth. Sunnhemp should be drilled or seeded in rows 38 inches apart at 30 pounds per acre. The growing season in the continental U.S. is not long enough to produce viable seed. Sunnhemp becomes fibrous with age, but the plants are succulent for about eight weeks after seeding. Sunnhemp is often planted in midsummer after cool-season vegetables or sweet corn crops are harvested. It will produce high biomass and biomass nitrogen in 45 to 60 days. Seed is not readily available at this writing in early 2006, but availability may increase if demand increases. While some *Crotalaria* species are toxic to animals, sunnhemp forage is not. Sunnhemp should not to be confused with showy crotalaria, a noxious weed species.

Summer Nonlegumes

Buckwheat (*Fagopyrum esculentum*). Buckwheat is a very rapidly growing broadleaf summer annual, which can flower in four to six weeks. It reaches 30 inches in height and is single-stemmed with many lateral branches. It has both a deep taproot and fibrous roots. It can be grown to maturity between spring and fall vegetable crops, suppressing weed growth and recycling nutrients during that period. It is succulent, easy to incorporate, and decomposes rapidly. Buckwheat flowers are very attractive to insects, and some farmers use this cover to attract beneficial insects into cropping systems. Buckwheat is an effective phosphorous scavenger. The main disadvantage to buckwheat is that it sets seed quickly and, if allowed to go to seed, may become a weed in cash crops. Thus, the optimal time to incorporate buckwheat is one week after flowering, before seed is set. Buckwheat can be planted anytime in the spring, summer, or fall, but is frost-sensitive.

Sorghum sudangrass (*Sorghum bicolor* × *Sorghum sudanense*). Sorghum sudangrass is a hybrid of grain sorghum and sudangrass. It is a warm-season annual grass, most often planted from late spring through mid-summer. It grows well in hot, dry conditions and produces a large amount of biomass. Often reaching 6 feet in height, it can be mowed to enhance biomass production. Sorghum sudangrass is very effective at suppressing weeds and has been shown to have allelopathic properties. The roots of sorghum sudangrass are good foragers for nutrients and help control erosion. Sorghum sudangrass does well when planted in mixtures, providing effective support for viney legumes like velvetbean. If frost-killed, the residue can provide a no-till mulch for early planted spring crops like broccoli. When stressed by drought or by frost, this cover crop can produce prussic acid, which is toxic to cattle.

German (foxtail) millet (*Setaria italica*). German or foxtail millet is an annual warm-season grass that matures quickly in the hot summer months. It is one of the oldest of cultivated crops. German millet has a fairly low water requirement. Because of its shallow root system, however, it doesn't recover easily after a drought. Grain formation requires 75 to 90 days. German millet forms slender, erect, and leafy stems that can vary in height from 2 to 4 feet. The seed can be drilled from mid-May through August at a rate of 10 to 15 pounds per acre. A small seeded crop, German millet requires a relatively fine, firm seedbed for adequate germination. To avoid early competition from germinating weed seed, it should be closely drilled in the row or sown in a *stale* seedbed—a seedbed that has been prepared, with early emerged weeds killed just before planting the cover crop. Coarse, sandy soils should be avoided.

Pearl millet (*Pennisetum glaucum*). Pearl millet is a tall annual bunchgrass that grows 4 to 10 feet tall. It is also often referred to as cattail millet because its long, dense, spike-like inflorescences resemble cattails. Though it performs best in sandy loam soils, pearl millet is well adapted to soils that are sandy, infertile, or both. Pearl millet can be planted from late April through July at a rate of 15 to 20 pounds per acre. Pearl millet matures in 60 to 70 days. In North Carolina studies, pearl millet was not as readily killed by mechanical methods (mowing and undercutting) as German or Japanese millet.

Japanese millet (*Enchinochloa frumentacea*). Japanese millet is an annual grass that grows 2 to 4 feet tall. It resembles and may have originated from barnyard grass. Japanese millet is commonly grown as a late-season green forage. If weather conditions are favorable, it grows rapidly and will mature from seed in as little as 45 days. Japanese millet can be planted from April to July at a rate of 10 to 15 pounds per acre. It performs poorly on sandy soils.

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