Overview of Cover Crops and Green Manures

Fundamentals of Sustainable Agriculture

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Abstract: *Cover crops could be considered the backbone of any annual cropping system that seeks to be sustainable. In this publication we summarize the principal uses and benefits of cover crops and green manures. Brief descriptions and examples are provided for winter cover crops, summer green manures, living mulches, catch crops, and some forage crops. To impart a sense of the importance of these practices in sustainable farming, we summarize the effect of cover crops and green manures on: organic matter and soil structure, nitrogen production, soil microbial activity, nutrient enhancement, rooting action, weed suppression, and soil and water conservation. Management issues addressed include vegetation management, limitations of cover crops, use in crop rotations, use in pest management, and economics of cover crops. A selection of print and Web resources are provided for further reading.*

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Introduction

Cover crop information abounds. In the past ten years, the number of research reports, Extension bulletins, Experiment Station reports, and popular press articles on cover crops has increased dramatically. For example, the third quarter 1998 issue of *The Journal of Soil and Water Conservation* contains 17 research reports on cover crops. Several excellent field handbooks have also been written. Consequently, rather than attempting to address that large body of information, this publication serves as an overview of cover crops and their uses and provides a resource list. The resource list gives ordering instructions and prices for readers who want current information in more detail.

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Principal Uses of Cover Crops and Green Manures

"Green manuring" involves the soil incorporation of any field or forage crop while green or soon after flowering, for the purpose of soil improvement. A cover crop is any crop grown to provide soil cover, regardless of whether it is later incorporated. Cover crops are grown primarily to prevent soil erosion by wind and water. Cover crops and green manures can be annual, biennial, or perennial herbaceous plants grown in a pure or mixed stand during all or part of the year. In addition to providing ground cover and, in the case of a legume, fixing nitrogen, they also help suppress weeds and reduce insect pests and diseases. When cover crops are planted to reduce nutrient leaching following a main crop, they are often termed "catch crops."

Winter cover crop

A winter cover crop is planted in late summer or fall to provide soil cover during the winter. Often a legume is chosen for the added benefit of nitrogen fixation. In northern states, the plant selected needs to possess enough cold tolerance to survive hard winters. Hairy vetch and rye are among the few selections that meet this need.

Many more winter cover crops are adapted to the southern U.S. These cool-season legumes include clovers, vetches, medics, and field peas. They are sometimes planted in a mix with winter cereal grains such as oats, rye, or wheat. Winter cover crops can be established by aerial seeding into maturing cash crops in the fall, as well as by drilling or broadcasting seed immediately following harvest.

Summer green manure crop

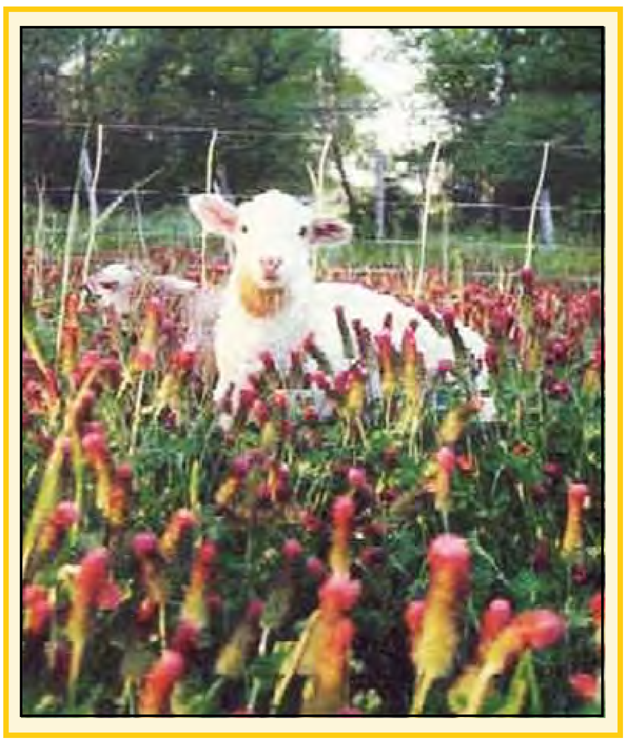
A summer green manure occupies the land for a portion of the summer growing season. These warm-season cover crops can be used to fill a niche in crop rotations, to improve the conditions of poor soils, or to prepare land for a perennial crop. Legumes such as cowpeas, soybeans, annual sweetclover, sesbania, guar, crotalaria, or velvet beans may be grown as summer green manure crops to add nitrogen along with organic matter. Non-legumes such as sorghum-sudangrass, millet, forage sorghum, or buckwheat are grown to provide biomass, smother weeds, and improve soil tilth.

Living mulch

A living mulch is a cover crop that is interplanted with an annual or perennial cash crop. Living mulches suppress weeds, reduce soil erosion, enhance soil fertility, and improve water infiltration. Examples of living mulches in annual cropping systems include overseeding hairy vetch into corn at the last cultivation, no-till planting of vegetables into subclover, sweetclover drilled into small grains, and annual ryegrass broadcast into vegetables. Living mulches in perennial cropping systems are simply the grasses or legumes planted in the alleyways between rows in orchards, vineyards, Christmas trees, berries, windbreaks, and field nursery trees to control erosion and provide traction.

Catch crop

A catch crop is a cover crop established after harvesting the main crop and is used primarily to reduce nutrient leaching from the soil profile. For example, planting cereal rye following corn harvest helps to scavenge residual nitrogen, thus reducing the possibility of groundwater contamination. In this instance, the rye catch crop also functions as a winter cover crop. Short-term cover crops that fill a niche within a crop rotation are also commonly known as catch crops.



Forage crop

Short-rotation forage crops function both as cover crops when they occupy land for pasturage or haying, and as green manures when they are eventually incorporated or killed for a no-till mulch. Examples include legume sods of alfalfa, sweet clover, trefoil, red clover, and white clover, as well as grass-legume sods like fescue-clover pastures. For maximum soil-improving benefits, the forage should not be grazed or cut for hay during its last growth period, to allow time for biomass to accumulate prior to killing.

Benefits of Cover Crops and Green Manures

Organic matter and soil structure

A major benefit obtained from green manures is the addition of organic matter to the soil. During the breakdown of organic matter by microorganisms, compounds are formed that are resistant to decomposition—such as gums, waxes, and resins. These compounds—and the mycelia, mucus, and slime produced by the microorganisms—help bind together soil particles as granules, or aggregates. A well-aggregated soil tills easily, is well aerated, and has a high water infiltration rate. Increased levels of organic matter also influence soil humus. Humus—the substance that results as the end product of the decay of plant and animal materials in the soil—provides a wide range of benefits to crop production.

Sod-forming grass or grass-legume mixtures are important in crop rotations because they help replenish organic matter lost during annual cultivation. However, several years of sod production are sometimes required before measurable changes in humus levels occur. In comparison, annual green manures have a negligible effect on humus levels, because tillage and cultivation are conducted each year. They do replenish the supply of active, rapidly decomposing organic matter (1).

The contribution of organic matter to the soil from a green manure crop is comparable to the addition of 9 to 13 tons per acre of farmyard manure or 1.8 to 2.2 tons dry matter per acre (2).

Table 1 shows dry matter production of several winter-annual legume cover crops grown in the southern U.S. Approximately 2.2 tons per acre per year of crop residue is considered adequate to maintain soil organic matter at constant levels in continuously cropped soils (3). This figure will vary according to climate, region, and cropping system.

Table 1. Average biomass yields and nitrogen yields of several legumes (4).

Cover Crop	Biomass	Nitrogen
	Tons/acre	Lbs./acre
Sweet clover	1.75	120
Berseem clover	1.1	70
Crimson clover	1.4	100
Hairy vetch	1.75	110

Nitrogen production

Nitrogen production from legumes is a key benefit of growing cover crops and green manures. Nitrogen accumulations by leguminous cover crops range from 40 to 200 lbs. of nitrogen per acre. The amount of nitrogen available from legumes depends on the species of legume grown, the total biomass produced, and the percentage of nitrogen in the plant tissue. Cultural and environmental conditions that limit legume growth—such as a delayed planting date, poor stand establishment, and drought—will reduce the amount of nitrogen produced. Conditions that encourage good nitrogen production include getting a good stand, optimum soil nutrient levels and soil pH, good nodulation, and adequate soil moisture.

The portion of green-manure nitrogen available to a following crop is usually about 40% to 60% of the total amount contained in the legume. For example, a hairy vetch crop that accumulated 180 lbs. N per acre prior to plowing down will contribute approximately 90 lbs. N per acre to the succeeding grain or vegetable crop. Dr. Greg Hoyt, an agronomist at North Carolina State University, has estimated that 40% of plant tissue nitrogen becomes available the first year following a cover crop that is chemically killed and used as a no-till mulch. He estimates that 60% of the tissue N is released when the cover crop is incorporated as a green manure rather than left on the surface as a mulch. Lesser amounts are available for the second or third crop following a legume, but increased yields are apparent for two to three growing seasons (5).

To determine how much nitrogen is contained in a cover crop, an estimate is needed of the yield of above-ground herbage and its percentage of nitrogen. A procedure to make this determination is available in the *Northeast Cover Crop Handbook*, in *Farmer's Fertilizer Handbook*, and in *Managing Cover Crops Profitably*. A description of these publications complete with ordering information can be found in the **Resources** section below.

The procedure involves taking a field sample, drying it, weighing it, and sending a sample off for forage analysis, which includes an estimate of protein content. Once the protein content is known, simply divide it by 6.25 to obtain the percentage of nitrogen contained in the cover crop tissue. Finally, to obtain pounds of legume nitrogen per acre, multiply the nitrogen figure by the pounds-of-biomass figure.

Forage legumes are valuable in rotations because they generate income from grazing or haying and still contribute nitrogen from regrowth and root residues. A high percentage of biologically fixed nitrogen is in the top growth (Table 2).

Table 2. Percent nitrogen in legume tops and roots (6).

Crop	Tops	Roots
	% N	% N
Soybeans	93	7
Vetch	89	11
Cowpeas	84	16
Red clover	68	32
Alfalfa	58	42

Soil microbial activity

A rapid increase in soil microorganisms occurs after a young, relatively lush green manure crop is incorporated into the soil. The soil microbes multiply to attack the freshly incorporated plant material. During microbial breakdown, nutrients held within the plant tissues are released and made available to the following crop.

Factors that influence the ability of microorganisms to break down organic matter include soil temperature, soil moisture, and carbon to nitrogen (C:N) ratio of the plant material. The C:N ratio of plant tissue reflects the kind and age of the plants from which it was derived (Table 3). As plants mature, fibrous (carbon) plant material increases and protein (nitrogen) content decreases (7). The optimum C:N ratio for rapid decomposition of organic matter is between 15:1 and 25:1 (6).

C:N ratios above 25:1 can result in nitrogen being "tied up" by soil microbes in the breakdown of carbon-rich crop residues, thus pulling nitrogen away from crop plants. Adding some nitrogen fertilizer to aid the decomposition process may be advisable with these high carbon residues. The lower the C:N ratio, the more N will be released into the soil for immediate crop use.

The C:N ratio is more a function of the plant's N content than its carbon content. Most plant materials contain close to 40% carbon. To determine the C:N ratio of any plant material, divide 40% by its nitrogen content. For example let's say hairy vetch contains 4.2% nitrogen: 40/4.2= a C:N ratio of 9.5. A procedure for determining the nitrogen content of cover crop biomass was previously addressed in the section on nitrogen production. Estimating the nitrogen contribution of a cover crop is very helpful when adjusting N-fertilizer rates to account for legume nitrogen.

Table 3 provides a nice comparison of the typical C:N ratios that can be found in different types of crop residues. The important point is that lush green manures are richer in nitrogen relative to carbon, especially in comparison to highly lignified crop residues like corn stalks. It will take a lot longer for soil microbes to break down corn stalks than fresh hairy vetch.

Table 3. Common C:N ratios of cover crops.

Organic Material	C:N Ratio	Reference
Young rye plants	14:1	4
Rye at flowering	20:1	4
Hairy vetch	10:1 to 15:1	8
Crimson clover	15:1	6
Corn stalks	60:1	4
Sawdust	250:1	9

Nutrient enhancement

In addition to nitrogen from legumes, cover crops help recycle other nutrients on the farm. Nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and other nutrients are accumulated by cover crops during a growing season. When the green manure is incorporated, or laid down as no-till mulch, these plant-essential nutrients become slowly available during decomposition. Dr. Greg Hoyt developed a method for estimating nutrient accruement by cover crops in order to reduce the soil test recommendation of fertilizer for the following crop (10). Table 4 shows the biomass and nutrients accumulated by several cover crops he worked with.

Table 4. Biomass yield and nutrient accruement by selected cover crops (10).

Crop	Biomass* lbs/ac	Nitrogen lbs/ac	Potassium lbs/ac	Phosphorus lbs/ac	Magnesium lbs/ac	Calcium lbs/ac
Hairy Vetch	3,260	141	133	18	18	52
Crimson clover	4,243	115	143	16	11	62
Austrian W. P.	4,114	144	159	19	13	45
Rye	5,608	89	108	17	8	22

*Dry weight of aboveground plant material.

Certain broad-leaved plants are noted for their ability to accumulate minerals at high concentrations in their tissue. For example, buckwheat, lupine, and sweetclover are noted for their ability to extract P from soils. Likewise, alfalfa and other deep-rooting green manures scavenge nutrients from the subsoil and translocate them upwards to the surface rooting zone, where they become available to the following crop.

The breakdown of green manures in soil influences mineral nutrient availability in another way. During decomposition of organic matter, carbonic and other organic acids are formed as a byproduct of microbial activity. These organic acids react with insoluble mineral rocks and phosphate precipitates, releasing phosphates and exchangeable nutrients (6).

Rooting action

The extensive root systems of some cover crops are highly effective in loosening and aerating the soil. In Australian wheat experiments, the taproots of a blue lupine cover crop performed like a "biological plow" in penetrating compacted soils (11). When cover crops are planted after a subsoiling treatment, they help extend the soil-loosening effects of the deep tillage treatment. The rooting depths of several green manures grown under average conditions are listed in Table 5.

Table 5. Typical rooting depths of several green manure crops (2).

Depth (feet)	Green Manure Crop
5 to 7	Red Clover, Lupine, Radish,
	Turnips
3 to 5	Common Vetch, Mustard,
	Black Medic, Rape
1 to 3	White Clover, Hairy Vetch

Weed suppression

Weeds flourish on bare soil. Cover crops take up space and light, thereby shading the soil and reducing the opportunity for weeds to establish themselves. The soil-loosening effect of deep-rooting green manures also reduces weed populations that thrive in compacted soils.

The primary purpose of a non-legume green manure—such as rye, millet, or sudangrass—is to provide weed control, add organic matter, and improve soil tilth. They do not produce nitrogen. Thus, whenever possible, annual grain or vegetable crops should follow a legume green manure to derive the benefit of farm-produced nitrogen.

Providing weed suppression through the use of allelopathic cover crops and living mulches has become an important method of weed control in sustainable agriculture. Allelopathic plants are those that inhibit or slow the growth of other nearby plants by releasing natural toxins, or "allelochemicals." Cover crop plants that exhibit allelopathy include the small grains like rye and summer annual forages related to sorghum and sudangrass. The mulch that results from mowing or chemically killing allelopathic cover crops can provide significant weed control in no-till cropping systems. Living mulches suppress weeds during the growing season by competing with them for light, moisture, and nutrients.

Soil and water conservation

When cover crops are planted solely for soil conservation, they should provide a high percentage of ground coverage as quickly as possible. Most grassy and non-legume cover crops, like buckwheat and rye, fulfill this need well. Of the winter legumes, hairy vetch provides the least autumn ground cover because it puts on most of its above-ground growth in the spring. Consequently, it offers little ground cover during the erosion-prone fall and winter period. Sowing a mix of leguminous and grassy-type cover crops will increase the ground coverage, as well as provide some nitrogen to the following crop.

The soil conservation benefits provided by a cover crop extend beyond protection of bare soil during non-crop periods. The mulch that results from a chemically or mechanically killed cover crop in no-till plantings increases water infiltration and reduces water evaporation from the soil surface. Soil cover reduces soil crusting and subsequent surface water runoff during rainy periods.

Retention of soil moisture under cover crop mulches can be a significant advantage. Dr. Blevins and other researchers showed consistently higher soil-moisture levels for corn grown in a herbicide-killed, no-till bluegrass sod than for corn grown in conventionally plowed and disked plots (12). They concluded that the decreased evaporation and increased moisture storage under the no-till mulch allowed plots to survive a short-term drought without severe moisture stress.

Vegetation management to create a cover crop mulch

Herbicides are the most commonly used tools for cover crop suppression in conservation tillage systems. Non-chemical methods include propane flamers, mowing and mechanical tillage.

Mowing a rye cover crop when it heads out in late spring provides sufficient kill (13). The rye must be in the pollination phase, or later, to be successfully killed. When the anthers are fully extended and you can thump the stalk and pollen falls down, it is time to mow. If mowed earlier, it just grows back. Flail mowers generally produce more uniformly distributed mulch than do rotary cutters, which tend to windrow the mulch to one side of the mower. Sickle bar mowers create fairly uniform mulch, but the unchopped rye stalks can be more difficult to plant into. If late spring weather continues cool and wet, more rye regrowth will occur than if the weather remains warm and dryer. Typically, if rye is mowed at the pollination stage, regrowth is minimal and not a problem to crops grown in the mowed mulch.

In a Mississippi study, flail mowing, or rolling with rolling disk colters spaced at 4 inches, was usually as effective as herbicides in killing hairy vetch, crimson clover and subterranean clover (14). Timing is a key factor when using mowing or rolling to control cover crops. Mechanical control was most effective when the legumes were in the seed formation growth phase (mid to late April) or when stem lengths along the ground exceeded 10 inches (14). If mowing was followed with a pre-plant herbicide application of Atrazine, the legume kill was even more effective.

Researchers at Ohio State University developed a mechanical cover crop killing tool used to take out a cover crop without herbicides. They call it an undercutter because it uses wide V-blades which run just under the soil surface to cut off the cover crop from its roots. The blades are pitched to 15 degrees allowing the blades to penetrate the soil and provide a slight lifting action. Mounted on the same toolbar behind the cutter blades is a rolling basket to flatten and distribute the undercut cover crop. The undercutter was tried on several cover crops and effectively killed crimson clover, hairy vetch, rye, and barley. These undercutters could be made from locally available stock by innovative tinkerers.

Steve Groff of Cedar Meadow Farm in Lancaster County, Pennsylvania, uses a 10-foot Buffalo rolling stalk chopper from Fleischer Manufacturing (15) to transform a green cover crop into a no-till mulch (see Figure 1). Under the hitch-mounted frame, the stalk chopper has two sets of rollers running in tandem. These rollers can be adjusted for light or aggressive action and set for continuous coverage. Steve says the machine can be run up to 8 miles an hour and does a good job of killing the cover crop and pushing it right down on the soil. It can also be used to flatten down other crop residues after harvest. Groff improved his chopper by adding independent linkages and springs to each roller. This modification makes each unit more flexible to allow continuous use over uneven terrain. Following his chopper, Groff transplants vegetable seedlings into the killed mulch. He direct-seeds sweet corn and snap beans into the mulch. For more information on this system, order Steve's videos listed under the **Videos** section of this publication, or visit his Web page, which is listed under the **Web Resources** section. At the Web site you can see photos of these machines in action, and test-plot results comparing flail mowing, rolling, and herbicide-killed cover crops.

Figure 1. Steve Groff's modified rolling stalk chopper. (From www.cedarmeadowfarm.com)

Two USDA-ARS researchers, Drs. Aref Abdule-Bake and John Teasdale of the Beltsville Maryland Research Center, have developed a cover-crop roller (Figure 2) that acts, in principle, similarly to Steve Groff's rolling chopper. In their extensive research trials using hairy vetch, they no-till planted tomatoes into a mechanically killed hairy vetch cover crop (Figure 3). Details of their research—and other useful information on flail-mowing of cover crops and direct no-till seeding of sweet corn and snap beans into mechanically killed cover crops—can be seen in the USDA Farmer's Bulletin No. 2279, listed under the **Web**

Resources section below. As of this writing the bulletin is available only on-line because the first printing of it was all distributed to farmers and their advisors in a very short time.

Figure 2. A homemade roller to kill cover crops (From USDA Farmer's Bulletin No. 2279).

Figure 3. Transplanting tomatoes into mechanically killed hairy vetch. (From USDA Farmer's Bulletin No. 2279).

Planting cover crops known to readily winter-kill is another non-chemical means of vegetation management. Spring oats, buckwheat, and sorghum fill this need. They are fall-planted early enough to accumulate some top growth before freezing temperatures kill them. In some locations, oats will not be completely killed and some plants will regrow in the spring. Winter-killed cover crops provide a dead mulch through the winter months instead of green cover. They are used primarily in regions where precipitation is limited, such as West Texas, and in situations where farmers want to plant early in the spring and avoid overwintered cover crops altogether.

Limitations of cover crops

The recognized benefits of green manuring and cover cropping—soil cover, improved soil structure, nitrogen from legumes—need to be evaluated in terms of cash returns to the farm as well as the long-term value of sustained soil health. For the immediate growing season, seed and establishment costs need to be weighed against reduced nitrogen fertilizer requirements and the effect on cash crop yields.

Water consumption by green manure crops is a concern and is pronounced in areas with less than 30 inches of precipitation per year. Still, even in the fallow regions of the Great Plains and Pacific Northwest, several native and adapted legumes (such as black medic) seem to have potential for replacing cultivation or herbicides in summer fallow. There is always additional management required when cover crops of any sort are added to a rotation. Turning green manures under or suppressing cover crops requires additional time and expense, compared to having no cover crop at all.

Insect communities associated with cover crops work to the farmer's advantage in some crops and create a disadvantage in others. For example, certain living mulches enhance the biological control of insect pests of summer vegetable crops and pecan orchards by providing favorable habitats for beneficial insects. On the negative side, winter legumes that harbor catfacing insects such as the tarnished plant bug, stink bug, and plum curculio can pose problems for apple or peach orchardists in the eastern U.S. Nematodes encouraged by certain legumes on sandy soils are another concern of farmers, as are cutworms in rotations following grain or grass crops.

Cover crops in rotation

Cover crops can fit well into many different cropping systems during periods of the year when no cash crop is being grown. Even the simplest corn/soybean rotation can accommodate a rye cover crop following corn, which will scavenge residual nitrogen and provide ground cover in the fall and winter. When spring-killed as a no-till mulch, the rye provides a water-conserving mulch and suppresses early-season weeds for the following soybean crop. Hairy vetch can be planted behind soybeans to provide nitrogen for corn the following spring. Hairy vetch is *not* a good cover crop to use when small grains are included in the rotation—if the vetch ever goes to seed it can become a terrible weed in the small grain crop. In these cases, crimson clover, sweet clover, or red clover should be used, depending on location.

Many vegetable rotations can accommodate cover crops as well. Buckwheat can follow lettuce and still be tilled down in time for fall broccoli. Hairy vetch works well with tomatoes and other warm-season vegetables. The vetch can be killed by flail mowing and tomato sets planted into the mulch. For more details on the vetch-tomato system see Steve Groff's Web page, listed under **Web Resources** below. *Managing Cover Crops Profitably* has a nice section on crop rotation with cover crops, starting on page 34. For ordering information on this handbook, see the **Publications in Print** section below.

Pest management benefits of cover crops

In addition to the soil improving benefits, cover crops can also enhance many pest management programs. Ecologists tell us that stable natural systems are typically diverse, containing many different types of plants, arthropods, mammals, birds, and microorganisms. Growing cover crops adds diversity to a cropping system. In stable systems, serious pest outbreaks are rare, because natural controls exist to automatically bring populations back into balance.

Farmers and researchers in several locations have observed and documented increased beneficial insect numbers associated with cover crops. The cover crops provide pollen, nectar, and a physical location for beneficial insects to live while they search for pest insects. Conservation tillage proves a better option than tilling because it leaves more crop residue on the surface to harbor the beneficial insects. Strip tilling or no-tillage disturbs a minimum of the existing cover crop that harbors beneficial insects. Cover crops left on the surface may be living or in the process of dying. At either of these stages they protect beneficials. Once the main crop is growing, the beneficials move onto it. By having the cover crop in place early in the growing season, the population of beneficials is much higher sooner in the growing season than would be the case if only the main crop were serving as habitat for the beneficials.

Innovative farmers are paving the way by interplanting cover crops with the main crop and realizing pest management benefits as a result. Georgia cotton farmers Wayne Parramore and sons reduced their insecticide and fertilizer use by growing a lupine cover crop ahead of their spring-planted cotton (16). They started experimenting with lupines on 100 acres in 1993 and by 1995 were growing 1,100 acres of lupines. Ground preparation for cotton planting is begun about 10 days prior to planting by tilling 14-inch wide strips into the lupines. Herbicides are applied to the strips at that time and row middles remain untouched. The remaining lupines provide beneficial insect habitat and also serve as a smother crop to curtail weeds and grasses. The lupines in the row middles can be tilled in later in the season to release more legume nitrogen.

Dr. Sharad Phatak of the University of Georgia has been working with cotton growers in Georgia testing a strip cropping method using winter annual cover crops (17). Planting cotton into strip-killed crimson clover improves soil health, cuts tillage costs, and allows him to grow cotton without any insecticides and only 30 pounds of nitrogen fertilizer. Working with Phatak, farmer Benny Johnson reportedly saved at least $120/acre on his 16-acre test plot with the clover system. There were no insect problems in the test plot, while beet armyworms and whiteflies infested nearby cotton and required 8 to 12 sprays to control. Cotton intercropped with crimson clover yielded more than 3 bales per acre compared with 1.2 bales per acre in the rest of the field (17). Boll counts were 30 per plant with crimson clover and 11 without it. Phatak identified up to 15 different kinds of beneficial insects in these strip-planted plots.

Phatak finds that planting crimson clover seed at 15 pounds per acre in the fall produces around 60 pounds of nitrogen per acre by spring. By late spring, beneficial insects are active in the clover. At that time, 6- to 12-inch planting strips of clover are killed with Roundup herbicide. Fifteen to 20 days later the strips are lightly tilled and cotton is planted. The clover in the row-middles is left growing to maintain beneficial insect habitat. When the clover is past the bloom stage and less desirable as a preferred habitat, beneficials move onto the cotton. Even early-season thrips, which can be a problem following cover crops, are limited or prevented by beneficial insects in this system. Movement of the beneficials coincides with a period when cotton is most vulnerable to insect pests. Following cotton defoliation in the early fall, the beneficials hibernate in adjacent non-crop areas.

Phatak points out that switching to a whole-farm focus while reducing off-farm inputs is not simple. It requires planning, management, and several years to implement on a large scale. It is likewise important to increase and maintain organic matter, which stimulates beneficial soil microorganisms. Eventually a "living soil" will help keep harmful nematodes and soil-borne fungi under control (17).

The two *Creative Cover Cropping* videos from California, listed under the **Videos** section below, show footage of cover crop systems used to provide beneficial insect habitat and how to manage them. *Managing Cover Crops Profitably* has a section on using cover crops for pest management starting on page 25. See the **Publications in Print** section for ordering information. Additional concepts and practices associated with cover crops as a tool to build soil health and increase agroecosystem diversity in relation to pest management are contained in the following ATTRA publications: *Farmscaping to Enhance Biological Control* and *Alternative Nematode Control*.

Table 6. Optimum nitrogen rates and profitability of several cover crops (19).

Cover Crop	Corn Yield	Optimum N rate
	bu./acre	lbs N/acre
No cover crop	142	100
Winter wheat	142	126
Hairy vetch	148	79
Austrian winter peas	153	107
Crimson clover	148	94

Economics of cover crops

The most obvious direct economic benefit derived from legume cover crops is nitrogen fertilizer savings. In most cases these savings can offset cover crop establishment costs. Indirect benefits include herbicide reduction in the case of an allelopathic rye cover crop, reduction in insect and nematode control costs in some cases, protection of ground water by scavenging residual nitrate, and water conservation derived from a no-till mulch. Longer-term benefits are derived from the buildup of organic matter resulting in increased soil health. Healthy soils cycle nutrients better, don't erode, quickly absorb water after each rain, and produce healthy crops and bountiful yields.

With annual cover crops, the highest cost is seed. Hairy vetch and crimson clover typically range from 50¢ to $1.50 per pound. With a 20-pound per acre seeding rate, seed costs range from $10 to $30 per acre. With a 25-pound seeding rate at 85¢/lb and a $6.50 no-till drilling cost, it would cost $28 to plant an acre of this cover crop.

In a Maryland study, hairy vetch was compared to a winter wheat cover crop or no cover crop at two different locations (coastal plain and piedmont) (18). Corn was grown following the cover crops. Nitrogen fertilizer was used with the cover crops at varying rates. The most profitable cover crop and nitrogen fertilizer combination used more than 100 lbs of additional nitrogen per acre plus the cover crop. At $2.50 per bushel corn price, highest returns at the coastal plain location were realized with 120 lbs of additional nitrogen per acre. Profits were as follows: $53.75 per acre from no cover crop, $95.62 from hairy vetch, and $32.47 from winter wheat cover crop. All corn crops needed additional nitrogen. Lower N rates were less profitable. At the piedmont location, also with $2.50 corn, winter fallow was most profitable at $68.03 with 40 lbs per acre additional N, hairy vetch was profitable at $56.57 with 40 lbs per acre, and winter wheat was profitable at $30.12 with 100 lbs of additional nitrogen.

In another Maryland study (19), optimum nitrogen rates for corn were determined when corn followed four cover crops, compared to a winter fallow (no cover crop) treatment. Corn was grown following each cover crop treatment at various nitrogen rates over a three-year period. The results are shown in Table 6. The optimum nitrogen rate is the rate above which no additional yield increases are realized. The researchers concluded that cover crops can benefit a succeeding corn crop not only by supplying nitrogen but also by increasing maximum yield of the system (19).

Many studies have shown that legume cover crops can replace a portion of the fertilizer nitrogen requirements for a following crop. Some of these replacement values can be seen in Table 7. The economic value of these nitrogen replacements can be calculated by using a local nitrogen price. These costs can then be compared to cover crop seed and planting costs. These simple nitrogen cost comparisons do not take into account the benefits of improved soil tilth and increased water infiltration resulting from cover crops.

In a Kentucky study (25), economic returns above direct expenses for no-till corn were $64 greater with hairy vetch plus 90 lbs of nitrogen fertilizer per acre than with no cover crop plus the same nitrogen rate. This advantage was mostly due to the yield increase under the legume cover crop of 36 bushels per acre. Some researchers have stated that advantages of legume cover crops can only be realized if they increase yields of a following crop over yields obtained from no cover crop. In other words, the nitrogen replacement value is insufficient to offset the establishment costs of the cover crop without an increase in crop yield. When these yield increases beyond the nitrogen benefit occur, they are due to improved soil water use efficiency and other soil health benefits from the cover crop.

Table 7. Nitrogen fertilizer replacement value of legume cover crops.

Cover Crop	N replacement value (lbs/acre)	Reference
Hairy vetch	80-89	Ebelhar, et al., 1984 (20)
Hairy vetch	170	Utomo, et al., 1990 (21)
Winter legumes	64-69	Hargrove, et al.,1986 (22)
Hairy vetch	110	McVay, et al., 1989 (23)
Crimson clover	88	McVay, et al., 1989 (23)
Winter legumes	75	Tyler, et al., 1987 (24)

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2281 16th Avenue
P.O. Box 848
Columbus, NE 68602-0848
800-228-1405
402-564-3244

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Resources

In most states the Extension service and Agricultural Experiment Stations offer free or low-cost publications on cover crops to state residents. Examples include: *Effects of Winter Cover Crops on Yield of Cotton and Soil Properties* (Arkansas Agricultural Experiment Station Bulletin 924), *Planting Guide for Forage Crops* (North Carolina Extension Service publication AG-226), and *Cover Crops* (Mississippi Cooperative Extension Service Publication 1552). Contact these local sources to obtain information adapted to your immediate area.

Publications in Print

Managing Cover Crops Profitably, 2nd Edition. 1998. The Sustainable Agriculture Network. This publication is one of the most comprehensive hands-on resources available. The book is organized by the different geographic regions of the United States. Covered in the book are selection of the best species for your location, planning profitable crop rotations, crop yield benefits following cover crops, and fertilizer reduction realized from cover crops. Chapters on 18 different cover crop species and charts rating many factors for each species, including drought tolerance, nitrogen yield, and seeding rates. The top six high-performing cover crops for each region are discussed. This publication may be ordered for $19.00 plus $3.95 shipping from:

Sustainable Agriculture Publications
210 Hills Building
University of Vermont
Burlington, VT 05405-0082
802-656-0471

Excerpts from the 2nd Edition can also be found on the SAN Web site: http://www.sare.org/mccp2/

Northeast Cover Crop Handbook. 1994. 118 pages. Marianne Sarrantonio. Among the topics covered in this comprehensive and practical manual on using cover crops are how to choose the right cover crop for your operation, building a rotation around cover crops, choosing the best species for the whole farm, estimating the nitrogen contribution from a green manure, looking at soil improvements from cover crops, and lowering the cost of cover cropping. The book is well written and easy to read, with lots of drawings and simple charts. The appendix contains detailed management practices for 20 cover crop species, cover crop seed sources, and other information sources. To order this publication send $12.00 plus $5.50 shipping and handling to:

Rodale Institute Bookstore
611 Siegfriedale Road
Kutztown, PA 19530
800-832-6285
610-683-6009
http://www.rodaleinstitute.org

Green Manuring: Principles and Practice of Natural Soil Improvement. 1989. 51 pages. This publication contains an excellent review of the benefits and uses of green manure cover crops. This 51-page spiral-bound book is largely based on green manuring trials in Switzerland and is supplemented with cover crop data compiled by Woods End Agricultural Institute of Maine and The New Alchemy Institute of Massachusetts. Although much of the discussion is based on the use of green manures in Switzerland, the cultural practices are just as applicable to farming systems in the United States. Tables include seeding rates and cost of seed per acre, biomass yields and nutrient contents, and characteristics of selected living mulches. The 1989 edition, unlike the earlier editions, also contains an extensive list of seed sources in the U.S. It is available for $20, which includes shipping and handling, from:

Woods End Agricultural Institute
PO Box 297
Mt. Vernon, ME 04352
207-293-2457
http://www.woodsend.org

Covercrops for California Agriculture by P.R. Miller, W.L. Graves, W.A. Williams, and B.A. Madison is California Extension Leaflet No. 21471, published in December of 1989. This 24-page leaflet contains information on using cover crops for soil improvement, selecting cover crops, growing and working in cover crops, biological interactions, and an appendix on cover crop management systems. It can be obtained for $3.50 plus $2.00 shipping and handling from:

University of California, ANR
Comunication Services
6701 San Pablo Avenue
Oakland, CA 94608-1239
510-642-2431
http://anrcatalog.ucdavis.edu

Cover Cropping in Vineyards by Chuck Ingles, University of California Publication number 3338. Published in 1998 with 168 pages. The publication offers cover cropping methods for enhancing vineyard performance. Provides detailed information on how cover crops promote ecological stability. Useful to vineyard owners, managers, consultants, and pest control advisors. Available for $20 plus $5 shipping and handling from:

University of California, ANR
Comunication Services
6701 San Pablo Avenue
Oakland, CA 94608-1239
510-642-2431
http://anrcatalog.ucdavis.edu

Cover Crops: Resources for Education and Extension. 1998. 3-ring binder. To order, send $20.00 postpaid, U.S. check or money order (payable to "UC Regents"; write title of publication on the check) to:

UC SAREP
University of California
One Shields Ave.
Davis, CA 95616-8716
530-752-7556
530-754-8550 FAX
sarep@ucdavis.edu
http://www.sarep.ucdavis.edu

Videos

No-till Vegetables by Steve Groff. 1997. Steve is a 15-year no-till farmer in Lancaster County, Pennsylvania, who uses cover crops extensively in his crop fields. Steve farms 175 acres of vegetables, alfalfa, and grain crops on his Cedar Meadow Farm. This video leads you through selection of the proper cover crop mix to plant into and how to control cover crops with little or no herbicide. You will see Groff's mechanical cover-crop-kill method, which creates ideal no-till mulch without herbicides. Vegetables are planted right into this mulch using a no-till transplanter. He grows high-quality tomatoes, pumpkins, broccoli, snap beans, and sweet corn. After several years of no-till production his soils are very mellow and easy to plant into. You'll also hear comments from leading researchers in the no-till vegetable area. Order this video for $21.95 plus $3.00 shipping from:

Cedar Meadow Farm
679 Hilldale Road
Holtwood, PA 17532
717-284-5152
http://www.cedarmeadowfarm.com

Creative Cover Cropping in Annual Farming Systems. 1993. Produced by the University of California, this video depicts opportunities and constraints of cover crop use. The film shows many types of cover crops used in various annual cropping systems for soil fertility and pest management. 24 minutes. Item number V93-V.

Creative Cover Cropping in Perennial Farming Systems. 1993. Produced by the University of California. Teaches how cover crops can be used to protect and improve soil fertility, enhance pest control, and provide other benefits. Creative management options are shown with a wide variety of cover crops used in orchards and vineyards. 27 minutes. Item number V93-W.

To order either or both of these videos send $15.00 plus $4.00 shipping and handling each to:

University of California
ANR Communication Services
6701 San Pablo Avenue
Oakland, CA 94608-1239
510-642-2431
http://anrcatalog.ucdavis.edu

Web Resources

USDA's Sustainable Agriculture Network (SAN)
http://www.sare.org/

This site offers the first edition of Managing Cover Crops Profitably on-line and a database of other sustainable agriculture research and education projects. Many of these projects have a cover crop component and some are focused on cover crops.

Managing Cover Crops Profitably
http://www.sare.org/handbook/mccp2/index.htm

The on-line version of the first edition mentioned in the paper publication listed above. It summarizes more than 30 cover crops by region. Published in 1991.

UC SAREP Cover Crop Resource Page
http://www.sarep.ucdavis.edu/ccrop

This is the database of all databases when it comes to cover crops. The UC-SAREP Cover Crop Database includes more than 5,000 items gleaned from more than 600 separate sources, including journal articles, conference proceedings, standard textbooks, unpublished data, and personal communications from researchers and farmers. The information in the database concerns the management and effects of more than 32 species of plants usable as cover crops. More *than 400 different cover crop images are also available for online viewing. One limitation — the database is regionally geared to the Mediterranean climate of California. Ideally, each region of the U.S. should enjoy such site-specific information.*

The Farming Connection
http://sunsite.unc.edu/farming-connection/covercro/home.htm

This site has farmer features and links to other cover crop sites. It also contains seed sources, general information, Steve Groff's No-till Vegetables video listing, and the first edition of Managing Cover Crops Profitably.

Ohio State On-line Ag Facts
http://ohioline.osu.edu/agf-fact/0142.html

This site has an on-line version of Cover Crop Fundamentals by Alan Sundermeier, publication number AGF-142-99. This publication covers the benefits of cover crops, planting times, types of cover crops, managing cover crop growth, and return on investment.

Michigan Cover Crops, Michigan State University and Kellogg Biological Station
http://www.kbs.msu.edu/Extension/Covercrops/home.htm

The Basics of Green Manuring
P. Warman. EAP Publication 51, Ecological Agriculture Projects
http://eap.mcgill.ca/Publications/EAP51.htm

Cover Crops & Green Manure Crops for Vegetable Farms
Ohio Vegetable Production Guide 2000
http://www.ag.ohio-state.edu/~ohioline/b672/b672_1.html

Summer Cover Crops for Tomato Production in South Florida
http://www.imok.ufl.edu/veghort/pubs/workshop/Bryan99.htm

Cover Cropping in Potato Production
EAP Publication 71, Ecological Agriculture Projects
http://eap.mcgill.ca/Publications/EAP71.htm

Cedar Meadow Farm's New Generation Cropping Systems
http://www.cedarmeadowfarm.com

Steve Groff's New Generation Cropping Systems Web page. Shows action shots of no-till planting into mechanically killed cover crops and ordering information for Steve Groff's No-till Vegetables video mentioned above.

USDA Web Site
http://www.ars.usda.gov/is/np/tomatoes.html

1997. By Aref Abdul-Baki and John R. Teasdale. USDA Farmers' Bulletin No. 2279. 23 p. This Web site provides the USDA Farmer's Bulletin that features the no-till vegetable cropping system developed by scientists at the USDA-ARS Vegetable Laboratory in Beltsville, Maryland. This system relies on hairy vetch established in the fall, followed by a mow-down treatment the following spring to prepare a no-till bed to transplant tomatoes and other vegetable crops.

Sustainable Agriculture Network Web site
http://www.sare.org/htdocs/pubs/mccp/

Managing Cover Crops Profitably, *1st Edition (1991).*

Sustainable Agriculture Network
http://www.sare.org/htdocs/pubs/resources/index.html

Order the on-line version of: Managing Cover Crops Profitably, 2nd Edition (1998).

Multiple Impacts Cover Crops.
John Luna, Oregon State University
http://ifs.orst.edu/pubs/multiple_impacts_cover_cro.html

A comprehensive piece on cover crops and their benefits.

Cover Cropping in Row and Field Crop Systems
http://www.sarep.ucdavis.edu/ccrop//slideshows/rfshow01.htm

An online educational slide series that provides visual images and text describing the benefits and uses of cover cropping in annual crops like vegetables. 52 slides.

Cover Crop Biology: A Mini-Review
Robert L. Bugg
Sustainable Agriculture Research & Education Program, University of California
http://www.sarep.ucdavis.edu/ccrop/ccres//35.htm

Cover Crops for Sustainable Agriculture – IDRC
http://www.idrc.ca/cover_crop/index_e.html

Cover Crops and Living Mulches. Sustainable Practices for Vegetable Production in the South
Dr. Mary Peet, NCSU
http://www.cals.ncsu.edu/sustainable/peet/cover/c02cover.html

Planting Dates, Rates, and Methods of Field and Forage Crops. University of Florida, Institute of Food and Agricultural Sciences
http://edis.ifas.ufl.edu/AA127

Uses of Cover Crops by Janet Wallace, NSOGA
http://www.gks.com/nccrp/usesofcc.php3

Organic Matter/Cover Crops: Green Manure Crops for Vegetable Farms. Obtaining Acceptable Stands of Clover and Green Manure Crops. 2000 Ohio Vegetable Production Guide, Bulletin 672-00.
http://ohioline.osu.edu/b672/organic_matter_cover_crops.html

Additional Information from ATTRA

ATTRA can provide more information on specific cover crops via reprints, summaries of research, and other resources. This includes materials on living mulches, summer green manures, winter cover crops, and allelopathic cover crops, as well as on specific cover crops like hairy vetch and subterranean clover, and on the more obscure cover crops such as crotalaria, velvet bean, sesbania, and phacelia.

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The electronic version of **Overview of Cover Crops and Green Manures** is located at:
HTML
http://www.attra.ncat.org/attra-pub/covercrop.html
PDF
http://www.attra.ncat.org/attra-pub/PDF/covercrop.pdf