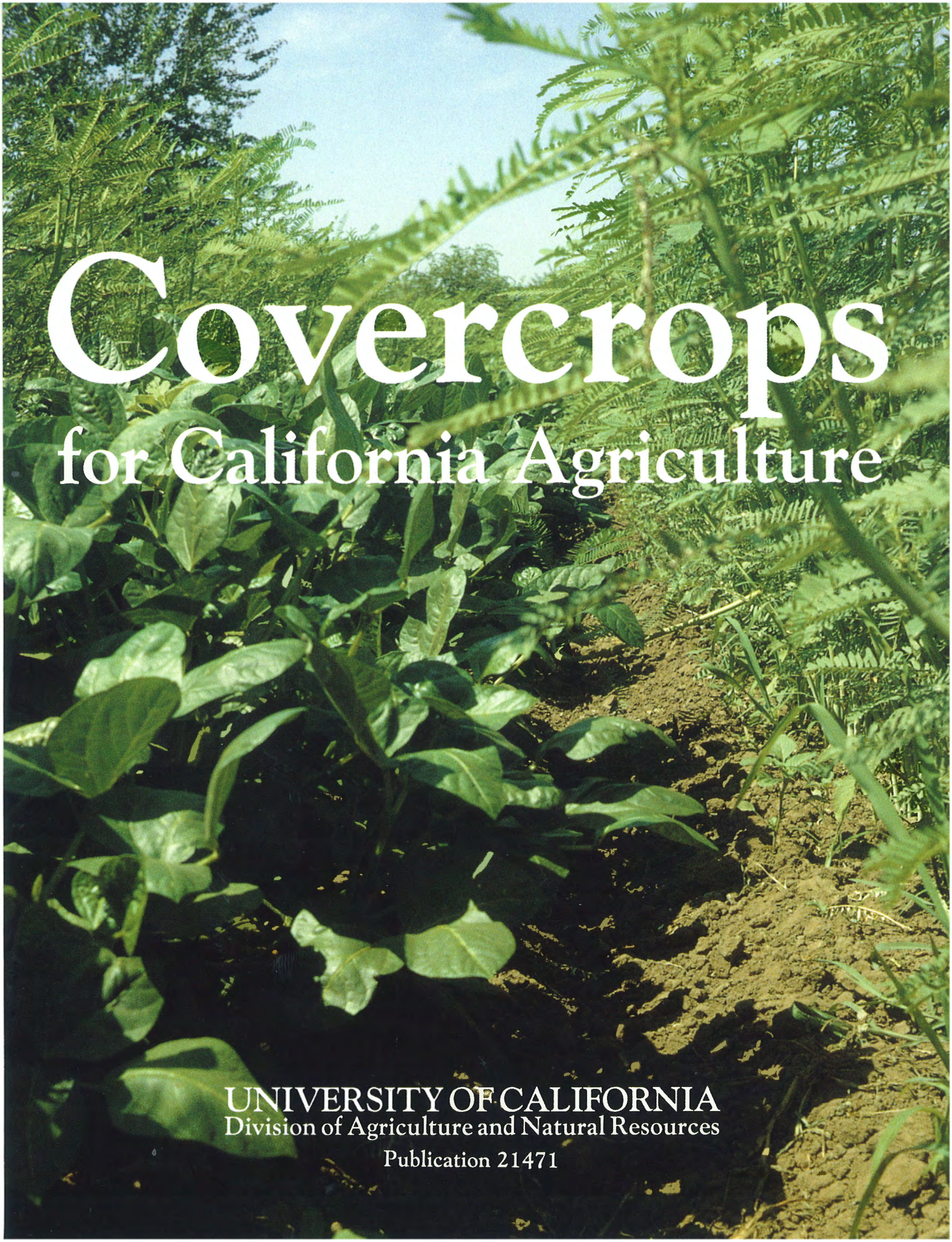


Covercrops
for California Agriculture

UNIVERSITY OF CALIFORNIA
Division of Agriculture and Natural Resources

Publication 21471

Covercrops
for California Agriculture

The Authors

P. R. Miller is Postgraduate Researcher, Agronomy and Range Science, Davis;
W. L. Graves is Farm Advisor, San Diego County;
and W. A. Williams is Professor, Agronomy and Range Science, Davis.
B. A. Madson, author of the original 1951 edition, was Professor of Agronomy, Agronomist for the Agricultural Experiment Station, and Director of Field Stations, College of Agriculture, University of California, Davis.

Why Use Covercrops?

1. For many agricultural soils, covercrops offer the only practical means of supplying the organic matter necessary to keep soil in a high state of productivity.

2. Organic matter makes the soil more friable, improves its tilth, and facilitates water penetration.

3. As organic matter decays, it can provide nitrogen and other soil nutrients for succeeding crops.

4. The soil microorganisms that benefit from the decay of succulent covercrop residue contribute to a healthier soil ecosystem.

Ordering Information

For information about ordering this publication contact:

University of California
Division of Agriculture and Natural Resources
Communication Services –Publications
6701 San Pablo Avenue
Oakland, California 94608-1239

telephone: (510) 642-2431;
in California only, 1-800-994-8849
FAX: (510) 643-5470
e-mail: anrpubs@ucdavis.edu

Leaflet 21471

Printed in the United States of America.

Production: Jim Coats, *Senior Editor;* Franz Baumhackl, *Senior Artist.*

Acknowledgements

The Jessie Smith Noyes Foundation, the UC Davis Student Experimental Farm, and the UC Sustainable Agriculture Research and Education Program (SAREP) provided support for this project. The authors thank Fred Thomas for providing illustrations for this publication and Daniel Cohen for information on brassicas.

Cover photo: Cowpea and sesbania. Dense shade cast by the cowpea canopy effectively inhibits in-row weeds early in the crop cycle.

Printed in soy-based ink.

Contents

How a Covercrop Helps the Soil

Farmers and farm advisors know that by periodically adding organic matter to the soil they can help the soil maintain its highest state of productivity. Commercial fertilizers can help maintain yield levels in many soils, but growers have observed that the increases in yield that follow a liberal application of organic matter often exceed the expected benefits, based on the plant nutrient elements contained in the organic matter.

Soil organic matter consists largely of stable humus formed from the decomposition of plant roots and other plant residues. When a plant dies or when plant material is mixed with the soil under favorable moisture and temperature conditions, the plant material decomposes rapidly. The material soon loses its original identity and cellular structure, becoming a dark, structureless residue called humus. High moisture, warm temperature, and good aeration all favor the activity of the soil microorganisms that carry out this process of decomposition.

The character of the added organic matter also influences the rate of decomposition. Green succulent material such as vetch decays rapidly because the high soluble carbohydrate and nitrogen content of its biomass stimulates microbial decomposition. Dry material such as mature grass or grain straw, low in nitrogen and other mineral nutrients and high in structural carbohydrates such as cellulose, decays much more slowly. Regardless of the origin of the organic material, however, the resulting humus appears to have about the same composition. Humus in the soil continues to decompose, but much more slowly than fresh organic residues.

Cultivation decreases organic matter

The organic matter content of a virgin soil represents a balance between the annual rate of plant residue addition and the rate of decomposition. Cultivation disturbs this balance, usually decreasing the organic matter because cultivation creates conditions that favor more rapid decomposition. This is particularly true of irrigated land, where the soil is kept moist throughout the warmer part of the year, greatly favoring microbial action. With continuous cropping, a new balance will be restored between the annual addition of crop residues to the soil and the rate of decomposition. Soil organic matter content in this new equilibrium will often be considerably less than that of the virgin soil.

Organic matter improves soil structure

Organic matter benefits the soil in a number of ways. First, it improves the physical condition of the soil by making it more friable, improving its tilth, and facilitating water infiltration. As the organic matter content decreases, soil becomes less friable and more likely to puddle and run together, and the rate of water infiltration decreases. Some evidence indicates that it is not so much the amount of organic matter as it is the type of organic matter that is important.

High-nitrogen plant residues decay rapidly and have a transitory influence on the physical condition of the soil. At the height of the decomposition process, soil microorganisms multiply in response to the abundant nutrient supply. Soil microbiologists have shown that fungal mycelia bind soil particles together and that gums secreted by bacteria cement soil particles into crumbs. This activity results in improved soil tilth.

Low-nitrogen plant residues have a markedly different effect on soil physical properties. They are more resistant to microbial decay and persist longer in the soil than more succulent materials. They probably provide physical channels that improve the movement of air and water into the soil.

In short-term experiments, low-nitrogen covercrops and crop residues have increased the rate of water infiltration more than high-nitrogen materials. For example, single barley covercrops were incorporated at different stages of growth in the spring and compared to a winter fallow treatment at Davis. With advancing barley development from boot to dough stage, nitrogen (N) concentration fell from 2.7 to 1.2 percent and the infiltration rate increased 60 percent (table 1). On a more permeable soil, corn crop residue (0.7 percent N) increased infiltration twofold over a cowpea covercrop (2.5 percent N) (table 2).

Similar results occurred at the Imperial Valley Field Station. After three seasons of Sudangrass covercropping (1.3 percent N) alternating with winter cash crops, infiltration improved 45 percent over fallow, whereas the improvement from sesbania covercropping in first and third years (2.9 percent N) was not significant (10 percent improvement).

Added organic matter and nutrient availability

Added organic matter also increases the available plant nutrients in the soil. The decay process liberates nutrient elements from the organic matter, and those nutrients become available to succeeding crops.

The availability of plant nutrients is influenced to some extent by the composition of the added organic material. If a low-nitrogen material such as grain straw is added to the soil, it may depress succeeding crop growth. Straw is very low in nitrogen, normally containing not more than 0.3 to 0.6 percent (dry basis), but it is rich in cellulose and thus provides energy for microorganisms. As a result of the high carbon:nitrogen ratio of this food supply, the soil organisms multiply rapidly. The organisms cannot secure all the nitrogen they need from the straw, so they draw some of their supply from other sources, particularly the free soil nitrogen pool that would normally be available for the succeeding crop. In effect, the microorganisms are competing with the crop for available nitrogen. When the straw has decayed so much that most of the energy-rich compounds have been used, microbial activity decreases, and available nitrogen again begins to accumulate in the soil.

Addition of a material high in nitrogen (1.5 percent or more) has no such detrimental effect on the succeeding crop. Such material contains all the nitrogen needed by the soil microorganisms, so they have no need for the free soil nitrogen. Legumes normally contain more than 1.5 percent nitrogen, as do some nonleguminous plants at the stage of growth at which they usually are worked into the soil as green manure crops.

If the source of the organic matter is a legume, such as alfalfa, clover, or vetch, it may substantially increase the available nitrogen content of the soil. Such sources of organic matter do not actually increase the supply of other nutrient elements, but they may serve to make some of the mineral nutrients, such as phosphorus or potassium, more readily available to plants.

Table 1. Infiltration rate improvement from a single barley winter covercrop plowed down at several stages of growth on Zamora loam soil at Davis, California

Treatment	Dry weight	N	Infiltration rate
	lb/a	%	*gal/hr/100-ft furrow*
Fallow	—	—	8
Barley boot	3,100	2.7	10
Barley bloom	5,800	1.6	11
Barley medium dough	6,800	1.2	16
LSD .05	1,100	0.5	5

Table 2. Infiltration rate improvement from summer crop residues and a covercrop on Yolo loam soil at Davis, California

Treatment	Dry weight	N	Infiltration rate
	lb/a	%	*gal/hr/100-ft furrow*
Fallow	—	—	43
Cowpea covercrop	5,000	2.5	47
Cotton crop residue	7,300	1.6	64
Corn crop residue	6,000	0.7	100
LSD .05	1,300	0.2	18

How to add organic matter

Organic matter may be added in three ways:

1. Incorporation of crop residues.
2. Application of manure or other organic materials such as composts.
3. Use of covercrops.

In practically all systems of farming, some organic matter is continually added to the soil from crop residues, weeds, and other volunteer growth. The amount varies greatly, however, depending on the type of farming and the kind of crops grown. Where annual and perennial crops are grown in a systematic rotation, and especially where such crops as alfalfa or clover are used in relatively short rotations, they may add sufficient organic matter to the soil to maintain it in good condition.

In California, however, many cropping systems use no soil-building rotations. This is often true of high-value crops such as cotton, sugar beets, processing tomatoes, vegetables, and orchard crops. Even on unirrigated grain land, the addition of crop residues to the soil, while important, may not be sufficient to keep the soil in good physical condition.

Barnyard and other organic manures cannot be produced in sufficient quantities to cover the extensive areas needing organic matter. Covercrops offer a practical alternative method of supplying the organic matter needed to keep soil in proper physical condition and in a high state of productivity.

The value of covercrops has been proven

Covercrops are not new to California agriculture. Growers have used them for more than 80 years, particularly in orchards. Their use has increased recently because of increases in the cost of nitrogen fertilizer as well as changing attitudes that favor more sustainable production methods. Despite the growing popularity of covercrops, they remain untried in many situations where they could be profitably employed.

Unfortunately, no statistics show the acreage planted to covercrops each year. A portion (probably less than 25 percent) of California's covercropped area consists of volunteer covercrops. These resident weeds are allowed to grow during the winter and worked into the soil the following spring. The rest of the acreage is seeded to covercrops as a means of soil improvement.

Measured in terms of the yield of succeeding crops, the effect of a covercrop depends on the physical, chemical, and biological characteristics of the soil. Effectiveness also varies with climatic conditions, choice of covercrop species, total covercrop growth, and stage of maturity at the time of incorporation into the soil. Covercrop failure may result from choosing a covercrop unsuitable for the locality, failing to use proper inoculation procedures for legumes, or improperly timing cultural practices.

An effective source of nitrogen

From time to time over the past 40 years, short-term trials have demonstrated the ability of legume covercrops to supply nitrogen in field crop rotations. Trials at Davis and Santa Maria followed purple vetch covercrops with sugar beet crops fertilized with several levels of nitrogen. Both sugar yield and petiole analyses of the beets showed that the purple vetch contributed the equivalent of 80 pounds per acre (lb/a) of fertilizer nitrogen. A recent experiment in Davis used a Lana woollypod vetch covercrop, and corn planted after the vetch was incorporated showed a yield response equivalent to that obtained from 200 lb/a of fertilizer nitrogen. Rice also responds well to the nitrogen fixed by leguminous covercrops, such as woollypod and purple vetch.

Corn following oats (*foreground*) and Lana woollypod vetch (*background*). The nitrogen released from the vetch biomass is immediately available to the following crop.

Usefulness in vineyards and orchards

Some vineyards and orchards grow on steep slopes where soil erosion can be a major problem, and significant erosion can occur even on gentler slopes if clean tillage is used. Covercrops reduce the erosion threat by slowing the flow of water, lessening the effect of raindrop impact, and increasing the rate of water infiltration.

An actively growing covercrop modifies the microclimate, making the temperatures of the crop surface and the air above it cooler than they would be for a bare

Table 3. Soil nitrogen and organic matter improvement after 5 years of subclover covercropping at Ramona, San Diego County

Soil depth	1983	1988	LSD .01
in	*total N ppm*		
0–2	710	1,320	290
2–6	590	750	70
	organic matter %		
0–2	1.3	2.6	0.8
2–6	1.0	1.2	0.2

soil. In spring, this cooling can delay the onset of flowering in some tree crops, reducing the probability of frost damage. By the same token, if cold temperatures do threaten more sensitive stages of growth, the lower temperatures in covercropped orchards may increase the risk of frost damage. Close mowing of covercrops at these sensitive stages will reduce the possibility of damage from radiation frosts. In warmer months, a covercrop reduces the amount of sunlight reflected to the crop surfaces above, a particularly important benefit in crops subject to sunburn and mite infestations.

Covercrops can also aid in insect control by harboring natural enemies such as ladybird beetles, lacewings, and other beneficial insects. Dust, which favors such pests as spider mites and is itself an environmental pollutant, can be controlled by covercrop use. The previously discussed benefits to soil physical condition and nutrient supply also apply to vineyards and orchards. Table 3 shows the long-term improvements in fertility and organic matter that can be obtained from properly managed subclover covercrops in Southern California.

Covercrops in vineyards and orchards can have some drawbacks, and these must be minimized. Growers can manage covercrop plant growth by selecting the proper species for the situation and removing residues when harvesting requires a smooth soil surface, such as for nut crops. Some weeds may be harder to control with covercropping (e.g., Johnsongrass). Certain covercrop species may favor rodents and some insect pests, and thus may require control measures. The grower must consider water usage and nutrient competition by the covercrop when devising a soil management program for a vineyard or orchard crop. Growers must also consider the costs of covercrop seed and cultural practices in the overall economics of the crop production plan. The proper choice and appropriate management of a covercrop can mitigate these disadvantages.

Annual ryegrass and crimson clover mixture in wine grapes, King City. Alternate rows are covercropped each year to allow winter pruning on fallow ground.

How to Select a Covercrop

We can grow covercrops during the winter or summer. Most California growers, however, use winter-growing species. The reasons for this preference are two:

1. Winter crops can be grown more cheaply than summer crops because they normally require little or no irrigation.
2. Winter crops fit more easily into most farming practices and interfere less with other farm operations.

A large number of species and varieties of plants can be grown as covercrops in California. Most of these are legumes, though nonlegumes are important in some situations. A covercrop derives its value from the amount of nitrogen or organic matter it will add to the soil. Good growth of a well-inoculated legume will frequently add 100 to 200 pounds of nitrogen to an acre of soil.

Legumes for Irrigated Annual Crop Rotations

Annual legumes are suited to cereals, row crops, and vegetable crop rotations. They grow rapidly and have a high capacity for nitrogen fixation. Properly managed legume covercrops can supply all of the nitrogen needed by the subsequent cash crop. Since most growers plow covercrops down before maturity, they must purchase seed each year or grow it elsewhere on the farm. Although the value of the nitrogen produced by a legume covercrop generally exceeds the cost of purchasing and planting the seed, the presence of a growing covercrop may interfere with the timing of field operations. Where these conflicts occur, the grower must be sure to choose a species and a seeding rate that will give the desired results in the growing period available to the covercrop.

Growers using organic production methods in accordance with the California Organic Food Act (California Health and Safety Code 26569.11) will find legume-covercrop nitrogen to be one of the most economical sources of nitrogen available.

Vetches

The vetch species can grow during the coldest months of the year and withstand some waterlogging during wet winter periods. In common rotations, they precede spring- and summer-planted crops such as safflower, corn, cotton, rice, tomatoes, and summer vegetables. With the exception of the fava or horse bean, all species of vetch that can be grown in California are slender, viny plants.

Most vetch covercrops grow on irrigated land, except in some areas along the coast. To assure a good stand, growers must seed the crop into moisture in the fall before the soil gets cold, or must irrigate it immediately after seeding. If you delay germination until after the first fall rain, which may not come until November or December, the soil may be so cold that the stand will be poor and the results disappointing. This is particularly true in the Central Valley. The more moderate winter temperatures along the coast seldom become too cold for good germination.

Vetches have compound leaves made up of several pairs of leaflets, but with no terminal leaflet. In its place in most species is a tendril growing from the end of the midrib, enabling the vetch to cling to other plants with erect growth habits.

These species grow well in California or have shown promise in some sections of California:

Woollypod vetch (Lana)	*Vicia dasycarpa*
Purple vetch	*Vicia benghalensis*
Common vetch	*Vicia sativa*
Hairy vetch	*Vicia villosa*
Fava bean (bell)	*Vicia faba*

Woollypod vetch. The Lana cultivar is the most recently introduced variety that is successful in California. It competes with purple vetch in much of the state, since both grow rapidly in mild winter conditions.

Woollypod vetch flowers about 3 weeks earlier than purple vetch, so it can set seed in dryland conditions that would be unfavorable to other vetch species. Seed production is prolific, but the pods are prone to shattering.

In general appearance, woollypod resembles hairy vetch and is more prostrate than purple vetch. It is less hardy in winter than hairy vetch, but hardier than purple vetch.

The USDA Soil Conservation Service selected the Lana variety from germplasm introduced from Turkey in 1937, and it became commercially available in the 1950s. Lana vetch has been used successfully as a covercrop and in some rangeland situations. Lana is the most common variety sold by retail seed outlets. When used as a covercrop, the plants seldom attain their maximum growth before being plowed under. However, because this species usually grows more than most vetches during the winter and early spring, its dry matter yield normally exceeds that of the other species. When planted at Davis on October 16 and harvested at its maximum growth on March 30, Lana has produced yields of 6,700 lb/a dry matter and 250 lb/a nitrogen.

Purple vetch. A vigorous viny species, purple vetch is distinguished by being markedly hairy to pubescent overall. It produces a compact raceme or cluster of purple flowers borne on a long stem or peduncle that arises from the leaf axis. The seeds are quite distinctive, being velvety black, with a white hilum, or eye.

Purple vetch first came into prominence as a covercrop in the middle 1920s. Owing to its superior performance and wide adaptation, it rapidly increased in popularity and soon became the most important covercrop species in most agricultural areas of the state.

The species does well where winter temperatures do not fall too low. It has successfully withstood temperatures of 20°F, but prolonged periods of cold weather at or near this point are likely to prove injurious.

Common vetch. Another species is known as spring, Oregon, white, or common vetch. Its growth habit varies, but commonly grown strains resemble purple vetch. The herbage is usually smooth, with little pubescence or down, and the flowers are large and blue or bluish purple, or white in a few cultivars. The flowers are borne without a stem in the axil of the leaf. Each raceme contains only a few flowers.

Once the most important covercrop species, common vetch has for the most part been replaced by Lana and purple vetch. Though adapted to about the same conditions and not quite so sensitive to cold as these other two species, common vetch grows less than they do, both during the winter and overall.

Hairy vetch. Because hairy vetch is better adapted than most species to sandy soils, it is also known as sand vetch. Hairy vetch produces a rather coarse viny growth. The herbage, including the leaves and stem, is quite hairy, though smooth strains also exist. The blue flowers grow in loose racemes, which in turn grow on long stems or peduncles.

Hairy vetch is more winter hardy than the other vetches. At higher elevations with low winter temperatures, you can seed it early enough to establish before the ground freezes, and it will remain dormant during the winter and renew growth when the soil thaws in the spring. In the valleys areas without severe winters, however, hairy vetch still goes dormant, and makes little or no growth until spring. This makes it an inappropriate choice if the covercrop must be plowed under early.

Fava bean. While the fava bean is a vetch, it differs markedly from the previous species in its habit of growth: coarse, erect, and stemmy, with a large taproot and large leaflets. The white flowers have one black spot on each wing, and are borne in sessile axillary racemes.

The common variety, known as broad or Windsor bean, has a flat seed about 1 inch long and ¾ inch wide. The small-seeded varieties known as bell beans have much rounder seeds that range from ⅜ inch to more than ½ inch in diameter. Their smaller size makes bell beans preferable as covercrops.

While adapted to about the same conditions as Lana and purple vetch, the bell bean is more sensitive to low temperatures and other adverse climatic conditions, and in many areas its performance is less reliable. Its susceptibility to black aphids seldom affects its use as a covercrop, but often interferes with seed production. Growers use bell bean mainly in the central coast areas, and to a limited extent in the Sacramento and San Joaquin valleys. It is a much less important covercrop than Lana or purple vetch.

Other winter legumes

Besides the vetches, a number of other winter legumes are used as covercrops or show considerable promise:

Field peas (*Pisum sativum* ssp. *arvense*). The field pea belongs to the same species as the garden pea and, in general, it has similar growth characteristics. As a rule, garden peas have white flowers, while many of the field peas have colored flowers. Field pea varieties vary widely in their time of maturity, total vegetative growth, and other characteristics.

Growers use field peas to some extent for soil improvement, but for various reasons this has never become a very popular practice. A likely reason is economics: the high cost of the seed and the large amount of seed required to plant an acre combine to make seeding expensive. The most common varieties used in California are the Austrian winter pea and its derivatives.

The Austrian winter pea is a large, vigorous-growing type adapted to a wide range of soil conditions. Like hairy vetch, it resists cold damage, going dormant during the winter. Appreciable growth does not begin until spring. If permitted to grow until May, Austrian winter pea will usually produce as much growth as most other legumes. The Austrian winter pea has smaller leaflets than the less hardy varieties.

Californians grow a considerable acreage of Austrian winter pea for seed in response to demand from the southern states. Two strains, the Early Austrian and the Dixie Wonder, differ from Austrian winter pea only in that they mature earlier.

Berseem clover (*Trifolium alexandrinum*). An annual clover species, berseem clover recently became available in California. Because its seeds are small, it must be planted early in fall and sprinkle-irrigated much like alfalfa in order to establish a stand. Once established, it will grow vigorously and reach a height of 18 inches by the end of January. Very responsive to mowing or grazing, berseem clover resprouts quickly from the crown. Thus, berseem clover's main advantage is that it can be mowed every time it reaches 14 to 18 inches of height during the late winter and spring seasons (five or six times), and the clippings can be used for animal forage, compost preparation, or green manure on adjacent areas.

Berseem clover before the second cutting, Woodland.

The Multicut variety has the best growth rate in the Central Valley and irrigated desert valleys of Southern California. Bigbee, a variety from the southern United States, grows more slowly than Multicut but is a little more winter hardy.

***Melilotus* spp.** Of the several species of melilotus, the most important as a covercrop is sour clover, *Melilotus indica*. An erect stemmy plant similar in its habit of growth to the sweet clovers, sour clover is an annual and bears small yellow flowers in short, dense racemes. It varies in height from a few inches to several feet depending on environment. In the northern half of the state, the winters are too cold for satisfactory growth. At one time growers used it extensively in Southern California, particularly in orchards, but more recently it has been replaced by bare chemical fallow. Its chief virtue was that the seed was abundant, cheap, and easy to grow where adapted.

The other sweet clover species, such as the annual white-flowered hubam (*Melilotus alba*), are little used. Their growth comes too late in the spring to fit into the usual covercrop program.

Fenugreek (*Trigonella foenum-graecum*). The growing habit of fenugreek resembles that of its close relative melilotus. It seldom attains a height of more than 2 feet. Its white flowers are sessile, a few in each raceme, and have blue markings. The long, slender pods are almost round in cross-section. Fenugreek seeds are yellow to brown, angular, and like the herbage have a strong aromatic odor.

Fenugreek seldom produces as much growth as some of the other legumes under favorable conditions. It can, however, germinate at low temperatures, and can thus be seeded later in fall than the vetches. It is one of the few legumes that can be seeded as late as December with a good chance of securing a stand. This makes it usable on unirrigated as well as irrigated land.

Summer annual legumes

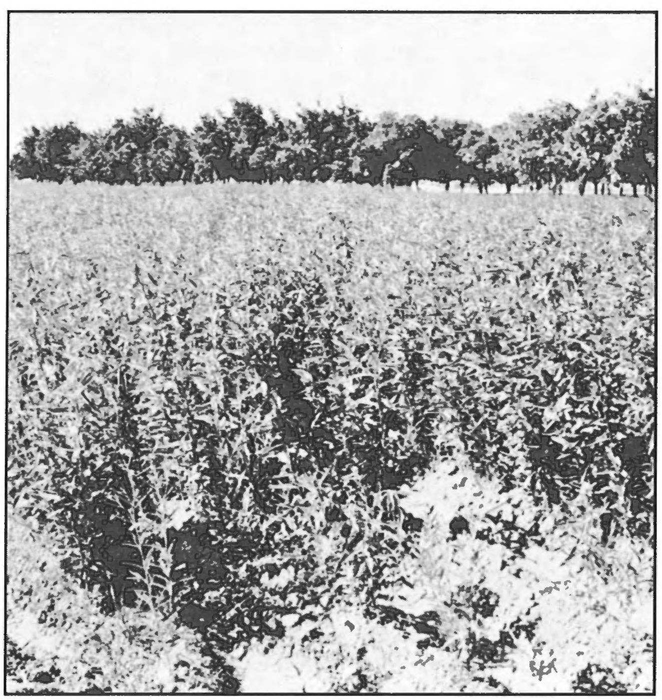
The species in another group, the summer annual legumes, are characterized by their ability to grow rapidly and with minimal irrigation during short, 60- to 90-day summer growing periods. In common rotations, they can follow early sweet corn or early processing tomatoes and precede fall-planted crops such as vegetable brassicas and cereal grains. All summer annual legume species are susceptible to frost.

Cowpeas (*Vigna unguiculata*). One of the many tropical bean species, the cowpea (also commonly known as blackeye bean) is not closely related to the pea. Cowpeas, the most productive heat-adapted legume grown in California, provide a satisfactory covercrop in 60 days. They grow best on deep, well-drained, acid-to-neutral soils where a strong taproot system can take advantage of the moisture held in the soil profile.

Before planting, preirrigate the fields, and then plant the large seeds into moist soil. The dense large-leaved seedling canopy will shade out any in-row weeds brought up by subsequent irrigations. A dense, viny canopy about 2 feet high forms withing 60 days. Cowpeas are commonly grown for the their edible dry bean, so an abundant supply of inexpensive seed is available for covercrop use.

Crotalaria (*Crotalaria juncea*). In some parts of the world, farmers grow crotalaria (also known as sunnhemp) as a fiber crop. As a covercrop, it grows quickly, and its erect, fibrous stems produce a great deal of residue. Later in the growth cycle, crotalaria's 6-foot-high canopy effectively shades out weeds. Crotalaria performs best on well-drained acid soils, but is less demanding than cowpeas in terms of soil fertility.

The use of crotalaria as a forage crop should be viewed with caution, since it can be toxic to farm animals. The length of California's summer days generally prevents the plant from producing seeds (also toxic).



Irrigated crotalaria as a summer covercrop, Newman.

Sesbania (*Sesbania bispinosa*). Though sesbania requires more water than other summer legumes, it can by the same token tolerate heavy soils and waterlogged conditions. A poor weed competitor as a seedling, it can grow as tall as 10 feet in 60 days of hot summer weather. The stiff, tall stems leave a great deal of residue.

Legumes for Integrated Cereal/Livestock Production

Recent years have seen increased interest in minimum tillage practices for cereal (wheat and barley) farming in California as a way to reduce soil erosion and fuel energy inputs. Certain annual-reseeding legumes can work as rotation crops in this type of farming system.

For an annual legume to be self-regenerating in this crop rotation system, the legume must have a fairly hard seed that will carry it over the cereal-growing part of the cycle. This farming system requires integration of cereal and livestock production. The livestock component is necessary to help recycle the legume's nitrogen for the next cereal crop, control weeds, and produce meat and fiber that will contribute to the economic success of the farming operation.

Legume pasture for integrated cereal/livestock farming systems has been highly successful in South and Western Australia, where it is called *ley farming*. Growers have had the most success with annual medics and subclovers.

Annual medics (*Medicago* spp.). There are several annual medics, including our naturalized bur clover (*Medicago polymorpha*). Annual medics do best on basic soils (pH greater than 7). Among the most common medic types and varieties are:

Bur (called bur clover in California) (M. *polymorpha*)
- Serena (very early—65 days to flowering)
- Circle Valley (mid-season type)

Barrel (M. *truncatula*)
- Jemalong (mid-season, older variety)
- Sephi (mid-season, new variety)
- Paraggio (mid-season, new variety)

Strand (M. *littoralis*)
- Harbinger (early to mid-season)

Snail (M. *scutellata*)
- Robinson (mid-season)
- Sava (mid-season)

Medics must be grazed during their active growth season, from February until their flowering period to reduce grass competition. Once seeds are mature, livestock can graze on the plant residue through the summer and up until cereal planting. In addition to the benefits of nitrogen recycling, weed control, and meat and fiber production, grazing helps to stimulate flowering and optimize seed production for subsequent plant regeneration.

Seeding rates can vary from 6 to 12 lb/a depending on seedbed preparation. For best results, mix more than one variety, unless information from variety testing in your area suggests otherwise. Seed early in the fall before the first rains.

Subclover (*Trifolium subterraneum*). Subclover is a prostrate plant, and its name refers to the fact that it buries its seed pod after flowering. This is an ideal mechanism for regeneration. Unlike medics, subclovers have fewer hard seeds and regenerate best in the year after seed set. They do not fare as well as medics in close rotations, but a number of early maturing, relatively hard-seeded Australian varieties have recently been developed: Nungarin, Northam, and Dalkeith.

Subclovers grow best in acid-to-neutral soils, and compete well with weeds under close grazing by livestock. Subclovers have larger seeds than the medics, and should be seeded in mixes at heavier rates early in the fall, before the first rains. Neither medics nor subclovers will tolerate more than a minimum of tillage; the seeds must remain close to the soil surface for proper regeneration.

Legumes for Orchards and Vineyards

The method of floor management in an orchard or vineyard dictates the selection of covercrops. Where floor management practices require annual covercrops, self-seeding species can reduce the cost of seed inputs. Where floor management permits and water is inexpensive, we can use perennial covercrop species.

Temperatures in covercropped orchards and vineyards tend to be lower than in bare-floor plantings, but a close mowing at the time of frost risk will minimize the temperature difference. Let the covercrops regrow after mowing in order to resume biomass production, nitrogen fixation, and seed formation during favorable spring growing conditions.

First-year subterranean clover in almonds, Chico. The use of reseeding annual covercrops can accommodate floor management practices that require little or no tillage.

Self-seeding winter annual legumes

Lana woollypod vetch (*Vicia dasycarpa*). Woollypod vetch is the most productive legume adapted for use in orchards and vineyards lower than 4,000 feet where conditions are adequate for its growth. It grows vigorously and matures in late May. Lana does not tolerate frequent mowing, and can be mowed no lower than 5 inches. Where the possibility of frost damage requires frequent, close mowing of the covercrop, Lana vetch will not reseed itself. In vineyards, Lana vetch aggressively climbs trellises, and can cause maintenance problems.

Rose clover (*Trifolium hirtum*). Rose clover grows well in acid-to-normal soils of low fertility. It can be mowed to a height of 2 to 4 inches throughout the growing season, and will set seed in the month of May.

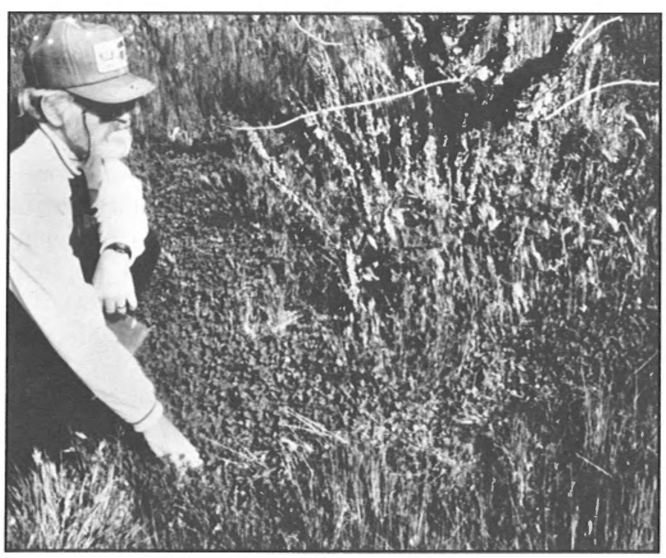
There are three common commercial varieties of rose clover:

Hykon—the earliest to mature

Kondinin—the most tolerant of acid pH

California common or Wilton—the latest to mature, adapted to areas with more than 14 inches in annual rainfall

Crimson clover (*Trifolium incarnatum*). Similar in appearance to rose clover, crimson clover is a taller, more erect plant. It can be mowed to 3 to 5 inches and will set seed late in May, but it will reseed only under excellent moisture conditions.



Fifth-year subclover in a Southern California vineyard, Santa Ysabel.

Annual medics (*Medicago* spp.). The annual medic species include bur clover or medic (*Medicago polymorpha*), barrel medics (*Medicago truncatula*), strand medic (*M. littoralis*), and snail medic (*M. scutellata*). They are low growing and adapted to neutral-to-alkaline soils. Mow annual medics frequently to a height of 3 to 5 inches during their growing season in order to improve weed competition and seed set. They will set seed from March to May, depending on the variety.

Subclover (*Trifolium subterraneum*). This species of clover is low growing and a poor weed competitor if ungrazed in the seedling stage. Frequent mowing at 2 to 4 inches will allow subclover to compete with weeds and to have a good seed set. Subclover is adapted to acid-to-neutral soils and will set seed from April to May, depending on the variety. The developing burs pull the seed heads into the soil surface, thus effectively replanting themselves. Here are the varieties by maturity class:

Early to mid-early season
- Nungarin
- Northam
- Geraldton
- Daliak
- Dalkeith

Early mid-season to mid-season
- Seaton Park
- Trikkala
- Enfield
- Esperance

Mid-season
- Clare
- Woogenellup
- Howard
- Mt. Barker

Late mid-season
- Larisa
- Nangeela
- Meteora

Late
- Tallarook

Perennial legumes

Strawberry clover (*Trifolium fragiferum*). The hardiest perennial clover species available for orchards and vineyards is strawberry clover. It tolerates alkaline soil conditions, infrequent irrigation, heat, and full sun exposure. Strawberry clover spreads by means of stolons, and its low growth habit allows it to tolerate frequent mowing. Of the varieties on the market, these three are the most important:

- Salina—a California variety that lacks cold tolerance
- Palestine—an Australian variety
- O'Conners—an Australian variety

Strawberry and white clover mixture in prunes, Hamilton City. Heat-tolerant strawberry clover and shade-tolerant white clover make a good mixture in orchards with sunny and shady patches. These perennial clovers require no-till floor management.

White clover (*Trifolium repens*). The white clover is more susceptible to heat and water stress than strawberry clover, but more tolerant of cold and heavy orchard shade. White clover also spreads by means of stolons, and has a low growth habit. Varieties can be divided into three types: small, intermediate, and large growth habit. Ladino is a general name for tall varieties that compete well and grow quickly, but do not tolerate frequent mowing. Most unnamed U.S. varieties are intermediate types, as are introductions from abroad such as Huia from New Zealand. The small types often have "wild white" in their names, and persist the best under frequent mowing; they do not compete well with infrequent mowing. Dutch clover is another term for white clover, and does not denote a specific plant-type.

Narrowleaf trefoil (*Lotus tenuis*). Narrowleaf trefoil grows flat along the ground, with 20- to 40-inch stems arising from a crown. Its deep, branched taproot makes the plant relatively drought tolerant. Narrowleaf trefoil remains green during the winter, begins growing in February, and tapers off in July. It is tolerant of poor drainage and salty soil. In recent years this species has been unavailable from seed companies.

Nonlegumes for Row Crops, Vegetables, Orchards, and Vineyards

Any plant that will make good growth in the time available may be used as a covercrop, and a number of nonlegumes are used in this way. The most important are cereals and mustards. These crops do not add nitrogen to the soil, but where improvement of soil physical conditions is most important their rapid vegetative growth will often offset the lack of nitrogen addition.

These species are usually the best at removing excess nitrates from soil and storing nitrogen in their biomass. When planted after crops that are inefficient users of nitrogen (such as lettuce), these covercrops can reduce the potential for contaminating groundwater with leached nitrates.

Cereals

Cereal crops improve the tilth of the surface soil and stimulate the growth of some succeeding crops. As covercrops, they often can be grown where other covercrops have proved unsatisfactory. They are easily started, even during cold, unfavorable weather, and the seed is relatively cheap and abundant. They will usually grow more than other covercrop species during the winter months.

While we can use any of the cereals, rye and barley are most common. Use rye on poor soils or on sandy or rocky soils where it should produce better growth than the other species. Only use the spring types of rye. Since rye does not tiller heavily, use a high seeding rate.

Barley, on the other hand, will make a quicker and heavier growth than other cereals. Growers often use it in preparation for crops that plant in the spring.

Mustards and other crucifers

Many mustards, rapeseeds, and other species in the mustard family (crucifers) can be suitable as cover crops. The advantages of crucifers include rapid early growth and ground cover, easy incorporation, high nitrogen content (recycling existing soil nitrogen or applied nitrogen), and low seeding rates and seed costs. In addition, some crucifer varieties may have specific allelopathic and nematicidal effects.

Traditional sources of mustard seeds for orchards and vineyards have included many hard-seeded varieties or species. In an orchard, this may be tolerable or, sometimes, desirable. In annual cropping systems, this could create a near-permanent source of weed seeds. Varieties that have been developed as annual seed crops for oilseed production or condiment use (table mustard) can minimize this problem.

Rapeseed and canola varieties developed for oilseed production are commonly grown in Canada and are increasingly becoming available in the United States. These derive from two species: rapeseed (*Brassica napus*) and turnip rapeseed (*Brassica rapa*, *B. campestris*). Varieties of white mustard (*Sinapis alba*, also called *Brassica hirta*) and Indian mustard (*Brassica juncea*, also called oriental and brown mustard) are commercially available in the United States and Canada. European commercial varieties exist for all these species, as well as for oilseed radish (*Raphanus sativa*). White mustard and oilseed radish varieties have been developed in northern Europe specifically for their nematicidal properties in sugar beet rotations.

Black mustard, (*Brassica nigra*, Trieste), one of the traditional covercrop species in California, is no longer in common production for table mustard use, although some farmers are increasing seed. Black mustard may have some potential as an allelopathic inhibitor of other weed species.

Spring types of *B. juncea*, *B. rapa* (*B. campestris*), and oilseed radish have the fastest early growth. For maximum biomass over a longer period, winter canola and winter rapeseed varieties of *B. napus* have done well. Ethiopian mustard (*B. carinata*) is intermediate in habit, with rapid early growth and fairly high accumulation of biomass.

Self-seeding grasses

On erosion-prone orchard and vineyard land, winter annual grasses make the most rapid growth with the first fall rains, providing the best protection against erosion from winter rains. Blando brome (*Bromus mollis*), Zorro annual fescue (*Festuca megalura*), and annual ryegrass (*Lolium multiflorum* and *L. rigidum*) are self-seeding grasses suitable for orchard and vineyard floors.

Summer grasses

In table grape vineyards, summer grasses can reduce dust, sunburn, and heat problems. Closely mowed Sudangrass (*Sorghum sudanense*) can provide rapid summer cover in these situations. Where excess water or nitrogen makes rank vine growth a problem, Sudangrass can reduce the availability of nutrients and water to the vines.

Species mixtures

Mixed stands of legumes and nonlegumes can be planted to combine the benefits of several species. Mixed stands have the advantage of providing better grazing for animals, and better hay if the covercrop is to be harvested for animal feed. Mixed stands also compete better and suppress weed populations where such problems exist.

Grasses will also compete with legumes in a mixed stand. The grasses' uptake of soil nitrogen can make legumes more efficient at nitrogen fixation. If grasses are too vigorous and numerous, however, they can outcompete the legumes for light and water, severely limiting legume growth and nitrogen fixation. If this occurs, reduce the proportion of grass seed in the planting mix. If grasses are well fed with soil nitrogen and turned under early in the vegetative growth stage, they will not interfere with the decomposition of interplanted legumes and the release of nitrogen to the subsequent crop.

The tissues of grasses that are nitrogen starved or are turned under late in their life cycles will have high carbon:nitrogen ratios. The decomposition process of this biomass will tie up legume nitrogen that would otherwise be available to the subsequent crop. We do not, therefore, recommend mixed grass-legume covercrops for low-nitrogen soils.

How to Grow a Covercrop

The value of a covercrop depends largely upon its rate of growth and the amount of dry matter it produces. We must, therefore, provide conditions for growth that are as favorable as possible. Take these five factors into account:

1. seedbed preparation
2. fertilization
3. inoculation
4. time of planting
5. seeding rate

Seedbed preparation

Prepare seedbeds for a covercrop the way you would for a commercial crop. For small-seeded crops like the clovers, provide a firm seedbed that is well-supplied with moisture close to the surface. Larger-seeded crops like vetches and cowpeas can be planted deeper, so a looser, more open seedbed may be satisfactory. To assure prompt germination, however, the soil must be firm and moist at the depth to which you plant the seed. The seedbed for a larger-seeded covercrop should be about the same as for sorghum or beans. The crop should be able to germinate and become established as quickly as possible.

With the proper no-till equipment, we can drill many covercrops directly into the residue of the previous crop without incurring the expense of additional tillage. No-till planting reduces weed competition, and standing crop residue can provide support for viny legumes such as vetch. Winter covercrops benefit from being planted on beds in heavy or poorly drained soils.

Fertilization

While we can recommend no general fertilization program, we know that many soils are deficient in one or more of the elements needed for plant growth. In legume plantings, the soil elements most commonly deficient are phosphorus and sulfur. In many irrigated areas, vetches and other legumes respond markedly to a single superphosphate containing sulfur as well as phosphorus.

Soils vary so greatly in their fertilizer needs that, unless the grower knows from experience that a soil lacks certain elements, he or she should consult a local Cooperative Extension Farm Advisor.

Inoculation

Most growers know that legumes make their best growth when well supplied with nitrogen-fixing bacteria, the presence of which is indicated by the occurrence of red-centered nodules on the plant roots. These bacteria can take nitrogen from the air and supply it to the plant. Legumes planted on soil that has little available nitrogen will usually make healthy growth if well inoculated with nitrogen-fixing bacteria. If these bacteria are absent, the growth will be very poor, and the crop may even fail.

Nodule-forming bacteria are not normally present in the soil, so we must supply them artificially the first time we plant a field to a specific legume. If we grow the same legume on the land repeatedly and at short intervals for several years, the bacterial population will build up in the soil such that further seed inoculation may not be needed. Using the same legume on the same land year after year, we will probably need to inoculate only for the initial planting.

The same strain of bacteria will not grow on or produce nodules on all legumes. Each species or group of species requires a specific strain. The same strain of bacteria will effectively inoculate alfalfa, sweet clover, and fenugreek, but will not grow on the medics, true clover, or on vetches, peas, or lathyrus. Be sure to secure a bacterial strain suited to the species you will plant.

For the most satisfactory results, inoculate seeds with a commercial inoculant prepared by a reputable laboratory. Many firms that sell legume seed also sell inoculants. The bacteria are sensitive to high temperatures, sunlight, and drying conditions, so when you use commercial inoculants, take these precautions in addition to following the manufacturer's directions:

- Do not purchase the inoculants long before you plan to use them. Unless stored under refrigeration, the bacteria may deteriorate greatly before being applied to the seed.
- Never inoculate in direct sunlight.

- Never inoculate more than 1 day before you plant the seed.

A more thorough explanation of inoculation procedures is covered in Bulletin 1842 (*Range-Legume Inoculation and Nitrogen Fixation by Root-Nodule Bacteria*), available from ANR Publications or your local UC Cooperative Extension office.

For best results, plant inoculated seed by drilling it as soon as it is dry enough to handle. If you must broadcast the seed, cover it with soil using a cultipacker roller or harrow immediately afterward to prevent drying or direct sunlight from destroying the bacteria.

Time of planting

The single most important factor in determining the success or failure of a winter covercrop is the time of planting. As indicated earlier, most species used as winter covercrops require a moderately high soil temperature for germination. If we plant after the soil becomes cold, much of the seed may rot, and the stand will be poor. In the Sacramento and San Joaquin valleys, for example, plantings made after the middle of November often fail. In these areas, seed the crop before the first of November, and preferably before the middle of October.

Along the coast from San Francisco south and in Southern California, the soils do not as a rule get cold as early as they do in the Central Valley. Even in these areas, though, we will generally get better results if we plant by early November.

Besides fostering prompt germination and a good stand, early planting gives the plants an opportunity to make appreciable growth and establish their roots while the weather is still warm. They will, therefore, be better able to take advantage of an occasional favorable period during the winter, producing a heavier tonnage by the time they must be worked into the soil in the spring.

As already stated, species vary in their ability to germinate at low temperatures. Fenugreek and the cereals will germinate in colder soil than will other species. However, even these crops make much better growth if we can start them early, providing them with a longer period of favorable growing conditions. Late-planted covercrops may grow to only a few inches' height by the time of turning under, with insufficient growth to cover the ground. The benefit obtained from such a planting may not justify its expense.

Most of the covercrops in Northern California grow on irrigated land, so growers can provide the moisture necessary to start the crop at the most favorable time. On unirrigated land, germination obviously depends upon the advent of fall rains. Rain that comes early and in sufficient quantity to germinate the seed and maintain growth will produce a good covercrop. If the rain does not come until late November or December, poor results are likely. Covercrop production is far more of a gamble on dry land than on irrigable land.

Seeding rate

The amount of seed required to plant an acre will vary with seed size, plant growth habit, and conditions at the time of planting. Table 4 lists seeding rates that will yield good stands of a variety of covercrops on most of the crops we have discussed.

Table 4. Covercrop seeding rates in pounds of seed per acre

Crop	Seeding rate	Crop	Seeding rate	Crop	Seeding rate
	lb/a		*lb/a*		*lb/a*
Legumes		Legumes		Nonlegumes	
woollypod vetch	40–60	crotalaria	20–40	mustard, small-seeded	5–7
purple vetch	50–65	sesbania	10–20	mustard, large-seeded	10–12
common vetch	60–75	rose clover*	15–20	wheat	60–90
hairy vetch	40–50	crimson clover*	15–20	barley	60–90
fava beans	125–175	bur clover*	15–20	oats	60–90
field peas	70–90	barrel medics*	15–20	rye	60–90
berseem clover	15–20	strand medic*	15–20	Blando brome	5–10
sour clover	15–25	subclover*	20–30	Zorro fescue	10–15
hubam clover	20–30	strawberry clover	5–15	annual ryegrass	10–15
fenugreek	35–45	white clover	5–15	Sudangrass	20–30
cowpeas	30–50	narrowleaf trefoil	5–10		

*The initial seeding of self-seeding legumes in orchards may fall below the indicated rates.

Although the cost of seed is an important expense when we grow a covercrop, it is poor economy to save on seed at the risk of obtaining a poor stand. The goal is to maximize the production of biomass to be incorporated into the soil. We must use enough seed to ensure a good stand, rapid ground cover, and maximum accumulation of dry matter.

When the crop is planted early and conditions are good for germination and growth, we can use lower rates. Under less-favorable conditions (i.e., when temperatures are low), higher planting rates may be justified.

When you plant a covercrop, especially on preirrigated land, drill the seed deep enough for it to contact moist soil. The vetches, peas, and cereals all have large seeds, and we can safely plant them 2 inches deep. Plant smaller-seeded species less deeply (less than 1/2 inch). However, when the planting of winter covercrops is delayed until late in the season, plant all species closer to the soil surface to aid emergence in cold soils.

How to Work a Covercrop In

The usual way to dispose of a covercrop is to plow it under, but this practice may not always be appropriate. Plow a heavy crop under, and it will form a layer that will be too slow to decay.

For better results, disk the crop in with a heavy covercrop disk. This technique chops the organic matter up and incorporates it with the soil where it will decay quickly. Two or three diskings may be needed to work a heavy crop in immediately.

In orchards, most growers disk only enough to kill the growing plants. Complete incorporation with the soil is unnecessary, and in some cases undesirable.

When to work a covercrop in

The other crops we grow will determine the time to incorporate the covercrop. We will obtain the greatest benefit if we allow the covercrop to grow as much as time and conditions permit.

In many sections of California, fall-planted covercrops grow little during the cold winter months. As daylength increases and seasonal temperatures start to rise in the spring, covercrops begin rapid growth. This usually occurs toward the end of February or early in March. If we allow the covercrop to grow until the end of March, it should make several times as much growth as it has through February (table 5). A covercrop that is worked down early in March may add little nitrogen or organic matter to the soil.

Nitrogen contribution of legumes

When we use a legume covercrop, we need to know how much nitrogen it will contribute to the subsequent crop in order to determine whether the crop will require

Table 5. Dry matter and nitrogen in aboveground biomass of two fall-planted legumes at Davis (planting date: October 16, 1986)

Sampling date	Lana woollypod vetch dry matter	Lana woollypod vetch N	Austrian peas dry matter	Austrian peas N
	lb/a			
January 21, 1987	2,200	89	1,200	38
February 24, 1987	3,900	168	1,900	70
March 30, 1987	6,700	247	5,600	206

supplemental nitrogen. At plowdown, we can estimate the nitrogen available from the covercrop by the following method:

1. Cut and weigh the fresh covercrop from 16 square feet (4 by 4 feet).
2. Multiply the fresh weight in pounds by a factor (given below) to estimate the pounds of nitrogen per acre contained in the covercrop.
3. Repeat this sampling 5 to 10 times over the field, depending on its uniformity, and average your results. Samples should be free of dew.

The factors are:

Lana woollypod	16
Purple vetch	16
Bell beans	10
Berseem clover	13
Cowpeas	12

If, for example, we harvest 13 pounds fresh weight of vetch from a 4' by 4' area, we know there are 208 pounds of nitrogen per acre of covercrop (16 × 13 = 208).

These multiplication factors apply to a wide range of growth stages. As the legume crop approaches maturity, the nitrogen concentration on a dry basis lessens, but the dry matter percentage of fresh weight increases, so the factors remain stable with advancing maturity.

Leguminous covercrops begin to decompose and release nitrogen as soon as we turn them under. We can plant the subsequent crop without delay.

Biological Interactions

The presence of fresh or partially decomposed organic matter in the seedbed will change the soil ecosystem, and can alter the chances of establishing a successful crop stand. Covercrop residues can improve the emergence rate of small-seeded crops by reducing soil crusting problems. On the other hand, residue on the soil surface can encourage maggot damage to large seeds, particularly when cool spring weather delays emergence. Succulent covercrop residues always create a surge in microbial populations, forming the base of a diversified community of soil organisms to compete with pathogenic soil organisms.

Living covercrops can interact with other living organisms in agricultural ecosystems in both beneficial and damaging ways. Some covercrop species cause increases in parasitic nematode populations that will harm subsequent, sensitive crops, while others serve to suppress the same nematode populations.

A covercrop can act as a useful trap for pathogens or serve as an off-season reservoir for viruses and their vectors. It may form an attractive environment for beneficial insects or a a breeding ground for damaging insects. Fava beans attract ladybugs, but also host several aphid species.

Farmers who want to introduce covercrops into their rotations should have a flexible approach to the cultural practices involved in working the covercrop in and planting the subsequent crop. Techniques to maximize the covercrops' positive effects and minimize their negative consequences will depend on soil type, weather, and the other crops in the farming system. Because conditions vary, each farmer must follow the practices best suited to the individual field. Keep in mind, however, that producing a covercrop involves considerable expense, and that the covercrop's value is proportional to the amount of organic matter produced.

Eight Points to Remember

1. For many farms, covercrops offer the only practical means of supplying the organic matter needed to maintain soil physical, chemical, and biological properties. Barnyard and other manures cannot meet the requirements of extensive areas.

2. Cultivation decreases the amount of organic matter in the soil and increases soil erosion on sloping land.

3. As organic matter decays, it provides nutrient elements for succeeding crops. Covercrop legumes substantially increase the nitrogen available to the subsequent crop.

4. The value of a covercrop is determined primarily by the amount of organic matter and nitrogen it will add to the soil. Therefore, use the crop that will produce the greatest growth in the particular region and the allotted time.

5. Most winter covercrops should be planted with irrigation, since early seeding is necessary for a good stand and a lack of rain coupled with no irrigation can prevent satisfactory results.

6. Most winter covercrops should be seeded before the first of November. Seedbed preparation is important.

7. The best way to work a covercrop in is with a heavy covercrop disk. Two or three diskings may be necessary. In an orchard, you need not completely incorporate the covercrop.

8. Allow legume covercrops to grow as long as possible before working them into the soil.

References

Altieri, M. A., and L. L. Schmidt. 1986. Cover crops affect insect and spider populations in apple orchards. *Calif. Agric.* 40(1):15–17.

Anonymous. 1967. Growing summer cover crops. *USDA Farmers' Bull.* 2181.

Anonymous. 1984. *"Legume inoculants and their use." Food and Agric. Org.*, United Nations, Rome.

Elmore, C. L., W. L. Peacock, L. P. Christensen, W. L. Graves, and D. R. Donaldson. 1989. Vineyard floor management. In: *Grape Pest Management*, 2d ed., D. L. Flaherty, editor. *Univ.Calif. ANR Pub.* 4105.

Finch, C. U., and W. C. Sharp. 1981. *"Covercrops in California orchards and vineyards." USDA Soil Cons. Serv.*, Davis, CA.

Gibson, Eric. 1987. Taking cover—No-till orchards. *Calif. Farmer* 267(3):14,22.

Graves, W. L., W. A. Williams, V. A. Wegrzyn, D. Calderon M., M. R. George, and J. L. Sullins. 1987. Berseem clover is getting a second chance. *Calif. Agric.* 41(9&10):15–18.

Heath, M. E., R. F. Barnes, and D. S. Metcalfe. 1988. *Forages: The Science of Grassland Agriculture. Iowa State Univ. Press*, Ames, IA.

Hofstetter, Robert. 1988. Cover crop guide. *The New Farm.* January, pages 17–28.

Madson, B. A. 1951. Winter covercrops. *Univ. Calif. Agric. Exp. Stn. Ext. Serv. Circ.* 174.

Mertz, W. M. 1918. Green manure crops in Southern California. *Univ. Calif. Agric. Exp. Stn. Bull.* 292.

Miller, P. R. 1988. Legume covercrops for Northern California. *Small Farm News. Coop. Ext. Small Farm Center, Univ. Calif.*, Davis, CA. July/August. pages 1, 4, 5.

Munoz, F. N., and Walter L. Graves. 1987.*"Legumes for orchard, vegetable and cereal cropping systems." Univ. Calif. Coop. Ext.*, San Diego County.

Murphy, A. H., M. B. Jones, J. W. Clawson, and J. E. Street. 1973. Management of clovers on California annual grasslands. *Agric. Exp. Stn. Ext. Serv. Circ.* 564.

Phillips, D. A., and W. A. Williams. 1987. Range-legume inoculation and nitrogen fixation by root-nodule bacteria. *Univ. Calif. Agric. Exp. Stn. Bull.* 1842.

Power, James F. 1987. Legumes: Their potential role in agricultural production. *Am. J. Alternative Agric.* 2:69–73.

Proebsting, E. L. 1958. Fertilizer and covercrops for California orchards. *Univ. Calif. Agric. Exp. Stn. Ext. Serv. Circ.* 466.

Sallee, W. R., and F. L. Smith. 1969. Commercial blackeye bean (cowpea) production in California. *Univ. Calif. Agric. Exp. Stn. Ext. Serv. Circ.* 549.

Smith, M. S., W. W. Frye, and J. J. Varco. 1987. Legume winter cover crops. *Adv. Soil Sci.* 7:96–139.

Taylor, N. L. 1985. *Clover Science and Technology. Am. Soc. Agron. Monogr.* 25:1–616.

Westcott, M. P., and D. S. Mikkelsen. 1987. Comparison of organic and inorganic nitrogen sources for rice. *Agron. J.* 79:937–43.

Westcott, M. P., and D. S. Mikkelsen. 1988. Effect of green manure or rice soil fertility in the United States. pp. 257–73. In: *Green Manure in Rice Farming: Proceedings of a Symposium 25–29 May 1987. Internat. Rice Res. Inst.*, Los Baños, Philippines.

Williams, W. A. 1966. Management of nonleguminous green manures and crop residues to improve the infiltration rate of an irrigated soil. *Soil Sci. Soc. Am. Proc.* 30:631–34.

Williams, W. A., L. J. Berry, R. M. Love, and Y. P. Osterli. 1959. Woollypod vetch. *Agron. Prog. Rept., Univ. Calif.*, Davis, CA. 5:1–4.

Williams, W. A., and L. D. Doneen. 1960. Field infiltration studies with green manures and crop residues on irrigated soils. *Soil Sci. Soc. Am. Proc.* 24:58–61.

Williams, W. A., L. D. Doneen, and D. Ririe. 1957. Production of sugar beets following winter green manure cropping in California. II. Soil physical conditions and associated crop response. *Soil Sci. Soc. Am. Proc.* 21:92–94.

Williams, W. A., and D. C. Finfrock. 1962. Effect of placement and time of incorporation of vetch on rice yields. *Agron. J.* 54:547–49.

Williams, W. A., D. S. Mikkelsen, K. E. Mueller, and J. E. Ruckman. 1968. Nitrogen immobilization by rice straw incorporated in lowland rice production. *Plant Soil* 28:49–60.

Appendix

Management systems and covercrop recommendations for orchards and vineyards*

Management	Orchard or vineyard type	Recommended covercrops
Non-tillage systems		
Frequent clipping	Citrus Fruit—apple, apricot, olive, pear, prune Nut—almond, walnut, pistachio Vineyard—table, wine	1. Blando brome: useful if clipped no shorter than 2–4" 2. subclover, bur clover, or other medics: can be sown alone or in mixtures 3. Zorro fescue: most tolerant of drought 4. annual ryegrass 5. Sudangrass 6. berseem clover
Infrequent clipping	Citrus Fruit—apple, apricot, olive, pear, prune Nut—almond, walnut, pistachio Vineyard—table, wine	1. Blando brome: best all-around annual grass for this type of management 2. rose and crimson clover: taller than subclover or medics by 3–5"; rose reseeds more reliably than crimson; can be seeded with subclover or black medic 3. Wimmera 62 ryegrass: excellent on heavy soils where volume of material is not a problem; good where water tends to pond 4. Lana woollypod vetch: use where you need a large volume of legume; not useful with more than 2 or 3 mowings before April 1 5. narrowleaf trefoil: low-growing perennial legume; use on soils with good moisture-holding capacity, since summer moisture is essential 6. strawberry and ladino clover: low-growing and sod-forming perennial legumes; require more frequent moisture and produce less forage than trefoil
Tillage systems		
Annually fall-seeded cover followed by summer fallow	Fruit—apple, apricot, peach, pear, plum, prune Nut—almond, walnut, pistachio Vineyard—table, wine	1. cereal rye: tall-growing, rapid development 2. barley, wheat, oats: widely used for cover 3. annual ryegrass: leafy, with a heavy, fibrous root-producing system 4. when a legume is desired, use purple vetch or another vetch, fava beans, field peas, berseem clover 5. mustards: tall-growing, good tap root

Continued

* Adapted from Finch and Sharp (1981).

Appendix—*Continued*

Management	Orchard or vineyard type	Recommended covercrops
Annually fall-seeded cover followed by volunteer summer annuals	Fruit—apricot, peach, plum Vineyard—table, wine	1. cereal rye: tall-growing, rapid development 2. barley, wheat, oats: widely used for cover 3. annual ryegrass: leafy, with a heavy, fibrous root-producing system 4. when a legume is desired, use purple vetch or another vetch, fava beans, field peas, berseem clover 5. mustards: tall-growing, good tap root
Reseeding winter annual cover followed by summer fallow	Citrus Fruit—all Nut—all Vineyard—all	1. Blando brome, Zorro fescue 2. subclover or bur clover, medics: can be sown alone or in mixtures; low-growing; best adapted to soils with good moisture-holding capacity 3. rose and crimson clover: annual legumes, taller than subclover or medics by 3–5"; can be seeded with either subclover or black medic 4. Wimmera 62 ryegrass: excellent for use on heavy soils where volume of material is not a problem; good where water tends to pond 5. Lana woollypod vetch: use where a large volume legume is needed; not useful with more than 2 or 3 mowings before April 1
Reseeding winter annual followed by volunteer summer annuals	Citrus Fruit—apricot, peach, plum Vineyard—table, wine	covercrops same as above
No winter cover followed by volunteer summer annuals	Citrus Vineyard—table, wine	volunteer species
No winter cover followed by annually seeded summer annuals	Citrus Vineyard—table, wine	1. Sudangrass 2. cowpeas 3. crotalaria and sesbania

Covercrop Index

3m-rep-8/96-WJC/FB