INTEGRATED PRODUCTION

Role of cover crops in integrated crop production systems

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Producers use cover crops for a number of reasons: to improve or maintain soil quality (structure, organic matter, and aggregation); to reduce runoff and water erosion; to reduce nutrient leaching; to recycle nutrients; to aid in soil drainage; to add nitrogen (N) through biological fixation; to control weeds and pests; to trap snow and provide crop protection; and for other reasons. Consequently, a number of plant species may be used, and their use must be integrated successfully into a number of cropping systems in order to achieve the desired purpose. Thus, the possible combinations of cover crops and cropping systems are almost endless. This makes it impossible in a short summary such as this to discuss all possibilities in detail.

To solve this problem, we discuss predominant cover crop practices for major agricultural production systems in each of seven regions in North America (Figure 1). Mention is made of some promising alternative practices and systems. These discussions usually include effects of practices on soil and water quality and crop production, as well as on other factors as appropriate.

Southeast region

The climate of southeastern states is moderate to subtropical, with 40 to 60 inches of precipitation annually. Driest months in the region are August to November. Three primary physiographic regions exist—the relatively flat to gently rolling Coastal Plains and Delta region, the rolling Piedmont Plateau and deep-loess soils, and hilly to mountainous Appalachian and Ozark Mountain ranges. Intensive cultivation is common on the Coastal Plains and Delta, producing cotton (*Gossypium hirsutum* L.); corn (*Zea mays* L.); soybeans [*Glycine max* (L.) Merr.]; peanuts (*Arachis hypogaea* L.); rice (*Oryza sativa* L.); citrus; and other fruits, vegetables, and crops. In the Piedmont, livestock operations often predominate, concentrating on dairy, beef, swine, and poultry production. Soybeans, sorghum [*Sorghum bicolor* (L.) Moench], and corn (often for silage) are produced on more-favored sites. In the mountainous regions, generally little agriculture is found.

Producers frequently use cover crops on the intensively cultivated sandy Coastal Plains soils for soil erosion control, control of nutrient cycling, improved soil physical properties and water relations, and to maintain surface and groundwater quality. Winter cover crops commonly used include crimson clover and hairy vetch grown with annual row crops. Double cropping is often utilized. Other cover crops sometimes used include subterranean (*Trifolium subterraneum* L.) and berseem (*Trifolium alexandrinum* L.) clover, rye (*Secale cereale* L.), and oats (*Avena sativa* L.). The highly acid and compacted nature of the subsoils of many Coastal Plains soils restricts growth of many species.

Frequently, legume cover crops significantly reduce the amount of fertilizer N required by the grain crop that follows. For example, Lemon et al. (33) demonstrated in eastern Texas that fertilizer N rate for grain sorghum could be reduced 54 pounds/acre when a legume cover crop (subterranean or berseem clover) was used. Brown et al. *(9)* showed that cotton required 30 pounds/acre less fertilizer N when grown after hairy vetch (*Vicia villosa* Roth subsp. *villosa*) than without hairy vetch, whereas a rye cover crop increased fertilizer N requirement by 30 pounds/acre. Touchton et al. *(61)* also

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showed that use of crimson clover (*Trifolium incarnatum* L.) as a cover eliminated the need to fertilize grain sorghum. However, in Virginia, Moschler et al. *(41)* found rye to be much more effective than crimson clover for production of no-till corn.

Touchton et al. *(60)* grew crimson clover or hairy vetch before cotton in Alabama. They found that the green manures had no effect on soil organic matter, total N, or bulk density, but increased water infiltration rate. They concluded the cover crops would be economically feasible if cotton planting was delayed a few weeks to allow legumes to reseed and if the practice were used for at least 3 years.

Many of the same cover crop species are used on the Piedmont and deep-loess soils, mainly with corn, sorghum, and soybeans *(58)*. The major benefit from the use of legume winter cover crops was their contribution of available N to the summer crop, often equivalent to 67 to 89 pounds fertilizer N/acre. They concluded that improved soil-water relations may be as important as the N benefit. Although a number of environmental benefits may also accrue, in general these are not yet well documented. Over 60 years ago, Pieters and McKee *(45)* developed a list of research needed to develop cover crops. These included (a) selection and development of adapted species; (b) development of appropriate seeding and management practices; (c) characterizing soil-water relations; *(4)* characterizing effects on soil properties; (d) quantifying control of soil erosion and leaching; (e) quantifying N availability and cycling; and (f) investigating effects on weeds, diseases, and pests. This list of needs is still current.

Extensive research in Kentucky has enriched our knowledge of the effects of cover crops on grain yields, soil properties, and environmental relationships *(3, 37, 63)*. Frye et al. (*14*) summarized much of this and related research. In western Tennessee, Tyler et al. *(62)* showed that corn yields were greater when following hairy vetch, Austrian winter peas (*Pisum sativum* L.), or crimson clover than following wheat (*Triticum aestivum* L.) or no winter cover, regardless of the amount of fertilizer N applied. Wagger *(65)* and McVay et al. *(39)*, in the Piedmont areas of North Carolina and Georgia, showed that hairy vetch and crimson clover largely eliminated the need for fertilizer N on corn in that region, whereas rye cover crop required up to 178 pounds/acre N. Berseem clover and winter peas were less effective. Compared with bare soil, both hairy vetch and crimson clover increased infiltration rates and total N and C in the surface 0.2 inches of soil. Hargrove et al. *(19)* also demonstrated beneficial effects of crimson clover and hairy vetch on soil properties, erosion control, and water relationships. Ott and Hargrove *(43)* concluded that hairy vetch with 0 to 45 pounds fertilizer N/acre was economically feasible for corn production.

Only limited research has been conducted in the Southeast on use of perennial cover crops. Box et al. *(4)* showed that corn planted in perennial grass after killing grass strips in the center of the row was subject to severe water stress, which was eliminated by irrigation. Elkins et al. *(13)* maintained corn and soybean yields grown in a perennial grass mulch suppressed with herbicide, but were not able to do so when grown in suppressed alfalfa (*Medicago sativa* L.). Smith et al. *(58)* reported that they could maintain corn yields when grown in mowed and herbicide-suppressed crownvetch (*Coronilla varia* L.) or bigflower vetch (*Vicia grandiflora* Koch). They concluded, however, that under these conditions the legumes contributed nothing to the N nutrition of the corn.

There are only limited reports from this region in recent years of use of cover crops with winter wheat production. In eastern Texas, Brandt et al. *(5)* found that subterranean clover interseeded with soft red winter wheat reduced wheat yields due to increased competition. However, N immobilized in the clover was used by the next wheat crop. There was little effect the third year, and there were differences between subterranean clover cultivars.

Cover crops can and probably do have a measurable impact on improving water quality in the Southeast. This is the region where cover crops are most successful and are used the most.

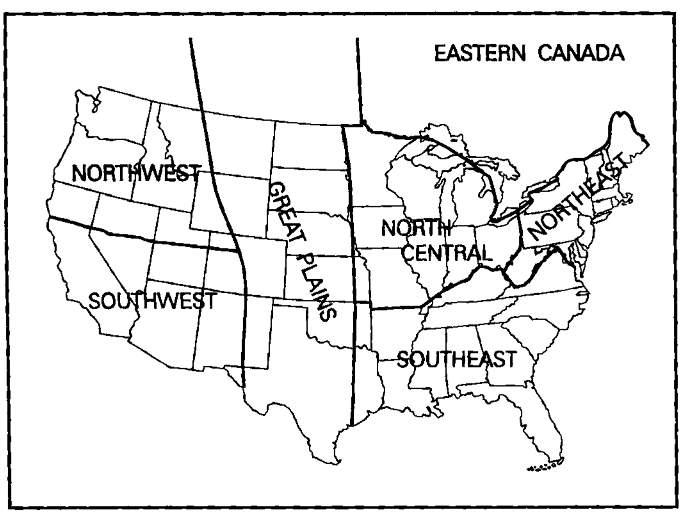

Figure 1. Regions of North America discussed in this chapter.

Northeast region

Climate of this region is generally temperate and humid during the summer and cool and wet in winter. Annual precipitation generally exceeds 40 inches and is fairly well distributed throughout the year. Maximum summer temperatures seldom exceed 95° F, while minimum winter temperatures are usually 14 to -4° F. Growing season increases from about 100 to 200 days from north to south. Agricultural soils in the Northeast are often confined to river valleys and alluvial or lacustrine plains. With a few exceptions, extensive continuous areas of cultivated soils are rare. Much of the region has bedrock near the surface or is too steep or poorly drained for use in agriculture. Soils developed under forest are predominantly Alfisols, with moderately to strongly acid surface soils.

Because dairying is the most extensive agricultural activity, corn silage is often produced, and most grain and concentrates are imported. These activities result in bare soil being exposed over the winter and an excess of dairy manure for the land area available for disposal. Other concentrated livestock feeding operations are also common—swine, broiler, and turkey production, each with associated environmental problems. In addition, potato (*Solanum tuberosum* L.) and vegetable production are important in some regions, often resulting in highly fertile soils being left over the winter without protection.

Soil erosion and nitrate (NO_3) pollution are major problems, and they arise from the fact that winter precipitation is relatively high in this region. The region often receives more than 20 inches of precipitation between fall harvest and spring planting, during which time the soil surface is often nearly bare and residual NO_3 may leach. Extensive research to study the potential for using cover crops to address some of the environmental problems is in progress at a number of locations.

Much of this research is concentrated on the Chesapeake Bay watershed, which drains most of the southern part of this region. Dairy and poultry feeding operations are common, with a limited area of cultivated land available for waste disposal. Consequently, overloading with livestock wastes causes NO_3 pollution of surface water and groundwater. Holderbaum et al. *(24, 25)* showed that cover crops could immobilize several hundred pounds of residual NO_3/acre, reducing winter leaching potential. Hairy vetch could immobilize up to 312 pounds N/acre. Crimson clover was also well suited and also could be used for haying or grazing. These cover crops were particularly effective for use after corn silage.

In the same region, Brinsfield et al. *(7, 57)* demonstrated that winter rye was superior to other small grains when planted in mid-September after corn silage. With increasing fertilizer rates, rye took up as much as 116 pounds N/acre and greatly reduced residual soil NO_3 in the upper 12 inches of soil. However, use of a cereal cover crop may increase the quantity of fertilizer N required to maintain corn yields because of the slower mineralization of N immobilized in cereal residues as compared with legumes *(18, 24)*.

Reduced soil-water content at corn planting time resulting from a cover crop may benefit corn production in the Northeast because many of the relatively poorly drained soils are too wet to work at corn planting time *(24)*. For this reason, producers often favor no-till planting. In the Chesapeake Bay area, N in no-till legume residues mineralizes sufficiently rapidly to be of benefit to the corn crop *(24, 25, 46)*.

Researchers have conducted somewhat similar studies in New York, Pennsylvania, and other northeastern states. In New York, investigators found that interseeding cover crops when corn is about 6 inches tall is the most suitable establishment method *(52, 53)*. When legumes are interseeded, fertilizer N applied to the next corn crop can be reduced about 45 pounds/acre. Alfalfa, red clover (*Trifolium pratense* L.), sweetclover (*Melilotus officianlis* Lam.), and hairy vetch were suitable legumes when interseeded, and rye and ryegrass were suitable nonlegumes. Only 25% of the N in hairy vetch could be accounted for in corn growth plus inorganic soil N when corn was no-till planted, compared with over 50% when researchers used conventional tillage.

At the Rodale Research Center in Pennsylvania investigators have evaluated over 220 accessions of over 100 different legume cultivars (M. R. Sarrantonio, personal communication). In 1990, 35 species judged suitable were interseeded into wheat, corn, and sorghum, and an additional nine cold-tolerant species were distributed to 23 farmers throughout the Midwest and Southeast. Jahnke et al. *(27)* summarized results of some of this research.

The climate of the Northeast favors the use of living mulches, but spring precipitation may be insufficient to ensure corn germination. In Pennsylvania, Hartwig *(20)* has conducted considerable research on crownvetch as a living mulch. With proper cultural practices, crownvetch can be established and maintained while cropping continuously to corn or other grain crops. Proper use of herbicides also is important. Corn grain yields were often reduced 5% to 10% when grown with crownvetch *(36)*. However, if the crownvetch is also used as fall and winter pasture, this loss may be recaptured.

Cover crops are being used on a limited scale in the Northeast and are particularly useful in the Chesapeake Bay area to help control water pollution problems.

Eastern Canada

To a large extent, problems with use of cover crops in eastern Canada are similar to those reported for all but the Chesapeake Bay area of the northeastern region. This results because of the similarity in soil, crops, and climate. An exception might be southern Ontario, where conditions are more similar to the corn-soybean producing areas of the eastern Corn Belt (North Central Region). Refer to those sections for a more complete discussion.

North Central region

Climate in the North Central region is continental, with hot, moist summers and cold winters. Annual precipitation ranges from about 26 to 47 inches from north to south, generally with well over 50% received in May, June, and July. The growing season ranges from 100 days in the northwestern part of the region to over 200 days in the southern and eastern portions. Soil is frozen during much of the winter, and most precipitation falls as snow during this time. Major agricultural soils are deep, fertile Mollisols developed from glacial till, loess, and alluvial deposits. Some Alfisols are found in the more northern areas. Most of the region has been glaciated. Corn and soybeans are the predominant crops produced, along with wheat, alfalfa, oats, and barley (*Hordeum vulgare* L.). Dairying is common in northern regions, and swine and beef are produced throughout the region.

Because corn and soybeans are the predominant crops, winter cover crops are most likely to be used during winter. Lack of winterhardiness limits use of a number of possible cultivars. No cultivar currently available is capable of reseeding itself before corn planting, necessitating annual reseeding and adding considerably to costs. In most areas there also are often only 20 to 40 days prior to corn planting during which cold-tolerant spring-seeded cover crops can grow. Spring growth of cover crops depletes soil-water content to some degree and occasionally may delay germination and emergence of the following corn crop, thereby reducing potential yield. This problem is more frequent in the drier northern and western parts of the region.

Climate restricts the number of crop cultivars that producers may use. Above about the 44th parallel, rye is about the only hardy winter cover crop. Further south, hairy vetch is suitable, and crimson clover is sufficiently winter hardy to survive in the southern extreme of the region. These climatic limitations strongly emphasize the need for breeding and selection programs that will provide additional plant resources. At some locations researchers are evaluating the potential for using cold-tolerant annuals [faba beans (*Vicia faba* L.), field peas, medic (*Medicago lupulina* L.), and lentils (*Lens culinaris* Medikus)] as short-season cover crops prior to corn planting.

To date, there is surprisingly little recently published information from the North Central region on the effects of cover crops on soil properties, environmental quality, and crop production. Although a number of new experiments have been initiated in recent years, few results have been published. The value of research conducted prior to the widespread introduction of fertilizer N is questionable in light of modern tillage and cropping systems and especially because average crop yields have increased two- to three-fold.

Russelle and Hargrove *(51)* discussed the role of cover crops in immobilizing residual soil NO_3 and thereby reducing NO_3 leaching potential. They concluded that a nonlegume, such as rye, while highly effective in scavenging the soil for residual NO_3, often immobilizes available soil N to the extent that more fertilizer N must be applied for the grain crop following rye than would be required if no cover crop were used. Pelchat *(44)* supported this with recent research in Indiana.

Eckert *(12)* recently evaluated rye as a cover crop for no-till corn and soybean production in Ohio. At only 1 of 12 site-year comparisons did rye increase corn production, while yields decreased in 4 of the 12 comparisons. In general, differences could not be explained by differences in N availability. There is a possibility that rye residues exhibited an allelopathic response that may have affected corn production. Liebman and Janke *(34)* discussed allelopathic responses of rye, particularly in regard to weed control.

Soybean and alfalfa are crops that also are highly efficient in immobilizing residual soil NO_3 *(23)*. Dwyer et al. *(11)* showed that soybeans have 2 to 10 times the rooting density of corn, especially in the surface soil and are much more efficient in using residual water and NO_3 than corn. This may explain why Varvel and Peterson *(64)* found that soybeans were much more effective than corn and sorghum in removing NO_3 from the soil profile.

Heichel *(21)* pointed out that the quantity of fixed dinitrogen (N_2) added to a soil by growing a legume depends on many factors, but predominantly on how the legume was managed and the level of available N in the soil while the legume was growing. If no forage is harvested or grazed-off, all the fixed N is added to the soil. However, for many grain legumes, such as soybeans, 80% or more of the N fixed may be removed in the grain. Consequently in such instances, there is a net removal, rather than an addition, of N from the soil following growth of the legume. Also, as available soil N increases, less N is fixed by the legume. The percentage of N in the legume originating from the soil may vary from 0% to 100%.

Cover crops are used very sparsely in the North Central region because of the agronomic and economic problems identified. Thus, their impact on water quality is small, but it could be rather large if researchers can develop acceptable methods and cultivars.

Great Plains region

Climate in the Great Plains is typically semiarid with most precipitation falling during the summer. Annual precipitation increases from 12 to 32 inches from west to east; May and June are the months of greatest precipitation. Winter precipitation (mostly received as snow) is usually less than 3 inches. Summer maximum temperatures are often higher than 104° F and winter minimums may be -13° to -49° F. Potential evapotranspiration normally exceeds precipitation during the growing season by several fold. Humidity is usually relatively low, and hot, dry winds are common. Soils within the Great Plains are typically developed under perennial grass vegetation. As precipitation declines from east to west, soil depth and organic matter content decrease while soil pH and salt content increase. In some areas, slowly permeable Natrisols have developed. Soil pH is generally in the 6.0 to 8.0 range, exchangeable potassium (K) levels are usually high, and available soil phosphorus (P) levels are often inherently low. Soil erosion by both wind and water has often been severe.

As a result of a harsh climate, soil erosion, and other factors, crop yield potential without irrigation is limited. The major crop produced is hard red wheat. In certain areas, sorghum, cotton, barley, durum (*Triticum durum* Desf.), sunflower (*Helianthus annuus* L.), safflower (*Carthamus tinctorius* L.), soybeans, alfalfa, and corn are also produced. These crops are also grown under irrigation, along with sugarbeets (*Beta vulgaris* L.), dry beans (*Phaseolus vulgaris* L.), and vegetables.

Power recently summarized use of cover crops in the Great Plains *(47)*. Brown summarized extensive research prior to 1960 on the potential for using green manures and legume-based rotations *(8)*. Results generally showed that while such practices could control soil erosion and maintain soil organic matter content, soil physical properties, and hydraulic conductivity, the water used by legumes dried the soil to such an extent that yield of the following wheat crop was reduced. As a result, most farmers developed a wheat-fallow system and used very few legumes or cover crops in Great Plains cropping systems.

Because of extensive use of summer-fallow on shallow and sandy soil, by 1970 saline seeps began to develop on landscapes. At these sites, water percolating through fallowed soils moved laterally over the surface of shales or other impermeable strata and eventually discharged as a hillside seep *(17)*. This water was usually highly saline (and high in NO_3) and salinized extensive areas downslope from the seep. To rectify this problem, researchers conducted a number of experiments to determine the best cropping and management practices to use on the intake areas. Black et al. *(2)* determined that deep-rooted crops, such as alfalfa and sunflower, were especially effective in intercepting water infiltrating these shallow sandy knolls, thereby cutting off the supply of water to the saline seep. In the worst situations, the thin sandy knolls needed to be seeded to a permanent crop, such as grass or alfalfa.

Renewed interest on the use of cover crops in the Great Plains became apparent during the energy crisis of the 1970s. At several locations in Montana, Sims et al. *(56)* showed that by growing black medic for 4 to 6 weeks early in the spring of the fallow year, soil water could be recharged and spring wheat grain yields in a wheat-fallow rotation could be maintained or increased without use of N fertilizers. Austrian winter peas and lentils also offered promise. In North Dakota, Power *(47)* showed that August-seeded soybeans, field peas, faba beans, and sweetclover all made significant fall growth to serve as cover during the winter of the fallow year. He proposed seeding one of these species in August with a low seeding rate of flax (*Linum usitatissimum* L.) to provide a snow trap, thereby restoring water to the surface soil in time for spring wheat seeding the next year.

Because the time of the year when the cover crop is growing is a major factor, the temperature requirement of each species is important. In temperature-controlled greenhouse studies, Zachariassen and Power *(66)* showed that soybeans, field peas, faba beans, and hairy vetch grew rapidly for the first 60 days, even at soil temperatures of 50° F. Lespedeza [*Lespedeza striata* (Thunb ex Murray) Hook and Arn.] and sweetclover required temperatures of 68° to 86° F, and grew rapidly after 60 days. At low temperatures and with more than 60 days growth, white clover (*Trifolium repens* L.) and crimson clover performed well. Soybeans exhibited exceptionally rapid early growth at all soil temperatures.

Brar et al. *(6)* found that root growth rate of 'Woodford' bigflower vetch and 'Cahaba' white vetch (*Vicia sativa* x *Vicia corduta* Wulf.) were outstanding at almost all soil temperatures, as was root growth for Austrian winter peas and arrowleaf clover (*Trifolium vesiculosum* Savi) at 59° to 77° F. Mosjidis *(42)* found that germination rate for sericae lespedeza [*Lespedeza cuneata* (Dum. Cours) G Don] increased 6% for each degree increase in soil temperature from 55° to 66° F.

Field experiments in eastern Nebraska *(47)* largely confirmed the controlled-temperature greenhouse research cited. Soybeans again exhibited outstanding vegetative growth rates compared with other legume species. Again, this may reflect the more intensive breeding effort that has gone into soybean development compared with other legumes. Hairy vetch, tangier flatpeas (*Lathyrus tingitanus* L.), and cowpeas (*Vigna unguiculata* L.) also exhibited relatively rapid growth and N uptake rates. In a field experiment using hairy vetch as a winter cover crop for dryland corn production, Power et al. *(48)* showed that corn grain yields could be maintained without addition of N fertilizers if the hairy vetch was disked in at corn planting, but not if killed and left on the soil surface with no-till planting. However, in years with little or no spring precipitation, the hairy vetch cover crop may deplete the water content of the surface soil to the extent that corn will not germinate. This is always a major hazard with cover crops in semiarid and subhumid regions.

In northeastern Nebraska, Moomaw *(40)* investigated the potential for using a living mulch and suppressing competition by use of herbicides, tillage, and crop shading. He used chewing red fescue (*Festuca rubra* subsp. *commutata* Gaudin) or ryegrass (*Lolium perenne* L.) in a dryland corn-soybean rotation, comparing them with red clover, hairy vetch, and no cover crop. June seeding of the cover crop usually resulted in best stand and greatest ground cover over winter. However, all cover crops reduced corn yields when compared with plots with no cover crop, primarily because of competition for water. Under irrigation in the Sandhills of Nebraska, Klocke et al. *(30)* showed that corn grown in a herbicide-suppressed bromegrass (*Bromus inermis* Leysser) sod produced less grain than when clean-cultivated. However, total dry matter of vegetation produced by the two systems was equal.

Researchers have conducted a considerable number of studies in the Canadian Prairie Province in recent years on the use of legume cover crops in spring wheat-fallow cropping systems *(10, 28, 57)*. In these studies, researchers often planted annual legumes, such as peas, lentils, faba beans, and medic, on fallow early in the spring and allowed them to grow 30 to 60 days, followed by spring wheat the next year. Using this system, Janzen et al. *(28)* showed that the N in the legumes was less than half as available to the wheat crop as was N from fertilizer. However, they found less than half as much ^{15}N from fertilizer in soil organic matter as that from the legume. Thus they concluded that the long-term advantage of the green manure was the replenishment of stable, soil-organic-N reserves in the soil.

In the more humid regions where annual cropping is possible (the Black soil zone), Slinkard et al. *(57)* showed that lentils were especially effective as a green manure cover crop. Even in the drier regions, however, there was little evidence of significant grain yield reduction when producers used legume cover crops in a spring wheat crop production system. Again, use of cover crops had potential to reduce soil erosion and maintain surface water and groundwater quality.

It is noteworthy to mention that none of the above discussion on use of cover crops in the Great Plains relates to cover crops used with winter wheat, the principal crop grown in the Great Plains. Very limited research is in progress on this topic, and we could find no recent publications.

Because of the extreme water deficit under which much of the winter wheat in the Great Plains is grown, researchers have not developed any dependable technology to ensure replenishment of water used by the cover crop. This problem remains as a high research priority for this region. In the Southern Plains, there is limited research in progress on double-cropping and crop rotations, but little on cover crops. Only limited research has been conducted to utilize cover crops under irrigation. Thus, the effect of cover crops on water quality in the Great Plains is largely unknown at this time.

Southwest region

The climate in the Southwest is generally semiarid to arid. A Mediterranean climate is experienced, with cool, moist winters and hot, dry summers. Most agriculture is under irrigation because annual precipitation is usually below 16 inches.

Some areas rarely have frost. Most agricultural soils are Aridisols, often with limited development. They are typically low in organic matter, variable in depth and texture, and have neutral to alkaline surface pH. Salt accumulations are often a major problem. Vegetables, citrus fruits and nuts, and cotton are major crops, along with alfalfa and some corn, barley, rice, and wheat. Many specialty crops are also produced.

Because of the highly diverse agriculture in this region, no one crop or cropping system dominates. Vegetable production is a major activity and offers many opportunities for use of cover crops *(31)*. Subclover, ryegrass, annual fescues, faba beans, oats, barley, and rye are cover crops used with such crops as sweet corn (*Zea mays* L.), lettuce (*Lactuca sativa* L.), tomatoes (*Lycopersicon lycopersicum* L.), and broccoli (*Brassica oleracea* L.). If cover crops are sufficiently suppressed with herbicides and weeds are controlled, crop yields often increase. Establishment of subclover cover during the cool winter months of central California restricts the use of herbicides for weed control for sweet corn and lettuce production *(32)*. However, when successfully established, subclover living mulch increased yields of the above crops and also increased soil organic matter content.

In central California study evaluating vetches, Austrian winterpeas, berseem clover, beans, oats, and an oat/vetch mixture as winter cover crops, Shennan et al. *(54)* found that corn and tomato yields with cover crops (especially vetch) were near maximum without fertilizer N and were equivalent to those obtained with no cover crop but with 134 to 223 pounds fertilizer N/acre. Soil NO_3-N levels under vetch were similar to those when 178 pounds fertilizer N/acre were added, and N mineralization rates were doubled. Vetch increased soil organic carbon (C), aggregation, aggregate stability, and reduced surface crusting. Tomato stand, water infiltration rate, and microbial activity also increased with vetch.

Effects of cover crops on soil properties and on orchard and vineyard production were similar to those for vegetable crops *(49)*. Generally, cover crops, especially legumes, increased yields of these crops if proper cultural practices were used. In addition, Hendricks *(22)*, working in almond orchards, showed that cover crops, especially vetches, enhanced beneficial insect populations and kept pest populations low. While populations of some pests temporarily increased, with proper management no species reached threshold populations that required treatment. Increased beneficial species included spiders and parasitic wasps. McHenry *(38)* found that continued use of legume cover crops in vineyards and orchards increased nematode damage, requiring a change of legume species periodically. Barley or rye were poor hosts for nematodes and could be successfully used.

Use of cover crops in the Southwest has potential to greatly improve water quality because most agriculture land is irrigated. Cover crops can be effective in removing residual water and NO_3 from a soil profile at the end of the growing season.

Northwest region

The Northwest lies in a winter precipitation climate, with cool, wet winters and mild to hot, relatively dry summers. The region generally receives little precipitation from May or June to October. The region is surrounded by mountains, with agriculture developed on the volcanic and alluvial soils along the major river valleys and high plateaus. The interior is comprised of the rolling to steep deep-loess soils of the Palouse region and the deserts in the Columbia Basin and similar regions. Irrigation is common in river valleys and the desert basins. Producers grow a wide variety of crops, including many fruits and berries, especially apples (*Malus domestica* Borkh.), vegetables, sugarbeets, corn, grass, and vegetable seeds, and many specialty crops, as well as alfalfa. Wheat is produced extensively in the dryland regions, along with some barley, lentils, and peas.

Use of cover crops in the orchards and vegetable crops of the Northwest would have problems and benefits similar to those discussed for the Southwest region. Because of the wide diversity of crops produced in the valleys and foothills of the Northwest, space limitations prohibit detailed discussion of these cropping systems. Commercial production of grass and legume seed is a major enterprise in many of these areas, and these crops generally do not fit into cover cropping systems.

Investigators have conducted considerable research on cover crop use in the extensive dryland region of the Northwest. Much of this research originated near the beginning of the 20th century. Rasmussen *(50)* and Granatstein *(16)* summarized this early research, in addition to much of the current work. In wheat-fallow rotations, researchers have proven that early spring seedings of field peas, Austrian winter peas, medics, lentils, and faba beans are effective as cover crops. Often, with more favorable precipitation, these crops may be allowed to mature and produce a marketable seed crop, thereby making their use more economically acceptable.

Likewise in the wetter regions, producers can grow these crops as a green manure for spring barley. In the mountains of western Montana, Sims *(55)* found many of these same species to be effective for spring barley and wheat production. Red clover seeded after wheat harvest also makes an acceptable cover crop if the crop receives sufficient precipitation in early fall for germination and stand establishment.

At Pendleton, Oregon where precipitation averages 16 inches, Rasmussen et al. *(50)* found that the average yield of wheat following peas (1980-1989) was 240 pounds/acre greater than that for wheat after wheat and 360 pounds/acre less than that for wheat after fallow. Thus, substitution of peas for fallow resulted in only a modest wheat yield reduction while gaining income from the peas harvested. In addition, beneficial effects of the rotation would improve soil physical, chemical, and biological properties. These results agree with earlier research in Oregon on this subject by Horner et al. *(26)*.

At two locations in the Palouse region of Washington, Kirkby *(29)* showed that medics were outstanding cover crops for wheat under annual cropping, whereas peas were best at a drier location. Goldstein *(15)* also found medics to perform well as a green-manure cover crop in that region. In nearby western Idaho, Mahler and Auld *(35)* generally concluded that 50% to 80% of the N in Austria winter pea residue became available the next growing season. Bezdicek et al. *(1)* showed that field peas and Austrian winter peas used less soil water than many other cover crops.

Results of cover crop research in the Northwest are similar to those in other regions, showing that cover crops can improve water quality by controlling runoff, leaching, and soil erosion. Cover crop practices used in this region are highly variable, however, because of the extreme variability in soils and cropping systems that exists.

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Strip management of crimson clover as a reseeding cover crop in no-till corn

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Production systems using a winter annual legume cover crop can benefit from the nitrogen (N) released by decomposing legume residue to the succeeding principal crop. Crimson clover (*Trifolium incarnatum* L.) is well adapted to the moderately acid Ultisols of the humid Southeast and is capable of providing 100% and 65% of the N requirement for sorghum [*Sorghum bicolor* (L.) Moench] and corn (*Zea mays* L.), respectively *(2, 4, 6)*.

Natural reseeding of crimson clover is desired to reduce the cost of annual seeding operations. Working with a grain sorghum production system, Touchton et al. *(6)* demonstrated the suitability of crimson clover as a reseeding cover crop in the lower South, because seed maturity coincides with ideal planting dates for grain sorghum. In a corn silage system there is some flexibility regarding optimum time for planting to allow for clover seed maturation. Myers *(5)* reported equal dry matter production from volunteer reseeded and volunteer strip-reseeded clover treatments in a no-till corn silage system, despite very low (less than 20%) clover seed viability at the time of desiccation (early May). With clover seed production ranging from 700 to 900 pounds/acre, Myers concluded that even a 2% to 3% germination rate would produce adequate stands. However, corn grain systems are not as flexible and early planting is preferred *(7)*.

We conducted this study to evaluate the effects of varying clover strip width and orientation (relative to corn rows) on soil water depletion, corn height, corn grain yield, and clover reseeding ability in a no-till grain production system.

Study methods

We conducted the experiment from 1988 to 1990 at Raleigh, North Carolina, on a Cecil fine sandy loam (clayey, kaolinitic, thermic Typic Kanhapludult) with 2% to 6% slope. We established 'Tibbee' crimson clover in the fall of 1987 over the entire experimental area. The following spring, a randomized complete block design was established consisting of a factorial arrangement of clover strip width (25%, 50%, and 75% of row area) and strip orientation (parallel or perpendicular to corn row).

Additional treatments included early desiccation (25% parallel strip established 2 weeks before corn planting), annual seeding, and mechanical disruption of clover growth. In the fall of 1989 and 1990, crimson clover was established by natural reseeding in all plots except the annual seeding treatment. Plot dimensions were 19 feet by 40 feet. An adjacent experiment contained a bare-fallow treatment from

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which we obtained additional data.

Clover strips were desiccated about 2 weeks before planting or at planting with paraquat and 2,4-D. The mechanical treatment involved clover disturbance by the no-till planting assembly only (double disk opener following a fluted coulter). Corn (cv, 'Dekalb-Pfizer 689') was planted in 38-inch rows with a no-till planter on April 14, 1989, and April 11, 1990. All plots were fertilized with 35 pounds N/acre as ammonium nitrate at planting and 100 pounds N/acre about 6 weeks after planting to minimize differences in the clover-N contribution to corn due to treatment. We provided residual weed control with a banded spray application of atrazine and alachlor centered over the rows at corn planting.

We collected clover biomass samples for dry weight and total N prior to chemical desiccation by harvesting 5.38-square-foot quadrats from each treatment. We monitored soil water gravimetrically at 0- to 6-inch and 6- to 12-inch depths from 3 weeks before planting to 3 weeks after planting at 10-day intervals in selected treatments. We measured corn height between growth stages V3 and V7, about 3 to 7 weeks after planting. Corn grain yields (adjusted to a 15.5% moisture basis) were determined by combine-harvesting the two center rows of each plot; corn grain was analyzed for total N.

Results and discussion

Soil water prior to corn planting was unaffected by clover treatment in 1989 (data not presented). Averaged over both years, annually seeded, 75% parallel, and mechanical plots had less soil water in the 6- to 12-inch depth than fallow plots 10 days after planting, and narrow strip plots had higher values than wide strip plots (Table 1). Differences tended to be greater in the 6- to 12-inch depth compared with the 0- to 6-inch layer, indicating precipitation was only sufficient to recharge the surface layer. In the drier 1990 environment, however, more water was retained in the surface 6 inches of soil for the early desiccated treatment compared to that for the 25% parallel treatment from 3 weeks before planting to 3 weeks after planting (data not presented).

Clover reseeding and establishment were successful for all strip-management treatments, with dry matter yields in the range commonly reported in the literature (Table 2). Strip orientation was not significant; consequently, strip width values shown were averaged across parallel and perpendicular row orientations. Greater dry matter production occurred in the annually seeded treatment, whereas the early desiccated treatment resulted in less dry matter yield compared with various strip-width treatments. We found similar dry matter yields in 25% and 50% strip plots; both tended to be greater than that for the 75% strip plots. Nitrogen content in clover top growth paralleled dry matter production and ranged from 78 pounds/acre for the early desiccated treatment to 119 pounds/acre for the annually seeded treatment.

Early season corn growth was affected by clover strip management both years (data not presented). Corn height was greatest in the early desiccated treatment, and 25% parallel plots had greater corn growth than the mechanical treatment due to physical impedance by the clover biomass.

Table 1. Soil-water content at two depths as affected by clover management, 2-year average.

	Soil-Water Content at Days After Planting			
	10 Days		*21 Days*	
Cover Management	*0-6 inches*	*6-12 inches*	*0-6 inches*	*6-12 inches*
	%, w/w			
25% strip, parallel	16.9	25.5	21.3	25.6
75% strip, parallel	15.6	21.7	19.9	23.9
Mechanical	15.8	21.1	20.3	26.1
Annual seeding	13.1	20.1	19.5	26.5
Fallow	17.5	30.3	20.9	29.8
LSD (0.05)	4.4	3.3	NS	5.8

Table 2. Clover dry matter production and total N content in 1990, as affected by strip management.

Treatment	*Dry Matter*	*Total N*
	pounds/acre	
Annual seeding	4,610	119
25% strip	3,930	104
50% strip	3,900	108
75% strip	3,320	85
Mechanical	3,450	86
Early desiccation	2,690	78
LSD (0.05)	680	35

Table 3. Corn grain yield, as affected by clover strip management, in 1989 and 1990.

	Corn Grain Yield	
Treatment	*1989*	*1990*
	bushels/acre	
25% strip, perpendicular	156	75
25% strip, parallel	161	84
50% strip, perpendicular	172	80
50% strip, parallel	167	72
75% strip, perpendicular	167	71
75% strip, parallel	167	77
Early desiccation	163	76
Mechanical	155	71
Annual seeding	164	76
LSD (0.05)	12	NS

These results agree with earlier reports of cover crops impeding corn emergence and early growth *(3)*. Once corn emerged above the senescing clover canopy (about 7 weeks after planting), corn heights were similar for all treatments.

Corn grain yield was unaffected by clover strip management in 1989 and 1990 (Table 3). Corn yield averaged 167 bushels/acre in a relatively wet 1989 growing season; an exceptional yield level for the Piedmont region. In contrast, low 1990 yields (76 bushels/acre average) resulted from water stress during tasseling and silking. These results confirm previous assertions that cover crop residues conserve soil water from frequent rains, but are of limited value after soil-surface water depletion during prolonged dry periods *(1)*.

In summary, clover strips did reseed in a no-till corn grain system, offering a viable alternative for reducing costs associated with annual seeding. Lack of significant yield differences also demonstrated that strip width or direction were not limiting factors under the conditions of this study. Results indicate a 25% or 50% desiccated strip can maximize clover-

N contribution without reducing corn grain yields in the Piedmont region.

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Crimson clover in a reduced-chemical-input cropping system

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In 1985 we initiated a long-term study in the Piedmont area of North Carolina to determine the agronomic and economic feasibility of cropping systems using reduced rates of chemical inputs. We sought to compare a reduced-chemical-input management system with a conventional management system in three cropping systems: continuous corn (*Zea mays* L.); continuous grain sorghum [*Sorghum bicolor* (L.) Moench]; and corn-wheat (*Triticum Aestivum* L.)-soybeans (*Glycine max* (L.) Mer.] in a 2-year rotation.We used crimson clover (*Trifolium incarnatum* L.) in the reduced-chemical-input management system to supply nitrogen (N) and to provide additional soil benefits associated with cover crops. Herein, we report on the contributions of crimson clover in this management system for the 1986-1989 growing seasons.

We compared various ways of seeding crimson clover. In the continuous corn cropping system, crimson clover was drilled immediately after corn harvest. In the continuous sorghum cropping system, crimson clover was allowed to naturally reseed. Crimson clover was overseeded into soybeans in the corn-wheat-soybeans rotation.

During 1986-1988, crimson clover produced large quantities of biomass (Table 1). The amounts are high in the range of dry matter yields reported by Hoyt and Hargrove *(1)*. There was not a consistent pattern of dry matter production of crimson clover, however, with the various cropping systems. Crimson clover reseeding in the sorghum produced spring biomass comparable with that from clover drilled after corn. Overseeding crimson clover into soybeans was not as effective as drilling after corn from 1986-1988. This was probably because of the later planting (about 3 weeks) and poorer soil-seed contact. Differences between seeding methods were not significant in 1989.

Temperatures in January 1989 reached record highs for about a week and clover growth was stimulated. A subsequent period of low temperatures and an ice storm killed large areas of clover in the plots. Consequently, crimson clover biomass was less in 1989 than in previous years (Table 1). Rainfall in April 1989 was excessive so kill dates were delayed 2 to 3 weeks. In 1988, killing clover early (April 11 versus April 25) reduced biomass by 50%. Earlier kill in 1989 (April 19 versus May 15) reduced biomass an average of 43%.

The quantity of N that accumulated in the aboveground biomass of crimson clover ranged from 116 to 178 pounds/acre in 1987, but differences were not statistically significant (Table 2). In 1988, N accumulation was greatest in crimson clover drilled after corn harvest. Killing the clover early resulted in a 43% reduction in N accumulation. Nitrogen con-

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Table 1. Dry matter yield of crimson clover used as a green manure crop for corn and sorghum.

	Dry Matter Yield							
	Kill Date							
	1986	1987	1988		1989		Annual Mean	
Cropping System	4/23	4/29	4/11	4/25	4/19	5/15	Early	Late
	pounds/acre							
Continuous corn	4,660a*	6,410a	2,870cd	5,750a	3,180a	4,590a	3,020	5,260
Continuous sorghum	4,570a	5,780ab	-	4,840ab	3,630b	-	4,760†	
Corn-wheat-soybeans	4,030a	4,910ab	-	3,870bc	3,260b	5,750a	3,260	4,640

*In a given year, values followed by the same letter are not significantly different at $p=0.05$.
†Does not include 1986 result because the crimson clover was drilled.

centrations in clover in 1989 were lower than those in previous years. This lower concentration, combined with lower biomass accumulation in 1989, resulted in lower quantities of N accumulated in 1989 *(2)*. Differences in accumulated N at the two kill dates were not significant.

Crop yields varied greatly during the 1986-1989 period due to several factors. Corn yields were low for 1986-1988 due to summer droughts and for 1989 due to small quantities of N supplied by clover. Thus, we cannot determine accurately the influence of the cover crop on corn yield.

Although naturally reseeded crimson clover in the sorghum plots accumulated large quantites of biomass and N during 1986-1988, yields of sorghum declined each year--1,775, 1,196, 794 pounds/acre, respectively. This was due mainly to increased johnsongrass infestation. The plots were almost free of johnsongrass in 1989 even though all the cultural practices remained the same as in past years. Yield of sorghum in 1989 was 1,713 pounds/acre. The reason for the virtual absence of johnsongrass is not apparent. The increased rainfall could have stimulated greater production of allelochemicals by microorganisms and increased leaching of allelochemicals into the soil.

In the 2-year rotation, differences in soybean and wheat yields due to management have not been significant. Yields of wheat in the 2-year rotation have been comparable with those in the conventional treatment receiving no fertilizer N.

Biological effects were the most observable features of using crimson clover as a cover crop. Arthropods were grouped into three categories: predators, pests, and detritivores. In corn, the population of predators and detritivores was higher and that of pests lower with the reduced-chemical-input management treatment than with the conventional treatment. In the 2-year rotation, there generally were more predators and pests with conventional management. Predator population tended to be greater where crimson clover was plowed down, but differences were not significant. With crimson clover, pest populations increased late in the season and detritivore populations increased in mid-season.

Cropping system had a major influence on lesion and spiral nematode populations. Lesion populations were at least twofold greater in conventionally managed corn and sorghum than in reduced-chemical-input treatments. Spiral nematode was more abundant in the 2-year rotation regardless of the management system.

Microorganism populations and biomass tended to be higher with reduced-chemical-input management. We noted the largest increase in microbe numbers with *Bacillus* in the reduced-chemical-input treatment compared with the conventional treatment. Generally, reduced-chemical-input management resulted in greater enzyme activity than did conventional management. Activity was higher in rotations than in monoculture, but management system had little effect within the rotation.

The feasibility of using crimson clover in a reduced-chemical-input system appears promising. Results have been restricted because of erratic climatic conditions and an inherent weed infestation of johnsongrass at the experimental site. However, the ability of crimson clover to produce large amounts of biomass and N and to enhance favorable biological activity in the soil supports the reduced-chemical-input concept. Research on both the agronomic and economic aspects of reduced-chemical-input management, and the key role of crimson clover in it, is continuing.

Table 2. Nitrogen accumulation in the aboveground biomass in crimson clover at time of kill in spring.

	Nitrogen Accumulation						
	Kill Date						
	1987	1988		1989		Annual Mean	
Cropping System	4/29	4/11	4/25	4/19	5/15	Early	Late
	pounds/acre						
Continuous corn	178a*	107cd	187a	80a	80a	94	152
Continuous sorghum	160a	-	133b	62a	-	116	
Corn-wheat-soybeans	133a	-	143b	90a	107a	90	125

*In a given year, values followed by the same letter are not significantly different at $p=0.05$.

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Cover crop management systems for broccoli

Francis X. Mangan, Stephen J. Herbert, and Gerald L. Litchfield

The impact of routine agricultural practices on groundwater has become an important environmental issue *(3)*. This is especially true in a state like Massachusetts where agriculture is often in close proximity to residential areas.

Cover crops reduce erosion, water and chemical runoff, and weed growth and add organic matter to the soil *(1, 2)*. Legume cover crops also add nitrogen (N). Of the winter annual legumes, hairy vetch (*Vicia villosa* Roth) is probably the most winterhardy. A weed suppressive, water-conserving mulch is produced when cover crops are mow-killed and left on the soil surface.

In this study, we evaluated the effects of several cover crop combinations and inorganic N fertilizer on broccoli (*Brassica oleracea* L.) growth. This research is part of a Low Input Sustainable Agriculture (LISA) grant in which researchers are studying the use of cover cropping systems for vegetable production in the Northeast. These systems have the potential to decrease dependence on chemical fertilizers and herbicides.

Materials and methods

A field experiment was initiated at the research farm in South Deerfield, Massachusetts, in the fall of 1989. The replicated main plots were three cover crop combinations: hairy vetch in combination with rye (*Secale cereale* L.) at the seeding rate of 40 and 56 pounds/acre, respectively; rye alone at 90 pounds/acre; and no cover crop. We combined each cover crop with two tillage treatments, conventional tillage and no-till, and two rates of N, 0 and 100 pounds/acre.

Cover crops were sown on August 25, 1989 and allowed to regrow in the spring. On May 22, 1990, when rye seed heads had emerged, we mowed all cover crop treatments with a PTO-driven sickle-bar mower and left them on top of the soil. We then used a PTO-driven rotovator to incorporate the conventionally tilled cover crop treatments into the soil. Broccoli plants were transplanted into the field on May 23, 1990. We applied N, as ammonium nitrate, to appropriate treatments on June 20, 1990. We harvested broccoli heads, and recorded the field weights when the heads reached a minimum width of 4 inches or if they began to flower.

Results

Yields. The addition of inorganic N resulted in a significant increase in yield of broccoli heads (Figure 1). Average yield for the four treatments in the rye-vetch cover crop combination was higher than the averages for the other two cover crop combinations. The vetch-rye tilled with no N had similar yield to tilled rye with 100 pounds/acre added N. Yield was greater with no cover crop than with rye alone. Results were probably due to the higher carbon (C)/N ratio of rye immobilizing N, whereas vetch-rye added N as the legume decomposed.

Time of harvest. Harvest date of no-till treatments for each cover crop combination was significantly delayed compared with tilled treatments (Figure 2). Differences in soil temperature and N availability among the treatments are thought to be responsible for this response. Soil temperature readings taken for the duration of the experiment showed tilled treatments had significantly higher temperatures, especially after a period of sun, than the no-till treatments. This was especially true for the two cover crop combinations. The thick mulch left on top of the soil kept the soil much cooler.

Another reason for these differences could be the difference in fertility rate between the two tillage systems. Previous research has shown that N will be made more readily available with the use of cover crops when they are incorporated into the soil compared with leaving the aboveground biomass on top of the soil *(4)*.

Conclusions

The hairy vetch legume added significant amounts of N to the soil, which contributed to the growth of broccoli. The rye

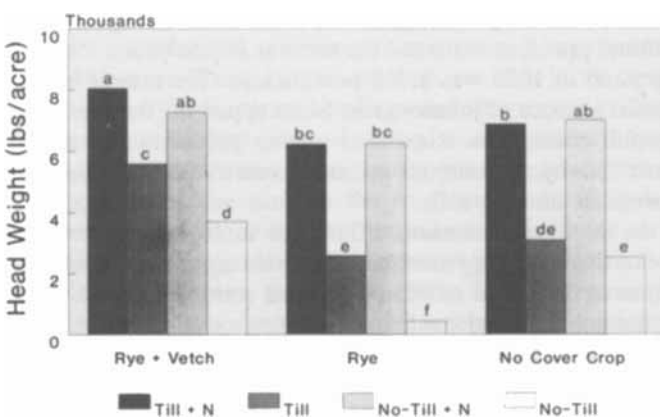

Figure 1. Weight of broccoli heads for the 12 treatments.

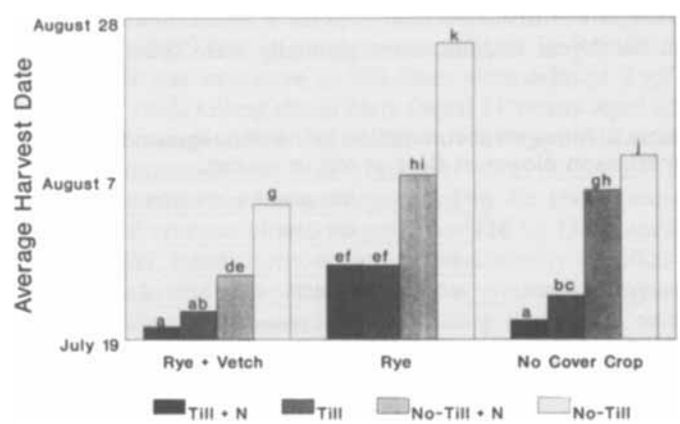

Figure 2. Average harvest date of broccoli heads for the 12 treatments.

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appeared to tie up N due to the higher C/N ratio. No-till treatments delayed the harvest of the broccoli due to the cooler soil temperatures and possibly slower degradation of the plant material, which would cause a slower release of N.

The delay in harvest could be a disadvantage to the no-till production of vegetables. However, this delay would have to be evaluated against the cost of plowing and disking the fields in conventional systems. In addition, the no-till rye-vetch system provided excellent weed control without the use of synthetic herbicides (data not reported).

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On-farm evaluation of legume interseedings in broccoli

C. M. Foulds, K. A. Stewart, and R. A. Samson

Popular literature provides examples of vegetable interseeding systems as early as the beginning of the 20th century *(2, 6, 8)*. Scientific studies, though, have concentrated on the use of living mulches in vegetables *(3, 4, 5)*. Interseedings are established at the same time or after the main crop is planted. Living mulches are established before the main crop is planted *(1)*. The additional time and labor required to manage living mulch systems may explain why farmers have not readily adopted this technique *(7)*. Interseeding systems, on the other hand, offer producers the potential of establishing a cover crop with little effect on field management requirements.

The objectives of our study were to make on-farm evaluations of forage growth, late-weed suppression, and effect on crop yield of five legume species interseeded in broccoli.

Methodology

We superimposed three experiments on existing broccoli (*Brassica oleracea* L.) fields over a 2-year period. In 1989, we established experiments 1 and 2 in the same broccoli field. We carried out experiment 3 in 1990 in an adjacent field. For all experiments, we used a randomized complete block design. Four to five weeks after we planted the broccoli on June 1 in 1989 and June 8 in 1990, we broadcast white clover (*Trifolium repens* L.) (6 pounds/acre), red clover (*T. pratense* L.) (10 pounds/acre), sweetclover (*Melilotus officianlis* Lam.) (10 pounds/acre), crimson clover (*T. incarnatum* L.) (15 pounds/acre), and hairy vetch (*Vicia villosa* Roth) (30 pounds/acre). We established a control plot with no interseeding. We did not test crimson clover in experiment 2. We cultivated all plots twice at 2-week intervals prior to interseeding. We cultivated experiment 1 a third time 5 days after interseeding. We also hand-weeded all experiments once prior to broccoli harvest. We recorded broccoli yields, fall forage, and weed biomass.

Results and discussion

Total and marketable broccoli yields were not affected by treatments (data not shown). Average total yields were 6,034 pounds/acre and 5,459 pounds/acre for experiment 1 and 3, respectively. We did not measure yields in experiment 2.

Hairy vetch and crimson clover were the most productive interseeded species overall. The third cultivation in experiment 1 appeared to reduce biomass of the other small-seeded

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legume species. We chopped broccoli residues on September 5 and September 30 in experiments 1 and 2, respectively. From September 5 to 30, the broccoli in experiment 2 produced an abundance of leafy biomass. Consequently, heavy residue was present at the time of chopping. The thick mulch that resulted in experiment 2 appeared to have impeded forage regrowth when compared with that observed for experiment 1 (Figure 1). Only in the case of red clover was biomass for experiment 2 slightly higher than that observed for experiment 1. We did not obtain statistical analysis to compare forage biomass between experiments 1 and 2.

The 1990 year was wet. Flooding and clubroot resulted in low marketable yields (3,507 pounds/acre for experiment 3 compared with 5,854 pounds/acre for experiment 1 in 1989). Because the broccoli crop was not competitive, we obtained high biomass for all the species (Figure 2).

Weed pressure in 1989 was relatively low, generally less than 351 and 22 pounds/acre for the controls in experiments 1 and 2, respectively. We observed no significant effects of cover crops on weed biomass. Fall weed growth was greater in 1990 and significant reductions in weed biomass resulting from cover crop treatments occurred. White clover, which yielded significantly less forage than hairy vetch and crimson clover, was as effective as the higher biomass-producing species in reducing weed growth (Figure 2).

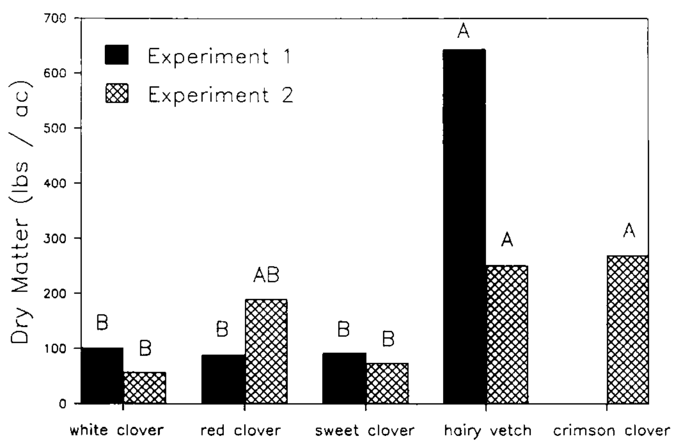

Figure 1. Fall forage biomass for experiments 1 and 2. Within each experiment, means followed by the same letter are not significantly different at the 0.05 level.

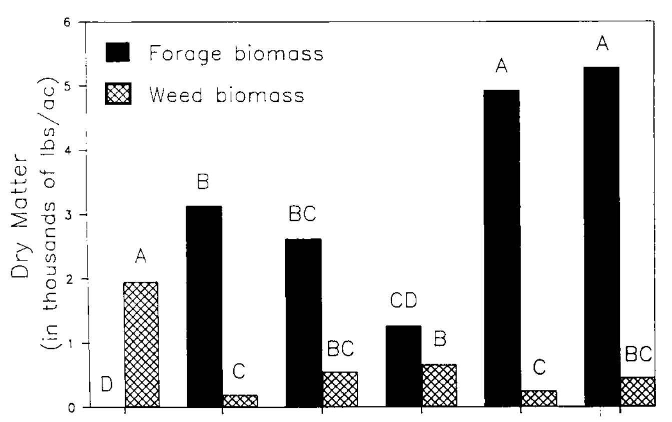

Figure 2. Fall forage and weed biomass for experiment 3. For each measurement, means followed by the same letter are not significantly different at the 0.05 level.

Field testing of legume forages as interseeded cover crops in broccoli showed potential for producing significant amounts of biomass without affecting crop yields. Hairy vetch and crimson clover were the most productive. None of the interseeded cover crops reduced broccoli yields. Late-weed growth was significantly reduced in 1990 by interseeding. Various field-management practices and climatic conditions appeared to be as important as the choice of species.

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Economics of no-till corn planted into winter cover crops

J. Bowen, L. Jordan, and D. Biehle

Using a cover crop in a no-till system has many benefits, including erosion control, soil-moisture conservation, nutrient cycling, and weed suppression *(5)*. These benefits may be difficult to measure in terms of economic returns.

Cover crops are gaining interest for their ability to trap nutrients and contribute nitrogen (N) through symbiotic fixation of atmospheric N_2 *(1, 3, 4, 6)*. Research has shown that an adaptable legume cover crop can recycle large amounts of N to a succeeding crop with the potential to reduce N-fertilizer inputs *(1, 3, 4)*; but more information is needed to determine if these benefits offset the cost of purchasing and planting the legume cover crop.

Our objective was to determine the cost-effectiveness of a hairy vetch (*Vicia villosa* Roth) cover crop in no-till corn in southeastern Indiana. Can the N produced by hairy vetch replace a portion of a corn (*Zea mays* L.) crop's N requirement that would normally be supplied by N fertilizer without reducing yields and profits? We compared net returns for no-till corn using hairy vetch and small-grain cover crops and no cover crop (previous crop residues) at three N-fertilizer rates.

Methodology

We conducted demonstration plots at the Southeast Purdue Agricultural Center during the growing seasons of 1989 and 1990. We replicated plots twice using hairy vetch, wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.), and no-cover treatments at three N-fertilizer rates: 0, 75, and 150 pounds/acre. The site was located on somewhat poorly drained Avonburg silt loam soils.

In 1988 and 1989, we no-till drilled cover crops on September 19 and November 2, respectively. The late-planting of cover crops in 1989 was due to delayed corn harvest. We planted hairy vetch at about 40 pounds/acre and wheat and rye at 90 pounds/acre. We planted no-till corn in mid- to late May the next spring. At planting, we used a mixture of paraquat, bladex, and atrazine to kill the cover crop and control weeds. We used a starter fertilizer solution of 19-17-0 (N-P-K) at 132 pounds/acre at planting and we side-dressed N-fertilizer treatments as anhydrous ammonia.

To determine economic comparisons, we calculated net returns using revenues (price times yield) subtracted from operating costs, which included seed, fertilizer, herbicides, equipment, labor, fuel, and repairs. We did not include land costs and drying costs in calculating net returns. We estimated costs using Purdue University custom rates *(2)*. We added 10% interest to operating costs. We used corn prices of $2.25/bushel, corresponding to local prices at harvest in both years.

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Table 1. Corn yield at three N-fertilizer rates.

	Corn Yield by N-Fertilizer Rates		
Cover Crop	*0 pounds/acre*	*75 pounds/acre*	*150 pounds/acre*
	bushels/acre		
Hairy vetch			
1989	136	202	208
1990	100	171	174
Average	118	187	191
Small grains			
1989	74	109	170
1990	81	161	180
Average	78	135	175
No cover			
1989	81	142	172
1990	70	160	178
Average	76	151	175

Table 2. Net returns* above operating costs.

	Net Returns by N-Fertilizer Rates		
Cover Crop	*0 pounds/acre*	*75 pounds/acre*	*150 pounds/acre*
	$/acre		
Hairy vetch			
1989	154	289	292
1990	71	220	216
Average	112	256	254
Small grains			
1989	39	107	233
1990	51	221	253
Average	46	164	243
No cover			
1989	74	200	257
1990	49	241	271
Average	63	221	264

*Net returns do not include land charges and grain drying costs.

Results

Dry matter production for hairy vetch was reduced by about 50% for the late-planting (November 2) in 1989 as compared with vetch planted in mid-September in 1988. Subsequently, the N produced by hairy vetch was dramatically reduced prior to planting no-till corn in 1990. N content of hairy vetch (aboveground) prior to no-till corn planting was 230 pounds/acre in 1989 and only 90 pounds/acre in 1990. Timely fall-seeding of hairy vetch may result in greater contribution of N to a succeeding corn crop, with the potential to enhance yields.

Over 2 years, average corn yields were greatest for hairy vetch treatments at 75 and 150 pounds N fertilizer/acre, with yields of 187 and 191 bushels/acre, respectively (Table 1). Corn planted into small-grain cover crops and no-cover had similar yields at the high-N-fertilizer rate with 175 bushels/acre. The data suggests that high yields can be attained at reduced-N-fertilizer rates by utilizing a hairy vetch cover crop.

Table 1 shows that no-till corn yields were about 30 bushels/acre greater in 1989 when planted into a vetch cover crop than in 1990. These higher yields may be a result of the much greater N produced by hairy vetch in 1989 (230 pounds/acre) as compared with 1990 (90 pounds/acre). For small-grain and no-cover treatments, corn yields were greater in 1990 than in 1989.

Table 2 compares profitability of cover crop treatments based on net returns over operating costs. We did not include land charges and grain drying charges in operating costs. Net returns averaged over the 2 years were greatest for the no-cover crop treatment at 150 pounds N/acre ($264/acre). Even though average yields were greater for the hairy vetch treatments at 75 and 150 pounds N/acre, average net returns were $8 to $10/acre less than those for the no-cover treatment. Operating costs were nearly $42/acre greater because of the added cost of purchasing seed and fall-planting a hairy vetch cover crop.

However, in the fall of 1988 when we planted hairy vetch on September 19, dry matter production and N content of hairy vetch cover crop were near optimum; and net returns in 1989 were $32/acre greater at 75 pounds N/acre than the no-cover treatment at the high-N-fertilizer rate and $35/acre higher when both treatments were compared with the 150-pound N/acre rate.

We concluded that the cost-effectiveness of using a hairy vetch cover crop in southeastern Indiana depends largely on timeliness of establishment. With timely fall-planting, hairy vetch can contribute substantial amounts of N to no-till corn, justifying reduced-N-fertilizer inputs while maintaining yields and providing economic benefits. If residual nitrate (NO_3) remained in the soil after corn harvest, hairy vetch could take up a portion of the NO_3 and prevent it from leaching into groundwater. When wet conditions or delayed harvest do not allow timely establishment, economics may not justify planting a hairy vetch cover crop.

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The promise of strip intercropping: Is it economically viable?

Craig Chase and Michael Duffy

Strip intercropping is an attempt to use the same benefits and resources available to multiple-crop rotations *(1)*. Such benefits as reduced fertilization and pesticide requirements and better erosion and water loss control can be accomplished through the use of multiple-crop rotations *(5)*. Moreover, the use of rotations can reduce potential groundwater and surface water problems *(3, 4)*. The difference between conventional multiple-crop rotations and strip intercropping is that the crops in the latter are planted in side-by-side strips ranging from 12 to 30 feet wide rather than bulk-planted. The crops within the strips are exchanged each year providing the rotation effect.

We designed this study to evaluate the economics of narrow-strip intercropping by comparing dollar valued benefits and costs from strip intercropping with those for conventional practices. We will provide a more detailed analyses in a later publication.

Narrow-strip intercropping involves most of the same inputs as conventional-rotational systems. Therefore, evaluating benefits and costs is a similar procedure. Although similar, no studies have been found to date which evaluate the benefits and costs of narrow strips.

We had three major objectives in this analysis: (a) to estimate and compare the per-acre production cost of a strip intercropping system versus other conventional systems; (b) to compare yields of the cropping systems under study; (c) to compare the expected economic returns per acre of the strip-intercropping system versus other conventional systems.

Materials and methods

The primary source of data for this analysis comes from a study being conducted at the Tom Franzen farm located near Alta Vista in Chickasaw County, Iowa. Our analysis covers only the 1989 crops.

Study design. The two tillage systems we evaluated at this location were conventional and ridge tillage. The three rotations evaluated were corn(*Zea mays* L.)-corn, corn-soybeans [*Glycine max* (L.) Merr.], and corn-soybean-oats (*Avena sativa* L.). The corn-corn and corn-soybean bulk-planted rotations used both tillage systems while the corn-soybean-oats rotation used only ridge tillage. The corn-soybean-oats strip intercropping system used only ridge tillage.

Production costs. Actual expenses were not kept for this

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study. The physical amount, type, and form of the inputs, however, were recorded. The expenses of the recorded inputs and machinery costs per operation were estimated using figures from "Estimated Costs of Crop Production in Iowa" (2). The machineryt costs consisted of both fixed and variable compnents.

The corn-corn conventional tillage system incurred $3/acre higher production costs, while costs for the corn-soybean rotation were $10/acre higher. These higher costs result from slightly different machinery operations. There was essentially no difference in costs between the ridge-tillage and narrow strip intercropping systems ($98 versus $101). The additional corn machinery costs incurred were for drying, handling, and hauling because of the higher yields of the strip intercropping system.

Table 1. Crop yields by system, crop, and rotation.

System/Rotation	Crop Yield Corn	Soybean	Oat
	bushels/acre		
Conventional tillage			
Corn-corn	115	-	-
Corn-soybean	130	40	-
Ridge tillage			
Corn-corn	115	-	-
Corn-soybean	130	40	-
Corn-soybean-oat	135	42	80
Strip intercropping			
Corn-soybean-oat	160	41	90

Table 2. Returns to land, labor, and management by system, crop, and rotation.

System/Rotation	Returns by Crop Corn	Soybean	Oat	Average
	$/acre			
Conventional tillage				
Corn-corn	112	-	-	112
Corn-soybean	153	162	-	158
Ridge tillage				
Corn-corn	117	-	-	117
Corn-soybean	165	174	-	170
Corn-soybean-oat	175	187	131	164
Strip intercropping				
Corn-soybean-oat	229	181	158	189

Results

Yields. Table 1 reports average yields by tillage system, crop, and rotation. Within a rotation, the yields were identical with conventional and ridge tillage. The strip-intercropping yields were, however, 19% greater for corn (160 versus 135 bushels/acre) and 13% greater for oats (90 versus 80 bushels/acre), but 2% less for soybeans (41 versus 42 bushels/acre).

Returns. Average 1989 Iowa corn, soybean, and oat prices that farmers received, as well as the cost assumptions outlined previously, were used in the economic returns analysis. Oat straw was assigned a market price and included in the returns calculation. Table 2 presents average returns to land, labor, and management for each system. The returns for corn-corn are the least, regardless of tillage system. For bulk planting, the corn-soybean and corn-soybean-oats ridge tillage returns were almost identical ($170 versus $167/acre). However, the average economic return to the strip-intercropping system was $192/acre, about $20/acre greater than for the bulk, ridge tillage corn-soybean and corn-soybean-oats rotations.

Discussion

Although we examine only one study over only 1 year, we do propose the following conclusions:

1. Returns from narrow strips relative to conventional planting are greatly influenced by yields. This situation is due to the lack of production cost differences beyond that incurred as a result of the rotation effect. Put simply, the economic comparison of bulk-planted versus strip intercropping will depend on yield comparisons.

2. Narrow strip intercropping does offer rotational benefits. However, whether or not narrow strips are preferred to bulk-planting is not so clear. At a minimum, the data presented here suggests the need for further research, especially with respect to yield impacts. Moreover, if extensively used, it is possible that a somewhat different set of pest problems could eventually develop for the strip-planting system.

3. The last comment concerns a cost not shown here, although it is relevant to the individual farmer's decision: that is, the amount of headlands needed for each field. Due to the amount and timing of traffic, the headlands are not available for harvest with strip intercropping systems. The percentage of land given up in the headlands will vary depending on field shape and size. In the Franzen farm example, strip intercropping incurred 12% higher returns. Whether headlands amount to 1% or 10% of total crop land will influence the system's relative profitability and desirability.

In this preliminary analysis, strip intercropping yields were the greatest among the alternatives. Additional yield and strip-width research, in addition to inclusion of headlands, will be necessary to determine the economic viability of narrow strip intercropping systems.

Future research plans. Our research plan for 1991 is to gather more data, particularly yield data. Two additional sites will be added. The first is the study being conducted at the Iowa State University McNay Research Center located in south central Iowa. The second site is at the Reichert farm in north central Iowa. In addition, we will more closely examine the issue of headland allowance.

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