RYE AND VETCH INTERCROPS FOR REDUCING

CORN N FERTILIZER REQUIREMENTS AND PROVIDING GROUND COVER

IN THE MID-ATLANTIC REGION

by

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(ABSTRACT)

Winter-annual cover crops reduce soil erosion by providing ground cover, while producing energy-cheap N for a subsequent crop. Incorporated cover crops or those left as no-till mulch can enhance soil structure and water infiltration. A series of studies was designed to test agronomic advantages of growing mixtures of rye plus hairy vetch and hairy plus bigflower vetches. Plots were arranged in randomized complete blocks and the study conducted for two consecutive cover crop/corn sequences. I measured N yield of cover crops, their ground-covering ability, and their influence on soil structure and a subsequent corn crop.

Nitrogen yields ranged from 53 to 187 kg/ha using either pure stands of hairy vetch or mixtures of hairy vetch plus bigflower vetch. Nitrogen yields for rye

plus hairy vetch mixtures ranged from 90 to 179 kg/ha. Rye growing in association with vetch had lower C:N ratios (47:1) than pure rye (59:1), apparently deriving additional N from vetch. Vetches were poor at covering the ground in the fall (< 15% cover) as compared to rye (> 41% cover) or mixtures of rye and vetch (25 to 45% cover).

When compared to vetch pure stands, corn yields were suppressed 5 to 42% by including rye with vetch due to N immobilization from the rye component and reduced N yield from the vetch component. Corn yields from hairy vetch or hairy:bigflower vetch mixtures were 15.5 Mg/ha and 16.2 Mg/ha respectively and statistically similar to rye + 140 kg N/ha (16.7 Mg/ha). Corn following the two-vetch mixture took up 129 kg N/ha, while corn following hairy vetch took up 114 kg N/ha. Using N fertilizer, corn N uptake was 183 kg N/ha following 140 kg N/ha fertilizer and 213 kg/ha following 210 kg/ha N fertilizer. Increased soil moisture seemed to be related to the presence of a surface mulch.

I was unable to detect any changes in water-stable soil aggregates in the upper 15 cm after 2 years of cover cropping. During 1988, water infiltration in no-till plots was lower than in plots that had been disk incorporated, but a tillage effect was not seen in 1989.

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I dedicate this ominous assemblage of words and numbers to the good earth, from which all life comes and returns. May the earth be the benefactor of the knowledge generated.

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Introduction

If agriculture is to continue to sustain mankind, mankind must continue to employ a sustainable agriculture. To be sustainable, in a historical time scale, agricultural systems must be economically sound, sociologically acceptable, environmentally benign, and resource efficient. Furthermore, sustainable agriculture must operate within the biological and ecological constraints of a given set of crops and a particular locale. This work is about such concerns: developing or improving cropping systems in the mid-Atlantic region, so agriculture can simultaneously be a servant to mankind and a friend to the environment. Specifically, the research involves using an old idea (intercropping) to meet two conservation objectives (providing erosion-reducing ground cover and energy-cheap N for a subsequent crop). A number of grass-legume intercrops have been screened for their ability to meet these two objectives. Additionally, the effects of tillage on a following crop's ability to utilize legume-supplied N was investigated. Finally, cover crop effects on soil structure and weed levels were ascertained.

The projects reported here were designed and conducted to meet the following objectives:

1. To examine seeding rates and cover-crop species combinations that might optimize ground cover, N production, and residual soil-N scavenging.
2. Determine if annual-vetch mixtures increase N production over that of the legumes grown in pure stands.
3. Observe corn yields following these cover crops (pure stand and intercrops) in the absence of N fertilizer.

4. Determine corn N-uptake characteristics when grown following cover crops or provided synthetic N under two tillage regimes (disk-incorporated vs. no-till).

5. Examine the effects of cover crops and tillage on soil moisture content during corn production.

6. Determine the effects of cover crops and tillage on soil aggregation and water infiltration.

7. Determine the effects of cover crops and tillage on weed production in corn.

Review of the Literature

Cover Crops for Reducing Non-point Source Pollution and Erosion

Non-point source pollution from agriculture has emerged into the public consciousness as a major environmental problem. For example, Chesapeake Bay studies suggest that agriculture is the largest non-point contributor of nitrogen (N) in the Bay's drainage area (Zinn and Blodgett, 1989). Nitrate contamination of groundwater supplies by agriculture is also of growing concern in the mid-Atlantic region and, indeed, globally. Blackmer et al. (1989) noted that farmers often apply more N fertilizer than is necessary or desirable economically or environmentally. They have proposed a new soil-N testing procedure to provide better estimates of N availability and help prevent excessive N applications. Several agricultural practices can reduce or eliminate the harmful side effects of excessive N applied for crop production. For example, having an N-scavenging cover crop, such as rye (*Secale cereale*), in place can help reduce nitrate leaching into groundwater during winter and early spring (Brinsfield, 1989; Groffman et al., 1987; Mitchell and Teel, 1977). When comparing spring oat (*Avena sativa*), barley (*Hordeum vulgare*), and rye for residual-N extraction following corn (*Zea mays*), Brinsfield (1989) found rye to be the most effective. Legume cover crops, while being able to fix their own N, can also scavenge residual N from the soil.

Another environmental concern facing agriculture is soil erosion. Between 2.7 and 3.1 billion tons of soil erode from U.S. cropland each year (USDA, 1986). Griffith et al. (1986) estimated 30% of total US cropland is losing soil faster than it is being reformed by natural processes. Yield reductions caused by soil erosion have largely been masked by commercial fertilizers; but before the advent of commercial fertilizers, topsoil losses caused 50% reductions in crop yields compared to fields with little erosion (Anonymous, 1981; Schertz et al., 1989; Uhland, 1949). Commercial fertilizer applications in excess of a soil's native productivity (prior to erosion) can also be added to true costs of erosion (Schertz et al., 1989). Off-site costs of soil erosion amount to two to eight fold the cost of erosion's effects on a soil's productivity (USDA, 1987). More than 50% of sediments in surface waters are from agricultural sources (USDA, 1987). Suspended soil degrades aquatic habitat all along the food chain, from depriving algae of sunlight to smothering eggs and fry of game fish (Robinson, 1989). Recent national legislation has sought to impose a soil-conserving ethic by removing erodible land from production. The Conservation Reserve Program, enacted in 1985, achieved three-quarters of its goal of retiring 16 million hectares to permanent conservation by 1990 (Postel, 1989). An estimated 800 million tons of soil per year have been saved as a result of the program (Postel, 1989).

The Virginia Cooperative Extension Service lists cover/green-manure crops and mulching as Best Management Practices to reduce conditions that degrade ground and surface waters (Wheaton and Hale, 1980). According to Hoyt and Hargrove (1986), any legume cover crop will reduce the erosion potential of a soil, although which legume cover crop provides the best erosion control has not been determined. Frye et al. (1985) estimated soil loss under cover-crop treatments on a 5% slope to be 2 Mg/ha/year as compared to 18 Mg with continuous, conventionally-tilled corn (planted on the contour with only corn residue left on the surface during winter). Holderbaum et al. (1990) estimated a cover-crop dry matter yield of 2 Mg/ha provides acceptable levels of residues for erosion control.

A few estimates are available on the erosion-reduction provided by mulches and crop residues. Wischmeier (1975) reported a 50% surface coverage by crop residue reduced soil loss to 32% of that with no mulch and that 100% coverage virtually eliminated soil loss. Griffith et al. (1986) reported a 65% erosion reduction with a 30% ground cover from previous crop residues. Using wheat (*Triticum aestivum*) straw, Meyer et al. (1970) found soil loss reductions of 80% with 2.24 Mg of straw/ha and 95% with 4.48 Mg/ha on a soil with 17% slope and moderate to slow permeability. Mannering and Meyer (1963) reported 87% ground cover is provided by 2.24 Mg of wheat straw/ha and 98% by 4.48 Mg of wheat straw/ha. They reported zero soil loss from initial and three consecutive wet runs of a rainfall simulator on a soil with 5% slope when using 4.48 Mg of wheat straw/ha . Soil loss was less than 560 kg/ha after three wet runs using 2.24 Mg/ha.

Cover crops as a soil and water-conserving mulch in conservation tillage continue to increase in popularity. In 1984, one-third of all harvested cropland was managed with conservation tillage practices (Hargrove and Frye, 1987); not all included cover crops, however. The use of conservation tillage has been predicted to rise to perhaps more than 45% of the total US cropland by the year 2000 (USDA, 1975).

Legume Cover Crops as an N Source for Corn

Legume cover crops are effective N-fertilizer substitutes for no-till corn (Ott and Hargrove, 1989). In most cases studied, corn grown following legume cover crops has produced optimal yields with minimal additional N fertilizer (Decker et al., 1987; Frye et al., 1985: Mitchell and Teel, 1977). Herbek et al. (1987) found fertilizer-N-replacement values of 50 and 73 kg N/ha for hairy vetch *(Vicia villosa)* and bigflower vetch (*Vicia grandiflora*), respectively. Their highest corn yields were from cover crop plus N fertilizer. Tyler et al. (1987) and Neely et al. (1987) reported N equivalents of 84 to 112 kg/ha with killed vetch. A New Jersey study, comparing corn yields following rye plus 200 kg N/ha with unfertilized hairy vetch, reported corn silage yields of 54 Mg/ha following vetch and 57 Mg/ha following rye plus N (Tisdale et al., 1985). The vetch system gave the highest net return per hectare and the lowest production cost.

The N benefits from legumes have been shown to extend beyond the first year following the transition to the non-legume crop. Using ^{15}N-labeled alfalfa (*Medicago sativa*) residue, Harris and Hesterman (1987) reported corn plant recovery values of 17 to 25% during the first year following legume residue application. They concluded that incorporated alfalfa residue contributed little plant-available N during the first year of decomposition and that the main value was longer term. With repeated cycles of legume cover crops, plant-available N may accumulate. Fox and Piekielek (1988), using labeled legume N, estimated fertilizer N equivalences of 187 kg N/ha following 3 years of alfalfa and 147 kg N/ha following red clover (*Trifolium pratense*). They concluded that fertilizer rates for corn could be reduced by 134 kg/ha the first year following 3 years of alfalfa and by 101 kg/ha following 3 years of red clover. They recommended reductions of 34 kg/ha for the second year following either of these legumes.

<u>Other Benefits of Cover Crops</u>

As a part of a farm's crop-rotation plan, cover crops can scavenge leachable N, provide soil organic matter, symbiotically fix N, assist in nutrient cycling, and improve soil structure and water infiltration. Cover crops can provide several indirect benefits as they decompose into soil organic matter; one of the most important is to enhance the soil-aggregation process. Some of the desirable consequences of improved soil aggregation include increased water infiltration, decreased bulk density, increased water-holding capacity, and increased pore space (Boyle et al., 1989).

Soil aggregates are formed chiefly by physical processes such as wetting and drying, freezing and thawing, cultivation, plant growth, and earthworm activity (Allison, 1968). Aggregates form in wet soils when fine soil particles are oriented, brought together, and then bound by various physical and chemical forces, which remain active when the soil dries (Allison, 1968). Sufficient binding exists, through ionic bonding of clay particles, to hold the dry aggregates together. An aggregate is stabilized through microbial processes involving organic matter and its breakdown products, chiefly polysaccharides and humic substances. These compounds serve as cementing agents to cause the primary soil particles to cohere (Burns and Davies, 1986). The aggregate is then strong enough to hold together upon wetting and is considered to be "water stable".

Because the substances responsible for aggregate stability (the cementing agents) are susceptible to microbial degradation, organic matter must be replenished continually to maintain an aggregated status (Harris et al., 1966). The goal is not simply to add cementing agents to the soil, however. A given farming practice must promote aggregation (through physical processes) in order for organic-matter additions to bring about increases in water-stable aggregates (Allison, 1968).

Many of our better agricultural soils, with intrinsically high organic matter, have an abundant supply of aggregate-binding substances and therefore stand to benefit little structurally from added organic residues (Allison, 1968). However, Boyle et al. (1989) contend that, under most agroecosystems, the amount of fresh organic matter needed to maintain steady-state aggregation exceeds the supply of available plant residues. Low-organic-matter soils, which occur in many parts of the southeastern U.S., stand to benefit structurally and in other ways from plant residue and organic matter additions.

The best-aggregated soils in the U.S. are those that have been in long-term grass production (Allison, 1968). This is due to the perennial activity both of aggregate-forming processes and aggregate-stabilizing humus. A grass sod extends a mass of fine roots throughout the topsoil, contributing to the physical processes that help form aggregates. For example, roots continually remove water from microsites, providing local wetting and drying effects that promote aggregation. Meanwhile, the roots are also producing food for the rhizosphere microorganisms, which generate the polysaccharides to bind the aggregates into water-stable units. Additionally, a perennial-grass sod provides protection from rain drops and erosion while these other processes are occurring. This combination of factors creates optimal conditions for establishment of a well-aggregated soil under a perennial cover. Conversely, cropping sequences that involve repeated annuals and extensive cultivation, provide less vegetative cover and organic matter and usually result in a rapid decline in soil aggregation (Harris et al., 1966).

In a review of the literature on organic matter contributions to tilth, Boyle et al. (1989) explained that aggregate stability is determined to a large extent by the degree to which plant growth is uninterrupted. Annual green manuring therefore rarely increases aggregates, but it often maintains aggregate status. Harris et al. (1966) reported a perennial grass-legume mixture to be best at maintaining soil aggregation, with cereals and root crops being least effective. Miller and Kemper (1962) incorporated 6.1 Mg of alfalfa per hectare as green manure for corn and noted an increase in aggregate stability, but the effect only lasted through the end of that crop season.

Time must pass before improvement in aggregation by organic-matter additions can be seen. Russell (1967) reported 4 years passed before grass production on a clay soil, which was formerly under cultivation, improved crumb structure. On another clay soil, 13 years of grass production were required before differences were seen (Russell, 1967). McVay et al. (1989) tested water-stable aggregates on two coastal plain soils under cover crops in Georgia. On a sandy clay loam soil, having poor initial soil physical conditions, water-stable aggregates of the > 250 micron size increased in the top 2.5 cm after 3 years of cover crops. Using the same procedures on a limestone-derived gravely clay loam soil, which had better initial physical conditions, they found no differences in aggregate stability after 3 years.

Cover crops can also play a role in weed suppression. Weed suppression can be by direct competition for growth requirements, or by toxins (i.e. allelopathy). Field trials by Putnam and DeFrank (1983) have shown that many annual weed species can be suppressed with residue from rye, corn, wheat, oat, barley, and sorghum (*Sorghum bicolor*). Lieble and Worsham (1983) identified phytotoxic compounds in wheat residue and concluded that proper selection and management of cover crops could possibly reduce the amount of herbicide used in no-till cropping systems.

Intercropping

Any agricultural practice must provide advantages over other available options in the eyes of the practitioner in order to gain acceptance. Such has certainly been the case with intercropping (growing two or more crops in association with one another, also called mixed cropping and polyculture). Intercropping has been important historically in this country and continues to be an extremely important practice in developing areas of the world. It still has potential in developed countries. Many of the impediments to adopting it and other appropriate strategies of diversification are sociological rather than technological (Risch et al., 1983). The trend away from mixed cropping in this country resulted from changes in land management, demands for standardized commodities from the food processing industry, and commercialization of farming (Francis, 1986).

Intercropping combinations may take many forms. Intercropping itself is the space-dependent form of multiple cropping and means simply growing two or more crops simultaneously in the same field (Vandermeer, 1989). Of the intercropping patterns, two of the most common are mixed intercropping (two or more crops grown without distinct row arrangement) and row intercropping (two or more crops grown in distinct rows).

As with most traditional systems, intercrop systems have evolved through many centuries of trial and error. To persist, intercropping had to have merit biologically, environmentally, economically, and sociologically. Intercropping is generally regarded by farmers as a technique that reduces risks in crop production. Some of the mechanisms by which polycultures reduce risk include yield compensation and pest reduction. Yield compensation occurs when one member of an intercrop fails and the other survives and compensates in yield to some extent, allowing the farmer an acceptable harvest. Pest levels are often lowered in polycultures, as the diversity of plants hampers movement of certain pest insects and pathogens and, in some cases, encourages beneficial insect populations (Altieri, 1983).

The decision to intercrop usually depends upon a farmer's particular needs. Norman (1971) conducted an economic survey of farmers in northern Nigeria. He identified the farmers' main reasons for practicing mixed cropping as profit and security. Gliessman et al. (1981) found the main value of intercropping for farmers in lesser developed countries to be sustainable yields for the long term rather than profit maximization in the short term.

Measuring Intercrop Performance

A most important aspect of multiple cropping is production intensification per unit of land. A useful and convenient method for assessing intercrop performance, as compared to pure stands, is the Land Equivalency Ratio (LER). The LER is defined as the relative land area required as pure stands, to produce yields equal to intercropping (Mead and Willey, 1980). An LER value of 1.0 indicates no difference in yields between intercrops and pure stands. Values above 1.0 indicate an intercropping advantage, while those below 1.0 indicate a reduction in crop yield in mixed stands. The numbers to the right of the decimal point (when LERs are > 1.0) indicate the percent of extra land area required in pure stand to equal the yield achieved by the intercrop. For example, a value of 1.25 can be interpreted as a 25% greater area requirement for pure stands or a 25% higher intercropping yield. In either case, the figure indicates a 25% greater biological efficiency for intercropping. An LER for a two-crop intercrop can be expressed as:

$$LER = LER_{crop\ A} + LER_{crop\ B} = (I_A/P_A) + (I_B/P_B)$$

where I = yield of individual crops in mixtures and P = yield of crops in pure stands (Mead and Willey, 1980; Vandermeer, 1989).

A concept that incorporates the time dimension into evaluation of intercropping efficiency is the Area Time Equivalency Ratio (ATER) (Hiebsch and McCollum, 1987). The ATER was developed primarily for environments that do not have a distinct growing season. Under these circumstances, the ATER compensates for the difference in occupancy time between the intercrop and each component monocrop. The ATER is actually a weighted LER, since the area-time required to produce in monoculture the quantity of any crop produced in the intercrop is generated. The ATER is of little value in areas with a cold or dry season. Its best utility is in an iso-climatic environment, where plant growth can continue year round.

Intercropping with Cover Crops

Mixtures of annual vetches plus rye would seem to be most promising for accomplishing both agronomic and conservation objectives. Rye and some vetches are particularly cold tolerant. Vetches are among the highest N producers in the legume family. Mixtures of rye and vetch would likely provide a good erosion-retarding fall cover. While vetches produce little fall ground cover, rye is commonly grown for effective winter ground cover. Growing rye in association with vetch can also provide a rye trellis for the vining vetch to climb on (Henson and Schotch, 1968) and possibly produce more vetch as a result. Scott et al. (1987) found rye and mixtures of rye:vetch and rye:austrian winter pea (*Pisum arvense*) superior to pure stands of hairy vetch or austrian winter pea at establishing ground cover 45 days after planting. A yield and quality advantage has been firmly established for legume-grass mixtures grown for forages (Trenbath, 1974), further suggesting potential advantages for rye and vetch mixtures.

Data on mixed intercropping of cover-crop species are not extensive. Mitchell and Teel (1977) included mixtures of rye plus hairy vetch, rye plus crimson clover (*Trifolium incarnatum*), and ryegrass (*Lolium multiflorum*) plus crimson clover in their study of cover crops for no-till corn. Henson and Schotch (1968) recommended seeding rates for mixtures of oat, wheat, barley, or rye grown in combination with hairy vetch. Holderbaum et al. (1990) studied mixtures of three annual vetches plus wheat. Droushiotis (1989) compared the advantages of cereals plus vetch or pea (*Pisum sativum*) with pure-stand performance of the mixture components. Additional studies of oat and pea or oat and vetch have been done by Hodgson (1956), Robinson (1960), Peters (1951), and Bledsoe and Hadden (1936).

Optimum seeding rates are important for reducing production costs and producing high cover-crop yields. Hodgson (1956) tested various seeding rates of oat and pea for protein production. He concluded a total seeding rate greater than 112 kg/ha was excessive. His highest N production was from 75 kg of pea plus 34 kg of oat. This mixture would constitute a full planting rate for pea and 40% for oat according to Virginia recommendations (Donohue et al., 1984). Seeding rates recommended in the literature for rye plus vetch mixtures vary. Henson and Schotch (1968) recommended reducing small-grain rates by one-half and seeding vetch at 22 to 34 kg/ha. Mitchell and Teel (1977) used high rates of rye (126 kg/ha) with 17 kg of hairy vetch seed in their cover-crop comparison for corn production in Delaware. Moschler et al. (1967) used 50 kg of rye plus 17.8 kg hairy vetch in a Virginia study. Droushiotis (1989) used what seem to be quite excessive rates of oat and common vetch (*V. sativa*) in a Cyprus study comparing mixtures and pure stands. Pure-stand rates were 185 kg/ha for oat (2.3 times the upper Virginia recommendations) and 126 kg/ha for common vetch (4.2 times the highest hairy vetch rate for Virginia). Unless seed germination rates in the Mediterranean area are commonly low, or the climate is detrimental to seedling survival, these rates bias the results of the Droushiotis experiment. No advantage for mixtures over pure stands was found. In my opinion, the excessive seeding rates affected mixtures more adversely than they did pure stands.

The seeding rate ranges for rye and vetch recommended by Virginia Cooperative Extension Service are 22 to 34 kg/ha for a pure vetch stand and 67 to 101 kg for a pure rye stand (Donohue et al., 1984). Recommendations for a mixture of the two range from 11 to 17 kg of vetch plus 31 to 63 kg of rye/ha (Donohue et al., 1984). No published data on which to base these seeding rates were cited. Published seeding rates ranged from a low of 31 kg rye plus 11 kg hairy vetch/ha (Donohue et al., 1984)) to a high of 126 kg rye plus 17 kg vetch/ha (Mitchell and Teel, 1977).

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Rye and Vetch Intercrops for Reducing Corn N Fertilizer Requirements and Providing Ground Cover

In an era of increasing environmental awareness and health consciousness, the need for components of a sustainable agriculture become ever more important. Looming instability of N-fertilizer prices (tied to the price of fossil fuels) necessitates preparedness for a time when ecological N sources will predominate. As part of a farm's rotation plan, cover crops can reduce soil erosion and produce energy-cheap N for subsequent crops.

Mid-Atlantic farmers could rely on winter-annual cover crops to simultaneously reduce fertilizer N inputs and nitrate leaching, while providing soil-protecting ground cover. The region is has a shorter growing season than where much cover-crop success has been demonstrated (southeastern US). Crimson clover, a cover crop that provides both quick ground cover and abundant legume N, is risky to grow in much of the mid-Atlantic due to freeze damage. Alternatively, rye:vetch mixtures may achieve adequate ground cover while providing N-scavenging of residual (leachable) N by rye and legume-N production. In spite of these potential benefits, few farmers in the mid-Atlantic currently use winter-annual legumes in their production systems. Only limited research has examined winter-annual legumes under mid-Atlantic corn-production conditions (Holderbaum et al., 1990, in Maryland; Mitchell and Teel, 1977, in Delaware; Radke et al., 1987, in Pennsylvania; and Moschler et al., 1967, in Virginia).

An experiment was conducted to examine seeding rates and cover-crop combinations that might optimize ground cover, N production, residual N scavenging, and corn yield without additional fertilizer N. The study examines mixtures of rye plus hairy vetch and the mixing of hairy and bigflower vetches in an effort to increase N production over the two legumes grown in pure stands.

Materials and Methods

Replicated small-plot experiments were established at the Whitethorne Experiment Station, near Blacksburg, Virginia (37° N, 80° W, and 600-m elevation), on a Hayter cobbly loam (fine, loamy, mixed mesic, Ultic, Hapludalf) located on a terrace of the New River. Physical characteristics of this soil include a loamy surface texture, 2 to 7 % slope, and well drained. As of March 1987, the site was supporting a tall fescue (*Festuca arundinacea*) plus white clover (*Trifolium repens*) sod and was being grazed by cattle (*Bos taurus*). The site had been in pasture for the previous 3 years and then corn for at least the next previous 3 years. Preliminary soil samples were taken in March 1987 to determine initial fertility levels. At that time, soil pH ranged from 4.9 to 5.5, and some residual N (15 to 34 kg NO_3/ha), P (33 to 134 kg /ha), and K (123 to 352 kg/ha) were present in the top 15 cm of the soil profile. Soil test recommendations for the cover crops were N (17 to 22 kg/ha), P (0 to 67 kg/ha), and K (0 to 67 kg/ha). No fertilizer was applied to cover crops. It was deemed uneconomical for growers to apply fertilizer to cover crops.

On 10 July 1987, the plots were disked repeatedly with an offset disk to kill and incorporate the pasture plants. Foxtail millet (*Setaria italica*) was planted on 16 July using a grain drill and a 28 kg/ha seeding rate. The millet crop was intended to extract and immobilize, in plant tissue, residual N. Due to extreme drought conditions (no rain from 7 July to 6 September), the millet crop failed.

The experimental area was treated with 4500 kg/ha dolomitic limestone on 8 September 1987. The area was chisel plowed and disked, and a seedbed was produced by field harrowing on 10 September 1987. Treatments were arranged as randomized, complete blocks with four replications. Plots were laid off at 3.66 m wide (to accommodate four corn rows, 0.91 m apart) and 15.24 m long. The experiment was run for two complete cropping sequences (cover crop followed by corn).

Fifteen seeding rates or combinations of three cover crops were grown as mixed intercrops or pure stands (Table 1.1). Cover-crop species included rye, hairy vetch, and bigflower vetch. Cover-crop species were selected for their known cold tolerance in the ridge and valley region of Virginia. Rye was included in this experiment for three reasons: (1) rye is a commonly grown, cold-tolerant, winter-annual cover crop in many parts of the US, (2) any small grain can serve as a trellis for a weak-stemmed climbing legume such as hairy vetch (Henson and Schotch, 1968) and possibly increase legume yield due to more sunlight exposure, and (3) biomass yield from the small grain can be used to estimate the residual soil N available.

Seeding rates for the study were selected with the dual (perhaps conflicting) objectives of establishing rapid ground cover and high N production. The most rapid ground cover would likely be achieved with full seeding rates of rye, but some compromise must be achieved to permit vetch establishment for legume-N accumulation during the legumes' typical spring burst of growth. Two legumes (hairy and bigflower vetches) were mixed in various ratios to test the

Table 1.1 Cover crop seed percentages and rates and N fertilizer added to corn used for the study.

Cover crop treatment	Cover crop seeding rate			N rate
	Rye	Hairy vetch	Bigflower vetch	
	kg/ha			
100* Rye (R)	100	0	0	0
100 Hairy vetch (H)	0	28	0	0
100 Bigflower vetch (B)	0	0	28	0
50H/50B	0	14	14	0
67H/33B	0	19	9	0
33H/67B	0	9	19	0
50R/50H	50	14	0	0
50R/75H	50	21	0	0
50R/100H	50	28	0	0
75R/75H	75	21	0	0
25R/50H/25B	25	14	7	0
25R/25H/50B	25	7	14	0
33R/33H/33B	33	9	9	0
50R/25H/25B	50	7	7	0
100R + 140N +	100	0	0	140

*The number preceding the cover crop represents the percent of the recommended seeding rate for a pure stand (Donohue et al., 1984)

+Nitrogen fertilizer applied to corn as NH_4NO_3 following cover-crop desiccation.

hypothesis that total N production of intercrops would exceed that of either species growing in pure stand. Since bigflower vetch enters the reproductive mode earlier than hairy vetch, it would seem likely that peak demand for soil nutrients and water would be more dispersed when these two legumes were grown in association. With its 2-week offset, hairy vetch could continue producing biomass and N while bigflower is flowering and setting seed, bigflower having already accrued its maximum N content earlier. Seeding rates used (Table 1.1) reflect percentages of recommended (Donohue et al., 1984) pure-stand seeding rates based on 100 kg/ha for rye and 28 kg/ha for hairy and bigflower vetches.

A Northrup King short-growing rye variety 'SS2', 'common' hairy vetch, and 'Woodford' bigflower vetch were planted in 1987. The rationale for the short-statured rye was to reduce the amount of high-C:N-ratio stem contained in the rye crop. One of rye's drawbacks as a cover crop is immobilization of soil N when used as a green manure or no-till mulch. The stem contains more C proportionally, than other plant parts; so reducing stem length (height) should reduce carbon loading to the soil. Additionally a 1-m-high cover crop is less manageable in terms of soil preparation and corn planting than is a 0.5-m-high one. Unfortunately (and much to my surprise), the SS2 rye was less cold tolerant than necessary. In 1988, 'Abruzzi' rye was substituted, because winter freeze damage to SS2 occurred in the previous season.

Cover crops were planted as pure stands or mixed intercrops using a grain drill on 10-cm centers on 25 September 1987. The following fall, row width was changed to 20-cm centers to prevent drill clogging on corn stump/root masses when set for the narrower row width. Cover-crop planting that year was done on

8 and 9 October 1988. Seeds of the various mixtures were mixed and inoculated with effective *Rhizobium* strains. No N fertilizer was applied to the rye crops.

On 30 March 1988, inspection of the vetches revealed many plants, particularly in the pure stands, were not nodulated. Inoculant was re-applied immediately by suspending inoculum in water and spraying the mixture over the crop. Rainfall (>5 cm) occurred within 24 h, which presumably washed the inoculum into the soil. Vetch plants appeared to "green up" within 10 days and produce adequate biomass in most plots. A spot inspection of vetch roots revealed nodulation where previously there was none. Several plots apparently received spotty application of "rescue" inoculation causing uneven growth to occur in those plots. Some treatments, particularly rye:vetch mixtures had adequately nodulated vetch plants at the time of rescue inoculation. Since the rye seed in the mixtures were also inoculated, the total amount of seed-provided inoculum was greater in those treatments. A different source of inoculum was used for the rescue inoculation.

Ground cover percentage was determined using a point frame (Grief-Smith, 1964; Raelson and McKee, 1982). Seasonal progression of ground cover was assessed by making measurements at intervals. During the 1987-88 cover crop season, point-frame measurements were taken starting 24 November (60 days after planting) and continued throughout the winter and spring on 20 December (86 days), 20 January (121 days), 26 February (154 days), 30 March (186 days), and 23 April (210 days). In the first year, five point-frame measurements were taken in each plot on each sampling date. In the second year, ten point-frame measurements per plot were taken. In 1988-89, sampling began 16 December (68 days after planting) and continued to 25 January (108 days), 27 February (141 days), 28 March (170 days), and 28 April (201 days).

Biomass produced by the cover crops was sampled by removing top growth to the soil surface from four 0.25-m^2 quadrats per plot. Sampling occurred from 13 to 17 May 1988 and 21 to 22 May 1989 by block. Mixtures of rye and vetch were hand-separated into their respective species components. Because of entanglement and similar morphology, no separation of hairy vetch and bigflower vetch mixtures was attempted. All samples were weighed, dried at 55 to 60 C for 60 h, and reweighed to determine yield. Cover-crop biomass samples were ground in a Wiley mill to pass a 1-mm mesh screen. Plant samples were analyzed for total N using the Kjeldahl method (Bremner, 1965).

Soil test recommendations for P and K for corn production were N (140 to 168 kg/ha), P (0 to 56 kg/ha), and K (0 to 56 kg/ha). Phosphorus and K fertilizer was applied for corn at 56 kg P (P_2O_5) and 56 kg K (K_2O_2) per ha over the top of cover crops on 27 April 1988 and 24 May 1989. The herbicides paraquat (2.34 L/ha), metolachlor (1.75 L/ha), and cyanazine, (3.5 L/ha) were tank-mixed and applied 17 May 1988 and 23 May 1989 by sprayer. An intensive rain shower followed the herbicide application in 1988, resulting in minimal desiccation of the cover crops by paraquat. A second application of paraquat at 1.17 L/ha on 22 May 1988 did desiccate the cover crops completely.

No-till practices were used to establish corn following desiccation of the cover crops. Pioneer 3233 corn was planted on 19 May 1988 and 22 May 1989 at a target population of 50,000 plants/ha. Skips were evident 2 weeks after planting and were replanted by hand in order to observe treatment effects with a uniform stand. Fertilizer N was applied as NH_4NO_3 to the rye plus N-fertilizer treatment at 70 kg N/ha on 28 May 1988 and 24 May 1989. A second 70 kg N/ha was applied when corn plants were 50 cm tall. Abundant rainfall occurred throughout both corn growing seasons. Corn was harvested as for silage (at 35 to 42% dry matter) from the central 12.2 m of the middle two rows in each plot on 14 to 16 September 1988 and 13 to 14 September 1989. Corn subsamples were weighed, dried at 55 to 60 C for 60 h, reweighed, and reported on an oven-dry basis.

Data were analyzed using analysis of variance procedures (SAS, 1982). Comparisons for year differences were made by calculating an F-statistic from the two error mean squares for the two separate years and comparing the calculated F with an F-distribution at the 0.05 probability level. Means were separated by F-protected LSD. Several other mean separation procedures were examined; each has limitations, and LSD was chosen as the most appropriate. A preference for type I errors was the main reason for using LSD. With LSD, the treatments can be more closely scrutinized to separate the best performers from the rest.

Results and Discussion

Cover-Crop Yields of Biomass and N

Cover-crop yields and ranking differed from year to year (Table 1.2). Analysis of variance revealed a year-by-cover-crop interaction (data not shown). A comparison of the interaction indicates the decline in biomass from 1988 to 1989 was closely related to the performance of rye. Apparently rye variety and row spacing affected biomass production more than differences between years *per se*;

Table 1.2. Cover-crop biomass production (oven dry) and year effect for 1988 and 1989.

Cover crop treatment	1988	1989	Year effect
	----------------Mg/ha--------------		
100 Rye (R)	7.8 d*	5.2 bcd	yes+
100 Hairy vetch (H)	3.8 g	4.8 cd	no
100 Bigflower vetch (B)	3.5 g	4.1 d	no
50H/50B	5.9 ef	4.3 d	yes
67H/33B	5.7 f	4.3 d	no
33H/67B	5.2 f	4.0 d	no
50R/50H	10.2 bc	6.3 ab	yes
50R/75H	10.9 b	6.7 a	yes
50R/100H	10.3 bc	7.0 a	yes
75R/75H	10.8 b	6.9 a	yes
25R/50H/25B	10.3 bc	5.9 abc	yes
25R/25H/50B	12.3 a	6.4 ab	yes
33R/33H/33B	9.1 c	5.8 abc	yes
50R/25H/25B	10.8 b	7.0 a	yes
100 Rye + 140N #	7.0 de	4.8 cd	yes

*Means within a column followed by the same letter do not differ significantly using F-protected LSD, alpha = 0.05.

+Signifies whether or not the cover-crop biomass means for a treatment were significantly different from 1988 to 1989 using F-protected LSD, alpha = 0.05.

#Nitrogen fertilizer applied to corn as NH_4NO_3 following cover-crop desiccation.

legume-only treatments were not different in biomass from 1988 to 1989 except for the 50/50 mixture of hairy and bigflower vetches. This observation lends additional support to the contention that rye treatments were the major source for the year-by-cover crop interaction. The lowest biomass producers were the hairy and bigflower vetch pure stands in 1988 and the pure stands or vetch-only stands in 1989.

Nitrogen yield in above ground biomass was not affected by the differences in rye variety and row spacing between years (Table 1.3). The N yield differences from one year to the next among treatments containing only vetch were likely due to poor nodulation in some plots during 1988. Nitrogen yields indicated great elasticity for that parameter across seeding rates of rye:vetch mixtures. In 1988, superior N yielders can be grouped by means followed by an 'a' or 'b' (Table 1.3). These were all intercrops. In 1989, many of the treatments were similar. In general, the rye pure stands and the 25R/50H/25B mixture were the least N-yielding cover-crop treatments, with bigflower vetch being included in 1988. The low placement of the 25R/50H/25B mixture is likely due to the competitive exclusion principle (Begon and Mortimer, 1986; Vandermeer, 1989) discussed in the next section.

Land Equivalency Ratios for Biomass and N

If several pure-stand populations are planted within a single experiment, several methods of calculating LER may be employed (Oyejola and Mead, 1982). For this experiment, only one pure stand of hairy vetch and two of rye were included among the treatments. The highest yields for rye were used for the most conservative calculation of LERs. Another method of determining LERs would be

Table 1.3. Cover-crop N yields and year effect for 1988 and 1989.

Cover crop treatment	1988	1989	Year effect
	----------------kg/ha---------------		
100 Rye (R)	57 e *	37 e	no+
100 Hairy vetch (H)	89 d	187 a	yes
100 Bigflower vetch (B)	53 e	148 abcd	yes
50H/50B	139 bc	178 ab	yes
67H/33B	164 ab	169 abc	no
33H/67B	139 bc	149 abcd	no
50R/50H	127 c	145 abcd	no
50R/75H	176 a	149 abcd	no
50R/100H	162 ab	168 abc	no
75R/75H	159 ab	157 abcd	no
25R/50H/25B	90 d	117 d	no
25R/25H/50B	169 a	139 bcd	no
33R/33H/33B	161 ab	135 cd	no
50R/25H/25B	132 c	118 d	no
100R + 140N #	48 e	37 e	no

*Means within a column followed by the same letter do not differ significantly using F-protected LSD, alpha = 0.05.

+Signifies whether or not the cover-crop N yields for that row were significantly different from 1988 to 1989 using F-protected LSD, alpha = 0.05.

#Nitrogen fertilizer applied to corn as NH_4 NO_3 following cover-crop desiccation.

to calculate them on a replication basis and average the four LERs together. This method requires separate yield determinations for each replication of the study. When the by-rep LERs are averaged, their mean will consistently exceed that of a mean calculation based on a single (mean) pure stand yield (Vandermeer, 1989). Oyejola and Mead (1982) presented arguments against using different divisors in different blocks and concluded the same pure-stand yield should be used for all blocks. LERs based on means could be considered the more conservative of the two methods. In this study, LERs were calculated by averaging pure stand yields and by averaging component yields and generating a single LER. Ratios in Tables 1.4 to 1.7 represent values calculated from means of mixture components and means of pure stands. No LERs for the three-way mixtures were generated, because the hairy plus bigflower vetch components of these mixtures were not separated, and using any of the two-vetch mixtures as representative of pure stands was not considered appropriate.

Intercrop advantages for both biomass and N yield were evident for all the rye:hairy vetch mixtures. High LERs for the 1988 data were largely a result of low pure-stand yields for hairy vetch and are probably not truly representative. The comparative value of the LER is quite sensitive to pure-stand yields. If pure-stand yields are less than their real potential, an inflated and misleading LER will be generated. Pure-stand yields for 1989 were better, and the subsequent LERs probably represent a more realistic assessment of the intercrop advantage. Nitrogen yields for vetch-mixture components were similar to those of pure hairy vetch during 1988 for all the treatments except 25R/50H/25B. In this three-way mixture, the competitive exclusion principle is likely in action. The competitive exclusion principle states that, when competition between two species

Table 1.4. Total biomass (oven dry), component biomass contributions, and land equivalency ratios (LER) for the rye:vetch mixtures, 1988.

Cover crop treatment	Biomass			LER
	Total	Rye	Vetch	
	---------------Mg/ha---------------			
50R/50H	10.2	7.4 ab*	2.9 c	1.68
50R/75H	10.9	6.5 b	4.4 a	1.98
50R/100H	10.3	6.0 bc	4.2 ab	1.87
75R/75H	10.8	7.0 ab	3.7 abc	1.87
25R/50H/25B	10.3	8.8 a	1.5 d	NA+
25R/25H/50B	12.3	8.0 ab	4.3 ab	NA
33R/33H/33B	9.1	4.4 c	4.7 a	NA
50R/25H/25B	10.8	7.7 ab	3.1 bc	NA
100 Rye	-	7.8 ab	-	NA
100 Hairy vetch	-	-	3.8 abc	NA

*Means within a column followed by the same letter do not differ significantly, using F-protected LSD alpha = 0.05.

+NA = not applicable.

Table 1.5. Total biomass (oven dry), component biomass contributions and land equivalency ratios (LER) for the rye:vetch mixtures, 1989.

Cover crop treatment	Biomass			LER
	Total	Rye	Vetch	
	--------------------Mg/ha--------------------			
50R/50H	6.3	3.3 cd*	3.1 bcd	1.27
50R/75H	6.7	3.8 bc	3.0 cd	1.35
50R/100H	7.0	3.1 cd	3.9 ab	1.42
75R/75H	6.9	3.1 cd	3.8 bc	1.39
25R/50H/25B	5.9	3.3 cd	2.6 d	NA+
25R/25H/50B	6.4	3.5 bcd	2.9 cd	NA
33R/33H/33B	5.8	2.7 d	3.1 bcd	NA
50R/25H/25B	7.0	4.4 ab	2.5 d	NA
100 Rye	-	5.2 a	-	NA
100 Vetch	-	-	4.8 a	NA

*Means within a column followed by the same letter do not differ significantly using F-protected LSD, alpha = 0.05.

+NA = not applicable.

Table 1.6. Total N yields, component N contributions and land equivalency ratios (LER) for the rye:vetch mixtures, 1988.

Cover crop treatment	N yield			
	Total	Rye	Vetch	LER
	------------------kg/ha------------------			
50R/50H	127	60 ab*	68 c	1.86
50R/75H	176	58 ab	118 a	2.40
50R/100H	162	51 bc	111 ab	2.13
75R/75H	159	56 ab	103 abc	2.13
25R/50H/25B	90	70 a	20 d	NA+
25R/25H/50B	170	66 ab	103 abc	NA
33R/33H/33B	161	39 c	122 a	NA
50R/25H/25B	132	55 ab	76 bc	NA
100 Rye	-	57 ab	-	NA
100 Vetch	-	-	89 abc	NA

*Means within a column followed by the same letter do not differ significantly using F-protected LSD, alpha = 0.05.

+NA = not applicable.

Table 1.7. Total N yields, component N contributions, and land equivalency ratios (LER) for the rye:vetch mixtures, 1989.

Cover crop treatment	N yield			LER
	Total	Rye	Vetch	
	-------------------	kg/ha	--------------------	
50R/50H	145*	29 ab+	116 bcd	1.40
50R/75H	148	34 ab	114 bcd	1.53
50R/100H	168	30 ab	138 b	1.55
75R/75H	157	28 ab	129 bc	1.45
25R/50H/25B	117	26 b	91 cd	NA+
25R/25H/50B	139	33 ab	106 bcd	NA
33R/33H/33B	135	24 b	110 bcd	NA
50R/25H/25B	118	34 ab	85 d	NA
100 Rye	-	37 a	-	NA
100 Vetch	-	-	186 a	NA

*Means within a column followed by the same letter do not differ significantly, using F-protected LSD alpha = 0.05.

+NA = not applicable.

(interspecific competition) is sufficiently strong, one species will drive out (exclude) the other. When interspecific competition is weak, the two species will co-exist in a condition Vandermeer (1989) calls competitive production. In the 25R/50H/25B mixture, vetch yield was low due to high competition among the two vetches or from rye even though rye was planted at a low seeding rate. Hairy and bigflower vetches were also likely contributing to the rye growing in association with them, thus enhancing rye's competitive advantage even more. In 1989, vetch growing in association with rye had less N yield than did pure vetch (Table 1.7). Rye's ability to scavenge residual soil N continued while growing in the presence of vetch as evidenced by similar N yields for mixture rye components and pure rye; though some vetch-supplied N was likely taken up by rye. Additionally, the vetch was also scavenging residual soil N, though this study did not address N sources in detail.

Judging by LERs above 1.0, an intercropping advantage was seen. The mixtures in this study were likely more productive than pure stands for the several reasons that intercrops work, when they do. Among these reasons are: different soil strata being occupied by two different root types, peak nutrient and water demands being offset (reducing interspecific competition), and facilitation provided by one species to the benefit of the other (e.g. rye serving as a trellis for vetch, and vetch providing some N to rye). The LER values substantiate the assertion of Trenbath (1974) that a yield and quality advantage has been firmly established for legume-grass mixtures when grown for forages.

Ground-Covering Ability of Cover Crops

The primary purpose for a ground-covering crop is to quickly produce thorough coverage, thereby protecting soil from erosion. Towards this end, pure rye achieved the highest value during 1988, with 94% ground cover 60 days after planting (Table 1.8). Three other mixtures containing one-half to three-quarters as much rye had statistically equivalent ground cover 60 days after planting in 1988. None of the vetch-only treatments approached the level of pure rye ground cover until the 186-day determination (30 March). Minimal fall growth is typical of annual vetches, which produce most of their above-ground growth in the spring.

Ground cover was lower in 1989 than in the previous year across all treatments, due to wider drill rows and perhaps to a different variety of rye (Table 1.9). Pure rye still provided more ground cover sooner after planting, with the 75R/75H mixture being equivalent to pure rye at day 68. At day 141, all rye-containing cover crops were similar and superior while all vetch-only treatments were lower (Table 1.9). Vetch treatments showed limited early ground-covering ability again in 1989 and remained at less than 50% levels until 170 days after planting (March 28). Interestingly, at the final sample date, all the vetch-containing treatments exceeded pure rye, which never achieved full ground cover on the wider row spacings used in 1989. Graphical representations of cover-crop-provided ground cover can be seen in Figs. 1.1 to 1.4.

Cover-crop biomass yields met the recommendations of Holderbaum et al. (1990) (2 Mt/ha) for adequate erosion protection. The percent-cover measurements agreed with Holderbaum et al.'s more subjective estimates (rye provided the best cover and rye:vetch next best), but pure stands of vetch did not

Table 1.8. Percentage ground cover provided by cover crops at various dates after planting, 1987-88.

Cover crop treatment	Days after planting 60	86	121	154	186	210
	Percent Ground Cover					
100R+	94 a*	96 a	99 a	99 a	99 a	100 a
100H	11 d	26 c	38 f	29 e	64 bc	88 b
100B	7 d	12 c	10 g	22 e	46 cd	95 ab
50B/50H	11 d	13 c	23 fg	23 e	41 cd	99 a
33H/67B	10 d	17 c	17 g	24 e	37 d	95 ab
67H/33B	13 d	23 c	24 fg	31 e	38 d	99 a
50R/50H	71 bc	84 ab	73 cde	80 bc	86 ab	98 a
50R/75H	62 c	70 b	69 de	64 cd	63 bcd	98 a
50R/100H	76 abc	86 ab	89 abc	82 b	95 a	100 a
75R/75H	87 ab	95 a	92 ab	88 ab	91 a	100 a
25R/50H/25B	71 bc	72 b	78 bcde	74 bc	87 ab	94 ab
25R/25H/50B	67 c	77 b	73 cde	77 bc	95 a	100 a
33R/33H/33B	62 c	70 b	65 e	56 d	85 ab	95 ab
50R/25B/25H	79 abc	82 ab	85 abcd	81 bc	80 ab	99 a

+R = Rye, H = Hairy vetch, B = Bigflower vetch.

*Means within a column followed by the same letter do not differ significantly using F-protected LSD, alpha = 0.05.

Table 1.9. Percentage ground cover provided by cover crops at various dates after planting, 1988-89.

Cover crop treatment	Days after planting				
	68	108	141	170	201
	-------------------------Percent Ground Cover------------------------				
100R+	35 a*	41 ab	36 a	60 cd	54 f
100H	7 e	12 e	19 b	76 ab	93 ab
100B	4 e	7 ef	8 c	40 e	82 de
50H/50B	4 e	10 ef	15 bc	51 de	77 e
33H/67B	5 e	6 f	9 c	61 cd	86 abcde
67H/33B	8 e	9 ef	15 bc	60 cd	86 abcde
50R/50H	25 c	41 ab	41 a	72 abc	88 abcd
50R/75H	26 bc	37 bc	39 a	77 ab	92 abc
50R/100H	27 bc	41 ab	40 a	80 a	94 a
75R/75H	31 ab	45 a	40 a	80 a	92 abc
25R/50H/25B	18 d	34 c	38 a	66 bc	83 cde
25R/25H/50B	17 d	28 d	36 a	76 ab	85 abcde
33R/33H/33B	18 d	33 cd	35 a	70 abc	84 bcde
50R/25H/25B	24 c	33 cd	40 a	70 abc	84 bcde

+R = Rye, H = Hairy vetch, B = Bigflower vetch.

*Means within a column followed by the same letter do not differ significantly, using F-protected LSD, alpha = 0.05.

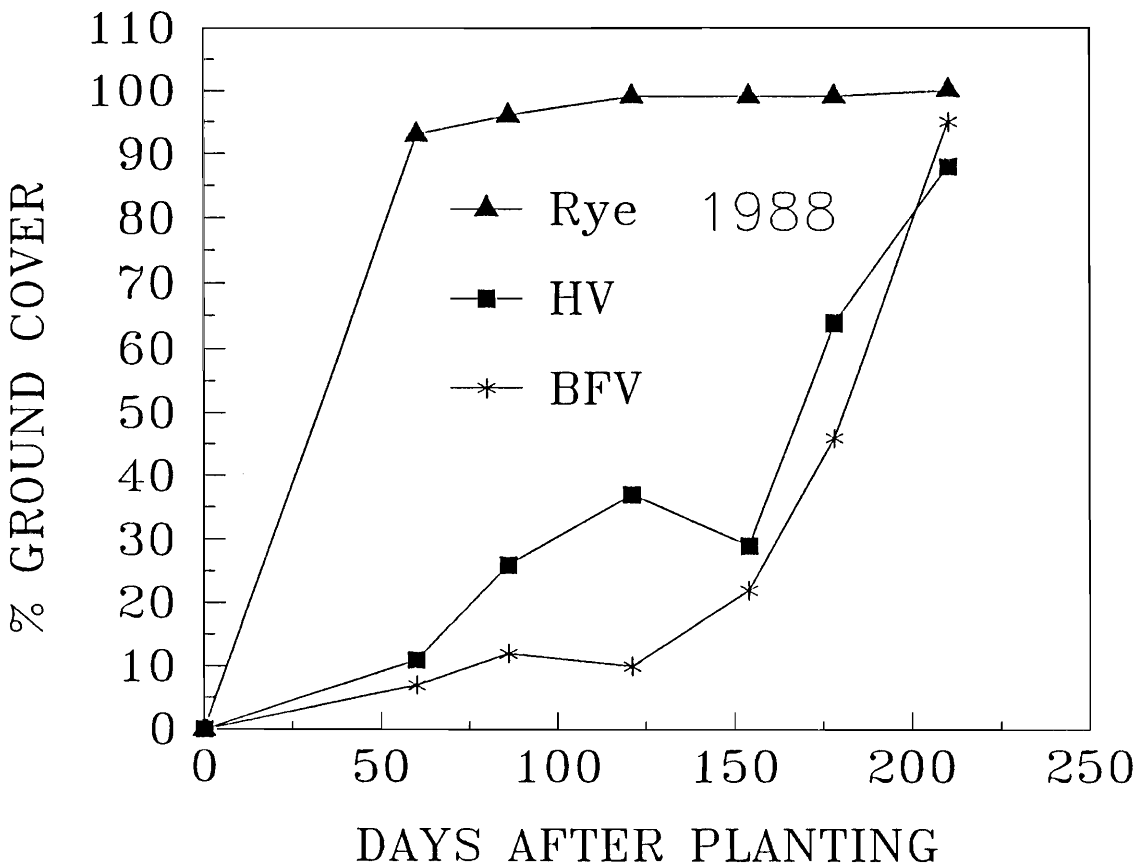

Figure 1.1. Change with time in ground cover provided by pure-stand cover crops, 1988.

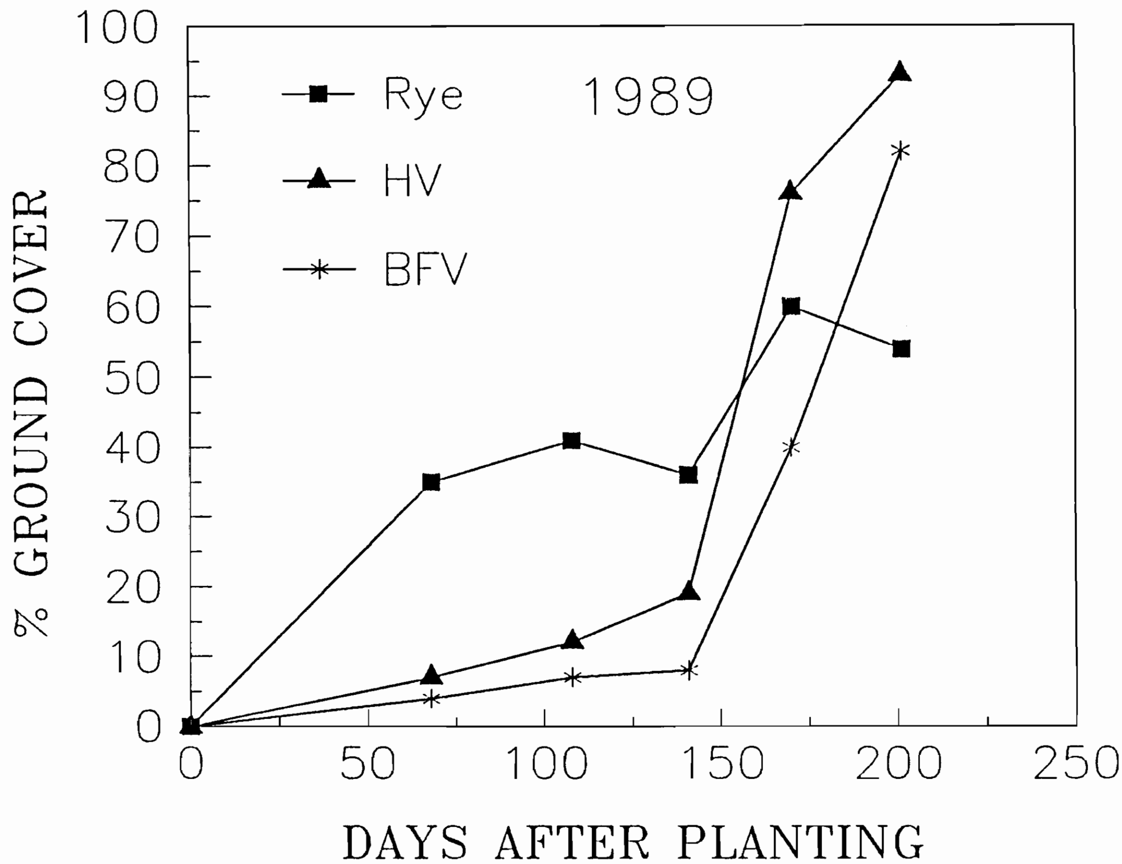

Figure 1.2. Change with time in ground cover provided by pure stand-cover crops, 1989.

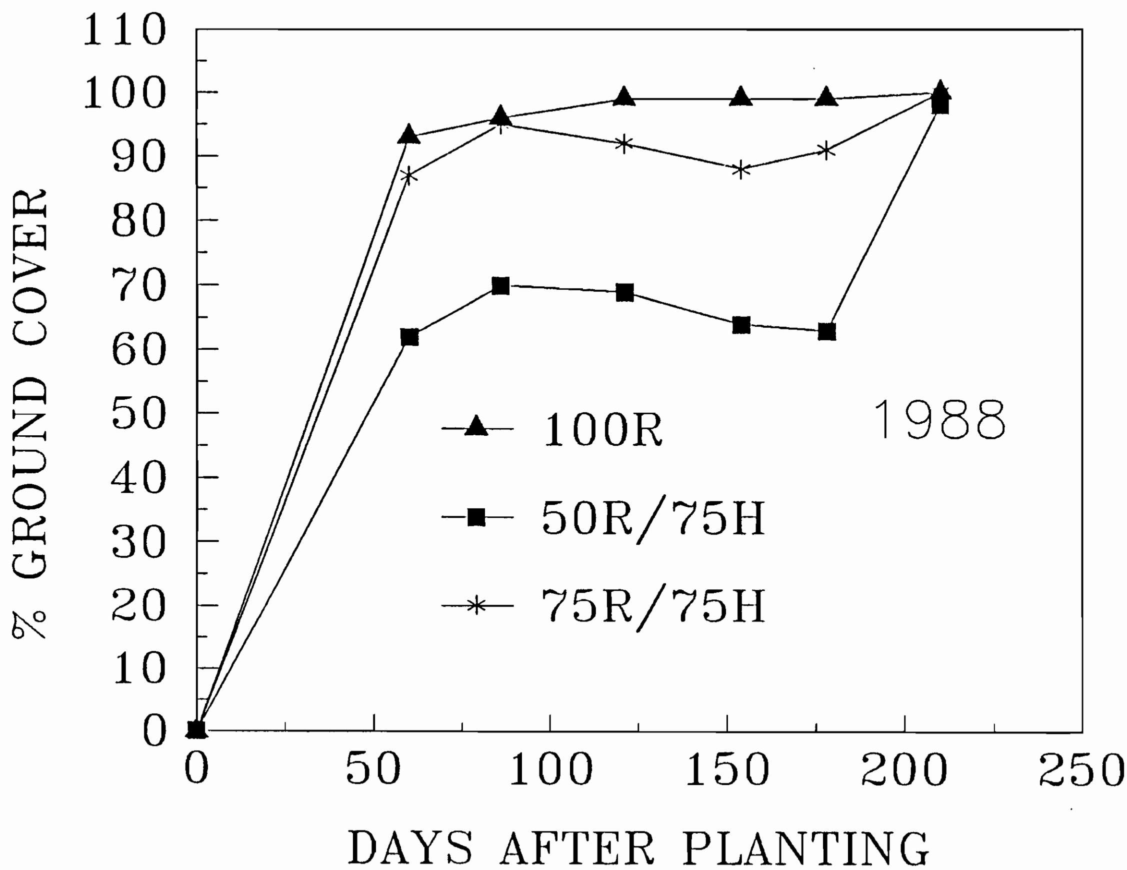

Figure 1.3. Change with time in ground cover provided by rye:vetch mixtures, 1988.

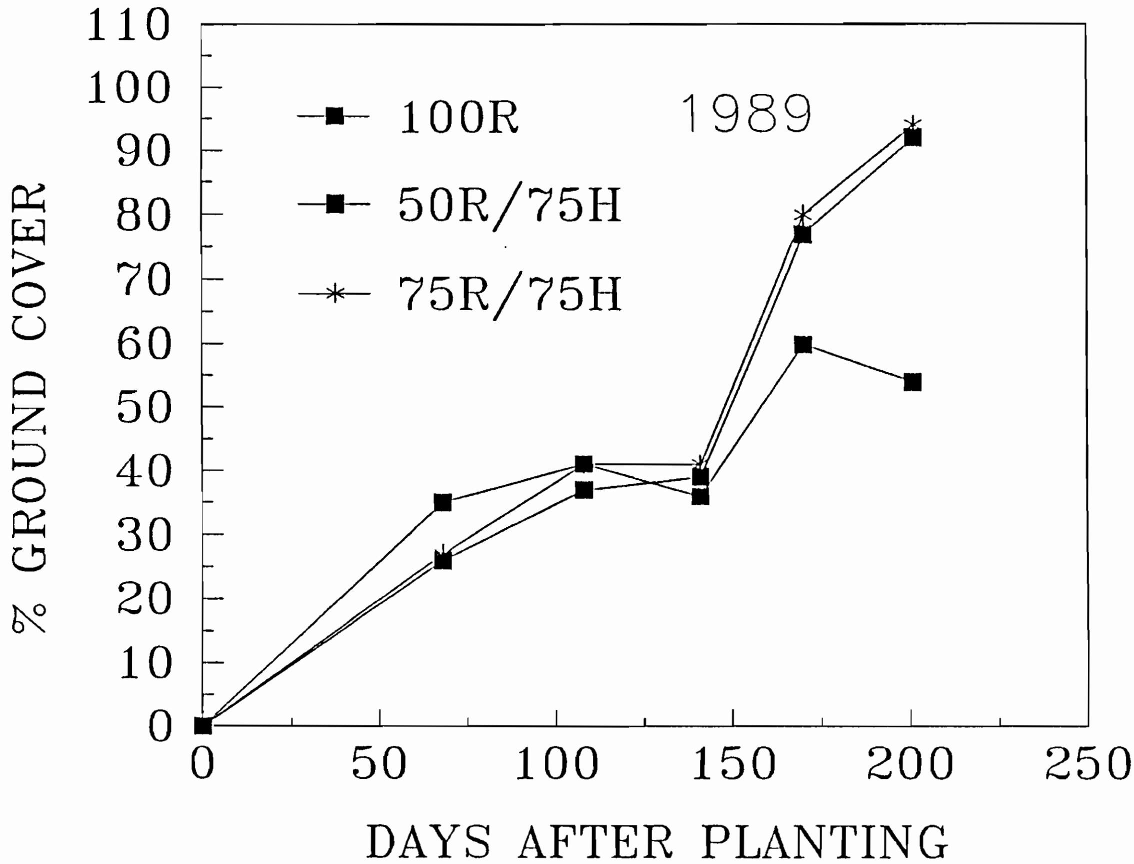

Figure 1.4. Change with time in ground cover provided by rye:vetch mixtures, 1989.

provide adequate fall coverage. All treatments with > 87% coverage should provide adequate protection to reduce erosion to less than 672 kg/ha for any rainfall event on a 5% slope (Mannering and Meyer, 1963). My data suggest, that the vetches will not provide adequate protection from soil erosion (as measured by percent ground cover) until very late in their life cycle.

<u>Corn Yields</u>

An F-test for similar variance structure between years revealed no significant difference. No significant interaction between year and cover crops was seen (P = 0.82). When years were pooled, the highest yielding treatments were the two-vetch mixtures, pure vetches, the 50R/100H, and the standard practice (Rye+140N) (Table 1.10). When separated by year, highest yields for 1988 were seen in the two-vetch mixtures, pure hairy vetch, and the standard practice treatment. Residual soil N contributed some to the 1988 yields, giving a needed boost to rye without N fertilizer and the low N-yielding bigflower vetch.

Highest corn yields in 1989 were again predominantly in vetch-only treatments and the standard practice. Rye-containing cover crops were generally lower producers of corn silage during 1989. Reductions in corn yield following rye-containing cover-crop treatments were likely due to immobilization of N by decomposing rye, which has a higher C:N ratio as compared to the vetch component. The addition of N fertilizer to the rye:vetch mixtures to optimize corn yields would seem to be in order. Mitchell and Teel (1977) reported corn grain yields of 5206, 5394, and 5331 kg/ha for a rye:hairy vetch mixture plus 0, 56, and 112 kg N/ha, respectively, in one year of their study in Delaware. The following

Table 1.10. Above-ground corn biomass (oven dry) yields following cover crops during 1988 and 1989.

Cover Crop treatment	1988	1989	avg.
	------------------------Mg/ha--------------------		
100 Rye (R)	11.6 ef*	8.6 f	10.0 c
100 Hairy vetch (H)	17.5 ab	15.5 abcd	16.5 a
100 Bigflower vetch (B)	13.5 def	13.8 abcde	13.6 abcd
50H/50B	17.1 abc	16.0 abc	16.6 a
67H/33B	18.0 a	16.2 ab	17.1 a
33H/67B	15.7 abcd	15.5 abcd	15.6 ab
50R/50H	12.2 ef	11.5 ef	11.9 c
50R/75H	12.6 def	11.7 ef	12.1 bc
50R/100H	14.6 bcde	12.9 bcde	13.7 abc
75R/75H	13.6 de	12.2 de	12.9 bc
25R/50H/25B	10.5 f	11.8 ef	11.1 c
25R/25H/50B	12.8 def	12.6 cde	12.7 bc
33R/33H/33B	14.0 cde	11.6 ef	12.8 bc
50R/25H/25B	12.1 ef	8.4 f	10.2 c
Rye + 140N	17.2 ab	16.7 a	17.0 a

*Means within a column followed by the same letter do not differ significantly, using F-protected LSD, alpha = 0.05.

year their grain yields were 7840, 8906, and 9157 kg/ha for the same series of N fertilizer rates. In two separate studies, Holderbaum et al. (1990) produced corn grain yields of 4.8 and 5.0 Mg/ha and 7.5 and 9.1 Mg/ha using a wheat hairy vetch mixture plus 0 and 90 kg N/ha. Ott and Hargrove (1989) recommend 56 kg N/ha be added to hairy vetch when N prices are low, to minimize risk and increase yields.

Conclusions

Mixing vetch with rye at various seeding rates generally increased overall cover-crop biomass production. In 1989, no advantage, in terms of their N yields, was seen in mixing two vetches together. Nitrogen yields seemed to indicate great elasticity of seeding rates for rye plus hairy vetch and for two vetches grown together. Seed costs for bigflower vetch during the time of this experiment were prohibitively high (> $6.60/kg) however. In areas where crimson clover is risky to grow due to freeze damage (mid-Atlantic), rye:vetch mixtures offer some alternatives for achieving adequate ground cover. Early ground cover can be achieved with rye plus vetch but will be lower than that of pure rye. Vetches are poor at covering the ground in the fall as compared to rye or mixtures of rye and vetch. Nitrogen scavenging by rye continues at some of its original capacity when growing with vetch, while additional N-scavenging can be provided by vetch growing in association with rye. Corn yields were suppressed by including rye with vetch as opposed to pure vetch. Some amount of N fertilizer would need to be added to make up for depression in corn yield due to N immobilization from the rye component. Corn yields from hairy vetch or hairy:bigflower vetch mixtures were equal to the standard practice for this geographic area, indicating that legumes can effectively supply all the N needs of a following corn crop.

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Cover Crop Contributions to N Supply and Water Conservation in Corn Production

Water and N are the two most frequent limiting factors in corn production. Winter-annual legume cover crops present an opportunity to substantially reduce fertilizer N requirements and to conserve soil moisture for corn production. In many cases, corn grown following legume cover crops produces near maximal yields with minimal additions of N fertilizer (Decker, 1987; Frye et al., 1985; McVay et al., 1989; Mitchell and Teel, 1977). No-till corn growing in killed cover crop mulch is assured higher soil moisture during drought than tilled, unmulched corn (Blevins et al., 1971).

Several methodologies have been employed to estimate corn responses to legume N. These include ^{15}N-labeled legume tissue applied to soil, yield comparisons between legume N and a range of N fertilizer rates, and total N recovered in corn plant tissue. In some cases, a combination of two or all three methods has used.

Using N-uptake methods, Mitchell and Teel (1977) estimated corn recovered 38% of the N contained in a cover-crop residue. Huntington et al. (1985) reported 29% cover-crop-N recovery by corn under no-till conditions. Herbek et al. (1987) found fertilizer-N replacement values of 50 and 73 kg N/ha for hairy vetch and bigflower vetch respectively. Tyler et al. (1987) and Neely et al. (1987) reported N equivalents for corn of 84 to 112 kg/ha from killed vetch. A New Jersey study compared corn yields following rye plus 200 kg N/ha with unfertilized hairy vetch (Tisdale et al., 1985). Corn silage yields of 54.4 Mg/ha following vetch and 57.1 Mg/ha following rye plus N were reported. The vetch system gave the highest net return per ha and the lowest production cost.

Tillage can affect the rate at which cover-crop N mineralizes. Varco et al. (1989), using ^{15}N procedures, reported 57% recovery of hairy vetch N by corn under conventional tillage and 51% with no-till. Wilson and Hargrove (1986) found the N release from crimson clover residue 4 weeks after desiccation to be 40% under no-till and 63% under conventional tillage. Huntington et al. (1985) reported a large release of legume N at corn silking using a no-till hairy vetch mulch. This timing of N release does not correspond well to typical corn uptake patterns. To compensate for this problem, they suggested offsetting the timing of cover crop kill and corn planting, or shallowly incorporating the killed cover crop to increase the amount of legume N mineralized early in the corn growing season. Huntington et al. (1985) also mentioned the possible value of supplemental N at corn planting time. One month after hairy vetch incorporation and corn planting, Utomo et al. (1985) found available soil N in conventionally tilled plots increased 99% over the quantity originally present, while the increase was only 13% in no-till plots. Corn yields were greater with conventional tillage than with no-till, presumably due to greater N mineralization. Using hairy vetch, Varco et al. (1989) noted that plowing plus disking a hairy vetch residue resulted in greater N recovery by corn than when killed and left on the surface.

Proper timing of cover crop kill offers potential opportunity to gain additional N release from herbicide-killed cover-crop residues. Wagger (1989) reported a faster N-release rate from hairy vetch and crimson clover when killed at an early corn planting time compared to being killed 2 weeks later. Additional N did accrue by delaying cover-crop kill and corn planting. The slower N release following the later kill offset the additional N content however.

In addition to N, killed cover crops can provide a water-conserving mulch. When comparing incorporation of green manure with planting into a no-till mulch, the differences seem to be primarily related to increased water-use efficiency with no-till. By having a mulch in place, water infiltration is increased and water evaporation from the soil surface is reduced. Comparing corn plots mulched with 0 or 6.7 Mg wheat straw/ha, Moody et al. (1963) noted available soil moisture to be 28% higher in July and 17% higher in August in the mulched plots as compared to unmulched ones. Mulched plots yielded 2.6 Mg/ha more corn grain than did unmulched ones. Higher soil-moisture contents were attributed to increased water infiltration and reduced runoff and evaporation. Blevins et al. (1971) showed consistently higher soil-moisture levels for corn grown in a herbicide-killed, no-till, bluegrass (*Poa pratensis*) sod than corn grown in conventionally plowed and disked plots. They concluded that the decreased evaporation and increased moisture storage seen with the no-till mulch allowed corn plots to survive a short-term drought without severe moisture stress.

In this study, I investigated the N-yielding ability of two vetches grown alone, together, or in mixtures with rye and the N recovery by a corn crop of the released N under two tillage regimes. The soil-water content under these various cover crop and tillage systems was also assessed.

Materials and Methods

Site Preparation

A replicated small-plot experiment was established in Montgomery County, VA at the Whitethorne Experiment Station on a Hayter cobbly loam (fine loamy, mixed mesic, Ultic, Hapludalf) in the summer of 1987. Physical characteristics of this soil include loamy surface texture, 2 to 7 % slope, and well drained. The site was located on a terrace of the New River. As of March 1987, the site was supporting a tall fescue plus white clover pasture sod and was being grazed by cattle. The land was in pasture for the previous 3 years and then corn for at least the next previous 3 years. Preliminary soil samples were taken in March 1987 to determine fertility levels and gradients to be considered when blocking. Soil pH ranged from 4.9 to 5.5, and some residual N (15 to 34 kg NO_3/ha), P (33 to 134 kg /ha), and K (123 to 352 kg/ha) were present in the top 15 cm of the soil profile. Soil test recommendations for the cover crops were N (17 to 22 kg/ha), P (0 to 67 kg/ha), and K (0 to 67 kg/ha). No fertilizer was applied to cover crops. It was deemed uneconomical for growers to apply fertilizer to cover crops.

On 10 July 1987, the plots were disked repeatedly with an offset disk to incorporate and kill the pasture plants. Foxtail millet was planted at a 28 kg/ha seeding rate on 16 July using a grain drill. The millet crop was intended to extract and immobilize in plant tissue, residual N, which was to be removed from the site by harvesting. Due to extreme drought conditions (no rain from 7 July to 6 September), the millet crop failed. The plots were limed with 4500 kg/ha dolomitic limestone on 8 September. They were chisel plowed and disked, and a seedbed was produced by field harrowing on 10 September.

Experimental Design

The the overall design is an unbalanced factorial with four randomized complete block replications (Table 2.1). Two tillage treatments (disk and no-till) and five cover crop treatments made up a 2 x 5 factorial arrangement for the purpose of studying cover-crop N yields. To study the effect of cover crops on a subsequent corn crop, several additional treatments were included for comparison. Four N rates (0, 70, 140, and 210 kg N/ha) for corn following fallow (no cover crop) were included under disk tillage. The 140 kg N/ha served as a "standard conventional practice" control under disk tillage for comparison with a "standard no-till practice" of a rye cover crop to which 140 kg N/ha was added to a no-till corn crop. For the purpose of studying corn yields, the rye plus 140 kg N/ha and the fallow plus 140 kg N/ha were added to the 2 x 5 factorial set of treatments, resulting in a 2 x 6 factorial set. The four N rates were analyzed separately to compare several N-fertilizer rates to cover crops. Statistical analyses consisted first of ANOVA (SAS, 1982) followed by mean separation using F-protected LSD (Steel and Torrie, 1980). Comparisons for year differences were made by calculating an F-statistic from the two error mean squares for the two separate years and comparing the calculated F with an F-distribution at the 95% probability level. Year data were averaged only when the variance structure between the two consecutive years was not different as indicated by the F-test. Plot size was 3.66 m wide (four corn rows, 0.91 m apart) and 15.24 m long. The experiment was run for two complete cropping sequences (cover crop followed by corn).

Table 2.1. Treatments used in the 2 x 5 and 2 x 6 factorial arrangements plus additional treatments.

Cover crop treatment	Seeding rate	Fertilizer N+	Tillage Method (Disked or No-till)
	------------kg/ha------------		
2 x 5 Factorial study			
Rye (R)	100	0	both
Hairy vetch (H)	28	0	both
Bigflower vetch (B)	28	0	both
Two-vetch	19H + 9B	0	both
Rye:vetch	50R + 19H	0	both
Additional Treatments			
Fallow	-	0	disked
Fallow	-	70	disked
Fallow*	-	140	disked
Fallow	-	210	disked
Rye*	100	140	no-till

*These two treatments were added to the 2 x 5 factorial as standard practice controls, for corn yield and soil moisture comparisons in a 2 x 6 factorial.

+N added to the corn crop as NH_4NO_3 following cover-crop desiccation.

Crop Management

The experiment involved planting corn into cover crops or winter-fallow plots with varying N rates. The cover crop species chosen, were selected for their known overwintering ability in the ridge and valley region of Virginia as compared to crimson clover and austrian winter pea. Rye was included in this experiment for three reasons: (1) rye is a commonly grown, cold tolerant, winter-annual cover crop in many parts of the US, (2) any small grain may serve as a trellis for a weak-stemmed, climbing legume such as hairy vetch (Henson and Schotch, 1968) and possibly increase legume yield due to more sunlight exposure, and (3) biomass yield from the small grain can be used to estimate the residual soil N. Cover crop treatments were pure stands of rye, hairy vetch, and bigflower vetch planted at recommended seeding rates and two mixtures of these species. Seeding rates for pure stands were 100 kg/ha for rye and 28 for hairy and bigflower vetches (Donohue et al., 1984). The mixture of rye plus hairy vetch was made by seeding together 50 kg/ha of rye with 18.75 kg/ha of hairy vetch. The mixture of two vetches was made by combining 18.75 kg/ha of hairy vetch with 9.25 kg/ha of bigflower vetch. Hereafter the mixtures will be referred to as the rye:vetch mixture and the two-vetch mixture.

A Northrup King short-growing rye variety 'SS2', 'common' hairy vetch, and 'Woodford' bigflower vetch were used in 1988. The rationale for the short-statured rye variety was to reduce the amount of high-C:N-ratio stem contained in the rye crop. One of rye's drawbacks as a cover crop is immobilization of soil N when used as a green manure or no-till mulch. The stem contains more carbon proportionally, than other plant parts, so reducing stem length (height) should reduce carbon loading to the soil. Additionally a 1-m high cover crop is less manageable in terms of soil preparation and corn planting than is a 0.5 high one. Unfortunately (and to my surprise), the SS2 rye was less cold tolerant than necessary. In 1989, 'Abruzzi' rye was substituted, because winter freeze damage to SS2 occurred in the previous season. Cover crops were planted as pure stands or mixtures using a grain drill on 10-cm centers on 25 September 1987. The second year planting row width was changed to 20 cm centers to prevent drill clogging on corn stump/root masses when set for the narrower row width. Planting was done on 8 and 9 October in 1988. Seeds of the various mixtures were mixed and inoculated with effective *Rhizobium* strains. No N was applied to the rye crops.

On 30 March 1988, a root inspection of the vetches revealed many plants, particularly in the pure stands, were not nodulated. Inoculum was applied to the plots immediately by suspending inoculum in water and spraying the mixture over the crop. Rainfall (>5 cm) occurred with in 24 h and presumably washed the inoculum into the soil. Vetch plants appeared to "green up" within 10 days and produced adequate biomass in most plots. A spot inspection of vetch plants revealed nodules where there were none before. Some plots apparently received spotty application of inoculation, however; uneven growth occurred in those plots. Some treatments, particularly rye:vetch mixtures had adequately nodulated vetch plants at the time of the second inoculation. It was assumed that since the rye seed in the mixtures were also inoculated, the total amount of seed-provided inoculum was greater in those treatments. It was also presumed that the inoculum used was of poor quality and caused the poor nodulation. A different source of inoculum was used for all remaining inoculations. In the second year of the study, no nodulation problems were apparent.

Fall-planted cover crops were killed in the spring either by disk incorporation or by desiccation with paraquat. Disking was done earlier (2 to 3 weeks prior to corn planting) than was herbicide killing (at corn planting). The earlier disking allowed initial decomposition of cover crops to compensate for the poor synchronization between legume N release and corn N-uptake patterns mentioned by Huntington et al. (1985). The later cover-crop kill by paraquat was to allow maximum accrual of N in the cover crops. Cover crops to be incorporated, as well as plots receiving N fertilizer only, were disked on 27 April 1988 and 8 May 1989.

Soil test recommendations for corn were N (140 to 168), P (0 to 56), and K (0 to 56). These recommendations assumed the P and K had been added to the cover crops, which they had not been. Phosphorus and K fertilizers were applied for the corn crop at 56 kg P_2O_5/ha and 56 kg K_2O_2/ha over the top of cover crops or fallow plots prior to disking or herbicide killing in both years. Herbicides paraquat at 2.34 L/ha, metolachlor at 1.75 L/ha, and cyanazine at 3.5 L/ha were tank mixed and applied to all plots 17 May 1988 and 22 May 1989 by tractor-mounted sprayer. An intense rain shower followed the 1988 herbicide application, resulting in minimal desiccation of the cover crop. A second application of paraquat at 1.17 L/ha was applied 22 May 1988 and did desiccate the cover crop completely.

Pioneer 3233 corn was planted on 19 May 1988 and 22 May 1989 at a target population of 50,000 plants/ha. Non-uniform corn stands emerged in both years. Stand counts were made on 5 June each year by counting plants occurring on 6 m of row. Skips were replanted immediately by hand in order to achieve the target population, so that treatment effects could be observed within a uniform stand.

Fertilizer N was applied as NH_4NO_3 to the N-fallow plots at half the total amount on May 28 1988 and 24 May 1989. The second N half was applied when corn plants were 50 cm tall.

Plant and Soil Analyses

Biomass produced by the cover crops was sampled from four, 0.25 m^2 quadrats per plot by removing top growth to the soil surface. Disk-incorporated cover-crop treatments were sampled 27 April 1988 and 8 May 1989. They and the N plots were disked immediately after sampling. The herbicide-killed plots were sampled for cover-crop biomass just prior to desiccation and corn planting (13 to 17 May 1988 and 21 to 22 May 1989). The rye:vetch mixture was hand-separated into the respective species components, weighed, dried, and reweighed to determine yield. No species separation of the two-vetch mixture was attempted. The two-vetch mixture and pure stands were weighed, dried at 55 to 60 C for 60 h in forced air, and reweighed. Cover-crop biomass samples were ground to pass a 1-mm mesh screen and analyzed for both total N (Kjeldahl method: Bremner, 1965) and total C (Pragel method: Ma, 1979).

Nitrogen uptake by the corn crop was assessed from four corn plants randomly selected from each plot at approximately 3-week intervals. Nitrogen-uptake sampling in 1988 occurred 23 June (35 days after corn planting), 18 July (60 days), 6 August (78 days), and 1 September (102 days). Samples for the 1989 corn season were taken 19 June (28 days following corn planting), 10 July

(49 days), 1 August (70 days), 21 August (90 days), and 15 September (115 days). Plant samples were dried, ground, and analyzed for total nitrogen (TN) using the Kjeldahl digestion procedure (Bremner, 1965). Corn was harvested as for silage (35 to 42% dry matter) on 14 to 16 September 1988 and 13 to 15 September 1989 by cutting at ground level the central 12.2 m of the middle two rows of each plot. Subsamples were dried at 55 to 60 C for 60 h with forced air, and yield data are reported as oven-dry matter per ha.

Soil samples were taken to a depth of 30 cm, divided into two 15-cm sections and analyzed for moisture percentage. To assess differences in soil water content, soil was sampled for soil moisture content at times when corn water demand was high on 6 August 1988, and 4 August and 10 August in 1989.

Soil samples were chilled in the field, analyzed within an 8-h period, or frozen until analyzed. Soil moisture content was determined gravimetrically. Samples were weighed as sampled, dried in a convection oven at 105 C for 24 h, and reweighed. Soil moisture was calculated on a dry weight basis as given by: {(wet weight - dry weight)/dry weight} x 100%.

Results and Discussion

Cover Crop Combined Results

F-tests showed yearly variances for cover crop yields (biomass and N) to be similar ($P<0.05$). A year-by-cover-crop interaction for biomass and N yield was apparent however. Therefore cover-crop production is discussed by separate years. Cover-crop differences between years were apparently due to the change in rye varieties and its row spacing, as the legume treatments were similar from one year to the next for biomass (Table 2.2). Pure-stand vetch N yields increased from 1988 to 1989. The difference was likely due to poor nodulation in 1988. For the two rye-containing treatments, the decrease in TN from 1988 to 1989 is of identical magnitude (27 kg/ha); therefore I conclude the decrease was due to the change of rye variety and its wider row spacing. The two-vetch mixture did not change in N yield from one year to the next. The two rye plantings grown in the two different years appeared to have different yield potential; though, whether this was due to row spacing or rye variety is unknown.

1988 Results

Analysis of variance showed significant ($P<0.05$) cover-crop-by-tillage interactions for both biomass and N yields in 1988. The differences between tillage treatments were a result of when cover crops were sampled and subsequently killed for their N; disk treatments were sampled 20 (1988) and 14 days (1989) earlier than no-till treatments. Under both tillage systems, the rye:vetch mixture yielded the most biomass in 1988, with rye being second (Table 2.3). When killed early (disked), biomass yields of both vetch pure stands and the two-vetch mixture were similar and inferior to rye alone or mixed with vetch. When herbicide-killed later (no-till), rye:vetch and rye were again first and second in biomass production, and the two-vetch mix was the third highest biomass producer. The vetch pure stands were similar and yielded less biomass than the rest. The source of interaction is the unequal increase in cover crop biomass across different cover crop treatments when additional growth time was allowed. All cover crops, except the hairy vetch pure stand, had significantly more biomass

Table 2.2 Cover-crop biomass and total N averaged across two tillage methods.

Parameter Year	Rye	Hairy vetch	Bigflower vetch	Two-vetch	Rye: vetch
Biomass	----------Mg/ha----------				
1988	7.0 *	3.6	3.0	4.5	9.6 *
1989	4.7	4.3	3.6	4.0	5.8
Total N	----------kg/ha----------				
1988	67 *	95	50	139	149 *
1989	40	165 *	126 *	149	122

*Means within a half column, followed by the same letter are not significantly different, by t-test using ANOVA root mean square error, alpha = 0.05.

Table 2.3. Effect of tillage (kill date) on cover-crop biomass production, 1988.

Cover crop treatment	Disked (27 April)	No-till (17 May)	Till/Date effect+
	--------------Mg/ha--------------		
Rye	6.2 b*	7.8 b	yes
Hairy vetch	3.4 c	3.8 d	no
Bigflower vetch	2.4 c	3.5 d	yes
Two-vetch	3.4 c	5.7 c	yes
Rye:vetch	8.3 a	10.9 a	yes

*Means within a column (disked or no-till) followed by the same letter are not significantly different by F-protected LSD, alpha = 0.05.

+Signifies whether the means for that row are significantly different.

at the later kill date. Hence biomass production proceeded in a parallel fashion in the 3-week interval between cover-crop kill in the two management regimes (disk vs no-till) except for hairy vetch. This response was atypical and likely due to poor nodulation of hairy vetch in several plots in 1988.

As with biomass, killing date (tillage) and cover crop interacted significantly with N yield in 1988. The two-vetch and the rye:vetch mixtures' superior N yield, when killed later, contributed to the interaction, since all other comparisons were statistically similar at both kill dates (Table 2.4). When utilized early (disk incorporated), N yields among the two mixtures and the pure stands of hairy vetch and rye were statistically similar (Table 2.4). Hairy vetch and rye pure stands were similar to the two-vetch mix, with rye being similar to bigflower vetch.

1989 Results

Significant tillage and cover crop main effects for both biomass and N yields were seen in 1989, but no interactions were detected. As in 1988, the rye:vetch mixture was clearly the greatest biomass producer (Table 2.5). Hairy vetch and the two-vetch mixture were similar and superior N yielders, with the two-vetch mixture also being similar to bigflower vetch. Bigflower vetch and the rye:vetch mixture were alike, while rye had the least amount of N in above-ground biomass.

Among the two tillage/kill systems, significantly greater biomass and N content had accrued by the later kill date. Biomass production went from 4.0 Mg/ha for earlier kill to 5.0 Mg/ha for later. Nitrogen content increased from 103 kg/ha to 138 kg/ha over the same period. Similar results were recently reported by Wagger (1989).

Table 2.4. Effect of tillage (kill date) on cover-crop total N production, 1988.

Cover crop treatment	Disked (27 April)	No-till (17 May)	Till/Date effect+
	------------kg/ha------------		
Rye	77 bc*	57 c	no
Hairy vetch	101 ab	89 b	no
Bigflower vetch	47 c	53 c	no
Two-vetch	113 ab	164 a	yes
Rye:vetch	121 a	176 a	yes

*Means within a column (disked or no-till) followed by the same letter are not significantly different by F-protected LSD, alpha = 0.05.

+Signifies whether the means for that row are significantly different.

Table 2.5. Cover crop biomass and total N averaged across two cover-crop kill dates, 1989.

Cover crop treatment	Biomass	Total N
	Mg/ha	kg/ha
Rye	4.7 b*	40 d
Hairy vetch	4.3 bc	165 a
Bigflower vetch	3.6 c	126 bc
Two-vetch	4.0 bc	149 ab
Rye:vetch	5.8 a	122 c

*Means within a column followed by the same letter are not significantly different using F-protected LSD, alpha = 0.05.

Carbon to Nitrogen Ratios

Analysis of cover crop C:N ratios showed a significant interaction between kill date and cover crop for both years. A test for year differences revealed no significant ($P > 0.05$) differences. One of the more interesting observations was the shift of C:N ratios, from earlier to later kill date, for rye growing in a pure stand compared to growing in association with vetch (Table 2.6). In both years, the rye pure stand and the rye portion of the rye:vetch mixture had similar C:N ratios at early kill. Both increased in C:N ratios by the later kill date, but the rye pure-stand increased more than the rye component growing in a mixture with hairy vetch. Looking at the C contents (Table 2.7) for rye and vetch, we see that N, not C, influenced the C:N ratios seen in Table 2.6. The reduced C:N ratio for the mixture rye component was a result of its higher TN percentage (Table 2.7); comparing the N percentages of the rye pure stand with the rye component of the rye:vetch mixture, one can see a higher N percentage in the rye grown with vetch. Carbon percentages are similar in both pure rye and rye growing with vetch. The reduced C:N ratios for the rye growing in association with hairy vetch are due to the rye in mixture taking up more N, apparently released by vetch, than did the rye in pure stand, which has no additional N source. But apparently the N was not available to the rye until after the earlier kill date. Nitrogenous compounds released from living legume roots and shoots are commonly recovered by non-legumes growing in association with them (Heichel, 1987). An increased N concentration of grasses grown in association with legumes has been shown with bluegrass and perennial pasture legumes (Craig et al., 1981; Lipman, 1912; Roberts and Olsen, 1942), wheat and hairy vetch (Roberts et al., 1989), and oats

Table 2.6. Effect of cover crop kill date on cover-crop C:N ratios+ by year.

Cover crop/ component	1988 27 April	1988 17 May	1989 8 May	1989 22 May
Rye in pure stand	34.1 a*	58.0 a	43.9 a	60.5 a
Rye from mixture	34.4 a	46.6 b	44.3 a	46.7 b
Hairy vetch in pure stand	13.7 c	17.4 d	10.9 b	10.8 c
Hairy vetch from mixture	15.6 c	15.9 d	11.3 b	10.9 c
Bigflower vetch	19.3 b	26.5 c	12.0 b	11.8 c
Two-vetch mixture	12.7 c	14.2 d	11.6 b	10.7 c

+All ratios are the number shown, to 1, e.g. 34.1:1.

*Means within a column followed by the same letter are not significantly different using F-protected LSD, alpha = 0.05

Table 2.7. Individual nitrogen (N) and carbon (C) components of pure stands and the rye:vetch mixture.

Year/ kill date	Rye N		Rye C		Vetch N		Vetch C	
	mix	pure	mix	pure	mix	pure	mix	pure
	---Percent---							
1988								
Earlier	1.22	1.23	42	42	2.67	2.98	42	41
Later	0.90	0.72	42	42	2.65	2.36	42	40
1989								
Earlier	0.97	0.98	43	43	3.72	3.70	41	40
Later	0.92	0.71	43	43	3.86	3.86	42	41

and field peas (Lyon and Bizzel, 1911). Increased N fixation by legumes growing with grasses compared to legumes grown in pure stands has also been documented (Brophy et al., 1987; Craig et al., 1981). The actual N transfer mechanism from legume to grass is unclear however. Excretion or degradation of root and nodule tissue is the usual explanation (Heichel, 1987).

Legume C:N ratios in 1988 showed bigflower vetch to have a higher C:N ratio than all other treatments at both kill dates (Table 2.6), probably due to poor nodulation. In 1989, all legumes had similar C:N ratios under both kill dates, and they were considerably lower than any rye stand. When years were pooled, similar trends were seen as in the separate years (Table 2.8).

Performance of the Rye:Vetch Mixture

The increase in biomass and N for the rye:vetch mixture from earlier to later is due more to the vetch component than to rye (Table 2.9). In both years, vetch significantly increased in biomass and N during the extended growth period, while rye did not. While providing support for the climbing vetch vines, the rye itself was not increasing in biomass. Progression in biomass production for pure rye during the same period in 1988 was significantly greater at the later kill date (Table 2.3). In 1989, the biomass increase in pure-stand rye was also significantly greater (4.3 Mg/ha at earlier date to 5.2 Mg/ha at the later date).

The land equivalency ratio (LER) defined by Willey and Osiru (1972) and expanded by Riley (1985) and by Hiebsch and McCollum (1987) is a convenient method of assessing the efficiency of crop mixtures compared to pure stands. Mixtures with land equivalency ratios larger than 1.0 are said to be more efficient than growing the components in pure stands, while values less than 1.0 show an

Table 2.8. Effect of cover crop kill date on cover-crop C:N ratios+ pooled across 2 years.

	Kill date	
Cover Crop	Earlier	Later
Rye in pure stand	39.3 a*	59.7 a
Rye in mixture	39.4 a	47.4 b
Hairy vetch in pure stand	12.3 b	14.1 d
Hairy vetch in mixture	13.4 b	13.4 d
Bigflower vetch	15.6 b	19.1 c
Two-vetch mixture	12.1 b	12.4 d

+All ratios are the number shown, to 1, e.g. 39.3:1.

*Means within a column followed by the same letter are not significantly different using F-protected LSD, alpha = 0.05

Table 2.9. Individual crop contributions of biomass and N and land equivalency ratio (LER) for the rye:vetch mixture.

Year/ Kill date	Biomass			Total N			LER	
	Total	Rye	Vetch	Total	Rye	Vetch	Biomass	TN
	-----------Mg/ha-----------			----------kg/ha----------				
1988								
Earlier	8.3	7.0	1.3	120	86	34	1.52	1.45
Later	10.9**	6.5	4.4**	176**	58	118**	1.98	2.34
1989								
Earlier	4.9	3.2	1.7	95	31	64	1.17	1.19
Later	6.7**	3.8	3.0*	148*	34	114*	1.35	1.53

* , ** significantly different at the .05 and .01 levels, respectively, by t-test using ANOVA root mean square error.

inefficiency in growing the two crops in a mixture. For the rye:vetch mixture, LERs for biomass and TN show definite advantage for growing the two crops together as opposed to pure stands, with the advantage being more pronounced at the later killing dates (Table 2.9).

Soil Moisture

Abundant rainfall occurred in Montgomery County, Virginia, throughout the 1988 and 1989 corn-growing seasons (Figs. 2.1 and 2.2), making it difficult to find a time when a moisture deficit might exist. One moderately-dry sample date was found in 1988, and two in 1989. Soil depth was included in the analyses as whole plots, with the cover crop and tillage treatments being included as split plots within each depth whole plot. All three sample dates were tested for significance, and their p-values are shown in Table 2.10. No significant differences in soil moisture occurred with depth across all sample dates; therefore means were averaged across both the 0 to 15 and the 15 to 30 cm sampling depths. Since the application of N fertilizer could affect the growth of corn and subsequently the soil moisture conditions, the rye plus 140N and the fallow plus 140N standard practice treatments were included in the soil moisture analyses and consideration.

There was a significant interaction between cover crop and tillage at the 6 August 1988 sample date. Under disk incorporation, the higher biomass-producing cover crops (rye and rye:vetch) had higher soil moisture (Table 2.11). Under no-till, the three treatments containing rye mulch were similar and among the highest retainers of soil moisture. As indicated in Table 2.11, all cover-crop treatments, except rye without N fertilizer, had higher soil moisture where a no-till

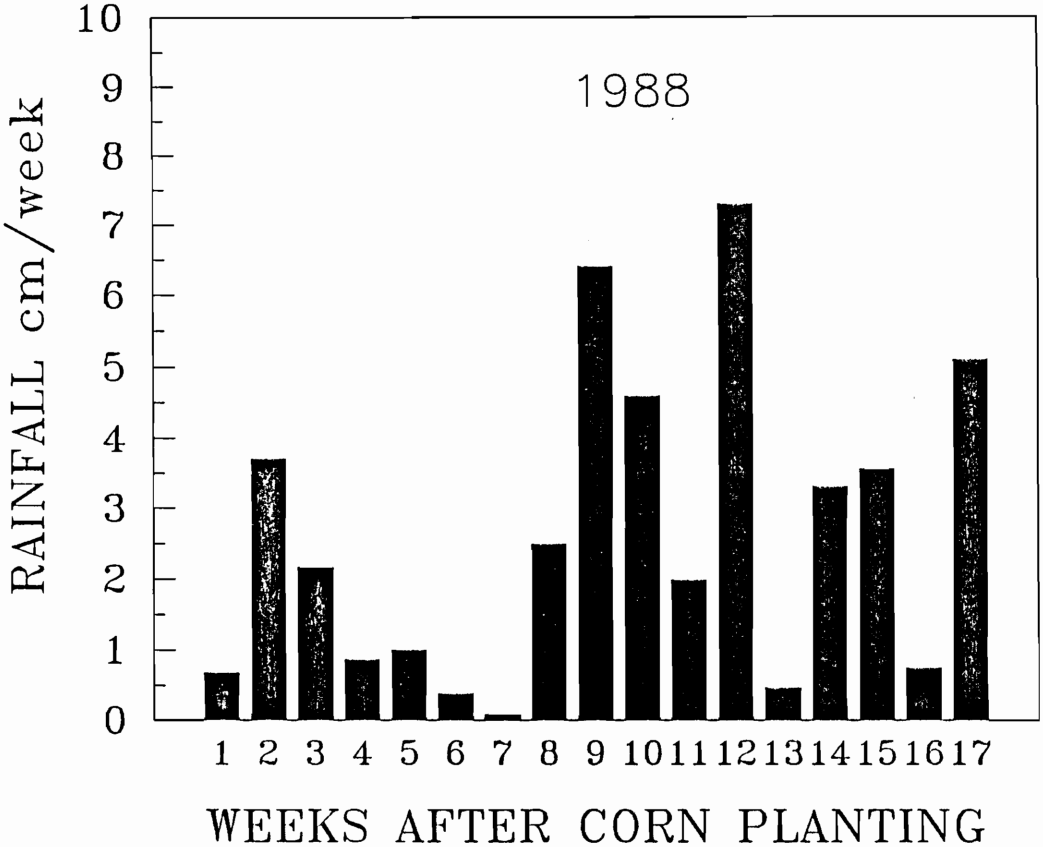

Figure 2.1 Rainfall in Montgomery County, Virginia, during the 1988 corn-growing season.

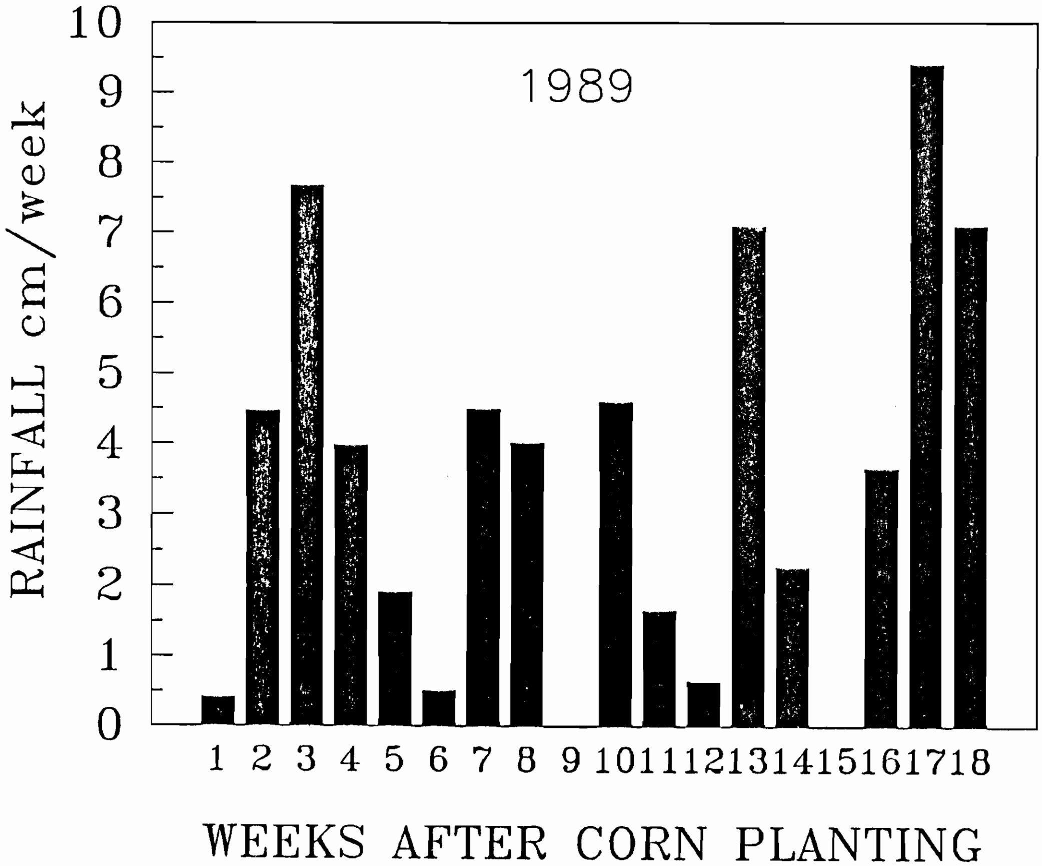

Figure 2.2. Rainfall in Montgomery County, Virginia, during the 1989 corn-growing season.

Table 2.10. Significance tests for soil moisture levels at various dates.

Source	6 Aug. 88	4 Aug. 89	10 Aug. 89
	--------------------------p-value--------------------------		
Rep	0.0009	0.0008	0.0005
Depth	0.4884	0.1325	0.0966
Cover crop	0.0001	0.0018	0.0001
Tillage	0.0001	0.0085	0.0773
Depth x cover	0.8464	0.4438	0.9717
Depth x tillage	0.7271	0.9538	0.8326
Cover x tillage	0.0002	0.2790	0.1506
Depth x cover x tillage	0.8994	0.4055	0.9440

Table 2.11. Effect of cover crop and tillage on soil moisture averaged across soil depths, 6 August 1988.

Cover crop	Disked	No-till	Tillage effect+
	---------% soil moisture---------		
Rye	16.2 a*	16.0 ab	no
Hairy vetch	12.7 b	14.6 c	yes
Bigflower vetch	11.4 bc	14.4 c	yes
Two-vetch	11.3 bc	14.8 c	yes
Rye:vetch	15.0 a	16.5 a	yes
Standard practice	11.0 c (Fallow + 140N)	15.3 bc (Rye + 140 N)	yes

+Signifies whether the soil moisture content was significantly different for disk versus no-till for each row of data.

*Means within a column followed by same letter are not significantly different using F-protected LSD, alpha = 0.05.

mulch was in place. The high soil water contents under the rye treatments may be misleading; the low water uptake potential of the smaller corn plants growing with only residual soil N did not deplete soil moisture to as great an extent as other treatments. Plants in this treatment were short and could not have extracted as much water as those receiving adequate N. The comparison between the tillage treatments for the rye plus 140N and the same fertilizer N in the absence of a surface mulch are much more revealing of the soil-conserving "mulch effect".

Moisture sampling dates in 1989 showed significant cover-crop effects on soil moisture content (Table 2.12). Higher soil moisture content generally was associated with higher cover crop biomass production for the 4 August sample date. At the dryer 10 August sample date, corn that followed rye without N fertilizer had highest soil moisture due to combined effects of mulch and reduced water uptake from the smaller unfertilized corn plants. On the 4 August date, the no-till plots had significantly greater mean soil moisture (17.6%) as compared to the disked plots (16.4%). The higher soil moisture seemed to be related to two separate factors: amount of mulch, and water uptake by the corn plants.

To test the hypothesis that soil moisture was related to cover crop biomass, spring cover-crop biomass yields and soil moisture were regressed. There was a significant ($P < 0.05$) effect of cover-crop biomass on soil moisture in 25 out of 27 linear regressions run on various depths, tillage, and sample-date combinations (Tables 2.13 to 2.15). All regressions indicated a positive response of soil moisture to increasing levels of cover-crop biomass. Poor fit (low r^2) was seen for data fitted either to linear or quadratic functions. Predictive value therefore was low.

Table 2.12. Effect of cover crop averaged across tillage and sample depth on soil moisture percentage, 1989.

Cover crop	4 August	10 August
	----------------percent----------------	
Rye	18.2 a*	15.3 a
Hairy vetch	17.0 ab	12.7 bc
Bigflower vetch	15.8 b	13.1 bc
Two-vetch	17.3 ab	12.7 bc
Rye:vetch	18.3 a	13.7 b
Standard practice	15.3 b (Fallow + 140N)	12.1 bc (Rye + 140 N)

*Means within a column followed by same letter not significantly different using F-protected LSD, alpha = 0.05.

Table 2.13. Probability estimates and correlation coefficients for soil moisture as influenced by cover-crop biomass, 6 Aug. 1988.

Tillage	Depth	P > F	r^2
	--cm--		
Disk	0-15	0.002	0.35
Disk	16-30	0.010	0.26
No-till	0-15	0.002	0.36
No-till	16-30	0.002	0.37
Disk	0-30	0.010	0.33
No-till	0-30	0.001	0.45
Disk & No-till	0-15	0.001	0.40
Disk & No-till	16-30	0.001	0.32
Disk & No-till	0-30	0.001	0.35

Table 2.14. Probability estimates and correlation coefficients for soil moisture as influenced by cover crop biomass, 4 Aug. 1989.

Tillage	Depth	P > F	r^2
	--cm--		
Disk	0-15	0.010	0.38
Disk	16-30	0.010	0.26
No-till	0-15	0.020	0.22
No-till	16-30	0.210	0.07
Disk	0-30	0.001	0.45
No-till	0-30	0.060	0.15
Disk & No-till	0-15	0.001	0.34
Disk & No-till	16-30	0.002	0.20
Disk & No-till	0-30	0.001	0.35

Table 2.15. Probability estimates and correlation coefficients for soil moisture as influenced by cover crop biomass, 10 Aug. 1989.

Tillage	Depth	P > F	r^2
	--cm--		
Disk	0-15	0.040	0.18
Disk	16-30	0.030	0.20
No-till	0-15	0.020	0.21
No-till	16-30	0.0302	0.21
Disk	0-30	0.020	0.22
No-till	0-30	0.010	0.24
Disk & No-till	0-15	0.007	0.15
Disk & No-till	16-30	0.001	0.21
Disk & No-till	0-30	0.001	0.21

The decomposition rate of the cover crops is unknown. However, with lower C:N ratios (Table 2.6) and lower initial biomass, the vetches would be expected to decompose faster, leaving less surface mulch and less potential water-holding organic material than the rye or rye:vetch treatments.

Nitrogen Uptake by Corn

Nitrogen uptake data were analyzed at each of four (1988) or five (1989) sample dates to assess differences among cover crops or N fertilizer rates. During the 1988 season, tillage and cover crops interacted to affect N uptake by corn at the first two sample dates (35 and 60 days after planting).

By the first sample date (35 days), corn growing in plots where cover crops were disk incorporated had accrued more N than in no-till plots in every case except with bigflower vetch. The exception of bigflower vetch could be due to its having less N production than did the other two legume treatments. The greater uptake of N under incorporation was likely due to the 2 weeks additional time those residues had to decompose and release tissue N into the soil. Additionally, disk-incorporated cover-crop residue would degrade faster, as a result of greater soil-to-residue contact compared to being killed and left on the surface under no-till. By the second sample date, differences due to tillage had started to diminish, with only hairy vetch and pure rye stands showing increased N accrual in corn plants under disk incorporation as compared to no-till.

Both cover crop and tillage main effects were significant but without interaction at the 78-day sample date, and only cover crop was significant at the 102-day sample date. At day 78, corn growing on plots that were disk incorporated had taken up significantly more N (79 kg/ha) than those under no-till (59 kg/ha). By this time, differences in cover-crop effects on N uptake were also apparent (Table 2.16). Corn following hairy vetch and the two-vetch mixture accrued the most N, with hairy vetch also being similar to bigflower vetch and the rye:vetch mixture. Rye was lowest and also similar to the rye:vetch mixture. Nitrogen uptake by corn under both tillage methods was similar at the last sample date (102 days), but cover treatments differed (Table 2.16). As with the previous date, corn that followed the two-vetch mixture or pure hairy vetch had highest N uptake. All other cover-crop treatments were statistically similar. Abundant rainfall towards the end of the 1988 corn-growing season likely contributed to a lack of tillage differences in N uptake, as conditions for abundant leaching were present. Others (Utomo et al., 1985; Varco et al., 1989) have reported increased N recovery when legume cover crops were incorporated rather than killed and left as mulch.

Tillage did not have a significant effect on corn's N uptake in 1989, except on the first sample date (28 days), but N uptake for all treatments was very low at this time(< 7 kg/ha). At day 49, corn growing in plots following either of the three vetch treatments had similar and superior N accrual than in plots with rye or the rye:vetch mixture, both of which were similar (Table 2.17). By day 70, the three vetch-only treatments were still similar, with the two pure stands of vetch also being similar to the rye:vetch mixture. The rye:vetch mixture and rye were alike and lowest. Ninety days after planting, hairy vetch and the two-vetch mixture were similar, with the two-vetch mixture being similar to bigflower vetch and the rye:vetch mixture. Rye was lowest. By the final sample date in 1989, hairy vetch and the two-vetch mixture were still similar and superior, with hairy and bigflower vetches being alike. Bigflower vetch was also similar to the

Table 2.16. Effect of cover crop on N recovered in corn plants at various times after planting, averaged across two tillage methods, 1988.

Cover crop treatment	Days after planting	
	78	102
	--------------kg/ha--------------	
Rye	54 c*	77 b
Hairy vetch	75 ab	133 a
Bigflower vetch	70 b	100 b
Two-vetch	90 a	137 a
Rye:vetch	60 bc	81 b

*Means within a column followed by the same letter are not significantly different using F-protected LSD, alpha = 0.05.

Table 2.17. Effect of cover crop on N recovered in corn plants at various times after planting, averaged across tillage method, 1989.

	Days after planting			
Cover crop	49	70	90	115
	---------------------------kg corn N/ha---------------------------			
Rye	15 b*	43 c	41 c	57 d
Hairy vetch	47 a	79 ab	92 a	114 ab
Bigflower vetch	43 a	74 ab	66 b	100 bc
Two-vetch	50 a	84 a	82 ab	129 a
Rye:vetch	28 b	58 bc	65 b	84 c

*Means within a column followed by the same letter are not significantly different using F-protected LSD, alpha = 0.05.

rye:vetch mixture. Pure rye was again lowest, as it was throughout the majority of the growing season.

Corn did not respond to N fertilizer increments in 1988, evidently due to residual soil N. At none of the four sample dates did any of the four N rates differ significantly (Fig. 2.3). In 1989, differences in corn's N uptake from N fertilizer were seen for the last half of the growing season (Table 2.18). Seventy days after planting, greatest N recovery was with the 210 kg/ha rate. For the last two sample dates, highest N recovery was in the highest two N rates, which were similar. Seventy kg/ha resulted in intermediate levels of N, and 0 kg/ha was lowest.

Seasonal trends in corn N uptake are plotted in Figs. 2.3 through 2.7. The seasonal trends for cover crop treatments in 1989 (Fig. 2.7) corresponded well with the findings of Huntington et al. (1985), who noted a mid-season lag in N recovery by corn following hairy vetch. The fact that N-uptake from the N-fertilizer treatments also resembled those of a cubic function in 1989 could be explained by the excessive rainfall throughout the growing season coupled with split application of N fertilizer. Excessive leaching likely occurred in this loamy soil both with cover crops and N fertilization, as the two lower N rates to sustained a dip in mid-season N uptake. Apparently half doses of the higher N rates were sufficient to carry the crop until the other half was applied (in spite of any leaching). Huntington et al. (1985) noted that N-uptake studies fail to account for N loss due to loss of pollen and abscising flower parts, tissue N loss, and other sources. These losses likely contributed to the mid season dip seen here. Huntington et al. (1985) recommended applying N fertilizer at corn planting following cover crops to offset the N-uptake lag. I suggest the supplemental N

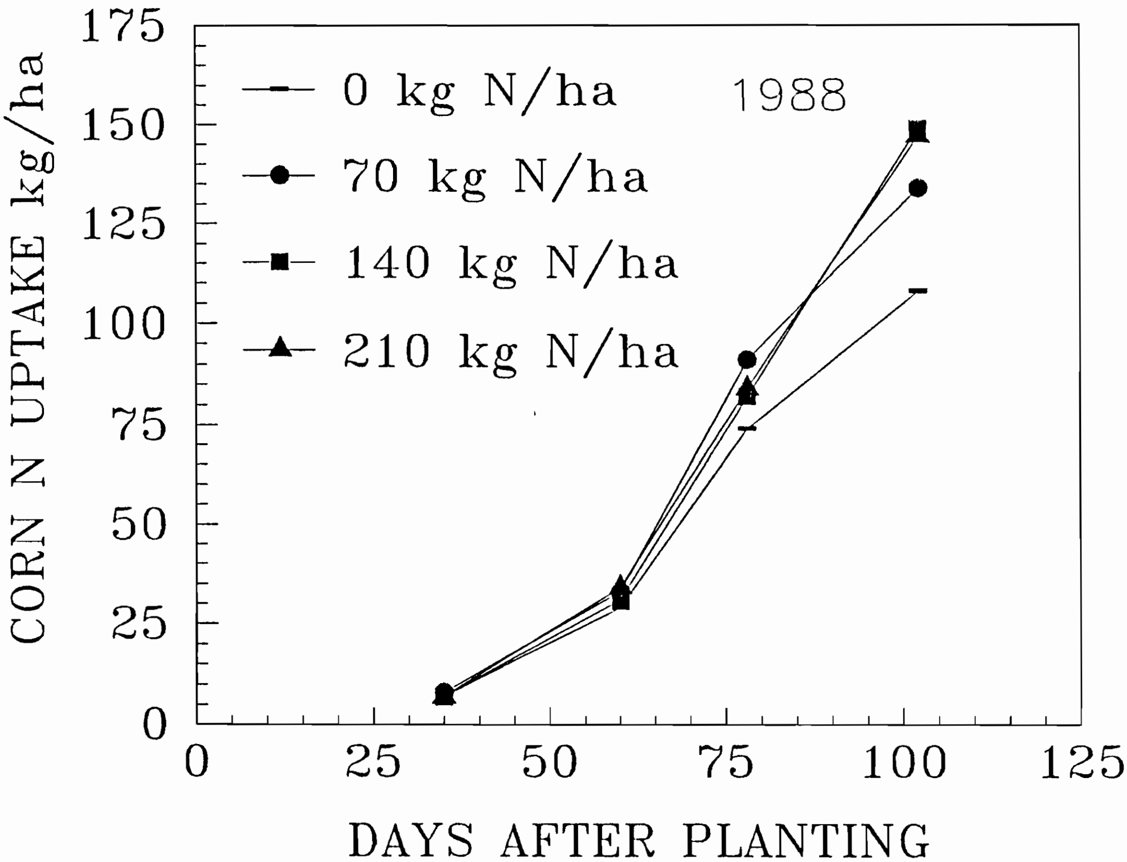

Figure 2.3. Effect of N fertilization on corn N uptake, 1988.

Table 2.18. Effects of N fertilizer on N uptake by corn through the season, 1989.

	Days after planting				
N rate	28	49	70	90	115
kg/ha	----------------------------------kg corn N/ha----------------------------------				
0	4 a*	37 a	61 b	52 c	61 c
70	5 a	39 a	84 b	96 b	130 b
140	6 a	56 a	74 b	150 a	183 a
210	5 a	54 a	131 a	150 a	213 a

*Means within a column followed by the same letter do not differ significantly using F-protected LSD, alpha = 0.05.

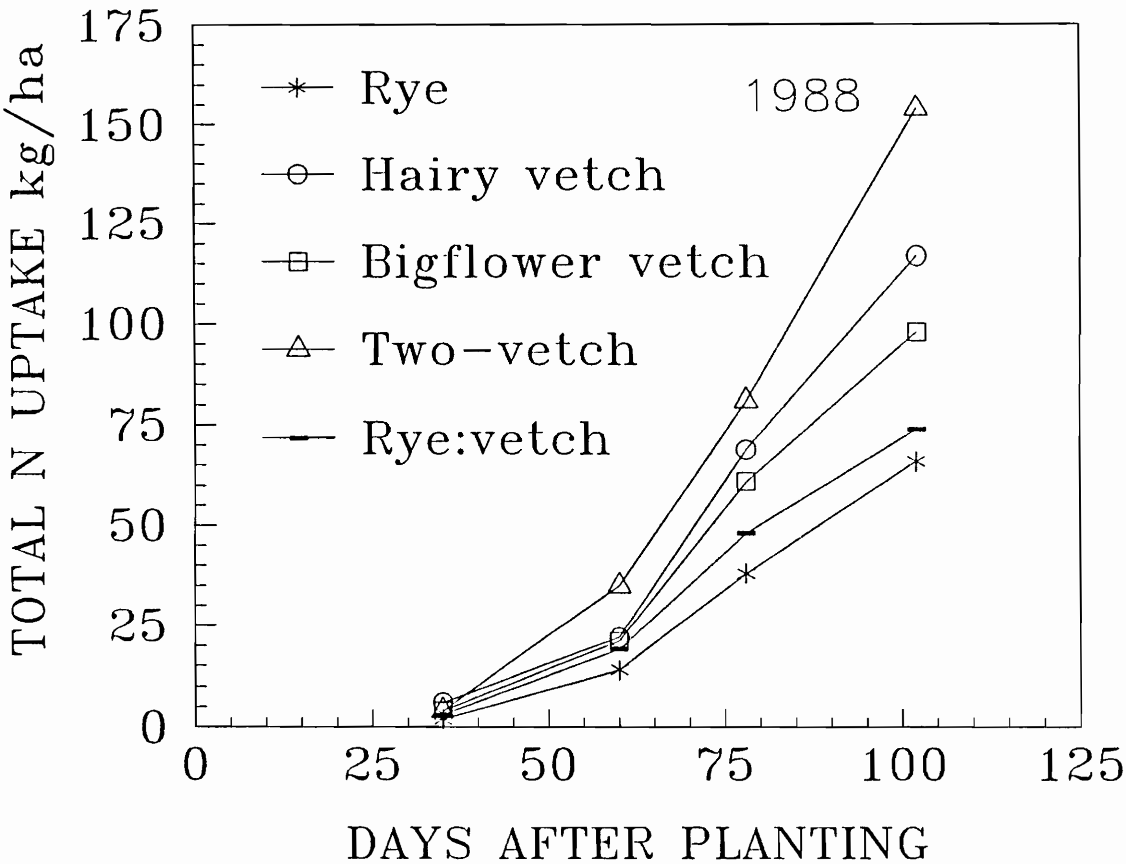

Figure 2.4. Effect of cover crops under no-till management, on corn N uptake, 1988.

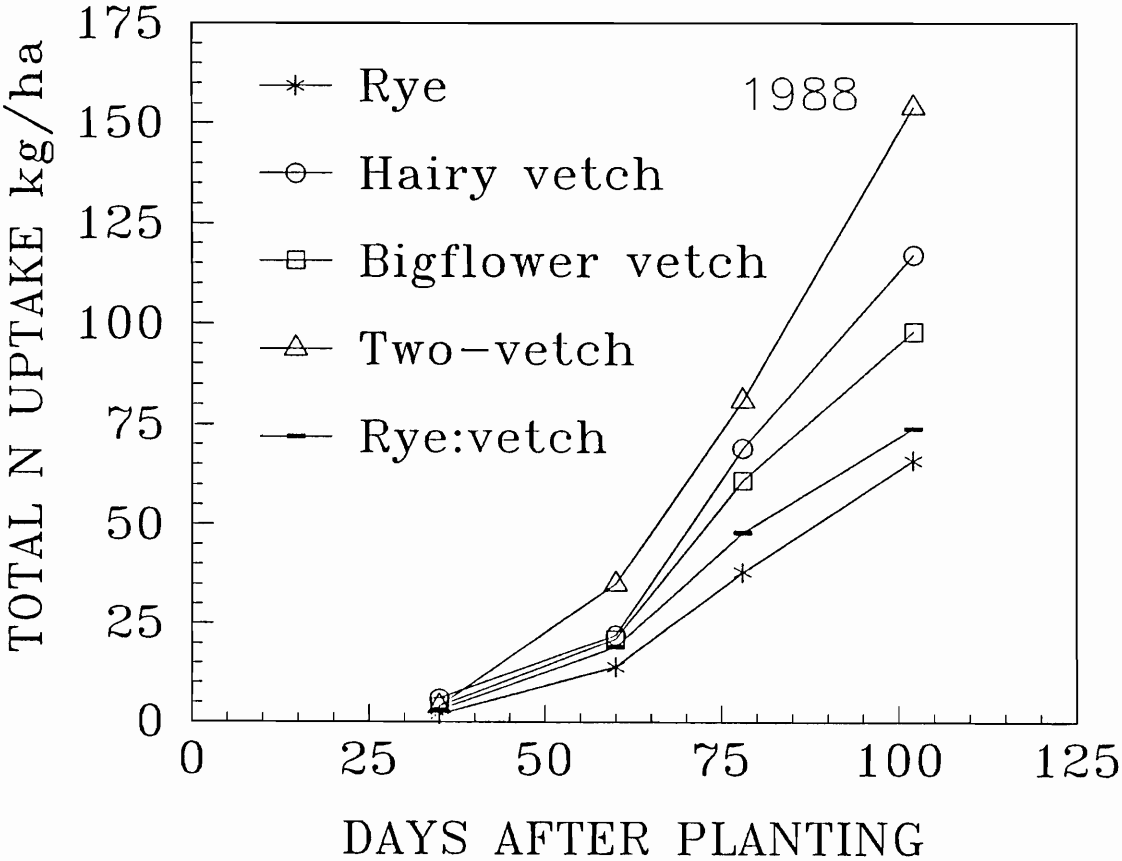

Figure 2.5. Effect of cover crops that were disk-incorporated on corn N uptake, 1988.

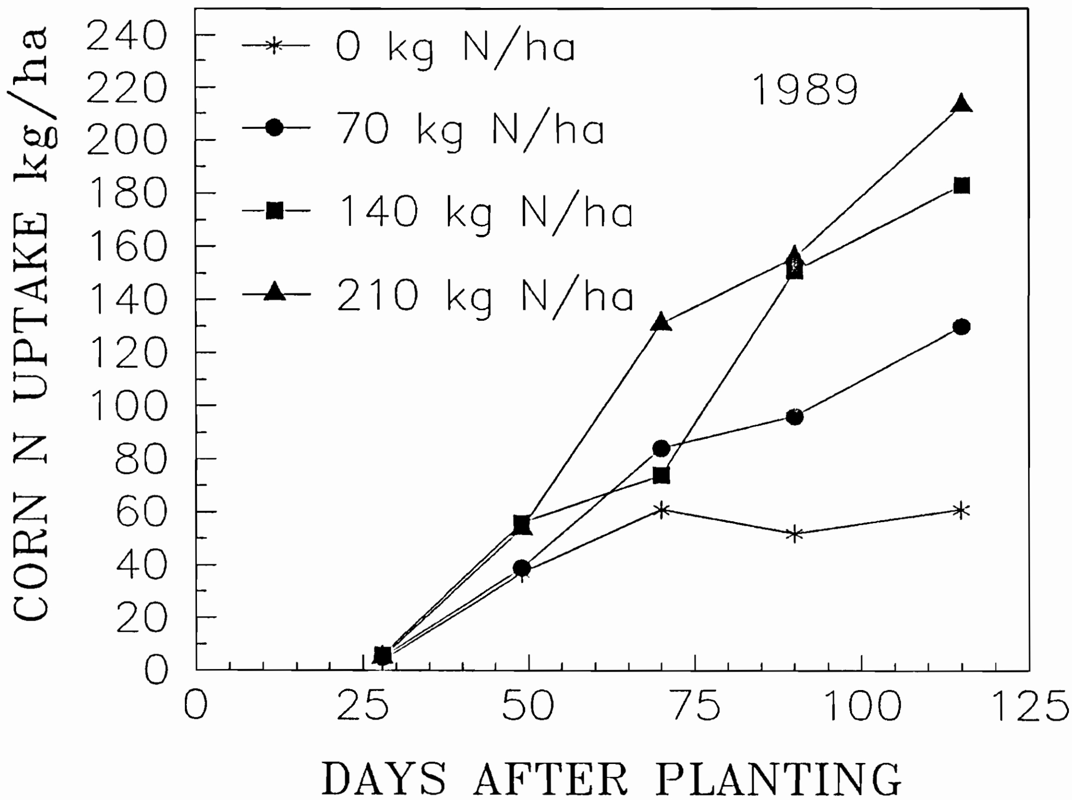

Figure 2.6. Effect of N fertilization on corn N uptake, 1989.

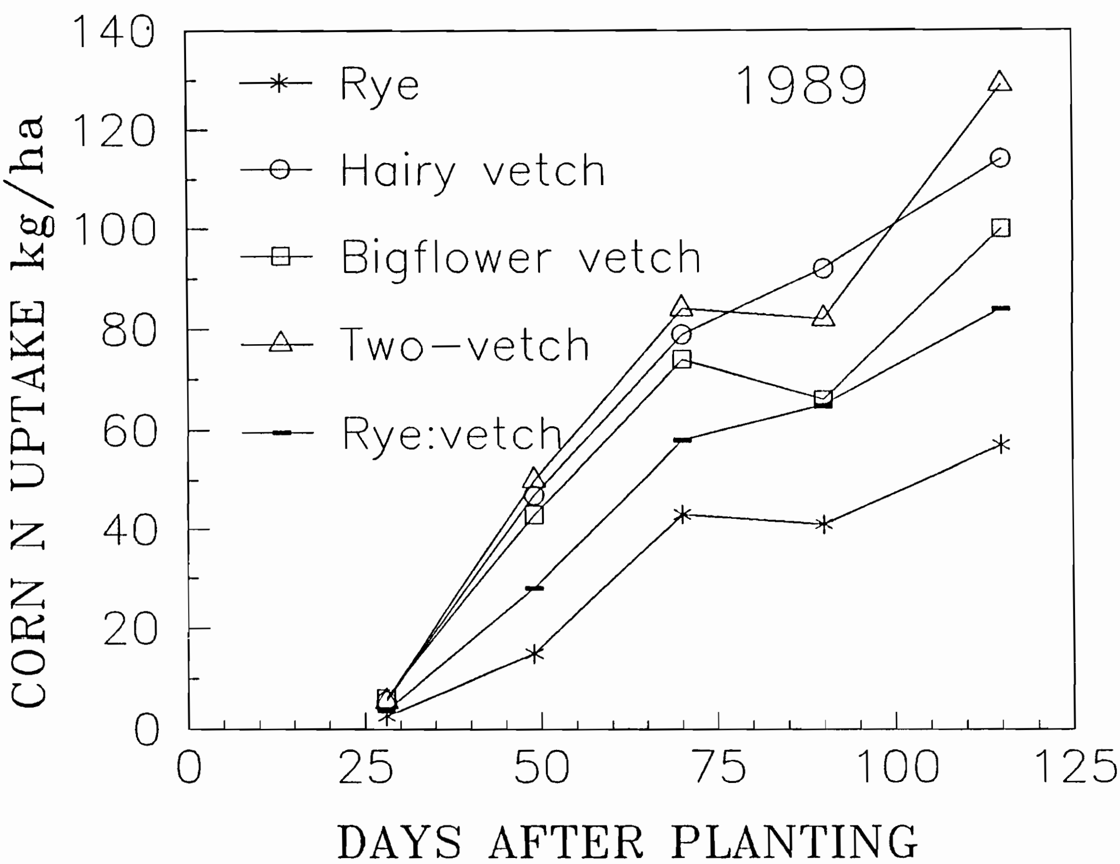

Figure 2.7. Effect of five cover crops averaged across two tillage methods on corn N uptake, 1989.

fertilizer be applied several weeks after planting to better compensate for the apparent "pre-silking" N deficit.

Corn Yields

For the purpose of making these findings more immediately meaningful to growers, the two "standard-practice" treatments were included in the corn-yield analysis. A significant year-by-cover-crop interaction was apparent in the overall analysis of variance. Corn yields declined for the rye treatment and the rye:vetch mixture from 1988 to 1989 probably due to depletion of residual soil N (Table 2.19). Yields increased in the standard practice control from 1988 to 1989 perhaps due to differing rainfall patterns or the excessive heat during August of 1988. Yields were similar for all the legume treatments from one year to the next.

Analysis of variance for 1988 corn yields revealed a significant main effect for cover crop (P = 0.02). No differences were discerned between till methods. The p-value for an interaction between cover crop and tillage was 0.07. When analyzed across both tillage methods, highest corn yields were realized following the two-vetch mixture, hairy vetch alone, or 140 kg N/ha (Table 2.19). The N fertilizer was also similar to all the rest. These yields are partially being influenced by residual N in the soil. Residual N gave a needed boost to the rye pure stand and the low-N-producing bigflower vetch during 1988.

For 1989, only a cover crop main effect was significant, with no interaction or tillage effect being detected. The two-vetch cover-crop treatment was equal to both standard-practice treatments averaged across tillage (Table 2.19). Corn yields following the two-vetch mix were similar to bigflower vetch, which was similar to hairy vetch. The rye:vetch mix was next to lowest and rye was lowest.

Table 2.19. Effect of cover crop on corn dry matter yields, averaged across tillage, 1988 and 1989.

Cover crop	1988	1989	Year effect+
	----------------Mg/ha	-------------------	
Rye	12.8 b*	8.8 e	yes
Hairy vetch	16.2 a	15.3 bc	no
Bigflower vetch	13.3 b	13.9 c	no
Two-vetch	16.4 a	16.4 ab	no
Rye:vetch	13.6 b	11.7 d	yes
Standard practice (Rye plus 140N) or (Fallow plus 140N)	15.2 ab	17.4 a	yes

+Signifies whether or not years were significantly different for that treatment row.

*Means followed by same letter are not significantly different, using F-protected LSD alpha = 0.05.

Corn yields under all N rates were similar in 1988 (Table 2.20). Nitrogen fertilizer treatments were among the highest corn producers in 1989. Corn yield from the highest N rate was not statistically different from the 140 kg rate, which was included in the 2 x 6 factorial comparison. Fertilizer rates at or above 70 kg/ha were equal and superior to the zero N treatment.

Conclusions

Acceptable N yield was seen for both years using pure stands of hairy vetch, mixtures of hairy vetch plus bigflower vetch, or rye plus hairy vetch. Increased N yield was seen where cover crops were allowed a longer period of time to grow (earlier kill by disking versus later kill by herbicide). A definite biomass yield advantage was seen for the rye:vetch mix as compared to the other cover crops. Carbon to N ratios were lower for legumes than for rye. Rye growing in association with vetch had lower C:N ratios than pure rye, apparently deriving additional N from vetch. Corn N uptake was greatest with the two-vetch mixture of hairy vetch. Using N fertilizer, highest corn N uptake was with the higher two rates of fertilizer. Increased soil moisture was related to the presence of a surface mulch. Corn yields comparable to the standard-practice of N fertilizer application were achieved in a mid-Atlantic state using legume cover crops without additional N fertilizer. Corn yields were suppressed somewhat when grown following the rye:vetch mixture due to N immobilization from the rye component. Some addition of N fertilizer would seem to be in order to offset this yield suppression.

Table 2.20. Effect of N fertilizer on corn dry matter yields, 1988 and 1989.

N rate	Corn Yield	
	1988	1989
kg/ha	--------------Mg/ha--------------	
0	13.5 a*	10.6 b
70	14.6 a	16.4 a
140	13.3 a	18.0 a
210	13.6 a	18.6 a

*Means followed by the same letter are not significantly different using F-protected LSD, alpha = 0.05.

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Effect of Tillage and Cover Crop on Soil Aggregate Stability and Soil Water Infiltration

Cover crops can provide several indirect benefits as they decompose into soil organic matter; one of the most important is to enhance the soil aggregation process. Some of the desirable consequences of improved soil aggregation include increased water infiltration, decreased bulk density, increased water-holding capacity, and increased pore space (Boyle et al., 1989). Plant roots occupy a larger volume when grown in a well-aggregated soil that is high in organic matter, as opposed to a finely pulverized soil, low in organic matter. Roots, earthworms, and soil arthropods can pass more readily through such a soil (Pipel, 1971). Plant nutrients and gases also diffuse more easily to and from roots in well-aggregated soils. Aggregated surface horizons also prevent glazing or crusting of the soil surface. Finally, well-aggregated soils are more erosion resistant, because aggregates are much heavier than their particle components. In short, the benefits of maintaining good soil aggregation through organic matter management (via cover crops) are many, varied, and interconnected.

Water infiltration describes the process of water entry through the soil surface. Among the interacting factors that influence infiltration are soil organic-matter content, aggregation, surface residues, and surface crusting. Because of its influence on aggregate stability, a decrease in soil organic matter is generally associated with a decrease in water infiltration. Parker and Jenny (1945) showed increases in infiltration with annual additions of animal manure when compared to plots receiving only urea fertilizer. A single addition of large amounts of straw or barnyard manure seldom affects water infiltration, although repeated applications can increase the infiltration rate (Boyle et al., 1989). McVay et al. (1989) reported increased water infiltration under a no-till hairy vetch mulch when compared to fallow plots receiving only N fertilizer. Touchtone et al. (1984) noted increased infiltration following 2 years of hairy vetch or crimson clover when compared to fallow.

Tillage can affect water infiltration directly or indirectly. Radcliff et al. (1988) found infiltration rates twice as high with no-till when compared to conventional till (37 mm/h vs. 16 mm/h). Further investigation showed the presence of mulch, not tillage, was the influencing factor; when mulch was added to the conventional tillage treatments, infiltration was increased. Their results indicate that, under conventional tillage of fallow plots, a surface crust rapidly developed, which limited infiltration when the mineral soil was exposed to raindrop impact.

The research reported here represents an attempt to assess any change in water-stable aggregates over a 2-year course of cover cropping and to estimate water-infiltration differences among tillage practices across various cover crops.

Materials and Methods

A 2 x 7 factorial experiment was used with two tillage methods (disk and no-till) by seven cover crops for a water infiltration study, and a 2 x 3 factorial for an aggregate stability study (Table 3.1). In actuality, the cover-crop treatments consisted of six cover-crop plantings and two matched "standard practice"

Table 3.1. Schedule of treatments (cover crops, N fertilizer, and tillage) for plots to be sampled for soil aggregate stability and water infiltration.

Cover crop treatment*	N rate+	Tillage
	kg/ha	(Disk or No-till)
100 Rye (R)	0	both
100 Hairy vetch (H)	0	both
100 Bigflower vetch (B)	0	both
67H/33B	0	both
33H/67B	0	both
50R/75H	0	both
100R standard practice	140	no-till
Fallow standard practice	140	disk

*Rye seeded at 100 kg/ha in pure stands. Vetches seeded at 28 kg/ha in pure stands.

Numbers in front of R,H,B = percent of pure-stand seeding rates used in each mixture.

+N fertilizer applied to succeeding corn crop.

controls. One control was winter rye into which corn was no-till planted. The second control (fallow) was allowed to support indigenous plant species during the winter and disked prior to corn planting. Both control treatments received 140 kg N/ha supplemental fertilizer to the corn crop. Treatments were replicated four times. Seeding rates are based on recommendations by Donohue et al. (1984) (100 kg/ha for rye and 28 kg/ha for hairy and bigflower vetches). Additional information on planting dates and other details of the experiment can be found in previous chapters.

Soil samples were taken to 15 cm on 26 November 1987 and again on 6 October 1989, to provide "before" and "after" observations of percent water-stable aggregates. Water-stable-aggregate percentage was determined by the sieve method of Kemper (1965). Change in the percent water-stable aggregates over the duration of the experiment was obtained by subtracting the value at the initial sampling date from the value measured after the 2-y period.

Water-infiltration rates were assessed on 4 August 1988 and 10 August 1989 using ring infiltrometers 15 cm in diameter and 25 cm tall. Four determinations per plot were taken. Rings were driven 5 cm into the soil, and water was added past an established top mark on the ring. The water-level decline was timed from the top mark to a second mark 2.54 cm below (Bouwer, 1986). Data for each parameter measured were analyzed using analysis of variance procedures (SAS, 1982), and means were separated by F-protected LSD.

Results and Discussion

Aggregate Stability

Differences in percent water-stable aggregates before and after the 2-year period were highly variable. Percent water-stable aggregates frequently decreased in some reps and increased in others but with no consistent block effect (Table 3.2). Three cover-crop treatments (50R/75H, 67H/33B, and 100R), for which I had complete data for both tillage practices, were selected for analysis of variance. A high coefficient of variation (CV) (297%) masked any differences, if they existed (Tables 3.3 and 3.4). When the "after 2 years cover cropping" percent water-stable-aggregate data were analyzed separately, only a rep effect was seen (Table 3.2).

I was unable to detect any changes in water-stable aggregates after 2 years of cover cropping. Other investigators have shown differences in the top 2.5 cm of soil after 3 years of cover crops on a soil that was poorly aggregated initially (McVay et al., 1989). My soil samples included the top 15 cm of soil. More years of organic-matter addition would likely be needed to see changes in the top 15 cm. Taking soil from too deep in the profile masked any changes in aggregation, if they were present at all. A loam soil having 15 to 20 % clay, as in the present study, has good aggregation potential. Three years of grass production prior to the experiment should have provided a good aggregate status at the outset. From the literature cited earlier, it seems that building aggregation is a long-term process. I thought that some decrease in aggregation would have occurred in the N fallow, conventionally tilled, fertilizer treatment as compared to the cover-crop treatments, however. Had I known at the start of the experiment the results of the

Table 3.2. Analysis-of-variance significance levels for various treatment effects on water-stable aggregation over 2 years using three cover-crop treatments.

Source	d f	2-year difference	After 2 years of cover crops
		-----------p-value------------	
Rep	3	.26	.017
Cover Crop	2	.90	.66
Tillage	1	.95	.27
Cover x Till	2	.70	.74
CV	-	297%	30%

Table 3.3. Effect of cover crops on change in water stable aggregates over 2 years and the percent water-stable aggregates after 2 years.

Cover Crop treatment	2-year difference	After 2 years of cover crops
	-------------%	-------------
100 Rye (R)	-5.3 a*	32.3 a
67H/33B	-3.1 a	31.0 a
50R/75H	-6.4 a	35.4 a

*Means within a column followed by the same letter are not significantly different using F-protected LSD, alpha = 0.05

Table 3.4. Effect of tillage on change in water stable aggregates over 2 years and the percent water-stable aggregates after 2 years.

Tillage method	2-year change	After 2 years of cover crops
	-----------%	-----------
Disk	-4.8 a*	30.7 a
No-till	-5.1 a	35.2 a

*Means within a column followed by same letter are not significantly different using F-protected LSD, alpha = 0.05

most recent literature (McVay et al., 1989; Boyle et al., 1989), I would not have done the study or I would have sampled less deeply.

Water Infiltration

Analysis of variance revealed a significant tillage effect on water-infiltration rates in 1988, with neither a significant cover-crop effect nor a tillage by cover crop interaction. In 1988, no-till plots had a lower infiltration rate than those that had been disk incorporated, but no tillage effect was seen in 1989 (Table 3.5). The results contradict those of Radcliff et al. (1988) who found increased infiltration in the presence of mulch (no-till treatments in the case of this study). The 1988 decrease in infiltration under no-till seems illogical and is likely due to methodology or random variation.

High CVs (87%) were associated with the 1989 data set. Several factors possibly contributed to the high variation. First of all, the disked plots were tilled when the soil was very wet. Disking in 1988 was done under more suitable soil moisture conditions and resulted in less cloddiness. A second reason for the variability (in both years) may have been infiltrometer size. Available infiltration rings were smaller than recommended by Bouwer (1986). Increased observations within a plot did not appear to compensate for the smaller rings. Bouwer (1986) explains a ring size of 1 m provides more accurate rates of vertical infiltration, and he recommends using as large a ring size as possible. Small rings are susceptible to lateral divergence of the water flow and can give erroneous readings. Additionally, the larger the ring the greater amount of spatial variability can be accounted for in a single measurement.

Table 3.5. Effect of tillage on water infiltration in 2 years.

Tillage method	1988	1989
	-------------mm H_2O/h-------------	
Disk	27 a*	28 a
No-till	13 b	25 a

*Means within a column followed by same letter are not significantly different using F-protected LSD, alpha = 0.05

Conclusions

Cover cropping may or may not have affected soil aggregation. Others have shown improvement in soil aggregation after 3 years of cover cropping. Soil samples taken for aggregate stability work should come from near the surface or the area expected to have the most influence on the soil aggregating factor being investigated. The water infiltration data were questionable at best, due to inadequate methodology. Differences likely were there but were not detected. Others have shown effects of cover crop mulch on water infiltration into soil.

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Effect of Tillage and Cover Crop on Weed Levels in Corn

As a part of a farm's crop rotation plan, cover crops can provide soil organic matter and symbiotically-fixed N, assist in nutrient cycling, and improve soil water relations. In addition, cover crops can play a role in weed suppression. Weed suppression can be by direct competition for growth requirements or by chemicals (i.e., allelopathy).

Allelopathic weed control benefits from grain crops, especially rye are well established (Putnam and Chung-Shih, 1986; Rice, 1984; Worsham, 1984). Barnes and Putnam (1983) noted 73% reduction in weed biomass in a no-till pea planting containing rye mulch when compared to plots with a mulch of poplar shavings. These results indicate that, in addition to a mulch effect by rye, allelopathy was reducing weed biomass. Field trials by Putnam and DeFrank (1983) have shown that many annual weed species can be suppressed with residue from rye, corn, wheat, oats, barley, and sorghum. Lieble and Worsham (1983) identified phytotoxic compounds in wheat residue and tested the effect of those substances on seed germination of selected weed species. The allelopathic compound with the greatest inhibitory effects, ferulic acid, inhibited germination of pitted morning glory (*Ipomea hederacea*) 23%, prickly sida (*Sida spinosa*) 85%, and large crabgrass (*Digitaria sanguinalis*) 100%. They concluded that proper selection and management of cover crops could possibly reduce the amount of herbicide needed in no-till cropping systems.

A reduction in tillage also changes weed levels as compared to conventional tillage (Triplett and Lytle, 1972; Wrucke and Arnold, 1985). Reduced tillage generally shifts weed composition to favor perennials (Aldrich, 1984). Many perennials have a high competitive ability in a no-till situation and become dominant over annuals. Putnam et al. (1983) found that no-till causes population shifts favoring monocots, especially grasses. The combination of no-till plus a rye cover crop can produce greater weed reduction than either alone. Putnam and DeFrank (1983) showed that small-seeded annual weeds could be suppressed by the allelopathic effects of cereals, while larger-seeded vegetables, particularly legumes, grew quite well under no-till mulches. In their study, eliminating tillage reduced weed growth by 32%, while the addition of barley, rye, or wheat residues to no-tilled soil reduced weed growth an additional 63%.

The purpose of the following study was to determine the effects of reduced tillage and cover crops on weed biomass production in a silage-corn-production system.

Materials and Methods

A 2 x 3 factorial arrangement (two tillage methods x three cover crops) of four randomized complete blocks was used to look at tillage and cover crop effects on weed growth. The two tillage methods were disk incorporation or no-till planting directly into the cover-crop residue. Cover-crop treatments were pure stands of rye (100 kg/ha seeding rate), hairy vetch (28 kg/ha), and bigflower vetch (28 kg/ha) (Donohue et al., 1984). All plots were treated with two herbicides: cyanazine at 3.5 L/ha and metolachlor at 1.75 L/ha. Crop management practices were as described in previous chapters.

Weed populations were sampled on 27 July 1988 in three, 0.5-m^2, randomly selected areas between the corn rows from each plot. In the second year, weeds were sampled on 20 July 1989 by removing three, 0.93-m^2, areas of weed biomass from each plot. The sample size was increased in 1989 due to the high coefficients of variation (CVs) experienced during 1988. The weed samples were cut at ground level, separated by species or type, dried at 55 to 60 C for 60 h, and weighed. Weeds were segregated into predominant species/categories: horsenettle (*Solanum carolinense*), nutsedge (*Cyperus spp.*), dock (*Rumex* spp.), dandelion (*Taraxacum officinale*), grasses (Poaceae), and other forbs. Realizing that cover-crop architecture and the resulting architecture of the no-till mulch produced from the cover crops could affect sunlight penetration to the soil surface and subsequent weed seed germination and growth, percent light interception readings were taken on the cover crops. Sunlight interception rates were determined 1 day prior to biomass sampling on no-till cover crop plots both years (17 May 1988 and 22 May 1989). Readings were taken from 12:00 noon to 2:00 pm eastern standard time using a photovoltaic cell placed first at the canopy surface and then at ground level, under the canopy (Wolf et al., 1972).

Analyses of variance were run on each of the weed species categories and on total weed biomass. Since CVs were high (41 to 142%) and some observations were zero, the data were transformed by taking the square root + 0.5 of each observation (Weisberg, 1985). Comparisons for year differences were made by calculating an F-statistic from the two error mean squares for the two separate years and comparing the calculated F with an F-distribution at the 95% probability level. Mean separation was by F-protected LSD (Steel and Torrie, 1980).

Results and Discussion

A significance level of 0.05 was not strictly adhered to, since 40% of the treatment effects below 0.10 were between 0.10 and 0.05. Higher CVs were considered to mask true differences, though square-root transformation did reduce CVs by 30 to 60%. Type II error rate (failure to detect real differences) increases with increasing CVs. The relative risks associated with type I versus type II error were considered (Carmer and Walker, 1988). Assumptions surrounding the risk of type I error include unnecessary herbicide application and abandoning one tillage method for another. Type II error risks include a false sense of security and potential yield reduction due to failure to adjust a crop or herbicide rotation in response to probable weed population shifts over time, or weed shifts due to tillage practices. A type II error could in many cases be offset by a post-emergent herbicide application, but increased expense would be incurred.

To facilitate discussion, p-values for weed categories with significant biomass differences have been summarized in Tables 4.1 and 4.2. A test for year differences showed horsenettle and nutsedge were significantly different between years; therefore these are discussed by separate years.

Horsenettle biomass was influenced by year, tillage, and cover crop (Table 4.3). The cover crop x tillage interaction (Table 4.1) differed from 1988 to 1989. Differences in horsenettle biomass seemed to be due primarily to years, secondarily to tillage, and finally to cover crop. Horsenettle was the predominant weed during the first year following rotation from pasture to a corn ecosystem, making up 87% of the total weed biomass in disked plots and 54% in no-till. By

Table 4.1. Significance tests for weed biomass by various species categories, pooled across years.

	Nettle	Nutsedge	Dande- lion	Total
	---------------------------P > F---------------------------			
Year	**<.05**	**<.05**	>.05	>.05
Cover crop	0.35	0.71	0.64	0.31
Tillage	**0.01**	0.24	**0.05**	0.22
Cover x Tillage	**0.10**	**0.01**	0.88	0.95
Year X Cover X Tillage	**0.02**	0.22	0.96	**0.06**

Table 4.2. Significance tests for weed biomass among various species categories by year.

	Nettle	Nutsedge	Dande- lion	Total
	----------------------------P > F----------------------------			
1988				
Cover crop	0.63	0.46	0.80	0.76
Tillage	**0.01**	0.45	0.13	**0.01**
Cover x Tillage	0.42	**0.03**	0.90	0.72
1989				
Cover crop	0.11	0.43	0.60	0.35
Tillage	0.21	0.13	0.22	0.25
Cover x Tillage	**0.06**	**0.08**	0.94	0.64

Table 4.3. Effect of tillage and cover crop on horsenettle biomass in late July.

Year/ Cover crop	Tillage method: Disk	Tillage method: No-till	Tillage effect+
	------------kg/ha----------		
1988			
Rye	155 b*	75 a	no
Hairy vetch	233 a	37 b	yes
Bigflower vetch	240 a	47 b	yes
1989			
Rye	5 b	13 a	yes
Hairy vetch	8 b	1 c	yes
Bigflower vetch	30 a	7 b	yes

*Means within a half column followed by the same letter do not differ significantly using Fishers LSD, alpha = 0.10

+Signifies whether the means for that row are significantly different.

year two, the weed species structure was more evenly distributed among several species, and horsenettle biomass was much reduced. Seemingly, horsenettle was susceptible to competition from other species to include corn. Solomon (1983) demonstrated the existence of a reversible autoallelopathy in horsenettle. Mature plants release a chemical inhibitor from their foliage that inhibits germination of horsenettle seed. When leaf litter is not replenished (in the event of death or elimination of parent plants), the seed inhibition declines and seeds germinate. By this mechanism, horsenettle can maintain a viable seed bank (seeds may germinate after 7 years) without competition from young seedlings. Meanwhile the seed have a dependable signal for when to germinate. Autoallelopathy could account for the reductions in horsenettle the second year if seeds did not germinate and only perenniating plants regenerated from the previous year.

In the presence of adequate soil N (legume treatments), greater horsenettle biomass was apparent in disked plots than in no-till ones for two consecutive years. All plots were disked each fall, but disked plots received an additional disking each spring. Shallow or deep tillage could readily spread a horsenettle infestation (Furrer and Fertig, 1960). Roots cut into small segments can produce new shoots from great depths. Smith and Calvert (1980) produced new shoots from 58% of sections 5 mm long from a depth of 20 cm in vermiculite. Furrer and Fertig (1960) obtained four plants out of every six root segments 15 cm long when planted at a depth of 45 cm. Disking could have caused higher horsenettle numbers in 1988 by cutting roots into smaller pieces and distributing them in the soil. Without adequate N (rye plots), no tillage effect was apparent in 1988; but in 1989, no-till had slightly more horsenettle than did disked plots. Also under no-till, the rye mulch permitted greater horsenettle biomass development than did either legume treatment for both years. The shading of horsenettle would have been greater under the thick, entangled vetch mat than in the erect rye, which allowed more sunlight to penetrate its canopy (Table 4.4).

The effect of cover crops on nutsedge biomass varied with tillage method in both years (Tables 4.2 and 4.5). In 1988, similar nutsedge levels were seen across both tillage methods for the two legume cover crops; however, when left on the surface, rye inhibited nutsedge growth more than when it was incorporated (Table 4.5). In 1989, no-till rye plots again had less nutsedge than those that were disked. Higher nutsedge levels were apparent under no-till with both legume cover crops however. Two factors are likely at work here. In the presence of adequate soil N, nutsedge plants are encouraged to produce above ground biomass to the detriment of tubers (Garg et al., 1967). Higher N would occur with the legume treatments but not with rye. This would explain the reduced nutsedge biomass in the rye plots under no-till for the 2 years. Under disk incorporation in the absence of adequate N, the opposite effect seemed apparent for both years. Disking has been reported to increase tuber sprouting of nutsedge (Taylorson, 1967). Low N levels in combination with high temperatures promote increased tuberization (Garg et al., 1967) These two factors could explain the observed increases in nutsedge levels with rye when disk incorporated and the increase in 1989. Nutsedge does not grow well in reduced light (Wills, 1975); therefore it is not a good competitor. Thick crop stands that form rapid canopies effectively reduce nutsedge (Stoller, 1975). High sunlight penetration was apparent in the rye cover and subsequent mulch (as much of the rye stand remained erect well into the growing season), which would seem to contradict the results of in 1989 (Table 4.4), where nutsedge increased in vetch plots (Table 4.5). High soil N

Table 4.4. Percent light interception of cover crops , 1988 and 1989.

Cover crop	1988	1989
	% light interception	
100 Rye	68.8 a*	40.2 c
100 Hairy vetch	70.7 a	94.9 a
100 Bigflower vetch	61.2 a	89.3 b

*Means within a column followed by same letter do not differ significantly using Fishers LSD, alpha = 0.10

Table 4.5. Effect of tillage and cover crop on nutsedge biomass in late July.

Year Cover crop	Tillage method Disk	 No-till	 Tillage effect+
	------------kg/ha-----------		
1988			
Rye	28 a*	2 c	yes
Hairy vetch	5 b	12 a	no
Bigflower vetch	2 c	9 b	no
1989			
Rye	52 a	2 b	yes
Hairy vetch	5 b	102 a	yes
Bigflower vetch	16 b	109 a	yes

*Means within a half column followed by same letter do not differ significantly, using Fishers LSD alpha = 0.10

+Signifies whether the means for that row are significantly different.

could be overcoming the light response. Competition from horsenettle was also likely reducing nutsedge populations, since horsenettle was higher in disked plots (Table 4.3).

Averaged across years and cover crops, dandelion biomass was lower in disked plots than under no-till (14 kg/ha vs. 43 kg/ha). Seeds of dandelion, being wind-dispersed, would have been buried when disked but left exposed under no-till. Dandelion is susceptible to competition from tall-growing grasses with which it is commonly found. By early May (later cover-crop kill date) pastures in the surrounding area had considerable grass production to their credit, thereby reducing the dandelion airborne seed load in the area via competition from grass.

Total weed biomass was influenced by year, cover crop, and tillage (Tables 4.1 and 4.6). No differences were seen among cover crops under either tillage system in either year. More weeds were found in disked plots under all cover-crop treatments during 1988. In 1989, more weeds were apparent under no-till where legume cover crops had been grown, but no tillage effect was seen in plots containing rye. The 1988 weed differences were largely associated with horsenettle. Comparing horsenettle biomass in Table 4.6 with levels in Table 4.3, a striking similarity with tillage differences can be seen. In 1989, nutsedge was a major contributor to the total weed biomass, with similar tillage effects trends being seen for total weeds under both legume treatments as was seen with nutsedge. Where rye was used, weeds other than nutsedge were influencing the outcome under no-till. Under no-till, nutsedge did make up the bulk of the total weed biomass. More weeds were seen under disk-incorporated cover-crop treatments in 1988 than 1989. Legume no-till plots had a net increase in total weed biomass over time with no change under no-till.

Table 4.6. Effect of tillage and cover crop on total weed biomass in late July.

Year Cover crop	Tillage Disc	No-till	Tillage effect+
	-------------kg/ha-----------		
1988			
Rye	193 a*	106 a	yes
Hairy vetch	258 a	87 a	yes
Bigflower vetch	255 a	100 a	yes
1989			
Rye	87 a	102 a	no
Hairy vetch	106 a	206 a	yes
Bigflower vetch	106 a	253 a	yes

*Means within a half column followed by same letter do not differ significantly, using Fishers LSD alpha = 0.10

+Signifies whether the means for that row are significantly different.

Conclusions

Weed levels were variable during the course of the study. Horsenettle was the dominant weed during 1988 while nutsedge predominated during 1989. Due to the variability and inconsistency and a lack of definitive evidence, no firm conclusions were drawn as to the effect of cover crops and tillage on weeds.

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General Conclusions

This study represents a contribution to the sustainable agriculture knowledge base, particularly for the mid-Atlantic region. As such, the data suggest approaches for reducing soil erosion and producing energy-cheap N that can be utilized by subsequent crops. Legume cover crops have been a mainstay in agricultural systems for many centuries. Only since the Habor-Bosh NH_3-fixing process was developed for munitions production, has commercial N fertilizer been cheap and widely used. When synthetic N prices rise to fall no more (as fossil fuel prices rise), growers will have to resort once again to ecological answers to solutions rather than temporary technological fixes. Cover crops will be among the ecologically-sound answers available.

With some additional research information to augment these data, solid recommendations on legume polyculture cover crops for the mid-Atlantic should become available. More information is needed on N fertilizer rates to be applied to rye:vetch mixtures for optimum corn yields, and more spring cover-crop management techniques need to be investigated. Transfer of this technology can come easily if growers are willing to make some compromises. Adjustments such as a later corn planting date seem essential to allow hairy vetch to produce a satisfactory amount of N. Bigflower vetch offers more flexibility in planting date due to its earlier maturity; but, as of now its seed costs are prohibitive. Most agriculturalists and farmers alike see N production as the primary advantage to growing cover crops. As long as N fertilizer is cheap or dairy sludge must be disposed of, farmers are less likely to use cover corps. Still, I see value to finding ecological answers today, so that we will be ready when the times demand them.

Appendix

Table A.1. Percent light interception rates of cover crops measured in the spring of 1988.

	27 April			17 May		
Treatment	Mean	S.D.*	C.V.+	Mean	S.D.	C.V.
	-----------------------------------		%	-------------------------------------		
100R	68.8	10.1	14.7	65.3	12.0	18.4
100H	70.7	9.0	12.7	82.7	6.1	7.4
100B	61.2	10.2	16.6	48.0	5.9	12.3
67B/33H	92.5	1.4	1.5	50.5	9.8	19.5
33B/67H	94.5	0.4	0.4	86.4	7.4	8.5
50R/75H	90.9	1.4	1.5	79.2	4.6	5.8
50R/50H	82.0	9.3	11.4	.	.	.
50B/50H	92.9	3.0	3.2	.	.	.
100R/140N	70.0	3.8	5.4	.	.	.
50R/100H	92.4	1.5	1.5	.	.	.
75R/75H	91.1	1.7	1.8	.	.	.
75R/100H	70.7	3.6	5.2	.	.	.
33R/33B/33H	88.1	6.5	7.4	.	.	.
50R/25B/25H	89.1	4.6	5.2	.	.	.
25R/25B/5H	78.0	5.3	6.9	.	.	.
100HW	74.6	3.4	4.5	.	.	.
50H	75.4	11.1	14.7	.	.	.
140N bare	30.8	7.6	24.8	.	.	.
75H	90.3	2.0	2.3	.	.	.

* S.D. = Standard deviation.

+ C.V. = Coefficient of variation.

Table A.2. Corn emergence following cover crops, averaged over 2 years.

Cover Crop treatment	Corn population
	---Plants/ha---
100 Rye (R)	39613 ab*
100 Hairy vetch (H)	45378 a
100 Bigflower vetch (B)	43859 a
50H/50B	41232 ab
67H/33B	37969 ab
33H/67B	41169 ab
50R/50H	34071 b
50R/75H	32988 b
50R/100H	34333 b
75R/75H	33137 b
25R/50H/25B	38118 ab
25R/25H/50B	38828 ab
33R/33H/33B	39513 ab
50R/25H/25B	38890 ab
100Rye + 140N to corn	41232 ab

*Means within a column followed by the same letter do not differ significantly, using S-N-K range test, alpha = 0.05.

Cover Crop Yields from the Second Chapter

For completeness, the 1989 cover-crop biomass data were separated by kill date and are shown in Table A.3 along side the 1988 yields. For 1989 early kill, biomass from the rye:vetch mixture was similar to biomass yields from rye and hairy vetch pure stands. The two-vetch mixture was similar to rye and hairy vetch grown alone. Big flower vetch was equal to hairy vetch and the two-vetch mix (Table A.3). When killed later, rye:vetch was the superior biomass producer, with all other treatments being similar.

When killed earlier, total N in hairy vetch and the two-vetch mixture were statistically similar and superior to one or two of the other treatments (Table A.3). Bigflower vetch and the two-vetch mixture were similar. The rye:vetch mixture and bigflower vetch were alike. Rye was the lowest total N yielder. When killed later, there were no significant differences between all the cover crop treatments, except rye, in terms of total N production. For total N, the pure stand of hairy vetch and the two-vetch mixture were alike, with the mixture also being similar to bigflower vetch (Table A.3). Pure rye and the rye + 140 N (control) treatment were similar and inferior to the rest.

Table A.3. Effect of tillage (kill date) on cover crop biomass and total nitrogen (TN) production, 1988 and 1989.

Tillage/ Cover Crop	1988 Biomass	1988 TN	1989 Biomass	1989 TN
	Mg/ha	kg/ha	Mg/ha	kg/ha
Incorporated (earlier)				
Rye	6.2 b*	77 bc	4.3 ab	42 d
Hairy vetch	3.4 c	101 ab	3.8 abc	143 a
Bigflower vetch	2.4 c	47 c	3.1 c	104 bc
Two-vetch	3.4 c	113 ab	3.7 bc	128 ab
Rye:vetch	8.3 a	121 a	4.9 a	95 c
No-till (later)				
Rye	7.8 b	57 c	5.2 b	37 b
Hairy vetch	3.8 d	89 b	4.8 b	187 a
Bigflower vetch	3.5 d	53 c	4.1 b	148 a
Two-vetch	5.7 c	164 a	4.3 b	169 a
Rye:vetch	10.9 a	176 a	6.7 a	148 a

*Means within a half column (incorporated or no-till) followed by the same letter are not significantly different by F-protected LSD, alpha = 0.05.

Table A.4. Effect of kill date on cover-crop biomass and N yield, 1989.

Kill date	Biomass	TN
	Mg/ha	kg/ha
Earlier	4.0 b	103 b*
Later	5.0 a	138 a

*Means within a column followed by same letter are not significantly different using F-protected LSD, alpha = 0.05.

Corn Emergence

Success in corn establishment varied primarily with tillage practice and secondarily with the cover crop. Analysis of variance indicated tillage was the primary source of variation in stand establishment ($P < 0.01$), with cover crop significance level at $P = 0.12$. Significantly poorer stands were seen where corn was no-till planted into unincorporated cover crops (39,325 plants/ha) as opposed to disked plots (44,618 plants/ha).

A highly significant ($P < 0.001$) interaction between cover crops and tillage was evident for 1989 corn emergence (Table A.5). Emergence was reduced where rye and the rye:vetch mixture were not incorporated or where pure legumes were disked in. The lower stand counts seen where vetch pure stands were incorporated contrasted with the equivalent emergence across tillage treatments for the two-vetch mixture. Higher emergence occurred where corn was planted into rye and rye:vetch that had been incorporated This is likely explained by poorer seed-soil contact under no-till conditions, where plant material had to be cut through and planted into. Highest corn emergence under no-till was with hairy vetch and bigflower vetch. Bigflower vetch was also equivalent to all other treatments. The rye:vetch mixture resulted in corn emergence lower than the hairy vetch pure stand (Table A.5). When cover crops were incorporated, the lowest corn stands occurred in bigflower vetch plots, which were similar to the other legume treatments. When incorporated, the rye:vetch mixture produced corn stands that were close to the 50,000 plants/ha target.

Corn emergence had similar variance structure across years. Pooled year data indicated a significant tillage by cover crop interaction (Fig. A.1). Lower plant emergence was seen where corn was no-till planted into high biomass-

Table A.5. Effect of cover crop and tillage on corn populations after emergence, 1989.

	Tillage method		
Cover crop	No-till	Disk	Tillage effect+
	--------------plants/ha---------------		
Rye	39,376 b*	49,114 a	yes
Hairy vetch	47,421 a	43,187 ab	yes
Bigflower	44,880 ab	38,529 b	yes
Two-vetch	41,070 b	43,187 ab	no
Rye:vetch	32,602 bc	47,844 a	yes

*Means within a column followed by the same letter are not significantly different, using F-protected LSD alpha = 0.05.

+Signifies whether the means for that row are significantly different.

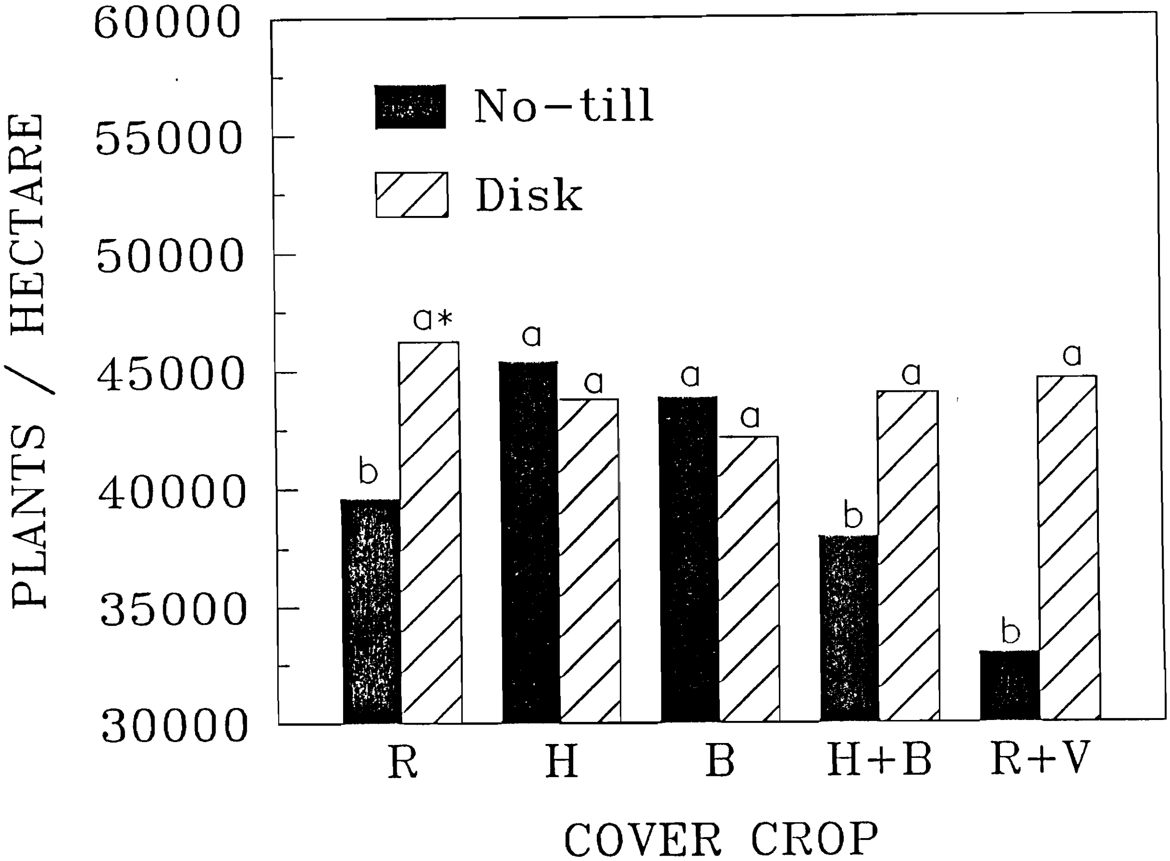

Figure A.1. Nature of the interaction between cover crop and tillage on corn emergence for data pooled across 2 years.

*Means within a pair, followed by same letter are not significantly different, using F-protected LSD, alpha = 0.05.

R, H, B = Rye, Hairy vetch, and Bigflower vetch respectively.

cover crops as compared to where cover crops were disk incorporated. This effect was particularly profound for the rye:vetch mixture. In the lower-yielding pure stands of hairy and bigflower vetches, tillage did not affect corn emergence. The data suggest that a cover crop biomass threshold exists, above which no-till planting could be problematic. The three-way interaction between year, cover crop, and tillage at 0.061 P level is difficult to address.

Surface residues, particularly rye, prevented good seed-soil contact. The planter performed better when cover-crop residue was incorporated than when planting into cover crops left on the surface. Planting difficultly was noted by Mitchell and Teel[1] (1977) when they reported "the tendency for rye straw to be forced into the soil opening made by the fluted coulter rather than be sheared cleanly by the coulter as was the case with vetch and clover". No-till planting into cover crop mixtures containing rye must include cutting the rye cleanly to get the seed into the ground. Replacing rye with wheat may provide a more succulent and "cuttable" cover crop, since wheat's maturity stage is several weeks behind rye's at corn-planting time.

[1] Mitchell, W.H. and M.R. Teel. 1977. Winter annual cover crops for no-tillage corn production. Agron. J. 69:569-573.

Table A.6. Effect of tillage, averaged across cover crops, on soil moisture levels, 1989.

Tillage method	4 August	10 August
	----------% moisture----------	
Disk	16.4 b	12.9 a
No-till	17.6 a	13.6 a

*Means followed by same letter are not significantly different using F-protected LSD, alpha = 0.05.

Table A.7. Effect of tillage on N recovered in corn biomass 78 days after planting, 1988.

Tillage method	Total N
	kg/ha
Disk	79 a*
No-till	59 b

*Means followed by the same letter are not significantly different using F-protected LSD, alpha = 0.05.

Table A.8. Effect of N fertilizer on corn total N recovery, 1988.

	Days after planting			
N rate	35	60	78	102
kg/ha	--------------------kg corn N/ha--------------------			
0	7*	29	74	108
70	8	33	91	134
140	7	31	82	149
210	7	34	84	147

*Means within each column are statistically similar using F-protected LSD, alpha = 0.05.

Table A.9. Effect of cover crop on corn dry matter yields, by tillage 1988.

	Tillage method		
Cover Crop	Disk	No-till	Average
	----------Mg/ha----------		
Rye	14.0 a	11.6 c	12.8 b
Hairy vetch	14.9 a	17.5 a	16.2 a
Bigflower vetch	13.1 a	13.5 abc	13.3 b
Two-vetch	14.7 a	18.0 a	16.4 a
Rye:vetch	14.5 a	12.6 bc	13.6 b
Control	13.3 a (fallow + 140N)	17.2 ab (Rye + 140N)	15.2 ab

Means followed by same letter are not significantly different using F-protected LSD, alpha = 0.05.

Table A.10. Effect of cover crop, and tillage, on corn dry matter yields 1989.

	Tillage method		
Cover crop	Disk	No-till	Average
	----------Mg/ha----------		
Rye	9.1 e	8.6 d	8.8 e*
Hairy vetch	15.1 bc	15.5 ab	15.3 bc
Bigflower vetch	13.9 cd	13.8 bc	13.9 c
Two-vetch	16.5 ab	16.2 a	16.4 ab
Rye:vetch	11.7 d	11.7 c	11.7 d
Control	18.0 a (fallow + 140N)	16.7 a (Rye + 140N)	17.4 a

*Means followed by same letter are not significantly different using F-protected LSD, alpha = 0.05.

Table A.11. Orthogonal contrasts for comparing corn yields following cover crops to the standard practice, control treatments, 1988.

Tillage/ cover crop	P > F
Disc Incorporated	
Rye	0.49
Hairy vetch	0.09
Bigflower vetch	0.85
Two-vetch	0.15
Rye:vetch	0.20
Control yield (Mg/ha)	13.3
No-till	
Rye	0.03
Hairy vetch	0.87
Bigflower vetch	0.12
Two-vetch	0.71
Rye:vetch	0.06
Control Yield (Mg/ha)	17.2

Table A.12. Orthogonal contrasts for comparing corn yields following cover crops to the standard practice, control treatments, 1989.

Tillage/ cover crop	P > F
Disc Incorporated	
Rye	0.01
Hairy vetch	0.02
Bigflower vetch	0.02
Two-vetch	0.20
Rye:vetch	0.01
Control yield (Mg/ha)	18.0
No-till	
Rye	0.01
Hairy vetch	0.28
Bigflower vetch	0.02
Two-vetch	0.63
Rye:vetch	0.01
Control Yield (Mg/ha)	16.7

Table A.13. Effect of year on sedge and total weed biomass under no-till.

Year	Sedge	Total
	---------kg/ha---------	
1988	8 b*	148 a
1989	69 a	122 a

*Means within a column followed by the same letter are not significantly different using unprotected LSD, alpha = 0.05

Table A.14. Weed biomass differences among years, averaged across two tillage methods and three cover crops.

Year	Dande-lion	Nutsedge	Other
	--------------------kg/ha------------------		
1988	21 b	10 b	5 b
1989	36 a	48 a	42 a

*Means within a column followed by same letter are not significantly different using Fishers LSD, alpha = 0.05

VITA

I hail from the southeastern US, where I have lived throughout my life. I come from a long line of tillers of the soil. My first 27 years were spent in hot and humid Mississippi. After finishing my B.S. at Mississippi State University, I started a northward adventure to North Carolina State University where I completed the M.S. in soil science in 1986. Since then I have resided at Virginia Tech. My northward travels may continue until I find tolerable summers and winters with a fair amount of snow. The focus of my education has been sustainable agriculture and ecology, which will ultimately be my career field.

Preston G. Sullivan