Choice and management of cover crop species and varieties for use in row crop dominant rotations

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CHOICE AND MANAGEMENT OF COVER CROP SPECIES AND VARIETIES FOR USE IN ROW CROP DOMINANT ROTATIONS

FINAL REPORT

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Resource Efficient Agricultural Production-Canada

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Executive Summary

The management of cover crops in four major field crops (corn, soybeans, winter wheat and spring cereals) was evaluated over a two year period on farms in South Western Ontario. The research was established within the framework of a corn soybean cereal rotation sequence. The presumption is that from an economic and environmental standpoint this sequence will develop in the 1990's to become the dominant farming sequence used in South Western Ontario on farms that do not grow forages. The experiments are classified in three stages around this rotation with overlap between years.

Stage 1 **Corn**	Stage 2 **Soybean**	Stage 3 **Cereal**

Individual findings are summarized below.

1 Comparison of Ryegrass Cultivars for Interseeding In Corn

There was no suppression of corn yield when ryegrass interseedings were performed on the final cultivation approximately 35 days after corn planting. Ryegrass cultivars demonstrated considerable differences in biomass production. Only one perennial ryegrass cultivar (Ellett) produced as much fall biomass as the four annual cultivars. In general, biomass production was low. To increase biomass production, the interseedings should likely be overwintered and restricted to sites with corn yields below 10 t/ha. Aside from the soil conservation value of the interseedings, a major benefit was weed suppression. Biomass of the weeds present on the sites (quack grass and a variety of annual grass and broadleaf weeds) was on average reduced by 50% by the productive ryegrass interseedings.

2 a) Rye Tillage Management Systems for Soybeans

Very high ground cover was obtained when winter rye was managed as a no-till mulch versus systems where the rye was disced or plowed Achieving adequate soybean stands proved difficult in the treatments where tillage occurred and soybean yields were low. In tilled plots, the most promising treatment appeared to be that in which rye was harvested as a forage and the stubble subsequently plowed before soybean planting.

2 b) Soybean No-till Systems with Rye.

In the drought year of 1988, better soybean stands and yields were obtained where soybeans were no-tilled into standing rye, than where rye was first mulched and soybeans subsequently no-tilled. A high soybean yield (3.0 t/ha dry matter) was obtained when planting before mowing was performed at rye heading. Delaying no-till seeding until rye anthesis (1 week later) reduced soybean yields to

1.7 t/ha as germination was delayed until the drought ended Rye harvested as a silage at heading yielded 3.45 t/ha dry matter and enabled timely no-till soybean planting. When the rye was left on the surface as a mulch, no annual weeds were observed in any of the treatments, and 100% ground cover was obtained.

2 c) Evaluation of Rye Varieties for No-till/Mow-kill Soybean Production

Rye varieties demonstrated considerable differences in early spring ground cover, biomass production at heading, and heading date. After no-till planting and mowing, Kustro grain rye, had 50% less regrowth than the forage rye Wheeler. Soybean yields were 40% lower on average on the rye cover cropped plots than the no-tilled soybeans without a rye cover crop. Soybeans on the rye mow-kill plots were shorter and chlorotic. The mow-kill system provided good weed control without herbicides and eliminated the need for a contact and broadleaf herbicide which was required in the no-till treatment without a cover crop.

2 d) High Moisture Winter Barley Soybean Relay Cropping

Dry weather, poor winter barley survival, and poor penetration by the no-till drill combined to cause poor success with this system. No soybeans suitable for combining were obtained from any of the relay cropped soybeans. The high moisture relay cropped winter barley (on average harvested at 43% moisture) provided for a winter barley harvest two weeks earlier than when left for grain. However, high moisture relay cropped winter barley, on average resulted in 35% lower winter barley yields than monoculture winter barley. The barley was likely harvested earlier than physiological maturity. When the relay cropped barley was combined as dry grain in 1989, a 50% reduction in barley yield resulted from barley lodging, and soybeans growing into the barley canopy.

3 a) No-till Winter Wheat and Red Clover Plowdown Following Soybeans.

No-till wheat systems of aerial seeding at leaf yellowing in soybeans and zero-till drilling after soybean harvest provided good establishment and wheat yields equivalent to conventionally tilled and planted winter wheat. Ground cover was substantially increased by both no till planting methods. Aerial seeding provided slightly higher ground cover than no-till drilling at both sites. On average, aerial seeding provided 90% ground cover when measured in late October and late April. Following winter wheat harvest, neither weed growth or fall biomass production of red clover plowdown was affected by the method of establishment of the winter wheat

3 b) Interseeding and Catch Crop Systems for Winter Wheat

In 1988, hairy vetch drill seeded in winter wheat in mid May produced significantly higher quantities of above ground biomass (3367 and 2554 kg/ha on the silt loam and sandy loam sites respectively in 1988) than other interseeded species (red clover, crimson clover, and nitro alfalfa). Clover established poorly on the sandy loam site in the drought year. On the silt loam site in 1988, establishment and biomass production were highest the earlier the red clover was seeded (March 15) while in 1989 the best establishment and biomass production was achieved at the latest seeding date (May 15). A fall catch crop of oilseed radish produced very high fall biomass in 1988 on the sandy loam site (3654 kg/ha) while the growth on the silt loam site (950 kg/ha averaged over two years) was poorer. The difference was likely related to low residual soil N on the silt loam site. Interseeded hairy vetch and oilseed radish seeded after wheat harvest were competitive with fall weed growth when a diverse weed flora was present. However, at the sandy loam site in 1989, all the cover crops were out competed by a heavy quack grass infestation

3 c) Interseeding and Catch Crop Systems for Spring Cereals

Red clover, hairy vetch and crimson clover interseedings were extensively killed in the drought on the sandy loam. Alfalfa was the interseeded cover crop producing the highest biomass. The few crimson clover plants that did survive the drought grew very well on the sandy loam soil. Blind harrowing, just prior to grain emergence, increased the weed infestation. On the clay loam site, hairy vetch seeded at blind harrowing produced very high fall biomass (3446 kg/ha) but climbed extensively in the grain at harvest.. The highest biomass producing system at both sites was the treatment in which liquid manure was applied; it stimulated growth of both oilseed radish and regrowth of the cereal. However, the oilseed radish seems to be more suited for use after winter cereals because the spring cereals regrew aggressively and provided approximately 50% of the fall biomass.

3 d) Interseeded Cover Crops and Mechanical Weeding Systems In Spring Cereals In 1989.

A more extensive study was performed to further evaluate mechanical weeding systems and their compatibility with establishment of red clover and the annual cover crops (crimson clover and hairy vetch). Hairy vetch introduced at finger weeding (approximately 30 days after main crop seeding) and drill seeding (approximately 45 days after main crop seeding) produced the highest fall biomass amongst cover crop treatments. Climbing of the hairy vetch in the grain at harvest was greatly reduced compared to 1988, with no appreciable climbing occurring in the drilled treatment. On the clay loam site, the mechanical weeding devices (finger weeding, harrowing, and rotary hoeing) doubled fall biomass production from the clover cover crops compared to surface broadcasting without shallow incorporation. Post emergent harrowing appeared to be too aggressive on the grain crop and caused significant plant loss, particularly in the wheel traffic areas. Both finger weeding and rotary hoeing significantly reduced weed biomass at grain harvest at the silt loam site. Overall, the rotary hoe appears to hold the most promise of the two devices as the finger weeder plugs where corn stalks are present.

4 a) Effect of 1988 Interseeded Cover Crop and Catch Crop Systems In Winter Wheat on Nutrient Cycling and Corn Yield In 1989.

The most promising cover crop treatments at the silt loam site and sandy loam site were evaluated for their effect on nutrient cycling and corn yield. Whether measured by differences in corn grain yield or leaf ear N content at silking, estimates of nitrogen release from cover crops were very similar. Unfertilized hairy vetch provided corn yields equivalent to corn fertilized with approximately 100 kg/ha fertilizer N at both sites. The other cover crop species tested: red clover (on the silt loam site), and crimson clover and oilseed radish (on the sandy loam site), provided unfertilized corn yields equivalent to corn fertilized with approximately 75 kg N/ha Sampling to determine differences in phosphorus nutrition among treatments taken at the five leaf stage indicated a high correlation between N and P content. Legumes cover crops showed positive effects on N and P content. Oilseed radish significantly reduced uptake of phosphorus and nitrogen at the five leaf stage.

4 b) Effect of 1988 Interseeded Cover Crop and Catch Crop Systems In Winter Wheat and August Manure Applications on Nutrient Cycling and Corn Yield In 1989.

Red clover generally provided higher leaf ear N contents and corn yields than other cover crop species tested (crimson clover, hairy vetch, nitro alfalfa). Unfertilized red clover provided corn yields equivalent to corn fertilized with approximately 50 kg N/ha Cultivation after the cereal grain harvest in 1988 reduced 1989 corn leaf ear N and corn yields by approximately 20% compared to the uncultivated control plot. Application of manure in August 1988 had little impact on leaf ear N or corn grain yield in 1989. Significant loss of nitrogen may have been experienced at this site as a result of wet field conditions and early release of nitrate from the annual cover crops. Comparisons indicated that although the five legume cover crop treatments had lower soil P than manure treatments, P content of the corn at the five leaf stage was increased significantly. Nitrogen levels in the corn at the five leaf stage were also increased significantly by the legume cover crops.

Choice and Management of Cover Crop Species for Use in Row Crop Dominant Rotations

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I. Introduction

The overall objective of the research trials was to develop crop production systems that maintain or enhance farm productivity and profitability while reducing as much as possible inputs of fertilizer, herbicides and tillage. We propose to achieve this through improving the biological efficiency of the cropping system by: increasing ground cover, adopting a regular rotation of crops, reducing nutrient losses and increasing nitrogen fixation, malting greater utilization of sunlight, improving soil quality and using weed-suppressing living and non-living mulches.

The use of the term cover crop has become almost synonymous with green manure or plowdown crops but there is a significant difference from the standpoint of soil conservation. Cash crops such as winter wheat can serve as cover crops, even if not used as a green manure, and may offer some advantages over traditional cover crops. Winter wheat is more easily established in soybeans or following soybeans than are traditional grass or legumes cover crops. Further, because it is removed as a crop in late July it allows considerable time subsequently for growth of a soil-improving interseeded cover crop or fall seeded catch crop. Our contention is that the cash crop farming system with the greatest potential for reducing soil loss, maintaining soil properties, improving nitrogen and phosphorus cycling and for being financially viable in the study area is a corn-soybeanwheat rotation. This rotation sequence is being developed by some of the leading conservation farmers in Southwestern Ontario.

Basic Rotation

	Year 1	**Year 2**	**Year 3**
Cash Crop	Corn	Soybeans	Winter Wheat
Cover Crop	Grass	Winter Wheat	Legume

We recognize the difficulty in evaluating a 3 year rotation during a shorter time period. However, evaluating each year of the sequence intensively during a 2 year period at several locations can provide considerable information on this system across a variety of management situations and environments. Spring grains were also included in the study as many farmers in the area use spring cereals as an alternative to winter wheat or have some fields in a corn–spring grain, two year sequence.

As much as possible a grass type cover crop is used prior to the soybean main crop and a legume cover crop prior to corn. In addition to their soil improvement value, most of the cover crop systems offer other incentives for their adoption. Some examples:

- As double crops: two crops are grown on the same land in one year e.g. buckwheat after winter wheat, winter rye (harvested as a forage) before soybeans, or soybean relay sown into high moisture winter barley.

- As a nitrogen source: red clover, crimson clover, nitro alfalfa and hairy vetch seeded in cereals
- As a weed suppressant to reduce herbicide use: winter rye in the mow-kill no-till soybean system, interseeded ryegrass in corn, oilseed radish after cereals
- As a means to reduce tillage costs : no-till and aerial seeded wheat systems, rye discing and mow-kill systems and high moisture winter barley-soybeans relay cropping.

Some examples of how a farmer might incorporate cover crops include:

		Crop	**Cover crop**
Beef farmer	Year 1	Corn silage	Winter rye
	Year 2	Winter rye silage Soybeans	Winter wheat
	Year 3	Winter wheat Red clover forage	Red clover
Hog farmer	Year 1	Corn grain	Ryegrass interseed
	Year 2	Soybeans	Winter cereal aerial seeded
	Year 3	Winter cereal	Liquid manure & oilseed radish
Cash crop farmer	Year 1	Corn grain	Winter rye Mow-kill
	Year 2	Soybeans	Winter wheat no-tilled
	Year 3	Winter wheat	Hairy vetch

The On—Farm Research Co-operators

All of the co-operators are located in South-Western Ontario, within four counties: Oxford, Perth, Wellington and Waterloo.

Keith Baechler, swine farmer, Rockwood
Larry Bender, hog, beef and poultry farmer, Tavistock
Robert Chesney, cash crop farmer, Innerkip
Craig, Keith and Quentin Martin, dairy and cash crop farmers, Winterbourne
Keith and Jeff Quinn, dairy farmers, Salford
David Reibling, beef and cash crop farmer, Tavistock
Carl Ruby, hog farmer, Tavistock
Carl Schlegel, beef farmer, Shakespeare
Harry Wilhelm, cash crop, sheep and poultry farmer, Tavistock
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II. Literature Review

THE ROLE OF COVER CROPS IN CROP, SOIL AND WEED MANAGEMENT

REAP—Canada Report
by Roger Samson

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One of the most underutilized methods of improving crop, soil, and weed management is the use of cover crops. Numerous advantages to their use can be realized including reduced erosion, increases in soil tilth, additions of organic matter, nitrogen fixation, improved nutrient cycling, weed suppression and increased biomass production per land unit area. Lack of use of cover crops and the resulting drop in natural fertility of the soil may be a major reason farmers have suffered declining or stagnating crop yields while at the same time experienced increases in problems with soil fertility and weeds.

Major problems appear to exist on current knowledge on how to economically incorporate cover crops into present day farming systems. Interseeded cover crops in particular need to be managed properly so as not to compete significantly with the main crop. Also a greater understanding of cover crop management needs to be evaluated in rotations as much of the research has been performed in continuous spring cereal or corn systems.

Cover Crops Systems for Soybeans

The most common cover crop system involving soybean production in Canada is winter wheat either direct drilled or aerial seeded into standing soybeans. No research has been done on the aerial seeding system to date but farmer recommendations are that **a** late soybean cultivar should be seeded and wheat flown in at a seeding rate of 150 kg/ha (Crabbe 1986). A late variety enables wheat to be aerially seeded when leaf yellowing in the soybeans coincides with the optimal wheat planting date. In areas where soybeans are grown in wide rows, interseedings of forage legumes and grasses have been successfully established (Palada *et al.* 1982; Robinson and Dunham 1954). However, in row widths of 75 cm. or less, aerial seeding at leaf drop may be the only way of establishing forages in soybeans. This method of establishment would likely be restricted to longer season areas only.

The use of a cereal cover crop prior to soybean planting offers considerable potential in reducing soil erosion and improving soil structure. There are two main systems of management using winter cereals in soybean production systems.

1. Ground Cover Systems: in which the cereal is mowed, herbicide killed or tilled to provide weed control, erosion control and improve soil tilth.
2. Soybean Relay Cropping Systems: In which the soybeans are planted into a growing winter cereal crop. The cereal is then harvested as grain by lifting the combine cutter bar above the height of the soybeans at harvest.

Ground Cover Systems Using Winter Rye

In ground cover systems using lye, several studies have examined the influence of various tillage systems of unharvested rye on soybean plant populations, yield and insect populations. In a two year study in Ohio, tilled rye treatments increased populations of seed corn maggots causing plant stand reductions and a significant yield reduction in one year (Hammond 1984). Soybean plant stands in the rye cover crop systems were considerably higher in no-till treatments than plowed or disced systems. Some authors have also reported reduced plant stands occurring in soybeans planted no-till into rye (Eckert 1988). Over four years, rye cover crops lowered no-till soybean yields by 1.25 bu/acre in a corn-soybean sequence and by 1.5 bu/acre in continuously grown soybeans. However, some studies have found that with long term use of rye or when difficult weed control problems occur rye significantly increases crop yield (Wrucke and Arnold 1981; Johnson and Webb 1987). Considerable effort needs to be put into no-till drilling and cover crop management techniques by researchers to alleviate current agronomic problems. One promising system that has been developed by Mike Strohm, an Illinois farmer, over the past five years is to mow the rye with a flail chopper after no-till drilling soybeans. The mowing provides a means to kill the rye mulch with minimal use of herbicides and enables the rye to act as a moisture conserving mulch (the rye lays chopped on the soil surface instead of standing as in herbicide kill systems).

Relay Cropping Systems using Winter Cereals

Relay cropping systems have received considerable research interest in the northern U.S. where the growing season is too short to perform regular double cropping of winter cereals and soybeans. Volak and Janke (1986) reviewed reports on relay cropping winter cereals and soybeans and cited research where relay cropped systems produced yields which were approximately 95% of both sole cropped winter wheat and sole cropped soybeans. However, in dry years other reports have cited complete mortality of relay cropped soybean seedlings (Chan *et al.* 1980).

Some of the problems that have been associated with the system include: soybean drilling damaging the winter cereal; inefficient weed control; poor soybean germination; soybean seedling damping off and soybeans interfering with wheat harvesting (Jeffers 1982; Volak and Janke 1986).

Several of the potential advantages of the system are: 1) enabling two crops per year to be grown in areas too far north for conventional double cropping; 2) the second crop is planted at a time when soil moisture is more readily available compared to double crop systems; 3) soil erosion is reduced as the small grain acts as a soil conserving mulch; 4) herbicide inputs may be reduced through competition, physical inhibition (mulching, shading) and allelopathy (toxins released by one species which interfere with the growth and germination of another) 5) energy use is reduced as the soybeans are planted no-till and low nitrogen levels are used on the winter cereal *(Chan et al.* 1980; Volak and Janke 1986).

Volak and Janke (1986), made several recommendations for winter wheat relay cropping with soybeans. First, date of seeding is important. The longer the delay , the more the soybean yield is decreased and the wheat damaged from field traffic. Second, seed to soil contact should be ensured through use of an appropriate planter and planting on soils with good friability. Third, try not to clip the soybeans at wheat harvest, especially flowers. More recently several researchers have recommended to restrict nitrogen applications to the winter cereal as excessive fertilization makes the winter cereal too competitive and increases annual grass competition with the developing soybeans (Reinbottet al 1987; McNamara *et al.* 1988).Cereal species that have been evaluated for relay cropping systems with soybeans have included spring oats, spring barley, winter barley, winter rye and winter wheat. Volak and Janke (1986) tested four cereal species and found that winter barley produced higher soybean yields than other species and that this was attributed to the early harvest date of winter barley. Under Canadian conditions winter barley may be the only suitable species for relay cropping with soybeans due to our short growing season. Harvesting of the winter barley as a high moisture feed grain may also make the relay cropping system less risky as it would enable removal of the winter barley approximately 10 days earlier than conventional harvesting. This would reduce competition with the soybeans, reduce the potential for damage to the soybean crop at harvest and improve winter cereal yield as interference with the soybean canopy would be limited and harvest losses reduced from not harvesting as a dry grain (McLaughlin *et al.* 1981).

Considerable potential exists in the system if methods can be developed to reduce cropping risks and relatively stable yields of winter cereal and soybean can be achieved in the 60 % level. Lower production costs for fertilizer, herbicide and tillage may be the key factor enabling farmers to develop the relay cropping technique if significant risks are present.

Interseeded Cover Crop and Catch Crop Systems in Cereals

Several systems of cover crop management can be used to take advantage of the 2-3 month growth period after harvest of winter or spring cereals. Cover crops can be undersown at planting in the case of spring cereals, oversown in both established spring and winter cereals or grown as catch crop following cereal harvest. The method of establishment used is generally dependent on the rate of growth of the cover crop. Perennial species are generally undersown at seeding or shortly thereafter while annual species are sown during cereal growth or seeded as fall catch crops shortly after cereal harvest.

Interseeding systems In cereals

The main advantages of interseedings is that they provide for an earlier establishment of the cover crop and this avoids the need for cultivation and seeding after harvest. As well, mid-summer sowing of perennial legumes does not always lead to successful establishment and fall biomass production is generally minimal. As a result the general practice has been to underseed perennial legumes at or shortly after seeding.

One of the concerns with interseeded cover crop systems (i.e. undersown or oversown) is that they can compete with the main crop or cause difficulty at harvesting. Forrest (1985) tested numerous species and varieties sown at planting over a five year period and found barley yields were not reduced while excellent plowdown crops were obtained. The findings of nine trials over five years found barley yields of 3215, 3216 and 3271 kg/ha for plots undersown to double cut red clover, single cut red clover and not undersown respectively.

Neither barley or oat varieties were affected when red clover was seeded at planting or when seeding was delayed until 10 days after planting (Gamble 1980). However the red clover plants showed reduced vigor and particularly poor forage establishment occurred with the delayed seeding.

Italian ryegrass, seeded at 20 kg/ha, was found to give over a 25% yield reduction in a one year barley study in England by Cussans (1972). Undersown red clover at planting and oversown white mustard *(Brassica /caber L.)* and oilseed rape *(Brassica campestris L.)* in mid-June tended to increase barley yield and the increase reached a statistically significant level, in the case of one of the varieties of oilseed rape. In the second year of the study Italian ryegrass was replaced by perennial ryegrass *(Lolium perenne L)* and the varieties of oilseed rape changed. No significant yield differences were found although there was a tendency for yields to be depressed by undersowing red clover or ryegrass as compared to oversowing the brassica species in mid-June.

In Australia, Brownlee and Scott (1974) tested the effect of different sowing rates of wheat and undersown black medic *(Medicago lupulina* L.) on yields of grain and subsequent forage production. For maximum economic benefit, wheat densities and medic densities were suggested that would result in a wheat yield reduction of 131 kg/ha. Studies of manipulating seeding rates in cereal plowdown systems have not to date been performed.

Several studies have also evaluated the effect of interseeded cover crops on winter wheat yield. Over three years Ngalla and Eckert (1987) in Ohio, drilled red clover in standing wheat in April and found yield reductions of about 3 bushels/acre on average per year. Janke *et al.* (1987) found no effect on winter wheat yield from drilling crimson clover and hairy vetch in wheat in early May while early frost seedings of hairy vetch grew tall and interfered with wheat harvest. Early introduction of hairy vetch has produced similar problems in spring cereals. When seeded with oats at planting, hairy vetch climbed extensively and completely lodged the oat crop at harvest (Duley, in Walters 1987).

Fall catch crop systems

Although not widely used in Canada, fall catch crop systems are very popular in European countries. Fast growing, cool season, frost tolerant annuals are the most widely used species for this short growth period.

Some of the species currently being used in Europe are oilseed radish *(Raphanus raphanistum),* white mustard *(Sinapsis alba),* and phacelia *(Phacelia tanacetifolia).* Almost no evaluation of these species has occurred in Canada to date but some farmers are experimenting with the use of phacelia and white mustard. Oilseed radish is being used extensively by organic farmers in Canada and is rapidly increasing in popularity. It is generally sown after winter cereal harvest in mid August as the earlier harvest of winter cereals enables timely planting of the oilseed radish. Winter cereals also provide less cereal regrowth than spring cereals and this enables better oilseed radish establishment and growth. However, white mustard can be planted several weeks later than the other species as it has very rapid fall growth (Monfort, 1987). It may be more suitable for use after spring cereals than the oilseed radish.

Effect of cover crops on subsequent crops

Improved crop performance and/or lowered cost for nitrogen can result from using legume or brassica cover crops. However, the brassicas appear to be more adapted to lighter soil types. In a continuous barley production system in Denmark, Stokholm (1979) studied the effects of cover crops on grain yields on a sandy soil and a clay loam soil over a six year period. Yield reductions of 1030, 620 and 300 kg/ha were obtained from underseeding Italian ryegrass, black medic, and red clover respectively. White mustard and fodder rape *(Brassica napus)* had no significant effect on crop yields. Stokholm attributed the yield reductions in the case of red clover and black medic to poor weed control. In the seventh year of the study, the effects of the six years of cover cropping was determined on a barley crop seeded with no cover crops. All previous systems with cover crops had positive effects on yields with white mustard, red clover and fodder rape being superior. At the lowest nitrogen level (30 kg/ha) the yield was increased 880, 800 and 670 kg/ha for each of the three species respectively.

On the clay loam site, average final year yield increases of 410, 400 and 380 kg/ha were obtained for each of fodder rape, red clover and white mustard, respectively. In the six previous years. none of the species had significant yield effects on barley although the red clover increased yields 290 kg/ha at the lowest nitrogen level used.

Kundler *et al.* (1985) evaluated the effects of stubble crop green manuring with crucifers and different methods of tillage on yield of continuously cropped winter wheat and continuously cropped spring barley over a nine year period. The highest yields in both cereal systems were obtained from the intermediate tillage system (protective tillage with medium deep (25 cm.) plowing after the cereal harvest and subsequent rotary tillage or discing 10-15 cm.) combined with stubble crop green manuring. Yield increases of 22% in winter wheat and 16% in spring barley were obtained over the conventionally tilled system without green manure use.

More frequently in Eastern Canada, studies have compared corn growth following cereal grain plowdown systems. Fulkerson (1982) evaluated corn yields from plowdown of Ottawa red clover and Saranac alfalfa managed as direct seedings or undersown under oats harvested as grain. Corn yields were slightly higher for the alfalfa at 6650 and 7650 vs 6400 and 7275 kg/ha for the red clover following the companion crop and direct seeding methods respectively. No check yields were reported.

When forages were direct seeded or undersown to oats harvested as silage, Bruulsema and Christie (1987) compared alfalfa, double cut red clover and single cut red clover for their effects on corn. Corn grain yields were similar for all species and cultivars. In general, legume plowdown supported corn yields equivalent to those receiving 90-125 kg/ha of nitrogen. Maximum economic corn yields were achieved with approximately 150 kg N/ha in check plots. However, the researchers reported there appeared to be no association with succeeding corn yield and plowdown N yield.

Fulkerson (1983) and Bruulsema and Christie (1987) have found that approximately 2/3 of this nitrogen is available to the following crop. Bruulsema and Christie (1987) reported that this was substantially higher than that reported by others working with different species.

Forrest (1985) carried out numerous trials on plowdown species established under barley and their effect on corn. In a trial comparing single cut red clover, double cut red clover, alfalfa and an annual alfalfa, double cut red clover produced the highest shoot biomass and subsequent corn yield. A summary of nine trials over five years found corn yields of 7965, 8322, 6524 and 8775 kg/ha for plots receiving a plowdown of single cut red clover, double cut red clover or nitrogen rates of 0 and 150 kg N/ha respectively. Although the yield was slightly lower with the double cut red clover there was a $26/ha advantage in net farm income from using the clover to supply nitrogen to the corn. Forrest reported that additional trials suggested economic yield increases can be achieved by using small quantities of nitrogen fertilizer along with the plowdown.

Interseeded Cover Crop Systems in Corn

Interseeding of legumes and grasses in corn crops was commonly used in the United States before the widespread use of herbicides. In Pennsylvania in 1840, it was reported, "A first rate agriculturalist and a member of the state senate is accustomed to sow a full crop of red clover in his corn at the time of the last cleansing... He has obtained heavy crops without the least injury to the corn”. (Stevenson 1955). In the following years a variety of other crops were used, both legumes and non-legumes, such as crimson clover, hairy vetch, sweet clover and rye. By 1935 domestic ryegrass largely superseded other species for use as a winter cover because of the ease with which a stand may be secured and the large amount of organic matter added to the soil (Stevenson 1955).

In the 1950's extensive research was done on corn-forage intercropping, primarily to evaluate corn as a companion crop for forage crop establishment. Many recommendations were produced:

- — planting wide spaced corn rows of 60-80 inches (Stringfield and Thatcher 1951; Larson and Willis 1957; Schaller and Larson 1955)
- — drilling and packing alfalfa over a fertilizer band (Tesar 1957)
- — cultivate twice and seed alfalfa in corn with a cultipacker type seeder up to the six leaf stage in corn (Jackobs and Gosset 1956).
- — prevent excessive ridging on the corn rows by planting in the tractors wheel tracks, cultivations then fill in the depression in which corn is planted (Vandoren and Hays 1958).
- — plant corn at the same rate as recommended for normal row spacing to obtain maximum yields from wide spaced rows (Vandoren and Hays 1958)

More recently Nordquist and Wicks (1974) evaluated establishment of alfalfa in irrigated corn conditions. Alfalfa stand and yield were increased 27% and 9% respectively, when alfalfa was planted simultaneously with the corn and the corn harvested as silage as compared to interseeding at final cultivation in grain corn. Scott *et al* (1984) evaluated the feasibility of establishing short term red clover hay crops by intercropping and obtained yields 87% that of direct seeded red clover stands.

Effect on seeding year corn yield

The feasibility of using interseeded cover crops in corn production systems for purposes of green manuring has received considerable attention since the late 1970's.

However, a major constraint to farmer acceptance of this system is that the intercrop should have little impact in the seeding year on the corn yield. Studies evaluating the seeding of corn and forages at the same time showed substantial yield reductions averaging approximately 25% (Ampong 1985; Nordquist and Wicks 1974; Jackobs and Gosset 1956; Schaller and Larson 1955; Tomar *et al.* 1986;). Alfalfa may be more competitive than red clover when seeded at this time (Ampong 1985; Tomar *et al.* 1986).

Studies have also shown that corn yields were not affected by intercrops during the year of establishment provided that corn was 0.15 to 0.30 m in height (approximately 35 days after planting) at the time of intercrop establishment (Ampong 1985; Hofstetter 1984; Jackobs and Gossett 1956; Nanni and Baldwin 1987; Scott *et al.* 1987). Under irrigated conditions, Nordquist and Wicks (1974) found yield reductions of 3% when alfalfa was interseeded at the final cultivation in corn. However dwarf corn hybrids were included in the average.

Biomass production from Interseeded cover crops

In New York, Scott *et al.* (1987) performed extensive studies evaluating 18 species and varieties as intercrops and cover crops. When seeding at 0.15 m -0.30 m corn height, ryegrass and medium red clover and a combination of the two were the most effective in terms of ground cover and dry matter production. Perennial ryegrass and rye *(Secale cereale* L.) could be successfully seeded at mid-silk and rye and rye-hairy vetch *(Vicia sativa* L.) mixtures were the best performers when seeded after silage harvest. In systems where conventional seeding and nitrogen rates for corn were used, annual or perennial ryegrass seeded at 0.15-0.30 m in height or at mid silk produced the largest total biomass. Total biomass produced by the ryegrass treatments averaged 3300 kg/ha while the red clover produced approximately 1800 kg/ha. When the system was managed in a continuous corn silage system without nitrogen over five years, corn yields dropped substantially particularly in the annual ryegrass treatment where leaf ear nitrogen was consistently lowest. Without nitrogen, red clover and red clover-ryegrass mixtures provided the greatest dry matter production and produced 79 kg N/ha by spring plowdown. From these plots ear leaf nitrogen was the same as that of the control receiving 17 kg N/ha. As the corn was a poor competitor due to nitrogen deficiency, part of the poor nitrogen response from the clover may have been due to the interseeded forage competing with corn for moisture and nitrogen as previously found by Kurtz *et al.* (1952).

In a one year study in Ontario, Ampong (1985) found that red clover seeded in grain corn after one cultivation produced approximately 425 kg/ha of shoot biomass by fall compared to 200 kg/ha for alfalfa. A system with no cultivation provided 340 kg/ha and 230 kg/ha of shoot biomass for red clover and alfalfa respectively. Working with sweet corn, Vrabel (1980) obtained fall shoot biomass yields of 760, 720, 675 and 660 kg/ha for white clover, red clover, ladino clover and alfalfa respectively, interseeded five weeks after planting. However some seeding rate errors were made, with ladino clover being seeded at 22.4 kg/ha and red clover at 6.7 kg/ha.

Hofstetter (1984) interseeded several species of forage in corn having an average height of 38 cm (time 1) and 84 cm (time 2). At time 1, spring shoot biomass of 970, 325 and 470 kg/ha were produced from hairy vetch, red clover and annual ryegrass respectively. At the second seeding time, spring shoot biomass of 1188, 840, 474 kg/ha were produced for each of the three species. Corn grain yields following plowdown were influenced by the cover crop species and nitrogen rate. Highest yields were obtained from the hairy vetch plowdown treatments that received 110 and 165 kg/ha of nitrogen.

Double Cropping Systems using Cover Crops As Forage

One of the primary concerns with using non-legumes as cover crops is that there is little direct financial benefit from the use of a cover crop. With legumes, farmers may reduce there nitrogen requirements but with grasses in particular there is no nitrogen benefit. One method of recovering the cost of seeding the cover crop is to use it as a forage source. This can also significantly increase total per acre productivity if the system is properly managed.

Winter cereals

Recent studies have been performed evaluating winter small grains as potential forage crops for double crop systems. Winter triticale and forage rye cultivars appear to be the most promising species for producing high quantities of forage biomass (Twidwell *et al.* 1985; Maiga *et al.* 1986; Daynard *et al.* 1984). Timing of harvest is important as yield increases rapidly after reaching the boot stage, while forage quality declines. Some of the quality problems associated with delayed harvest may be alleviated by including hairy vetch in the winter cereal mixture as hairy vetch contains approximately 25% protein (Twidwell *et al.* 1985; Ebelhar *et al.* 1984). However, the main concern in timing of harvest is the tradeoff between timely main crop planting and increased winter cereal yield (cereal biomass production is increased approximately 50% by delaying harvest from the flowering to the soft dough stage while this may reduce the main crop yield) (Twidwell *et al.* 1985). Experimentation on double crop systems has evaluated the use of spring harvested winter rye followed by seeding of beets, corn, fababeans, kale, potatoes, sorghum, sunflowers, and swedes. The most promising systems appear to include main crops of kale and potatoes in cooler season areas and corn and sorghum in warmer regions (Hostrup *et al.* 1982; Daynard *et al.* 1984). No studies were found which evaluated a double crop system of soybeans following harvest of winter rye. However, it is an increasingly popular practice in the Southern U.S. to double crop soybeans after winter wheat or winter barley harvested as grain (Camper *et al.* 1972; Hairston *et al.* 1987).

In most studies, rye double crop systems have increased biomass production over the total season versus a sole crop.

Daynard *et al.* (1984) tested several rye cultivars to measure the total seasonal biomass productivity of a two crop sequence in which rye is planted in late September and harvested in May, with corn being planted immediately thereafter and harvested as forage in mid-September. Wheeler

Table 1. Effect of Rye Cover Crop Management and Tillage Systems on Total Biomass Production

Rye Management	***Tillage System***	**Elora**	**Woodstock**
		Total Biomass	
No rye	No till	12.4	15.1
	Disc	13.8	13.9
	Plow	13.8	14.6
Rye harvested	No till	13.8	15.4
	Disc	15.2	17.1
	Plow	15.2	15.3
Rye left	No till	11.4	12.5
	Disc	11.7	11.1
	Plow	11.8	12.9

Rye spring biomass yields were 2.9 and 4.8 t/ha at Elora and Woodstock, respectively.

Daynard *et* al .1984

rye-corn double crop systems produced total biomass production of 21 t/ha (6.1 t/ha rye silage and 14.9 t/ha corn silage) vs 16.7 t/ha for the sole corn crop. On two different soil types in the Netherlands, Hostrup *et al.* (1982), found feeding units per hectare were increased by approximately 25% and crude protein production per hectare by 50% with a double crop system using rye and kale. Working in Poland, Waligorska (1982) found corn grown as a main crop yielded an average of 10.8 - 11.8 t/ha dry matter compared with total yields of 13.7 - 15.0 t/ha for corn or corn/fababean mixtures plus winter rye harvested at stem elongation and 11.4 - 2.7 t/ha for corn or corn/fababeans plus rye harvested at heading. Harvesting at stem elongation was superior to harvesting at the flowering stage in rye for maximizing dry matter production.

Optimizing the time of rye harvest has also been the subject of other studies. Daynard *et al.* (1984), examined the effect of planting dates (May 28 and June 15 at Elora; May 28 and June 19 at Woodstock) and tillage systems (no-till versus roto-tilling) on total biomass production. Corn growth and yield were depressed with the later planting dates particularly when corn was no-till drilled. However, total biomass production was highest at both locations when corn planting was delayed until the June planting dates (providing rye biomass of 5.2 and 6.4 t/ha) and the rye stubble incorporated.

Daynard *et al.* (1984), conducted a further study involving comparisons of the effects of three rye treatments X three tillage treatments. Rye X tillage interactions tended to exhibit the same trend, with no difference in tillage treatments on the no rye plots and no-tillage treatments generally being inferior to tillage treatments on plots which had previously grown rye which had been harvested.

Legumes and Brassicas

A significant period of growth exists after harvest of spring and winter cereals to produce considerable forage biomass. Perhaps the greatest biomass potential exists by utilizing frost tolerant species which can actively grow under cool days of short photoperiod. Frost tolerant Brassicas appear to offer the most potential. Several studies have indicated that these species can continue to grow until early November. Late July, early August seedings, of these Brassica species would normally be possible after a winter wheat crop in Southern Ontario. The main species with potential for use are kale, fodder rape, turnips and hybrid turnips. These species offer a high protein, high energy forage source that can be grown during a period when plant growth is generally slow and pasture quality and availability low.

In a two year study in Ontario, Fulkerson and Tossell (1972) obtained Oct. 30th kale dry matter yields of 4664 kg/ha and 2646 kg/ha when planted on July 30 and Aug. 12 respectively. Working in a no-till system in Connecticut, Guillard and Allinson (1984), obtained 7250 kg/ha of root and shoot dry matter from ‘Tyfon' hybrid turnip planted on July 29 in a no-till system. In Pennsylvania, Jung *et al.* (1984) had two year dry matter yields averaging 8000 kg/ha from late July, early August, seeded turnips and rape. The authors concluded that with adequate fertilization these species produce amounts of digestible energy equivalent to that of a corn crop yielding 7200 kg/ha (115 bu/acre).

Some farmers in Ontario have been harvesting or grazing red clover plowdown seeded in spring and winter cereals. However, little scientific evaluation of the use of fall red clover plowdown as a forage and its subsequent nitrogen value has been performed. Bruulsema and Christie (1987) managed red clover as a spring planted forage, left unharvested or harvested, and found nonsignificant effects on the following years corn yield. In the U.S. some recent reports have found winter legume cover crops that are managed for both forage and nitrogen potential to offer greater overall return to the farmer. Removal of a winter cover crop of crimson clover did not significantly reduce the availability of nitrogen to the following grain sorghum or corn crop (Touchton *et al.* 1982; Holderbaum *et al.* 1986). Working with corn in Maryland, Holderbaum *et al.* (1986) concluded that use of overwintering cover crops for spring silage or pasturing enhance the flexibility of utilizing the legume cover crop and increase the potential contribution of the cover as both a nitrogen source and forage. Two year average spring silage harvests of 5.03 t/ha, and pasture yields of 3.43 t/ha were obtained from the crimson clover prior to corn planting.

Effects on Soil Properties and Erosion

Soil erosion and ground cover

Intercrops and cover crops can have dramatic effects on reducing soil loss. The over riding principle of erosion control is the duration and intensity of vegetative cover (Siddoway and Barnett 1975). Mannering and Fenster (1977) maintain that this is because of the direct effect of growing vegetation and its protective and stabilizing influence on soils as well as the residual effects of vegetation in stabilizing soil structure. Tillage systems have been found to practically have no influence on runoff unless they change surface cover (Derpsch *et al.* 1986). However, most of the studies suggest that the combined use of cover crops (for ground cover and soil improvement), reduced tillage and crop rotation can greatly reduce runoff and soil erosion compared to plowed monoculture production systems.

Scott *et al.* (1987) performed extensive studies on ground cover improvements from interseeding various legume and grass species in corn used for silage. The most effective species and mixtures for increasing ground cover when standard corn populations and nitrogen fertilizer rates were used were ryegrass or red clover-ryegrass mixtures. Average November ground cover was improved approximately fivefold to 68-85% while May ground cover was increased 15 fold to 67-88%. Rye seeded after silage harvest provided approximately 35% fall cover and 60% spring ground cover. An additional advantage of increased ground cover through undersowing in corn is also the reduction of soil compaction at harvest (Vogtmann 1985).

Most studies evaluating the ability of cover crops to reduce runoff and soil erosion have been performed on corn.

In Germany, Schafer (1986) evaluated the effect of catch crops and reduced cultivation on soil erosion in corn. Catch crops reduced runoff to 12% of that from bare fallow and 25% of that from corn alone. In winter and during heavy rain in early summer the cover crops were particularly effective, reducing soil losses by 50% after closure of the corn canopy. A ten year study evaluating the effects of cover crops and mulch tillage in a continuous corn system was performed in South Carolina (Beale *et al.* 1955). Erosion losses were reduced by 85% if a plowed system was replaced by a mulched tillage system using a hairy vetch and rye cover crop. Annual soil losses averaged 0.43 1.22 and 2.81 tons/acre over the ten year period for each of the respective systems: cover crop + mulch tillage; cover crop + plowing; and plowing. Superior soil properties may have helped reduced runoff and erosion on the vetch-rye plots. Organic matter and soil aggregate stability increased on these plots and decreased on the plowed plots through the course of the study (Beale *et al.* 1955; Peele *et al.* 1946). Other authors have found that structural stability greatly influences soil erodibility (Voorhees 1979; Jackson 1988).

The benefits of cover crops in reducing runoff have also been evaluated in tropical climates. In Hawaii, A legume cover crop *(Crotolaria juncea)* decreased runoff by 20% on average in corn production systems. The tillage system used (no-till, chisel plow or moldboard plow) had little further effect on runoff when the legume cover crop was grown. Without the use of a cover crop erosion losses increased with amount of tillage.

However, the use of a cover crop enabled adequate protection from erosion without using minimum tillage techniques (Fahrney *et al.* 1987). After 7 years of studies on tillage systems and cover crops in Brazil, Derpsch *et al.* (1986) concluded that a no tillage production system used with appropriate mulch producing cover crops and crop rotations represented one of the most efficient production systems to conserve the soil and make permanent land use possible. Some studies also suggest that the type of cover crop used may influence runoff. In a study performed in Nigeria, deep rooted legume cover crops created higher infiltration rates than shallow rooted grasses (Wilson *et al.* 1982).

Soil organic matter additions

Cover crops affect the rate of loss of organic carbon in cropping systems through reduced erosion and incorporation of organic material. Pieters and McKee (1938) state "the main object of green manuring must be to maintain rather than increase the quantity of organic matter in soils". However, this was at a time when many of our soils had high levels of organic matter. More recently it has been generally accepted that green manures will maintain or increase organic matter or maintain or increase soil nitrogen levels but not both at the same time (Allison 1973; Warman 1980).

MacRae and Mehuys (1985), in a review on the effects of green manures, list more than 20 factors that affect accumulation of organic matter. They concluded that the relative influence of these factors and how they interact is not well understood. However, the majority of studies indicate that organic matter accumulation from green manures is enhanced by plant materials resistant to ready decomposition. This can be plant material typically low in nitrogen i.e. 1.5% nitrogen or less on a dry weight basis (Sowden and Atkinson 1968; Warman 1980) or material of high percentage lignin (Leuken *et al.* 1962). Italian and Westerwold ryegrasses are perhaps the species of choice for increasing organic matter in Eastern Canada due to their high biomass production, large root mass, and relatively low nitrogen content (Kunelius and Veinot 1982; Kunelius and Goit; 1982).

In the past 50 years organic matter levels have declined considerably in intensively cropped areas and this could perhaps be affecting the more recent conclusions. Joffe (1955) suggests that once a cultivated soil reaches an equilibrium level in soil organic matter, no management practice can lower it, and then it would be more feasible to increase soil organic matter content by incorporating green manures.

One long term study that supports the concept of Joffe was performed by Beale *et* al. (1955). An initial soil organic matter content of 1.2% was not decreased by 10 years of continuous corn and plowing. However, plots with a hairy vetch-rye cover crop increased organic matter content by 0.41% and 0.56% in plowed and mulched tilled treatments through the course of the study. A pure legume cover crop, crimson clover, increased O.M. by 0.15% and 0.40% in the plowed and mulch tilled treatments.

Soil physical properties

Soil physical properties generally follow organic matter with respect to influence by cover crops and tillage as: grass cover crops are generally superior to legume cover crops in improving aggregate stability; and differences in aggregate stability using cover crops are generally only seen after several years of use. In a one year study, Ampong (1985) found no significant effects on aggregate stability from either undersown red clover or alfalfa in corn. Benoit *et al.* (1962) working with a rye cover crop after corn found that annual additions may be necessary for several years before aggregate stability increases.

Grasses such as ryegrass which have an extensive root system tend to increase aggregate stability more rapidly than legumes (Clarke *et al.* 1967; Tisdall and Oarles 1979).

Working with summer seeded green manures in Ohio, Mortensen and Young (1960), found ryegrass to promote greater soil aggregate stability than sweet clover *(Melilotus alba* Desr.) or alfalfa which had no significant effect.

After a six year period of green manuring in a continuous spring barley system on a sandy soil in Denmark, Stokholm (1979) found Italian ryegrass *(Loliwn multiflorwn Lam.)* and red clover *(Trifolium pratense* L.) to give a significant improvement in aggregate stability. At another site on a clay loam soil, Italian ryegrass was followed by white mustard *(Sinapsis alba L.) as* the best two green manures for increasing porosity in the soil. Tisdall and Oades (1979) found that the reason that ryegrass is more efficient than legumes in improving the stability of aggregates is that it supports a large population of vesicular-arbuscular mycorrhizal hyphae in the soil to which clay particles attach firmly.

Effects on Soil Nitrogen

Nitrogen Production From Legume Cover Crops

The ability of plowdown legumes to supply nitrogen within a farming system is well documented. It has been the subject of considerable research interest in the past 10 years. However achieving nitrogen self sufficiency through the use of interseeded cover crops in Eastern Canada is more difficult than in more southerly climates where extended growing periods are present after crop harvest and before crop planting. This gives considerable advantage over most Canadian conditions where fall seeding of forage legumes is rarely successful and the spring growth period of legumes before timely planting of nitrogen demanding crops is limited.

The largest quantities of nitrogen being produced from interseeded cover crops are in spring and winter cereal grain systems. Norris (1981) compared nitrogen production of red clover from seeding under winter wheat, barley and oats. Averaged over two stubble heights, the highest nitrogen production was obtained from winter wheat at 146 kg N/ha, followed by barley and oats at 122 and 105 kg N/ha respectively. He attributed the differences to the time of companion crop removal which in the case of oats was 13 days later than winter wheat and barley. The barley plowdown system produced lower quantities of nitrogen than winter wheat mainly due to lodging at barley harvest which slowed growth of clover seedlings.

Very large above ground biomasses were obtained by Janke *et al.* (1987) in a one year study testing various winter wheat interseedings. Biomasses of 5,610 kg/ha and 3,820 kg/ha were obtained from crimson clover and hairy vetch respectively. According to an equation developed by Hoyt (1987) this would be equivalent to 139 kg N/ha and 157 kg N/ha produced from the two respective species. Using the same equation, Samson *et al.* (1989) produced 144 kg N/ha and 119 kg N/ha on a clay loam and sandy loam respectively from interseeded hairy vetch in winter wheat in a drought year. Almost all studies evaluating corn yields following hairy vetch cover crops have provided yields as high or higher than other cover crops (Walters 1987; Ebelhar *et al.* 1984; Frye *et al.* 1985; Neely *et al.* 1987; Herbek *et al.* 1987; Utomo *et al.* 1987). In the only study performed to date with hairy vetch in Ontario, Maitland and Christie (1989) found that a full season green manure of hairy vetch produced larger quantities of nitrogen for corn than red clover, sweet clover or alfalfa. Resulting corn yields were high on the vetch but yields were not entirely related to nitrogen production.

The majority of studies in Ontario have evaluated systems of providing nitrogen production from legume interseedings in spring grains. When oats were harvested as a silage (July 20), Bruulsema and Christie (1987) found no significant differences in nitrogen production between Mammoth red clover , Medium red clover and early or late alfalfa. Average nitrogen production was 140 kg/ha from 32 varieties and common lots tested. However, over a four year period, Fulkerson (1982) found different results when competition was increased. Total nitrogen produced was 110 kg/ha from Ottawa red clover while only 91 kg/ha was produced from Saranac alfalfa when oats were harvested as grain. When both plowdown species were direct seeded, nitrogen production was similar with red clover and alfalfa producing 135 and 130 kg N/ha respectively.

Fulkerson (1982) found that nitrogen production could be increased 20% from red clover plowdown in grain (even though shoot biomass was reduced) under a post harvest companion crop stubble height of 7 cm as opposed to a long stubble of 30 cm.

Nitrogen production studies from interseeded legume cover crops in continuous corn production systems in the Northern corn belt do not appear to offer great potential to reduce nitrogen requirements substantially. Scott *et al.* (1987) found that when conventional rates of nitrogen were applied to corn used for silage, interseeded red clover was the best performing species, producing approximately 55 kg N/ha by spring plowdown. However, this estimate of N production may be high as spring corn planting was delayed to enable significant spring clover growth.

Influence of tillage on nitrogen release and crop yields

With the growing interest in reduced tillage systems a number of studies have recently compared the impact of tilling in the residues of legumes versus leaving them on the surface in a no-till system. Almost all studies have found total nitrogen uptake is reduced in no-till systems. This may be a function of both reduced nitrogen uptake from the legume and reduced "priming effect" of the legume plowdown on soil organic N mineralization. In previous studies where no cover crop is used, the rate of mineralization and nitrification has been found to be higher with conventional tillage while that for denitrification is higher with no-till (Doran 1980).

In a review paper on legume winter cover crops, Smith *et al.* (1987) concluded that there was abundant evidence that decomposition and mineralization of N are slower for surface residues. This effect being commonly attributed to lower moisture and nutrient availability for decomposition at the surface.

Some studies suggest red clover is particularly not well suited to no-till systems. Over three years in Ohio, Ngalla and Eckert (1987) studied N sources in a rotation of winter wheat to no-till corn. Fertilizer N applied at 110 kg/ha was found to achieve much larger yield increases and returns than the use of red clover interseedings as a nitrogen source for no-till corn. Developing a system which enables reduced tillage and efficient nitrogen release from cover crops may only come from utilizing species with low C:N ratios (high N content). Wagger (1987) found residue N remaining after 16 weeks in a no-till system to be 56%, 31% and 24% from rye, crimson clover and hairy vetch respectively over two years. Residue breakdown was relatively slow in one of the years in which rainfall was limited. Ratios of C:N were on average 35:1, 15:1 and 10:1 for the three respective species. In a summary of nitrogen studies from no-till systems using legume winter cover crops, hairy vetch provided approximately twice as much nitrogen to the following crop compared to crimson clover (Smith *et al.* 1987). The nitrogen release to no-till corn following hairy vetch in six studies ranged from 40-200 kg N/ha and averaged approximately 120 kg/ha. In Kentucky, hairy vetch is proving to be an economically viable cover crop in no-till continuous corn systems as the cost of the seed equals the cost of the nitrogen fertilizer it replaces (Frye and Blevins 1989). Yields have consistently been higher and increasing annually in the system using hairy vetch winter cover crops compared to continuous corn without cover crops (in which yields have remained constant or declined slightly). However, economic analysis has shown that additional quantities of nitrogen fertilizer (50-100 kg N/ha) are required to maximize returns in no-till corn production using hairy vetch cover crops (Frye and Blevins 1989; Ott and Hargrove 1989). Achieving nitrogen self sufficiency using hairy vetch may be possible in tilled systems of production. Utomo (1986), compared no-till and conventional tillage of hairy vetch with varying levels of nitrogen and found conventional tillage to provide higher yields than no-tillage systems with no additional fertilizer added.

Table 2. Corn grain yields as affected by winter cover, N fertilizer , and tillage at Lexington, Kentucky, average 1984-1985.

		Grain Yields * by Fertilizer N Treatment		
Winter Cover	Tillage	0 kg/ha	85 kg/ha	170 kg/ha
			in kg/ha	
Fallow	Conventional tillage	4000	5900	6600
	No-till	2800	5700	6700
Hairy vetch	Conventional tillage	7100	6900	7700
	No-till	6400	7200	8000

***** Based on 15.5% moisture

Utomo 1986

Over two years Varco *et al.* (1987), found legume N uptake from tilling in hairy vetch to be 38% higher than leaving the residues on the surface. Lower yields under no-till with low or no fertilizer applied are a reflection of the slower mineralization of organic N where the soil is undisturbed and the plant residue is not mixed into the soil by tillage. (Varco 1986). In a study in Pennsylvania comparing farming systems, hairy vetch established following winter wheat harvest was found to produce higher corn yields than conventionally grown corn with 112 kg N/ha side dressed (Radke *et al.* 1987). Doran *et al.* (1987) studied the effect of this hairy vetch cover crop on soil microbial biomass, potentially mineralizable nitrogen, and soil nitrate contents. The hairy vetch plots were found to have microbial biomass levels 30% higher than row cropped plots prior to spring incorporation of the vetch. A large increase in nitrate nitrogen (103 kg N/ha) after plowdown of the vetch apparently resulted from mineralization of Organic N. Part of this mineralized N was suggested to come directly from microbial biomass, which decreased an equivalent of 37 kg N/ha during the same time period. This apparent manipulation of microbial biomass to supply nitrogen to crops may be more difficult to achieve in no-till systems. Doran (1980) found that higher microbial populations exist in the surface soil under no-till systems and they act as a greater sink for immobilization of surface applied fertilizer N. This results in an increased labile N reserve that may not become available unless tillage is performed.

Differences in total N uptake using legume cover crop production systems for corn may be more significantly influenced by soil priming effects than that of N release directly from the cover crop. In a one year N^{15} study evaluating nitrogen release from incorporation of legumes, Alder (1988) found total nitrogen uptake to be reduced in no-till corn. Legume N provided approximately 25% of the total N uptake and was not affected by incorporation. The 30% difference in total N uptake was attributed to an increased soil priming effect.

Reduced nitrate leaching

Schriefer (1984) states that the loss of broadcast nitrogen in corn is approximately 40-60%. Leaching of substantial quantities of nitrogen is a serious loss in the farming system and can increase the risk of pollution of drain water and groundwater. Cover crops can decrease the leaching of nitrogen in audition to preventing surface loss of nutrients by erosion.

In Denmark, Hansen and Rasmussen (1979) examined the impact of using reduced cultivation and green manures to prevent nitrogen leaching in a continuous spring barley system. Traditional cultivation systems of fall stubble treatment followed by a November ploughing resulted in leaching of 39 kg N/ha in the first year when water discharge was 400 mm, and 17 kg N/ha in the second year when water discharge was 200 mm. Reduced cultivation through straw mulch lowered nitrogen leaching by 40%. A system of straw mulching plus a second crop green manure of white mustard resulted in a nitrogen loss reduction of about 80% with 8 kg and 3 kg N/ha being lost in the first and second year respectively. In a review paper on nitrate pollution in Western Europe, Strebel *et al.* (1989) cited several other studies in which deep-rooted brassica catch crops were found to be very effective measures to reduce nitrate leaching. On sandy soils catch cropping reduced the mean nitrate concentrations of ground water recharge by about 50%.

Grass cover crops hold excellent potential as a means to reduce nitrate leaching in corn production systems.

Groffman *et al.* (1987), found that well established fall rye cover crops significantly reduced nitrate leaching in early spring compared to legume cover crops. The authors suggested that rye is a more effective scavenger of nitrates than clover.

Scott *et al.* (1987) examined the effect of 10 different intercrops and cover crops in a continuous corn silage system and found that annual ryegrass and rye consistently lowered ear leaf nitrogen compared to non-intercropped plots. This demonstrates the grass cover crops potential to capture residual soil nitrogen and this could prevent nitrogen leaching after corn silage harvest. The system could be used to advantage without reducing the following crops yield, if the following crop was a nitrogen fixing legume such as soybeans. Ultimately the most important role that cover crops can have in reducing nitrate leaching may come from enabling farmers to switch from fertilizer N sources to legume based N supplies for field crops. In a study by Varco *et al.* (1987), total recovery of nitrogen from hairy vetch was two to three times greater than from applied N fertilizer. The authors stated that it is obvious potential nitrogen losses are greater with fertilizer N than legume N but that further studies were needed.

Weed Suppressing Effects of Cover Crops

The use of live mulch and interseeded cover crops as methods of weed control appear to offer great promise as a method of weed management (Altieri and Liebman 1986). A major problem with the technique is that in addition to suppressing weeds the main crop yield can suffer competition. An alternative to this system of management is to plant a cover crop after main crop removal and then subsequently kill it prior to main crop planting the following year. However, this system is more suited to longer season areas of production or shorter season crops.

Interseeding and Live Mulch Systems of Weed Control

Akobundu (1980) defines live mulch as a crop production technique in which a food crop is planted directly in the living cover of an established cover crop without tillage or destruction of the fallow vegetation. However, others consider living mulch systems to include forage seedings made at and after main crop planting (Hinton and Minotti 1982).

In Nigeria, Akobundu (1980) found weed infestation in corn was heaviest in unweeded conventionally tilled and no tillage plots, but very low in unweeded live mulch plots of Centrosema pubescens and Psophocarpus palustris. Maize yield was reduced in all ground covers where weed infestation was heavy but not in the covers that effectively suppressed weeds. He concluded that this production system offers the opportunity for improving soil fertility, crop yield and reducing weed interference in otherwise impoverished soils of the humid tropics.

Degragario and Ashley (1986) screened fifty seven entries for use as living mulches/cover crops for no-till vegetables and selected several mulches that through timely mowing could control weeds well and produce high snapbean *(Phaseolis vulgaris L.)* yields. A rapidly maturing winter annual, field brome *(Bromus arvensis* L.) required no mowing prior to planting and produced high bean yields. "Companion" a commercial mixture of 80% "Elka" perennial ryegrass and 20% Ensylva creeping red fescue *(Festuca rubra* L.) provided outstanding weed control, bean yields were not significantly different from the field brome. Weed dry weight of "Companion" was equivalent to that of the hand weeded check and significantly better than that of the Altaswede red clover. In an earlier study by Degregario and Ashley (1985) sweet corn planted into "Companion" and Italian ryegrass living mulches produced the fewest weeds but lowest corn yields. The researchers noted that weeds did not occupy bare spots in "Companion" plots including dandelion which was present in all other entries and the weedy control. Ogg (1983) reported that in a Washington orchard study, "Elka" perennial ryegrass reduced dandelion (Taraxacum *officinale)* by 95% and annual weeds by nearly 100%.

In corn production studies in Pennsylvania, Hartwig (1976) has found that a living mulch of crown vetch *(Coronilla* varia L.) can be a competitive form of weed control that suppresses yellow nutsedge. Hartwig (1985) reported that he has maintained crown vetch seedings in excellent condition after 10 years in a no-till rotation with corn, small grains and forages and almost totally eliminated soil erosion. Crop yields are reported to be reduced not more than five to ten percent.

Table 3. Effect of Overseeding Legume Cover Crops on Corn Yield and Weed Stand 1981.

Time of Overseeding	***Legume Species***	Grain Yield t/ha	Weed Reduction %
A. 35 DAP	Medium red clover	7.30	76
(first cultivation)	Hairy vetch	7.13	72
	Control-no overseeding	7.49	—
B. 47 DAP	Medium red clover	6.96	40
(second cultivation)	Hairy vetch	7.35	27
	Control-no overseeding	7.13	—

DAP - days after planting

Palada *et al.* 1982

Vrabel *et al.* (1980) evaluated various legume mulches in corn and found ladino and white clover most effectively suppressed weeds while red clover was least competitive. Seeding living mulch five weeks prior to corn seeding rather than five weeks later provided better weed control but lowest corn yields.

Soybeans sown in narrow rows with winter wheat or winter rye at time of planting yielded as much or more than soybeans without companion crops in unweeded narrow rows or normally cultivated wide rows in a study by Robinson and Dunham (1954). Companion crop weed control was superior with the rye and about equal to that achieved by cultivation. Under Minnesota conditions they concluded that intersowing wheat or rye into soybeans was a relatively inexpensive method of weed control that could reduce soil erosion and organic matter losses associated with conventional soybean production. However, the author has evaluated this technique in Ontario with winter rye, a rust susceptible winter barley and winter wheat and found that competition to soybeans was severe and interseeded species were not killed after establishment of the soybean canopy as reported by Robinson and Dunham (1954).

In almost all of the above studies, if weeds were adequately controlled by interseeded cover crops, yields were reduced from cover crop competition. When herbicides, mowing or growth regulators are used to suppress the cover crop, yield performance was generally improved but the cost of using the living mulch technique would also increase (Vrabel *et al.* 1980; Hartwig 1976; Akobundu 1984).

Perhaps a more practical objective to avoid reducing the main crop yield is to interseed cover crops with the goal of suppressing late growth and flushes of annual weeds and preventing the infestation of perennial weeds. Renius (1961) states that green manures can be especially effective in reducing growth of late germinating weeds.

Palada *et al.* (1982) found that delayed overseeding of legumes could reduce weed numbers without reducing corn yields while providing 95% ground cover by fall (Table 3). Red clover has also been used to suppress annual weed growth showing a trend to suppress weed growth at cereal harvest and greatly restricting weed growth after harvest. No effect on yield occurred from the underseedings or M.C.P.A. herbicide which was applied to the cereal crop (Samson 1989).

Other researchers have found a reduction in perennial weed growth and reproduction after harvest from the use of interseeded cover crops in cereals. A number of studies have been performed in England on the effect of interseeding cover crop species on quack grass growth and development.

In the first year of a three year study, Dyke and Barnard (1971) planted 15 cm long quack grass rhizomes in barley and barley undersown with Italian ryegrass and red clover. Some of the quack grass could not be found in December, particularly in the clover plots, and the researchers could not be certain if it had died. Assuming the rhizomes were alive and equal in growth to those that were found, the clover plots gave 2.2 g of dry quack grass per station (site within sub-plot where individual rhizomes were placed 0.9 m apart to prevent rhizome competition), ryegrass plots 1.8 g, and plots not undersown 4.7 g. The undersown crops at least halved the final amount of whole plant quack grass, which was initially planted at 0.7 g per station. Dyke and Barnard (1976) in the second and third years of the study used underseeding in both fababeans and barley and found large differences in quack grass growth (Table 5).

The fababeans competed much less effectively than barley. Undersown cover crops greatly suppressed the development of quack grass. They suggested that some farmers troubled by quack grass might delay its increase in successive crops of cereals or beans by undersowing.

Williams (1972) seeded A. repens seeds into the plots of Dyke and Barnard in 1971 and found greater suppression from barley than beans and undersown red clover than undersown ryegrass. Shoot dry weight of quack grass was 15.9, 2.4 and 0.4 g for fababeans not undersown and undersown with ryegrass and red clover respectively. No quack grass seedlings were found to have rhizomes in any of the barley systems. All three fababean treatments produced rhizomes, with the least being found in the red clover underseeding system.

Table 4 Effect of Interseeded Clovers on Weed Growth

	At Cereal Harvest		**Fall Harvest**	
Interseeded Clovers	Forage	Weed	Forage	Weed
	in kg/ha		in kg/ha	
Alfalfa	63 ^{a}	166 ^{a}	819 ^{c}	194 ^{abc}
Single-cut red clover	222 ^{a}	96 ^{ab}	1428 ^{b}	31 ^{bc}
Double-cut red clover	205 ^{a}	119 ^{ab}	2162 ^{a}	14 ^{c}
Check	0 ^{b}	181 ^{a}	0 ^{d}	383 ^{ab}
M.C.P.A. herbicide	0 ^{b}	50 ^{b}	0 ^{d}	234 ^{ab}

Samson 1989

Table 5. Effect of Undersown Clover or Ryegrass on Quack Grass Growth when Undersown in Barley or Fababeans

	1 970	**1971**		**1972**	
	Barley	Barley	Fababeans	Barley	Fababeans
		quack grass dry matter per station			
No undersowing	4.7	4	18	0.7	2.5
Italian Ryegrass	1.8	1.9	4.7	0.4	0.8
Red Clover	2.2	0.5	3.4	0.5	1.9

(0.7 g dry quack grass planted per station) Dyke and Barnard 1976

In the first year of a study, Cussans (1972) found Italian ryegrass to reduce A. repens rhizome formed during the year by over 70%, but the yield of barley was reduced by over 25%. Undersown red clover and oversown rape varieties performed similarly, not reducing barley yield but reducing total dry weight of quack grass by 30-50%. In the second year of the study, Italian ryegrass was replaced by perennial ryegrass and had no significant effect on barley yield but reduced total quack grass dry weight by 40%. Red clover reduced quack grass total dry weight by 20% and the oversown rapes from 0 to 25%.

In a three year barley study, Cussans and Ayres (1975) compared the effect of oversown brassica (white mustard, oilseed rape, and fodder rape) rotary cultivation, and rotary cultivation and after barley seeding of brassica upon the growth of quack grass. The mean reduction in dry weight of aerial shoots of quack grass compared to the untreated plots was 42.1, 91.3 and 93.3% respectively for each of the three systems.

Weed suppression by ryegrass and rye

Rapidly growing grass crops with competitive canopies, large root masses, allelopathic properties and which are strong nutrient feeders can have major influence on weed growth. Two crops grown in Ontario which possess these features are ryegrass and rye.

Bann Hofman and Ennik,(1982) studied the effect of root mass of perennial ryegrass on quack grass. They concluded that the growth of rhizomes of quack grass is restricted and its spread is relatively small in perennial ryegrass swards with a high root density, especially in the topsoil layer. In a perennial ryegrass study, Cussans (1973) found that in the first year of the study the number of live tillers of quack grass declined from May to September but increased the following season as the ryegrass stand thinned. Hoogerkamp (1975) reviewed the literature on quack grass growth in European leys and cited several studies in which quack grass growth increased with increasing nitrogen application and length of stand. In many cases an explosion of quack grass occurred in the third or fourth year. One of the quack grass control methods suggested was to use a short term ley of Italian annual ryegrass at a high seeding rate and cut frequently. Another potential weed suppressing characteristic of ryegrass is that it is allelopathic. Naqvi and Muller (1975) reported that

Italian ryegrass exhibits allelopathy on plants because of the presence of toxins in root exudates and above ground parts.

Rye has been the subject of considerable study recently to assess its weed suppressing ability particularly with regard to its role as an allelopathic no-till mulch. Using crops with allelopathic properties is most effective in no-tillage systems because the crop residues are left on the soil surface where they can most effectively inhibit weeds. In systems where crop residues are incorporated into the soil, allelochemicals are more quickly decomposed and leached out of the soil profile. In addition short time intervals between the killing of the rye and planting of the subsequent crop are important in obtaining the maximum effect of these chemicals. The allelochemicals from rye residue may be by direct contact with tissue fragments or through the soil. The allelopathic activity of rye hasrecently been reviewed by Barnes and Putnam (1986). The authors mentioned several reports in which rye reduced growth of common annual weeds while having no effect on growth of large seeded grain legumes. Weed species that have been reported to be reduced by rye mulches included common ragweed *(Ambrosia artemisiifolia L.),* common lambsquarters *(Chenopodium alba),* redroot pigweed *(Amaranthus retroflexus),* barnyard grass *(Echinochloa crusgalli),* and fall panicum *(Panicwn dichotomiflorum* Michx) (Barnes and Putnam 1986; Johnson and Webb 1987). Rye has also been documented to restrict the growth of problem perennial weeds such as horseweed *(Conyza canadensis L.)* and quack grass (Biniak 1983; Johnson and Webb 1987).

Conclusions

In evaluating the literature on the role of cover crops in crop, weed and soil management strategies there is overwhelming evidence that a great need and potential exists for widespread reintroduction of cover crops. From both an economic and environmental standpoint it appears that almost every field crop system can enable the use of some type of cover crop either before harvest and/or after harvest It appears that cover crops, like crops and tillage systems, need to be rotated within the farming system if a more efficient nutrient cycling-weed control-soil fertility program is to be achieved. As well a more effective understanding of the choice and management of cover crops needs to be acquired to fully realize their potential in different environments and farm management systems. In Ontario, red clover is perhaps the only cover crop that is used on any significant acreage in the province. It appears that significant potential exists for the use of other annual cover crops such as hairy vetch and oilseed radish. These species appear to offer considerable potential for use in conservation tillage systems and in improving nitrogen cycling. Grass cover crops also appear to be promising for use in soybean production systems but there is less of an economic incentive for use as there is no nitrogen benefit More emphasis needs to be placed on their role as a weed suppressing mulch or double crop forage if they are to be economically used by farmers for soil conservation purposes.

Serious environmental concerns of soil erosion and soil degradation, surface and groundwater pollution, and global warming and carbon loading from agricultural practices can all be positively influenced by proper cover crop use and management. Practical and profitable methods need to be further developed to help cover crops play a more important role in the progression towards more sustainable farming systems.

III. General Materials and Methods

As much as possible, the trials were superimposed on the farmers normal field operations. Randomized complete blocks designs were used with 3 or 4 replications. In many trials two control treatments were included within each block as distribution of weeds in particular can be uneven in on-farm trials. The majority of plots were 25 to 40 meters in length and 3 to 10 meters in width.

Forage and Weed Biomass

Biomass determinations were made by hand shearing one metre square quadrats at the ground level. Weeds and forage were cleared of crop debris and soil before drying and weighing. Samples processed during the summer were dried in solar dryers. Fall harvest samples were oven dried at the Elora Research Station of the University of Guelph.

Crop Yields

A plot combine was used for harvesting cereal yields whenever possible. Quadrat sampling for grain yield was performed at least one meter from the plot edge. In calculating cereal yields planted with a drill, the harvest area was adjusted to 1.07 square meters because rows of grain required 7 additional centimetres to be properly centered within the quadrat area. Grain moisture levels were taken after threshing with a plot combine and yields were adjusted to a dry matter basis. Soybeans were oven dried after threshing with a plot combine. Corn yields were obtained from the corn-ryegrass interseeding experiments by harvesting the two centre rows (each 5 meters in length) of each plot. In the corn grown following the various interseeding and catch crop systems, three (each 4 meters in length) or four (each 3 meters in length) rows were hand harvested and subsequently shelled. Corn grain moisture levels were measured and yields were adjusted to a 15.5% moisture level

Ground Cover Measurements

Soil cover was measured with a residue recorder which consisted of 50 knots spaced at 10 cm intervals. Measurements were made by standing over the rope and looking straight down, counting the number of knots that touched crop residue. Stones, weeds or pieces of residue smaller than 1/8" x 1 1/4 " were not counted. This device was also used for measurement of rye regrowth (plus in one experiment weed cover). The rope was stretched diagonally across the plots with two counts taken per plot.

Soil and Plant Analysis

Forage subsamples were taken at the time of biomass harvest to determine forage analysis. Whole plants of corn were harvested at the ground level for nutrient analysis at the 5 leaf stage. Ear leaf sampling was performed at corn silking with the mid 1/3 of the leaf being analyzed. Soil sampling was performed to a depth of 15 cm on the same day as the corn sampling at the 5 leaf stage. The samples were sent to two laboratories in Guelph, Ontario for analyses, Agri-Food Laboratories and the University of Guelph. The tests used at these labs for soil analyses were the sodium bicarbonate test for P and ammonium acetate tests for cations. Wet chemistry methods approved by the AOAC were used for forage analysis.

Statistical Analysis

Analyses of variance were carried out on the data. When the F-Test was significant ($P < 0.05$), Duncan's multiple range test was used to compare means. In all multiple range tests, numbers within the same column followed by the same letter are not significantly different at the 0.05 level. In some instances, comparison contrasts were performed to evaluate differences between treatment groupings.

Glossary of Terms

A.D.F.	The acid detergent fibre content of forage represents a large proportion of the indigestible fibrous constituents (cellulose, lignin and insoluble ash) found in forage. A lower A.D.F. represents a higher digestibility.
C.H.U.	Corn heat units are based on the daily maximum and minimum temperatures and are used for rating the amount of heat required to bring a corn cultivar to maturity.
Lact.	Lactation
Main.	Maintenance
Prot.	Protein
RCBD	Randomized Complete Block Design

Weather Conditions

The 1988 cropping season was an extreme one. The season was characterized by a hot and record dry period from early May to mid July. The farmers in the Tavistock area (particularly Ruby, Wilhelm, and Yausie) experienced a second dry period from August 1 to September 15. Through late September and October, frequent rains, cool temperatures and increased cloud cover made fall field harvesting and planting difficult.

This unusual season had major impacts on some of the experiments particularly on the sandy loam sites. No data were taken in the winter barley-soybean relay cropping at the Quinn farm as few soybeans germinated in 1988. Other soybean trials had low plant populations. Many of the interseeded cover crops in the cereal trials germinated but died in the seedling stage during the drought.

The fall of 1988 was cloudy and wet. Two rye cover crop trials were not planted as conditions were too wet for seedbed preparation and seeding.

In 1989, conditions were also sub-optimal. The spring was extremely wet which delayed planting of the corn and soybean trials. However, midsummer growth conditions were superior to 1988. Late summer and fall were extremely dry resulting in poor fall growth of some of the cover crops. Rainfall was erratic throughout the study area in both years and the meteorological data may not be representative of precipitation that the nearby farms received. In both the late summer and early fall of 1988 and 1989 the Martin farm near Winterbourne, and the farms in the Tavistock area were unusually dry.

IV. Experiments

1 — Comparison of Ryegrass Cultivars for Interseeding in Corn

Several recent research trials as well as farmers' experiences in the early 1900's suggest that ryegrass is the most productive and easy to establish species for interseeding in corn (Stevenson 1955; Scott *et al.* 1987; Samson 1989). Ryegrass possesses many desirable characteristics for use as an interseeding in corn: 1) it establishes easily; 2) it grows rapidly in late fall and early spring; 3) it withstands fall wheel traffic; 4) it provides excellent weed suppression; 5) it provides larger improvements in aggregate stability than other cover crop species; 6) it enables use of post emergent broadleaf herbicides if necessary.

The basic system of management that we are suggesting relies mainly on mechanical weed control and establishment of the cover crop after the period of critical weed interference in corn. Early weed control in the corn is provided through the use of a herbicide band on the row and inter-row cultivation, or rotary hoeing and cultivation. Interseeding takes place 5 weeks after seeding when the corn is 15-30 cm. (6-12 inches) in height. A cultivator with a grass seeder box mounted on the rear is used at the time of second cultivation in order to remove weeds and interseed in one operation.

EXPERIMENTAL METHODS AND DESIGN

Statistical Design

Layout	RCBD
Number of treatments	10
Replications	3

General Information

	Site 1	***Site 2***
Cooperator	Carl Schlegel	Bruce Yausie
Soil Type	Clay Loam	Silt Loam
Previous Crop	Alfalfa	Corn
Plot Size	3.2 m x 25 m	3.2 m x 25 m
Corn Variety	Pioneer 3902	Pioneer 3790
Seeding Date	May 15, 1988	May 6,88; May 11,89
Seeding Rate	70,000 seeds/ha	70,000 seeds/ha
N Fertilizer	Preplant (urea)	Pre-emerge (28%)
N Fertilizer Rate	75 kg/ha	150 kg/ha
Weed Control	2 Cultivations + hand hoeing	2 Cultivations + 18 cm.; herbicide band at planting; (2.2 kg/ha Cyanazine, 1988; 2.2 kg/ha Atrazine, 1989).
Ryegrass Seeding	Cyclone seeder	Cyclone seeder
Ryegrass Seeding Rate	15 kg/ha	15 kg/ha
Ryegrass Seeding Date	June 24, 88	June 11,88; June 19, 89
Corn Harvest	5 m rows (2 centre)	5 m rows (2 centre)
Corn Harvest Date	Oct. 5, 1988	Oct. 4, 88; Oct. 4 89
Weed and Forage Fall Harvest	1 m^2 quadrat (3) (0.77m x 1.3m)	1 m^2 quadrat (3) (0.77m x 1.3m)
Fall Harvest Dates	Oct. 11-13, 1988	Oct. 6-8, 1988; Oct.16-19, 89
Fall Ground Covers		Nov 9, 88; Oct 23, 89

Little information is available concerning which ryegrass species (the annual or perennial ryegrass) might perform better as an interseed in corn or if there are important cultivar differences. This trial was established to determine the effect of interseeded species and varieties of ryegrass on forage biomass production, ground cover, weed growth and corn yields.

RESULTS AND DISCUSSION

Corn Yields

Interseeding ryegrass approximately 5 weeks after planting of corn had no negative impact on corn yield at either location (Tables 6 and 7). Average corn yields of 6.4 and 8.8 (two year average) t/ha were obtained on the clay loam and silt loam sites respectively. Both ryegrass biomass production and weed growth were higher on the lower yielding corn site, probably because of less competition from corn. A previous trial located on a neighbouring farm to the silt loam site produced yields of 13 t/ha in 1987. Although both weeds and ryegrass seedlings established on that site, very little biomass was produced from either by late fall (Samson 1989). It may be that the upper limit for satisfactory growth of the ryegrass interseedings would be in corn yielding approximately 10 t/ha. However, competition to the ryegrass interseedings could likely be reduced if the corn was harvested as silage or if an earlier maturing corn variety was chosen which would open its canopy earlier in the fall.

Ryegrass Biomass Production

Substantial differences in biomass production were observed amongst the four perennial ryegrass varieties selected. Ellen was superior to the three other cultivars at both locations. Grimalda perennial ryegrass appeared to be the least well adapted for use as an interseeding. It produced less than 113 the biomass of Ellen at both locations. All of the cultivars tested appeared to establish well. The differences in biomass accumulation were likely due to shade tolerance between cultivars.

Annual cultivars were consistently relatively good performers with much less variation in biomass. Bartolini appeared to be slightly less productive than the other annual ryegrass cultivars. The seeding rate used for both annual and perennial ryegrass cultivars (15 kg/ha) may have given some advantage to the perennial cultivars over the annuals. Visually there appeared to be a lower ryegrass density in the annual ryegrass plots compared to the perennial ryegrass plots. Recommended seeding rates for annual cultivars are generally 50-100% greater than those for perennial cultivars as the seed is generally larger for annual cultivars.

Overall, the shoot biomass production from ryegrass in the studies was relatively low. In both years there was significant moisture stress. In 1988, the ryegrass interseedings did not establish on the clay loam soil at the Schlegel Farm until late July when the drought ended. In 1989, the clay loam site was switched to the Reibling Farm (a neighbouring farm to the Schlegel Farm). A complete failure of the ryegrass interseedings occurred on this site. The corn was relatively late seeded (May 20) delaying interseeding until June 28. A one month long dry period occurred after interseeding

Table 6. **Comparison of Ryegrass Cultivars Interseeded In Corn on a Clay Loam Soli at the Schlegel Farm In 1988.**

Cultivar	**Corn Yield t/ha**	**Fall Forage Biomass kg/ha**	**Fall Weed Biomass kg/ha**
Condesa Perennial	6.64	330 ^{cd}	553 ^{cd}
Ellett Perennial	5.97	851 ^{a}	340 ^{d}
Grimalda Perennial	6.07	252 ^{d}	713 ^{abc}
Citadel Perennial	5.91	329 ^{cd}	620 ^{bcd}
Common Annual	6 46	680 ^{ab}	430 ^{cd}
Aubade Annual	6.29	620 ^{b}	442 ^{cd}
Barmultra Annual	6.89	666 ^{ab}	495 ^{cd}
Bartolini Annual	7.06	504 ^{bc}	404 ^{cd}
Check 1	5.65	0 ^{e}	946 ^{a}
Check 2	5.59	0 ^{e}	889 ^{ab}
C.V. %	12.3	28.2	29.6

which caused poor establishment. No cultivar data were recorded at this site. The earlier seeded ryegrass on the silt loam site obtained enough moisture early in the season for successful establishment.

Biomass production over the two year study could likely have been increased considerably if the plots were allowed to overwinter and regrow until mid-May. In corn silage studies in New York, interseeded perennial ryegrass produced approximately 2000 kg/ha of shoot biomass when managed as a spring plowed cover crop (Scott *et al.* 1987). In a study using a mixture of an annual and perennial cultivar a doubling of fall biomass accumulation occurred when the ryegrass was allowed to overwinter until incorporation in mid-May (Samson 1989). Consideration should also be given to the relatively large root system of ryegrass when estimating its value as a plowdown. The root biomass yield of ryegrass is approximately 50% that of the shoot biomass (Scott *et al.* 1987).

Weed Suppression

In general, the greater the biomass production from the ryegrass interseeding, the greater was the effect of ryegrass on weeds at fall harvest. The four annual cultivars and Ellen perennial ryegrass consistently reduced weed biomass by approximately 50% . The main weeds present in the trial were quack grass and a variety of annual weeds. These weeds were harvested separately but no significant reductions could be identified as both sites had a diverse and uneven weed flora. The main effect of the ryegrass appeared to be to suppress late flushes of annual weeds and growth of quack grass in the plots once the corn canopy opened in the fall. These weeds likely do not affect corn yield directly rather they increase the weed seed bank or in the case of quack grass, can become a problem in the following crop. One of the reasons ryegrass may be an effective competitor with weeds is that

Table 7. Comparison of Ryegrass Cultivars for InterseedIng In Corn on a Slit Loam Soli. Figures are for a two year average at the Yausle Farm In 1988-1989.

Cultivar	Corn Yield t/ha	Fall Forage Biomass kg/ha	Fall Weed Biomass kg/ha	Fall Ground Cover %
Condesa Perennial	9.05	153 ^{bcd}	160 ^{bc}	96.3 ^{a}
Ellett Perennial	8.92	236 ^{ab}	124 ^{c}	96.0 ^{a}
Grimalda Perennial	8.94	69 ^{de}	152 ^{bc}	93.5 ^{a}
Citadel Perennial	8.78	127 ^{cd}	202 ^{ab}	94.8 ^{a}
Common Annual	8.44	230 ^{ab}	105 ^{c}	97.2 ^{a}
Aubade Annual	8.57	287 ^{a}	123 ^{c}	97.5 ^{a}
Barmultra Annual	9.61	221 ^{abc}	136 ^{c}	96.6 ^{e}
Bartolini Annual	8.89	207 ^{abc}	102 ^{c}	97.3 ^{a}
Check 1	8.01	0 ^{e}	206 ^{ab}	87.0 ^{b}
Check 2	8.77	0 ^{e}	246 ^{a}	85.0 ^{b}
C.V. %	6.04	45.3	49.2	3.2

it possesses a large root system which can be effective in reducing growth of quack grass rhizomes (Baan Hoffman and Ennik 1982).

Ground Covers

Ground covers at the Yausie farm were significantly affected by the ryegrass interseedings. There was no significant difference amongst cultivars. Ground covers were high in the check plots due to the relatively high corn yield. The ryegrass likely plays a more important role in improving ground cover on lower yielding corn sites or where the corn is harvested as silage. Scott *et al. (1987),* found perennial ryegrass interseedings in corn managed as silage provided 70% ground cover vs 15% for non-interseeded treatments. When the sites were resampled the following spring the ryegrass ground covers generally increased while the corn silage residue was slightly lower.

Conclusions

Ryegrass established well at three of the four sites with Ellen perennial ryegrass and the four annual ryegrasses providing the greatest quantity of biomass at fall harvest. The ryegrass interseedings should likely be spring plowed prior to soybeans. The ryegrass would have greater opportunity for regrowth prior to soybean planting in mid-late May. As ryegrass ties up soil nitrogen, there would also be no negative nitrogen effect if the following crop was a legume. Spring biomass of the various ryegrass cultivars should also be examined as some annual ryegrass cultivars are prone to winter-kill. In addition to the soil conservation value of the interseeding system, a major benefit was a 50% reduction of the fall weed biomass which consisted of annual weeds and quack grass.

2 a) — Rye Tillage Management Systems for Soybeans

Winter rye has excellent potential for use as a cover crop in soybean production systems. It possesses several characteristics which make it preferable to other winter cereals: it is more winter hardy; it grows better at low temperatures; it has lower fertility requirements, it is more weed suppressive, it heads out earlier and has a larger root system.

Winter rye can serve several purposes:

1) Soil conservation and improving soil tilth

EXPERIMENTAL METHODS AND DESIGN

Experimental Treatments

- Rye disced
- Rye plowed
- Rye harvested and disced
- Rye harvested and plowed
- Rye mow-killed

Statistical design

Layout	RCBD
Number of treatments	5
Replications	3

General Information

	1987/88 Site	***1988/89 Site***
Cooperator	Harry Wilhelm	Harry Wilhelm
Soil Type	Silt loam	Silt loam
Previous Crop	Winter wheat	Winter wheat
Plot Size	2.9 x 30 m	2.9 x 30 m
Rye Seeding Date	Oct. 7,1987	Oct. 15,1988
Seeding Rate	100 kg/ha	100 kg/ha
Fertilizer Application	-	46 kg N/ha, May 1
Rye Shoot Biomass	1 m^2 quadrat (2 per rep) May 26	1quadrat (3 per rep) May 30
Soybean Variety	KG 60	Pioneer 0877
Seeding Rate	90 kg/ha (solid)	90 kg/ha (solid)
Inoculant	Grip (3 X rate)	Grip (3 X rate)
Soybean Planting	May 27	June 6 (no-till treatments) June 13 (tilled treatments)
Rye Mowing	5' rotary mower, May 27	5' rotary mower, June 12
Ground Cover	June 16	June 15
Rye Regrowth	June 23	June 15
Rotary Hoeing	—	June 27
Weed Control-tilled	Basagran (2.2 l/ha) + Assist (2.0 l/ha) July 5	Basagran (2.2 l/ha) + Assist (2.0 l/ha) July 14
Mow-killed	Poast (3.0 l/ha) + Assist (2.0 l/ha) July 5	—
Soybean Yield	1 m^2 quadrat (4), October 15	1 m^2 quadrat (3), October 13

2) Weed Control: winter rye suppresses perennial weeds such as quack grass during late fall and early spring when the field would otherwise lie uncovered (Biniak 1983).
— if mowed and used as a no-till mulch for soybeans, rye suppresses annual weeds through its allelopathic properties and by acting as a physical barrier to weed growth (Barnes and Putnam 1986).

3) Forage Source: harvested as a silage prior to soybean planting, rye can be used for raising dairy heifers or for feeding beef and dry dairy cows.

The objective of this experiment was to determine the effects of different management systems on ground cover and soybean yield. Traditional tillage systems of plowing and discing were compared to that of a system called "No-till/Mow-kill". In this system soybeans are no-tilled into standing rye in late May. The rye is subsequently mulched and left on the surface to provide weed control. The rye acts as a weed suppressant in three ways: as an overwintering competitor to winter annual weeds, as a physical mulch after mowing, and as a producer of allelochemicals which inhibit weed growth shortly after mowing.

In treatments 1 and 3, tillage was performed by making two passes with a double disc in 1988 and three passes in 1989 as the rye was difficult to incorporate. Treatments 2 and 4 consisted of plowing followed by a single discing in both years.

In 1988, heavy rains occurred on the clay loam site and the trial was replaced by the no-till soybean trial using a winter rye cover crop. The cooperating farmer felt conditions were not suitable for tilling the wet clay soil. In the fall of 1988 the tillage trial was to be seeded on a second clay loam site but wet field conditions prevented seeding of the rye.

RESULTS AND DISCUSSION

The biomass production from the rye was very low (1.01 t/ha dry matter) in 1988. This was likely due to the trial site being of low soil fertility. In the second year of the study, a small application of N fertilizer in the early spring of 1989 nearly doubled rye biomass production and increased protein level by 3.4% compared to the previous year (Table 8). The digestibility of the forage was superior with the May harvest dates as the A.D.F. levels were lower.

Table 8. Quantity and Quality of Rye Silage Harvested at Heading on a Slit Loam Soil at the Wilhelm Farm in 1988-89.

Sampling Date	Fresh Weight t/ha	Dry Weight t/ha	Moist. %	Prot. %	A.D.F.	Net Energy Lact.	Net Energy Main.	Net Energy Gain
May 26, 88	5.95	1.01	83	9.8	32.7	1.11	1.15	0.60
May 30, 89	9.47	1.80	81	13.2	32.5	1.07	1.11	0.62
June 5, 89	16.0	3.51	78	10.7	40.9	1.11	1.16	0.54

Table 9. Effect of Rye Cover Crop Management System on Ground Cover, Rye Regrowth and Soybean Yield on a Slit Loam Soli at the Wilhelm Farm In 1988.

Rye Cover Crop Management	Ground Cover % June 16	Weed Cover % June 23	Rye Regrowth % June 23	Soybean Yield t/ha
Disced	33.3 ^{b}	32 ^{bc}	1.3 ^{b}	1.44
Plowed	9.0 ^{c}	64 ^{a}	0.3 ^{b}	1.89
Harvested& disced	21.0 ^{bc}	20 ^{cd}	0.3 ^{b}	1.62
Harvested & plowed	4.7 c	54 ^{ab}	0 ^{b}	1.71
Mow-Kill	89.7 ^{a}	3 ^{d}	27.0 ^{a}	1.35
C.V. %	31.8	34.9	96.6	17.1

Ground Cover

The no-till/mow-kill system was far superior to the tillage systems in providing ground cover. Although rye biomass was relatively low in 1988, approximately 90% ground cover was obtained where the rye was mulched on the surface. If 30% ground cover is considered a minimum for conservation tillage systems, the only rye tillage system that would achieve this would be the disc-only treatment (Table 9). Plowing the rye greatly reduced ground cover. In 1989, rye ground covers were higher than in 1988 as the rye was much more advanced in growth and was more difficult to incorporate where it was not harvested. The extra tillage pass in the harvested disced treatment in 1989 may have been the reason ground cover was slightly lower in 1989 on this treatment (Table 10).

Weed Pressure and Soybean Yield

In 1988, weed pressure was dramatically altered by rye mulch. Few annual weeds were present in the mow-kill treatment while the plowed treatments in particular had a heavy flush of weeds. Plowed treatments also appeared to have better soybean stands than disced treatments which had a more uneven seedbed. The rye regrowth in the mow-kill treatment was killed by the use of a grass herbicide (Poast) during the drought. This caused some injury to the soybean plants and stunted their growth. The tillage treatments received no grass herbicide as only broadleaf weeds were present. However, yields in the tillage treatments were also affected by low plant populations and weed competition (the broadleaf herbicide used –Basagran– did not work well in the dry weather). Supplementary hand hoeing on the tillage treatments encouraged flushes of pigweed which flourished as a result of lack of competition from the thin soybean stand.

In 1989, soybean seeding was delayed as a result of wet conditions. The notill/mow-kill plots were planted 1 week earlier than the tillage treatments as a no-till drill was available and the field could be accessed for no-till planting. No weed measurements were made because the tilled plots

Table 10. **Effect of Rye Cover Crop Management System on Ground Cover, Rye Regrowth and Soybean Yield on a Silt Loam Soil at the Wilhelm Farm In 1989.**

Rye Cover Crop Management	**Ground Cover %**	**Rye Regrowth %**	**Soybean Yield t/ha**
Disced	74.0 ^{b}	0 ^{b}	0.45 ^{c}
Plowed	7.0 ^{d}	0 ^{b}	1.43 ^{b}
Harvested & disced	20.7 ^{c}	0 ^{b}	0.65 ^{c}
Harvested & plowed	1.3 ^{d}	0 ^{b}	1.68 ^{ab}
Mow-Kill	96.3 ^{a}	15.3 ^{a}	1.95 ^{a}
C.V. %	13.6	18.0	19.3

were rotary hoed to break the soil crust and improve soybean emergence. There were again thin stands of soybeans experienced on the tilled treatments, particularly on the disced treatments, and to a lesser extent on plots that did not have the rye harvested. Some seed corn maggots were observed in some of the soybean seedlings particularly on the disced treatments. Hammond (1984) found soybeans planted in tilled rye treatments (disced or plowed) to be more susceptible to reduced plant stand from seed corn maggots than when no-tilled in rye.

Soybean yields followed a similar pattern to that of the observed differences in plant stand in 1989. Yields were highest on the no-till/mow-killed plots which were planted one week earlier than the tilled treatments. The most promising tillage treatment appeared to be where the rye was harvested as silage and the ground subsequently plowed. Although ground cover was less than *5%* after harvesting and plowing, this system would provide excellent soil cover from late fall until late May. More favourable soybean yields would likely have been obtained from the disced and plowed treatments when the rye was unharvested if incorporation had taken place in mid-May.

Conclusions

From a conservation perspective the mow-kill system offered the best potential to achieve a high ground cover with a minimum of rye residue. If rye biomass was increased the system of rye harvested and disced may also supply a reasonable amount of ground cover and a forage crop before soybean planting. It would be of significant benefit if additional economic advantages could be given to the rye cover crop in addition to its soil conservation value. The no-till/mow-kill system offers an opportunity to reduce herbicide use considerably in a reduced tillage system while the harvesting of a forage prior to soybean planting may prove economical for livestock farmers.

2 b) — Soybean No-till Systems with Rye

The objective of this trial was to compare no-till soybean systems in which rye was harvested with several systems where the rye was mulched on the surface. Planting soybeans at rye heading (May 24) versus rye anthesis (June 1) was tested to determine if rye regrowth is reduced when the rye is mulched at a later stage. Mowing before planting and planting before mowing were evaluated to determine which system would be more advantageous to seed placement and to reducing rye regrowth. Forage quantity and quality were also assessed.

RESULTS AND DISCUSSION

Forage Quantity and Quality

Substantial quantities of dry matter were produced by harvesting rye at heading on May 24 (Table 11). Approximately 60% more dry matter was produced when harvesting was done

EXPERIMENTAL METHODS AND DESIGN

Experimental Treatments

1. Rye harvested and soybeans no-tilled (May 24)
2. Soybeans no-tilled and rye mulched early (May 24)
3. Rye mulched and soybeans no-tilled early (May 24)
4. Soybeans no-tilled and rye mulched late (June 1)
5. Rye mulc*hed and* soybeans no-tilled late (June 1).

Statistical design

Layout	RCBD
Number of Treatments	5
Replications	3

General Information

Cooperator	Jeff and Keith Quinn
Soil Type	Clay loam
Previous Crop	Winter wheat
Plot Size	2.9 m x 30 m
Rye Seeding Date	August 31, 1987
Seeding Rate	100 kg/ha
Manure Application	60,000 l/ha dairy manure (est), prior to rye planting
Rye Shoot Biomass	1 m^2 quadrat (2 per rep) May 24, early seeding date
Soybean Variety	June 1, at late seeding date
	KG 60
Seeding Rate	90 kg/ha, solid seeded
Inoculant	Powdered Peat (3 X rate)
Rye Mowing	5' rotary mower, May 24 and June 1
Ground Cover Evaluation	June 17
Rye Regrowth	Rope knot technique, June 24
Weed Control	Poast (4 l/ha),June 24
Soybean Yield	1 m^2 quadrat (4), October 17
Weed Biomass	1 m^2 quadrat (4), October 17

at the anthesis stage (June 1). The protein content declined from 12.0% to 9.8% between heading and anthesis.

Harvesting the rye at the heading stage enabled the timely seeding of soybean and provided fairly good yield and silage quality.

Ground Cover

Rye-soybean, no-till systems provided greater than 90% ground cover in all treatments (Table 12). Ground cover readings of 100% were measured in both the late planted mow-killed treatments which had 5.67 t/ha of rye biomass left on the surface. This system therefore offers excellent erosion protection.

Rye Regrowth

The treatment harvested as silage exhibited significantly more regrowth than the mown treatments. It appears that in addition to suppressing weeds the heavy rye mulch suppressed its own regrowth. All treatments were sprayed with a grass herbicide (Poast). However, it was probably not required on the mow-killed treatments as the regrowth was rather limited and no annual grass weeds were present. No significant differences were observed in rye regrowth between mowing methods or dates which may have been the result of the relatively low regrowth. It appeared easier to mow prior to planting since the drill tended to push the rye into the ground. The problem seemed greater when mowing was performed in the same direction as the planting. The high rye biomass production in this trial made mowing difficult (a small 1.6 metre rotary mower was used).

Soybean Yield

The highest yielding no-till treatment (3.04 t/ha) was the one in which soybeans were no-tilled early and then mowed Soybeans in the late planted treatments were late maturing and green pods were present at harvest. In the late mulched treatments, germination was delayed until mid-July when the drought ended. Planting into the standing rye enabled much better seed bed placement than was possible when the rye was mowed before planting.

Improvements in several areas could have enhanced the performance of all treatments.

Table 11. Quantity and Quality of Rye Silage As Affected by Harvest Date on a Clay Loam Soil at the Quinn Farm In 1988.

Sampling Date	Fresh Weight t/ha	Dry Weight t/ha	Moist. %	Prot.	A.D.F.	Net Energy Lact.	Net Energy Main.	Net Energy Gain
May 24 (Heading)	20.3	3.45	83	12.0	36.6	0.94	0.99	0.51
June 1 (Anthesis)	21.0	5.67	73	9.8	43.0	1.42	1.49	0.64

Table 12. Effect of Rye Management Systems on No-till Soybeans on a Clay Loam Soil at the Quinn Farm In 1988.

Rye Management System	Ground Cover %	Rye Regrowth %	Soybean Yield t/ha	Weed Biomass t/ha
Rye harvested	90.3	25.3 [a]	1.81 [b]	820 [a]
No-till first & mulch early	98.3	10.7 [b]	3.04 [a]	160 [b]
Mulch first & No till early	96 8	4.0 [b]	1.53 [b]	748 [a]
No-till first & mulch late	100.0	2.7 [b]	1.74 [b]	108 [b]
Mulch first & no-till late	100.0	0.7 [b]	0.57 [c]	575 [ab]
C.V. %	5.3	74.8	29.2	51

Ripple coulters and extra weight would have increased penetration of the drill improving plant populations (particularly in treatments 1, 3 and 5). The non-weighted drill and straight coulter had great difficulty penetrating the mats of rye mulch that resulted in the treatments which were mowed before planting.

Treatment # 1 in which 3.45 t/ha of rye was harvested prior to planting produced 1.81 t/ha of soybean or a combined total dry matter yield of 5.26 t/ha. With planter improvements and more favorable growing conditions, this double crop system could prove to be attractive to livestock producers.

Weed Biomass

Weed populations consisted almost entirely of perennial weeds on the mow-killed treatments. The treatments mowed after planting (2 and 4) had lower weed biomass than those mowed before planting (3 and 5). This appeared to be due to a sparse soybean plant population on the treatments drilled after the rye mowing. Treatment 1 (rye harvested) had both a sparse soybean stand and a lack of mulch which resulted in significant weed growth. It should likely have received a broadleaf herbicide but no spray was applied because application during the drought was expected to further stress the soybeans.

Conclusions

Planting before mowing appeared to provide a better plant stand then mowing before planting. This difference may have been greater than that would normally be experienced because of the very large quantity of rye biomass present on the surface after mowing. The earlier soybean planting date provided a higher yield than later planting and had no problem with the rye drying out the soil and preventing germination of the soybeans. It appears that from a moisture standpoint soybeans should be no-till drilled into rye at heading. Prior to this stage rye may increase soil moisture *versus* having no cover crop (Daynard *et al.* 1984). After the heading stage rye is accumulating large quantities of biomass rapidly and its moisture demand may dry out the soil excessively.

2 c) – Evaluation of Rye Varieties for No-till/Mow-kill Soybean Production

The objective of this trial was to identify the suitability of various rye cultivars for the notill/mow-kill system of soybean management. Mike Strohm, the Illinois farmer who developed the no-till/mow-kill system identified rye regrowth as a significant concern (Brusko 1987). Previous research and farmers' observations suggested that some cultivars of rye regrow less than others, and that varietal differences exist in regard to fall ground cover, biomass production, and weed suppression ability. Two control plots were also established to determine if the rye cover crop was reducing soybean yield when managed in a no-till system.

This trial was to be seeded on a second site (clay loam) but wet fall field conditions in October 1988 prevented seeding.

RESULTS AND DISCUSSION

Spring Ground Cover and Rye Biomass Production

EXPERIMENTAL METHODS AND DESIGN	
Statistical Design	
Layout	RGBD
Number of Treatments	10
Replications	3
General Information	
	1988/89 Site
Cooperator	Harry Wilhelm
Soil Type	Silt loam
Previous Crop	Winter wheat
Plot Size	3 x 30m
Rye seeding Method	broadcast and harrowed
Rye Seeding Date	Oct. 15
Rye Seeding Rate	100 kg/ha
N Application	46 kg N/ha, May 1
Spring Ground Cover	May 1
Rye Heading %	May 29, June 5
Rye Shoot Biomass	May 30
Soybean Variety	Pioneer 0877
Planting	No-tilled June 6
Seeding Rate	90 kg/ha, solid seeded
Inoculant	Grip (3 X rate)
Rye Mowing	5' rotary mower, June 12
Weed Control-check only	Round-up (2.5 l/ha, June 7; Poast (3.1 l/ha) + Assist (2 l/ha) July 3
Rye Regrowth	Rope knot technique, July 6 Rye heads/1 m^2 quadrat (3), Aug. 26
Soybean Yield	1 m^2 quadrat (3), October 9

Approximately 40% spring ground cover was obtained in the Kustro, Wheeler and two common seed lots (Oak Manor and tobacco) (Table 14). The Aroostook and Ryeman had some winter kill which resulted in thin plant stands and low ground cover. The control plots had no residue (the previous crop on the site was winter wheat; the straw was removed and the soil disked twice in the fall). Winter annual weeds (mainly shepherd's purse) were not counted in the ground cover of the non-rye seeded plots but provided considerable soil cover particularly after the fertilizer application. Round-up herbicide subsequently killed these weeds on the control plots. Some annual weeds were also present on the thin rye plots but there were almost no annual weeds present in the higher biomass-producing ryes. The annual weeds present in the rye plots were mulched upon mowing.

A small quantity of nitrogen fertilizer was applied in early May to the site as the rye appeared nitrogen deficient. The highest rye biomass production was obtained on the three common lots of rye, and Kustro (Table 13). These four lots of rye also had a relatively high dry matter content (> 21%). Wheeler rye which was bred specifically for high forage production, produced lower quantities of biomass than the earlier maturing grain types when harvested at early beading. It appears that early maturity is desirable if early dry matter accumulation is required.

Rye Regrowth

Rye regrowth did not appear to be related to an earlier heading date or high biomass accumulation. Kustro rye exhibited less regrowth than the other ryes. Wheeler forage rye exhibited considerable regrowth and appeared the least suitable to a mow-kill system of management. The Aroostook rye also exhibited high regrowth but this was likely encouraged by the lack of surface mulch.

Table 13. Effect of Rye Varieties on Heading, Regrowth, and Biomass Production on a Silt Loam Soli at the Wilhelm Farm In 1989.

Cultivar	Heading Average of May 29, June 5 %	Dry Matter %	Biomass t/ha	Rye Regrowth July 6 %	Rye heads Aug. 26 #/m^{2}
Aroostook	75.2 ^{a}	23.0 ^{a}	2.40 ^{bcd}	16.3	50.3 ^{ab}
Ryeman	26.3 ^{cd}	20.8 ^{ab}	1.93 ^{d}	20.7	30.0 ^{abc}
Kustro	53.8 ^{b}	21.2 ^{ab}	3.24 ^{abc}	11.0	20.0 ^{c}
Danko	45.8 ^{b}	17.5 ^{c}	2.33 ^{cd}	20.3	26.0 ^{bc}
Wheeler	23.0 ^{d}	19.2 ^{bc}	2.46 ^{bcd}	22.0	54.3 ^{a}
Common-Tobacco	80.5 ^{a}	22.1 ^{ab}	3.78 ^{a}	20.7	40.3 ^{abc}
Common-Oak Manor	76.8 ^{a}	21.9 ^{ab}	3.25 ^{abc}	19.3	34.0 ^{abc}
Common-Western	41.5 ^{bc}	21.4 ^{ab}	3.33 ^{ab}	19.3	36.7 ^{abc}
C.V. %	27.1	8.2	19.6	35.5	38.0

Table 14.

Effect of Cover Crop Varieties on Spring Ground Cover and Soybean Yield on a Silt Loam Soil at the Wilhelm Farm, 1989.

Cultivar	Ground Cover 1/5/89 %	Soybean Yield t/ha
Aroostook	14.0 ^{de}	1.29 ^{c}
Ryeman	12.0 ^{a}	1.22 ^{c}
Kustro	39.3 ^{a}	0.97 ^{c}
Danko	23.3 ^{cd}	0.99 ^{c}
Wheeler	42.0 ^{a}	1.12 ^{c}
Common (Tobacco)	37.7 ^{ab}	1.45 ^{bc}
Common (Oak Manor)	45.3 ^{a}	1.31 ^{c}
Common (Western)	28.3 ^{bc}	1.01 ^{c}
Check 1	0 ^{f}	1.96 ^{a}
Check 2	0 ^{f}	1.87 ^{a}
C.V. %	22.3	22.9

Soybean Yields

Planting of the no-till soybeans was delayed as a result of the wet spring which may partially explain the low soybean yields. Soybean yield was reduced by 40% on average on plots with winter rye. Other researchers have found yield reductions from the use of a rye cover but this was generally associated with a reduced plant stand (Eckert 1988). These plots had a relatively good plant stand and surplus moisture prior to the mowing of the rye. Rye regrowth was relatively low and cannot explain the large and consistent yield reduction. The reduced yield was suspected to be due to low soil fertility. The soybeans on the rye cover crop plots were chlorotic and shorter than the no-tilled beans that had no rye cover crop. Cooler soil temperatures could reduce nodulation in the soybeans, however this was likely not the case with a June planting. The lower yields may be potassium related. The soil tested in the lower range of medium for potassium and the corn planted adjacent to the plot area was below the critical level for ear leaf K. Rye has also been found to reduce extractable K when managed in a no-till system (Hargrove 1986). A fertility study is presently being conducted on this site to determine the cause of the stunting and chlorosis.

Conclusions

Further work needs to be conducted on methods to reduce the yield constraints that are being experienced in the no-till mow-kill system. Although considerable differences were observed in rye biomass production and regrowth, the specific rye variety had much less influence on yield than did using a rye cover crop. It is likely that varieties such as Kustro, with relatively good biomass production and reduced regrowth, could impact positively on soybean yield if the soybeans were planted in mid-late May and weed pressure was higher. The benefits could include reduced rye competition with soybeans or the alleviation of the need for herbicides to kill rye regrowth or annual weeds. If fertilization of the rye is required to produce an adequate quantity of rye biomass it likely makes the system less desirable. However, besides the soil conservation value of the rye cover crop, it appears to alleviate the need for both a burn back herbicide (Round-up) and for chemical control of annual weeds.

2 d) — High Moisture Winter Barley— Soybean Relay Cropping

Relay cropping consists of interplanting a second crop, in the younger stages of growth of an already established crop, thereby allowing two crops in one season where otherwise only one would be possible. It is mainly practiced using winter wheat and soybeans in areas with considerably longer growing seasons than that of Southern Ontario. The soybeans are generally no-till drilled in the winter cereal in mid May when the winter cereal is approximately 15-30 cm. in height. A system that could provide the opportunity for this system to work in Ontario would require the earliest possible date of removal of the winter cereal grain. This could be achieved by using winter barley which matures approximately 7-10 days earlier than winter wheat and a high moisture harvest of the winter barley which would reduce the harvest date by a further 10-15 days. Advantages of harvesting the crop

EXPERIMENTAL METHODS AND DESIGN

Treatments

- Winter barley
- Soybeans
- Winter barley — soybean relay crop.
- High moisture winter barley - soybean relay crop

Statistical Design

Layout	RCBD
Number of Treatments	4
Replications	3

General Information

	1987/88 Site	***1988/89 Site***
Cooperator	Harry Wilhelm	Larry Bender
Soil Type	Silt loam	Silt loam
Previous Crop	White beans	Alfalfa
Plot Size	2.9 m x 30 m	3.2 m x 30 m
Winter Barley Variety	OAC Elmira	OAC Elmira
Seeding Date	Oct 7, 1987	Sept 24, 1988
Seeding Rate	100 kg/ha	100 kg/ha
N Application	50 kg N /ha May 4	-
Herbicide Application	M.C.P.A.,May 20	-
Soybean Variety	KG 60	OAC Aries
Planting	No-tilled, May 27	No-tilled, May 19
Seeding Rate	90 kg/ha (Solid seeded)	90 kg/ha (Solid seeded)
Inoculant	Grip (3X rate)	Grip (3X rate)
Soybean Weed Control - check only	hand hoeing	hand hoeing
Winter Barley Harvest	1 m^2 quadrat (3)	Plot Combine
High Moisture	44.7%, July 7	41.2%, July 7
Dry Grain	13%, July 22	13%, July 19
Soybean Harvest	1 m^2 quadrat (3)	1 m^2 quadrat (3)
Harvest date	Oct. 5	Oct. 13

as a high moisture feed grain in early July are that the soybeans have less opportunity to grow into the barley canopy and the barley is less prone to loss from lodging, shattering, head loss and birds. As well, many livestock farmers could benefit financially by harvesting a feed grain when prices are generally high as well as providing more year round use of their high moisture silos. Even if the winter barley yield is reduced by 25% and the soybeans by 25% compared to normal crops, the relay cropping system may be more economical as the crops are also grown with a minimum of fertilizer and herbicide and the soybeans are grown without tillage.

The objective of this experiment was to compare relay cropping systems of high moisture winter barley-soybean and winter barley (normal maturation) with winter barley alone or a conventionally tilled soybean alone.

In each of the study years, a second site was established on a sandy loam location. In 1987/88 the winter barley had significant winter kill and the relay seeded soybeans germinated and died in the drought. The 1988/89 study site was abandoned as a result of a combination of winterkill and residual atrazine kill of the winter barley.

RESULTS AND DISCUSSION

Winter Barley Yield

Winter barley yields were low because of poor winter survival in year 1 and only fair survival in year 2. Winter hardiness could likely have been increased if the winter barley had been planted in early September, rather than late September or early October.

In both years of the study, the high moisture winter barley yielded approximately 40% less than the sole winter barley crop harvested for grain (Table 15). The barley was harvested slightly earlier than it likely should have been (44.7% moisture in 1988 and 41.2% moisture in 1989). Physiological maturity in barley is reached at 40% moisture (McLaughlin *et al.* 1981). However, this cannot entirely explain the large yield reduction. Poor winter hardiness may have contributed to the reduction in 1988. Substantial tillering occurred in the spring of 1988 as a result of the poor overwintering. The plants in those areas remained green much longer than the plants that wintered well. At high moisture harvest many of the green plants were still in the milky stage (approx. 65% moisture) while the earlier heading plants had nearly completely ripened grain. Although the average of the lot at high moisture harvest was 44.7% moisture, many of the "green" grains likely had not approached physiological maturity. In 1989, the crop was more even, was plot combined with very little loss, and it was harvested at a slightly lower moisture level. No explanation for the significant yield reduction can be provided except that dry matter accumulation was not yet complete and harvesting should not begin until winter barley reaches the 30-35% moisture level. Harvesting the mature relay cropped barley in 1989 proved difficult. Significant lodging of the barley occurred and the soybeans were etiolating and climbing into the barley canopy. The high moisture barley harvest occurred prior to soybean interference.

Table 15. Yields of Winter Barley and Soybean in Relay Cropping Systems In 1988-89.

	Wilhelm Farm 1988		Bender Farm 1989	
Cropping System	Barley Yield t/ha	Soybean Yield t/ha	Barley Yield t/ha	Soybean Yield t/ha
Winter Barley	2.36 [a]	-	3.74 [a]	-
Soybean	-	*1.21	-	3.43 [a]
Winter Barley - Soybean	2.16 [a]	0.27	1.91 [b]	0.29 [b]
High Moisture Winter Barley — Soybean	1.48 [b]	0.33	2.30 [b]	0.40 [b]
C.V. %	12.6	---	14.2	30.5

* Only one replication was harvested as planting was too shallow in two of the replications for good soybean establishment

Soybean Yield

In both years, no field harvest would have been obtained from the relay cropped soybeans as yields were very low, the beans were stunted and the pods were low to the ground. In 1988, a short soybean cultivar was used which exacerbated the low pod problem. Poor winter survival and slow early spring growth of the winter barley delayed soybean drilling until late May. This made the drought effect worse because little soil moisture remained at this time and germination of the soybeans was poor. In 1989, soybeans were planted in a timely manner but a poor soybean stand was obtained in the relay cropped soybeans.

Two problems that were encountered in both years of the study were: lack of penetration by the no-till drill in the hard, dry soil, and a lack of moisture after germination of the shallowly planted soybeans. In 1989, extra weights and 2 inch deep wavy coulters were used on the Tye no-till drill to try and obtain a deeper planting depth under the winter barley. However, obtaining an adequate seeding depth and soil cover over the seed remained a problem. When soybeans did germinate, a significant quantity of the shallowly planted seedlings were lost as a result of an extensive drought in 1988 and infrequent rains in 1989. In both years, soybeans growing on the relay cropped plots were reduced considerably in growth compared to the control plots. In 1988, the soybeans were very short at harvest with many of the pods in an unharvestable position for combining. Annual weeds (particularly wild buckwheat) quickly invaded the plots following harvest of the winter barley which provided very little straw mulch for weed control. In 1989, more straw mulch was present and annual weed pressure was low. However, the sparse population of soybeans that were present grew poorly. Relay cropped soybeans were etiolated as a result of competition for light with the winter barley. Although the cutter bar was raised for combining the winter barley, some clipping of the etiolated soybeans occurred when the barley was harvested as dry grain. However, the main problem in the plot combining was from wheel traffic damage which was much greater than what would be expected using a field combine. Probably the most significant problem with soybean yield was a chlorotic condition that was also experienced in the no-till/mow-kill soybean system in 1989. Relay cropped soybeans were considerably lighter in colour than the control plots. A potassium deficiency may have induced the poor N status of the relay cropped soybean as potassium plays an important role in the nitrogen fixation process. A soil test indicated potassium levels on the low end of the medium range and no potassium was applied to the winter barley or relay cropped soybean.

Conclusions

Dry weather, poor winter barley survival and poor penetration by the no-till drill combined to cause major problems with the high moisture barley-soybean relay cropping system. Two of these factors, winter hardiness and drill penetration, can likely be overcome. The winter barley breeding program at the University of Guelph has some promising winter hardy barley lines near release. As the soil is very hard, and difficult to penetrate with a drill with a large number of coulters, it may easier to obtain a plant stand if the soybeans were planted in rows. Spraying a narrow herbicide band over this area at planting might further improve the reliability of weed control for the soybean.

Dry weather and moisture consumption by the barley will always be a major concern with this system. Low production costs for inputs in the relay cropping system are likely required to make it feasible because stand failure of the soybeans is inevitable in drought years. If stand failure did occur with the soybeans, financial risk could also be reduced if an alternative cropping management was available. In most areas, buckwheat could be seeded and harvested as a double crop, particularly if the winter barley was harvested as a high moisture feed.

3 a) – No-till Winter Wheat and Red Clover Plowdown Following Soybeans, Fall 88 - Fall 89

Drill seeding of wheat after conventional seedbed preparation (cultivation or discing) is the most widespread method of establishing winter wheat. However, some farmers have had success with broadcasting wheat into standing soybeans at leaf yellowing or no-till planting wheat with a conventional grain drill after soybean harvest.

These conservation tillage systems have several potential benefits:

erosion control — ground cover will be increased

winter hardiness — greater snow trapping from crop residues

EXPERIMENTAL METHODS AND DESIGN

Wheat Establishment Methods

Aerial seed wheat, at yellowing in soybeans
Zero-till wheat after soybean harvest using a conventional grain drill.
Conventional seeding of wheat after cultivation

Statistical Design

Layout	RCBD
Number of Treatments	3
Replications	4

General Information

	Site 1	**Site 2**
Cooperator	Carl Ruby	Robert Chesney
Soil Type	Clay loam	Sandy loam
Corn Heat Units	2700	2800
Plot Size	6.6m x 25m	5.8m x 25m
Fertility Subplots	2 m x 2m	-
Wheat Variety	Frederick	Frederick
Aerial Seeding	Cyclone broadcast	Cyclone broadcast
Aerial Seeding Date	Sept. 8, 1988	Sept. 16, 1989
Aerial Seeding Rate	180 kg/ha	180 kg/ha
Conventional Tillage	1 cultivation	1 disking
Seeding Date	Oct. 1, 1988	Oct. 15, 1988
Seeding Rate	120 kg/ha	120 kg/ha
Ground Cover Evaluation	Oct. 6, 1988	Oct. 19, 1988
G.C.E. & Plant Counts	April 25, 1989	April 26,1989
Plant Density Counts	0.25 m^2 quadrat (3)	0.25 m^2 quadrat (3)
Red Clover Seeding Rate	10 kg/ha	10 kg/ha
Red Clover Seeding Date	April 11, 1989	April 20, 1989
Fertilization	*7 Treatments	100 kg N/ha
Application Date	April 28, 1989	April 20, 1989
Herbicide Application	—	M.C.P.A.
Wheat Harvest Date	July 25, 1989	July 15, 1989
Wheat Harvest Method	2.25 m^2 quadrat (1)	1 m^2 quadrat (3)
Clover and Weed Harvest	Oct 10-12, 1989	—
Fall Harvest Method	2.25 m^2 quadrat (1)	—

* The 7 fertility treatments applied to the winter wheat were two rates of liquid manure, two rates of compost and three rates of fertilizer (see Manure Management in Conservation Farming Systems report).

earlier seeding — the aerial seeding technique enables seeding wheat approximately 3 weeks earlier. This is critical in areas of less than 2700 corn heat units where soybean harvesting is frequently completed after the recommended wheat seeding period.

time saver — Aerial seeding and no-till drilling enable seeding to take place with only one pass over the field.

wet weather — aerial seeding and to a lessor extent no-till drilling enable seeding when conditions are too wet for conventional seeding

Two concerns of the conservation tillage systems are that perennial weed species may increase and frost seeded red clover for plowdown may not establish as well due to greater surface residue.

The objectives of this trial were to identify differences in ground cover, winter wheat establishment and grain yield between winter wheat conservation tillage systems. Weed growth and biomass production from red clover plowdown were also evaluated because some farmers expressed concerns that the no-till establishment methods might have some influence on these factors. Two sites were selected which represented the "boundary" between the use of aerial seeding techniques (generally used in areas < 2700 CHU areas) and zero-till techniques (generally used in areas of >2700 CHU).

RESULTS AND DISCUSSION

Ground Cover

Greater ground cover was obtained on the two conservation tillage systems compared to the conventionally tilled system (Table 16). The aerial seeding produced significantly higher fall ground cover than did zero-till drilling which may have been due to two factors: the zero-till drilling activity caused disturbance of the soil and some incorporation of residue; and the aerial seeded wheat experienced greater fall growth prior to measurement of groundcover as it was seeded approximately three weeks earlier.

At the early spring sampling date the ground cover in the no-till plots remained high. The conventional tilled plots doubled their fall ground cover ratings at the spring sampling date at both sites.

Winter Wheat Establishment

The aerial seeding system established stands relatively well at both sites (Table 17). A somewhat lower population of seedlings was obtained on the sandy loam site where equivalent seeding rates were used. The soybeans were more mature at this site and some of the seeds landed on dead soybean leaves on the soil surface. There was no significant difference between plant density of zero-till or conventionally tilled and drilled wheat at both locations. It appears that a conventional grain drill is suitable for successful establishment of winter wheat in uncultivated soybean residue.

Table 16.

Evaluation of % Ground Cover of Various Winter Wheat Establishment Methods on Two Farms, 1988-89.

	Ruby farm Clay Loam Soil		**Chesney Farm** Sandy Loam Soil	
Winter Wheat Establishment Method	Fall	Spring	Fall	Spring
	% Ground Cover			
Aerial seeding	86.3 [a]	91.5 [a]	93.8 [a]	91.0 [a]
Zero-till seeding	67.3 [b]	77.8 [b]	85.0 [b]	85.5 [a]
Conventional till	27.5 [c]	52.2 [c]	7.3 [c]	16.0 [b]
C.V. %	7.7	6.0	4.5	16.9

Table 17.

Evaluation of Winter Wheat Plant Density and Yield under Various Winter Wheat Establishment Methods on Two Farms In 1989.

	Ruby Farm Clay Loam Soil		**Chesney Farm** Sandy Loam Soil	
Winter Wheat Establishment Method	Plants /m^2	Yield t/ha	Plants /m^2	Yield t/ha
Aerial seeding	239 [a]	3.11	189 [b]	2.74
Zero-till seeding	149 [b]	3.02	288 [a]	2.53
Conventional till	156 [b]	3.10	260 [a]	2.56
C.V. %	17.3	12.4	12.2	16.4

Yield of Winter Wheat and Clover Plowdown

At both locations, there were no significant effects of method of wheat establishment on yield (Table 18). The method of establishment also had no significant effects on the April frost seeded red clover plowdown yield or fall weed biomass. The weed growth in the fall was quite variable because plots that received high rates of fertilizer (liquid manure or commercial N) had sections within plots of intense weed growth. No sampling of weeds or red clover was performed on the sandy loam site because weed pressure was intense on this site. M.C.P.A. herbicide was sprayed on the field and the clover was stressed beyond recovery as a result of the herbicide application and dry weather on the drought prone soil.

Conclusions

Both no-till seeding techniques provided much greater ground cover than conventionally tilled and planted winter wheat. Aerial seeding provided slightly greater ground cover than zero-tilling which was likely due to the more advanced stage of wheat growth going into the winter. No significant differences in yield of winter wheat or in fall growth of red clover plowdown or weeds was observed. No weed measurements were made at either site at the time of cereal harvest. When grown following soybeans, winter wheat appears not to respond to tillage. Evaluating sites with a greater pressure of perennial weeds such as quackgrass, Canada thistle or sow thistle may have provided differences in weed biomass.

Table 18.

Evaluation of Methods of Winter Wheat Establishment on Fall Red Clover Plowdown and Weed Biomass on a Clay Loam Soli at the Ruby Farm In 1989 (Average of 7 Fertility Treatments).

Winter Wheat Establishment Method	**Red Clover Biomass kg/ha**	**Weed Biomass kg/ha**
Aerial seeding	1303	146
Zero-till seeding	1315	152
Conventional till	1237	98
C.V. %	18.0	107.7

3 b) — Interseeded Cover Crop and Catch Crop Systems for Winter Wheat

In Ontario, a two to three month growing season remains after harvest of winter wheat. This period is generally used by farmers to reduce weed problems in the following crop by using herbicides or cultivation to control annual and perennial weeds or to grow a red clover cover crop for supplementary forage or plowdown. Red clover interseeded in spring and winter cereals can provide large quantities of fall biomass and supply much of the nitrogen required by a subsequent corn crop (Norris 1981; Bruulsema and Christie 1987). As well, red clover interseedings can act as a competitive mulch to weeds after harvest (Samson 1989; Dyke and Barnard 1976).

However some difficulties with these systems have been encountered. In wet seasons farmers have frequently found red clover interseedings to interfere with wheat growth, and in dry seasons to establish poorly. The use of interseeded red clover in winter wheat has also proven not to be an economical source of nitrogen for no-till corn production in Ohio (Ngalla and Eckert 1987). Several promising interseeded cover crops and fall seeded catch crop systems have been reported outside of Canada. In a one year study in Pennsylvania, hairy vetch and crimson clover drilled in winter wheat in early May were found to produce 3800 and 5600 kg/ha, respectively (Janke *et al.* 1987). In Ontario, oilseed radish and buckwheat are planted as catch crops after harvest of wheat by some farmers. In longer season areas, the buckwheat is being harvested as a grain. Few studies have looked at the benefits of catch cropping in Ontario.

European studies have revealed that brassica catch crops can reduce nitrate leaching by approximately 50%, suppress annual and perennial weeds and improve soil aggregate stability. (Hansen and Rasmussen 1979; Stokholm 1979; Kundler *et al.* 1985; Strebel *et al.* 1989).

The objectives of this study were to evaluate biomass and weed control potential of red clover interseeded at different times, and the potential for use of other species as interseedings in winter wheat or as catch crops following winter wheat.

A severe infestation of quack grass was present on the sandy loam site in 1989 after wheat harvest. The site was abandoned as the quack grass overtook the cover crops.

RESULTS AND DISCUSSION

Wheat Yield

At the silt loam and sandy loam sites there were no significant differences in wheat yield among the various treatments (Tables 19-21). Wheat yields were relatively high and provided considerable competition to the interseeded cover crops.

EXPERIMENTAL METHODS AND DESIGN

Experimental Treatments

Red clover (10 kg/ha Marino) frost seeded in mid March
Red clover (10 kg/ha Marino) frost seeded; in mid April
Red clover (10 kg ha Marino) drilled in wheat in mid May
Alfalfa (10 kg/ha Nitro) drilled in wheat in mid May
Crimson clover (15 kg/ha) drilled in wheat in mid May
Hairy vetch (30 kg/ha) drilled in wheat in mid May
Oilseed radish (20 kg/ha) seeded in mid August
Buckwheat (100 kg/ha) seeded in early August.
Cultivation after harvest (August 15)
Glyphosate (Round-up, 2.5 l/ha) after harvest
Check 1
Check 2

Statistical Design

Layout	RCBD
Number of Treatments	12
Replications	3

General Information

		Site 1	**Site 2**
Cooperator		Quentin Martin	Harry Wilhelm
Soil Type		Sandy loam	Silt loam
Previous Crop	1987-88	Barley	White beans
	1988-89	Alfalfa	White beans
Plot Size	1987-88	9.2 m x 40 m	9.2 m x 40 m
	1988-89	6.1 m x 40 m	6.1 m x 40 m
Variety	1987-88	Harus	Augusta
	1988-89	Frederick	Augusta
Fertilization		80 kg N/ha (28%)	80 kg N/ha (Urea)
N Application Date		April 25, 1988	May 12, 1988
		May 9, 1989	May 1, 1989
Red Clover Seeding (early)		March 16, 1988	March 16, 1988
		March 17, 1989	March 17, 1989
Red Clover Seeding (late)		April 11, 1988	April 11, 1988
		April 11, 1989	April 11, 1989
Cover Crops Drilled		May 9, 1988	May 16, 1989
(in 15 cm wheat)		May 15, 1989	May 16, 1989
Seedling Counts		1 m^2 quadrat (3) July 20	1 m^2 quadrat (3)
		July 20,1988; July.26,1989	July 18,1988; July 27, 1989
Wheat Harvest	1988	1 m^2 quadrat (3), July 20	1 m^2 quadrat (3), July 15
	1989	1 m^2 quadrat (3), July 26	plot combine, July 27
Cultivations		2	2
Buckwheat Seeding		Aug. 5, 1988; Aug. 2, 1989	Aug. 4, 1988; Aug. 3, 1989
Oilseed Radish , Seeding		Aug.14,1988; Aug. 12, 1989	Aug. 15,1988; Aug.14, 1989
Glyphosate Spraying		Sept. 9, 1988; —	Sept.10, 88; Sept. 11, 89
Fall Biomass Harvest		1 m^2 quadrat (3)	1 m^2 quadrat (3)
		Oct . 27,1988; —	Oct.18, 1988; Oct. 23, 1989
Ground Cover Evaluation		Oct. 27, 1988; —	Oct. 17, 1988; Oct. 23, 1989

Forage Counts

In 1988 the drought had more effect on the survival and growth of the cover crops on the sandy loam site than at the silt loam location. At both sites, alfalfa produced the greatest number of forage seedlings. Mortality of seedlings was pronounced on all treatments at the sandy loam site and this no doubt affected plant biomass production at this site. Red clover populations appeared to be most affected. On the silt loam site, the earlier the red clover was seeded the better the survival of the seedlings in 1988. In the wet spring of 1989, the latest seeding date for the red clover provided the best clover plant stand (Table 21).

Fall Forage Biomass

Hairy vetch was consistently the most productive interseeded cover crop in the trials. Hairy vetch produced 3667 and 2554 kg/ha dry matter at the silt loam and sandy loam locations respectively during the drought year of 1988. Dry matter production of the hairy vetch (as well as most other species) was lower in 1989 on the silt loam site. This may have been the result of low potassium availability. Although no tissue interpretation for the vetch and crimson clover was available. Hoyt (1987) had high legume biomass and tissue tests of 4.1% and 3.4% potassium for hairy vetch and crimson clover while those obtained at the silt loam site in 1989 were 2.04 and 1.89 for the hairy vetch and crimson clover respectively (Table 26). The potassium tissue tested on the Nitro alfalfa (1.7%

Table 19. Biomass Production, Establishment and Ground Cover In Winter Wheat Interseeding and Catch Crop Systems on a Sandy Loam Soil at the Martin Farm in 1988.

	At Cereal Harvest		**At Fall Harvest**		
Catch Crop	Wheat Yield t/ha	Forage Plants #/m^2	Forage Biomass t/ha	Weed Biomass t/ha	Ground Cover %
Red clover (early)	3.35	6 ^{d}	523 ^{d}	257 ^{ab}	88.0 ^{a}
Red clover (late)	4.36	14 ^{cd}	713 ^{d}	130 ^{bd}	87.7 ^{a}
Red clover drilled	3.78	5 ^{d}	491 ^{d}	196 ^{abcd}	87.0 ^{a}
Nitro alfalfa	3.98	70 ^{a}	1440 ^{c}	20 ^{e}	92.7 ^{a}
Crimson clover	4.38	33 ^{b}	1426 ^{c}	73 ^{cde}	96.3 ^{a}
Hairy vetch	3.82	26 ^{bc}	2554 ^{b}	30 ^{de}	92.7 ^{a}
Oilseed radish	3.74	0 ^{d}	3654 ^{a}	0 ^{e}	96.7 ^{a}
Buckwheat	3.50	0 ^{d}	1688 ^{c}	0 ^{e}	85.7 ^{a}
Cultivation	4.06	0 ^{d}	0 ^{d}	0 ^{e}	49.3 ^{b}
Glyphosate	3.70	0 ^{d}	0 ^{d}	89 ^{cde}	42.7 ^{b}
Check	3.53	0 ^{d}	0 ^{d}	200 ^{abc}	77.0 ^{a}
Check	3.56	0 ^{d}	0 ^{d}	300 ^{a}	74.0 ^{a}
C.V. %	11.8	69	36.4	82.6	14.8

Table 20. Biomass Production, Establishment and Ground Cover In Winter Wheat Interseeding and Catch Crop Systems on a Silt Loam Soil at the Wilhelm Farm In 1988.

	At Cereal Harvest		**At Fall Harvest**		
Catch Crop	Wheat Yield t/ha	Forage Plants #/m^2	Forage Biomass t/ha	Weed Biomass t/ha	Ground Cover %
Red clover (early)	4.43	79 ^{b}	1569 ^{b}	181 ^{ef}	97.3 ^{a}
Red clover (late)	4.00	53 ^{c}	1193 ^{cd}	281 ^{de}	92.7 ^{ab}
Red clover (drilled)	4.23	31 ^{d}	678 ^{f}	463 ^{bc}	88.7 ^{abc}
Nitro alfalfa	4.51	109 ^{a}	890 ^{ef}	342 ^{cd}	91.3 ^{abc}
Crimson clover	4.08	55 ^{c}	844 ^{ef}	482 ^{bc}	87.3 ^{abc}
Hairy vetch	4.31	77 ^{b}	3367 ^{a}	46 ^{fg}	100.0 ^{a}
Oilseed radish	4.45	0 ^{e}	1140 ^{de}	12 ^{g}	82.0 ^{bcd}
Buckwheat	4.55	0 ^{e}	1463 ^{bc}	4 ^{g}	78.3 ^{cd}
Cultivation	4.18	0 ^{e}	0 ^{g}	101 ^{fg}	27.0 ^{f}
Glyphosate	4.46	0 ^{e}	0 ^{g}	578 ^{ab}	53.3 ^{e}
Check	4.51	0 ^{e}	0 ^{g}	660 ^{a}	71.7 ^{d}
Check	4.43	0 ^{e}	0 ^{g}	521 ^{ab}	74.0 ^{d}
C.V. %	9.1	26.3	18.3	29.3	8.9

K) was at the critical level according to OMAF (1989) tissue analysis. The hairy vetch also appeared to be affected by the cutting height of the cereal residue. Where clipping of the cereal straw was low, hairy vetch regrowth was reduced.

Of the remaining species, red clover was more productive on the silt loam site in both years while the alfalfa and crimson clover performed better on the sandy loam site in the drought year.

Of the catch crops sown after harvest the oilseed radish produced high quantities of biomass on the sandy loam site (3654 kg/ha dry matter) but growth on the silt loam site was poor. This was likely related to low residual soil nitrogen as the oil radish and cereal regrowth appeared to be nutrient deficient at the silt loam site in both years. Buckwheat forage and grain yields were similar at both sites with 773 and 628 kg/ha of grain (not shown) being produced on the silt loam and sandy loam sites respectively in 1988. In 1989, buckwheat grew poorly on the silt loam and was completely killed at late flowering by an early frost. Buckwheat is also reported to be a poor potassium feeder as it has a small root system (Bauer 1921).

Weed Biomass at Fall harvest

In general, the greater the biomass production of the interseeded cover crops, the greater was the weed suppression. Hence, hairy vetch and red clover were the best two weed suppressants

Table 21. Biomass Production, Establishment and Ground Cover in Winter Wheat Interseeding and Catch Crop Systems on a Silt Loam Site at the Wilhelm Farm In 1989.

	At Cereal Harvest		At Fall Harvest		
Catch Crop	Wheat Yield t/ha	Forage Plants #/m^2	Forage Biomass t/ha	Weed Biomass t/ha	Ground Cover %
Red clover(early)	4.22	38 ^{cd}	908 ^{bcd}	503 ^{bc}	96.3 ^{a}
Red clover (late)	4.04	31 ^{d}	1089 ^{bc}	420 ^{bcd}	96.0 ^{a}
Red clover (drilled)	4.01	67 ^{a}	1319 ^{b}	364 ^{bcde}	99.0 ^{a}
Nitro alfalfa	4.18	31 ^{d}	346 ^{ef}	584 ^{bc}	78.3 ^{bcd}
Crimson clover	3.91	46 ^{bc}	482 ^{def}	637 ^{cde}	71.3 ^{cde}
Hairy vetch	4.12	55 ^{ab}	2106 ^{a}	313 ^{cde}	99.3 ^{a}
Oilseed radish	-	0 ^{e}	756 ^{cde}	72 ^{e}	91.7 ^{ab}
Buckwheat	-	0 ^{e}	496 ^{de}	107 ^{e}	89.0 ^{ab}
Cultivation	-	0 ^{e}	0 ^{f}	157 ^{de}	83.0 ^{abc}
Glyphosate	-	0 ^{e}	0 ^{f}	351 ^{bcde}	62.0 ^{de}
Check	3.87	0 ^{e}	0 ^{f}	1124 ^{a}	61.3 ^{e}
Check	3.86	0 ^{e}	0 ^{f}	1038 ^{a}	57.3 ^{e}
C.V. %	8.2	34.1	40.9	32.9	11.3

at the silt loam site. On the sandy loam site weed biomass was lower, hairy vetch, nitro alfalfa and to a lessor extent crimson clover were superior to the red clover treatments as weed suppressants.

Cultivation was effective in reducing weed growth. Weed control was further improved at the silt loam site by seeding oilseed radish or buckwheat. Glyphosate (Round-up) was not as effective as the cultivation treatments. This may have been due to the fact that most of the prominent weeds in the trials (foxtail, ragweed, wild buckwheat) were annual weeds which completed their life cycle 4-6 weeks after cereal harvest. Hence waiting one month to spray after wheat harvest (to enable regrowth of quack grass to be killed by Glyphosate) may enable significant reproduction of annual weeds. In 1989, the quack grass infestation on the sandy loam site appeared to be too severe for cultural control.

Fusilade, a selective grass herbicide, was sprayed over the entire site to kill the quack grass and try and salvage biomass accumulation of the legume cover crops. The herbicide only suppressed the quack grass growth and no fall data was obtained.

Ground Cover

Systems seeded with either an interseeded or fall seeded catch crop significantly increased ground cover compared to the control treatments. In 1988, cultivation or spraying with Glyphosate reduced ground cover compared to the control plots at both sites. On the silt loam site, hairy vetch and red clover generally provided the highest ground cover in both years of the study. In 1989, no reductions in ground cover were observed on the silt loam site from application of Round-up or from after harvest cultivation in the fall (as there was significant wheat regrowth).

Conclusions

Hairy vetch provided at least 50% more biomass than other interseeded species tested at the sandy loam and silt loam sites. No interference occurred with winter wheat harvest when vetch drilling occurred in mid-May in wheat yielding approximately 4 t/ha. In lower yielding crops, excessive climbing of the vetch could likely be a problem. Red clover established poorly on the sandy loam site during the drought of 1988. Establishment of red clover on the silt loam site also appeared to be affected by the weather. During the drought of 1988, establishment and biomass production were higher the earlier red clover was seeded while in 1989 (a year with a wet spring) establishment and biomass yield were highest on the latest seeded red clover. Oilseed radish appeared to have potential as a high biomass producing fall seeded catch crop but it requires adequate N fertility for optimum growth. High biomass producing cover crops were effective weed suppressants and provided high ground cover.

3 c) — Interseeded Cover Crop and Catch Crop Systems in Spring Cereals

The objectives of this trial are to examine the effect of timing of sowing of red clover and to compare it with other potential cover crops for use in a rotation to corn. Blind harrowing is being evaluated as a weed control measure and as a method to enable a later seeding of crimson clover and hairy vetch which may grow into the cereal canopy if seeded when the grain is planted.

In addition, liquid manure was added to some of the treatments to tests its effects on cover crop growth. By incorporating the manure after grain harvest and seeding oil radish, more of the nitrogen for the next years corn crop may be conserved. This may also reduce soil compaction. Hauling of the material is done on cereal residue when the soil is dry rather than on worked ground during the spring or fall period when the soil is frequently saturated.

RESULTS AND DISCUSSION

Grain Yield

The drought caused mixed grain yields to be extremely low at both locations (Tables 22 and 23). No significant differences were observed in grain yield among the various treatments. Direct combining of the treatments with interseeded hairy vetch would have been nearly impossible on the clay loam as the vetch was as high as the grain. On the sandy loam this would have also been the case except the vetch died approximately one month prior to harvest because of the severe drought. It may be that this climbing effect would be reduced in an average year where the grain crop is more competitive but more likely the vetch needs to be seeded when the grain is more advanced to reduce this risk.

Weed Biomass at Grain Harvest

Weed pressure differed greatly between the two sites. The clay loam site appeared to be nitrogen deficient while the sandy loam site had a history of liquid slurry applications. When the drought broke at the latter site a tremendous flush of weeds occurred when the grain was maturing and resulted in a very high weed biomass at cereal harvest. Contrasts run on the weed biomass data showed blind harrowing significantly increased weed pressure at grain harvest. This may have been due to the lack of germination of weeds under dry soil conditions experienced at planting. Other reports have indicated that harrowing at the wrong time can produce more weeds (Woodward 1983). Woodward suggested that prior to proceeding with the harrowing operation, weeds should be checked to see if the first tiny white roots are present.

At the clay loam site, the interseeded alfalfa, crimson clover, and hairy vetch reduced weed biomass significantly. Red clover was not as effective a weed suppressant as the other species, although it probably would have been under less droughty conditions. Blind harrowing appeared to have no significant impact on weeds at this site.

Fall Forage Biomass and Cereal Regrowth

Of the interseeded species hairy vetch produced the highest biomass on the clay loam site followed by the crimson clover. On the sandy loam, alfalfa and crimson clover produced the highest biomass. Delaying red clover seeding by blind harrowing had little impact on red clover growth. As was the case of the winter wheat trials, red clover and hairy vetch individually performed better on the heavier soil while alfalfa produced more biomass when grown on the lighter soil. The few crimson clover

EXPERIMENTAL METHODS AND DESIGN

Experimental Treatments

1. Red clover (8 kg/ha) at seeding (R)
2. Annual alfalfa (8 kg/ha) at seeding (A)
3. Blind harrow (immediately before grain emergence) (B)
4. Blind harrow + red clover (8 kg/ha) (B.R.)
5. Blind harrow + hairy vetch (25 kg/ha) (B.V.)
6. Blind harrow + crimson clover (12 kg/ha Dixie) (B.Cr.)
7. Blind harrow + red clover (8 kg/ha) + manure (B.R.M.)
8. Blind harrow + manure+ cultivation (B.M.C.)
9. Blind harrow + oilseed radish (20 kg/ha) + cultivation (B.O.C.)
10. Blind harrow + manure + oilseed radish+ cultivation (B.M.O.C.)
11. Blind harrow + cultivation after harvest (B.C)
12. No weed control (Control)

Statistical Design

Layout	RCBD
Number of Treatments	12
Replications	3

General Information

	Site 1	***Site 2***
Cooperator	Keith Baechler	Carl Ruby
Soil Type	Sandy Loam	Clay Loam
Previous Crop	Corn	Corn
Plot Size	6.1 m x 25 m	6.1 m x 25 m
Fertilization	Liquid manure	20-20-20.
Mixture seeded	50% Leger Barley 50% Donald Oats	50% Leger Barley 50% Donald Oats
Seeding rate	100 kg/ha	100 kg/ha
Seeding date	May 6	May 4
Early Forage Seeding	May 6	May 4
Blind harrowing	May 12	May 11
Grain & Biomass Harvest of forage and weeds	1 m^2 quadrat (3) August 4-6	1 m^2 quadrat (3) August 8-10
Manure application	60,000 l/ha August 20.	60,000 l/ha August 16
Cultivations	2	2
Oilseed Radish Seeding	August 20	August 16
Fall Biomass Harvest	1 m^2 quadrat (3) October 29-31	1 m^2 quadrat (3) October 26-28
Ground Cover Evaluation	November 4	October 17

Table 22. Grain yield, Biomass Production and Ground Cover of Spring Grain Interseeding and Catch Crop Systems on a Clay Loam Soli at the Ruby Farm In 1988.

	At Cereal Harvest			**At Fall Harvest**			
	Grain Yield t/ha	Forage Biomass kg/ha	Weed Biomass kg/ha	Forage Biomass kg/ha	Weed Biomass kg/ha	Cereal Regrowth kg/ha	Ground Cover %
R.	1.83	305 ^{d}	59 ^{abc}	1373 ^{c}	28 ^{b}	204 ^{de}	99.7 ^{a}
A.	1.82	629 ^{b}	28 ^{ef}	1312 ^{cd}	13 ^{b}	102 ^{e}	99.7 ^{a}
B.	1.89	0 ^{e}	61 ^{abc}	0 ^{e}	154 ^{a}	518 ^{d}	87.0 ^{b}
B.R.	1.96	257 ^{d}	44 ^{cdef}	1300 ^{cd}	26 ^{b}	144 ^{e}	99.0 ^{a}
B.V.	1.68	848 a	23 ^{f}	3446 ^{a}	9 ^{b}	103 ^{e}	100.0 ^{a}
B.Cr.	1.90	397 ^{c}	33 ^{def}	1790 ^{b}	40 ^{b}	291 ^{de}	96.7 ^{a}
B.R.M.	1.94	227 ^{d}	44 ^{cdef}	1010 ^{d}	34 ^{b}	917 ^{c}	98.3 ^{a}
B.M.C.	1.99	0 ^{e}	54 ^{bcd}	0 ^{e}	0 ^{b}	3031 ^{a}	99.3 ^{a}
B.O.C.	1.82	0 ^{e}	70 ^{ab}	234 ^{e}	6 ^{b}	1071 ^{c}	95.3 ^{a}
B.M.O.C.	1.72	0 ^{e}	78 ^{a}	1153 ^{cd}	0 ^{b}	2506 ^{b}	95.3 ^{a}
B.C.	1.70	0 ^{e}	55 ^{abcd}	0 ^{e}	21 ^{b}	1038 ^{c}	88.0 ^{b}
Control	1.91	0 ^{e}	51 ^{bcde}	0 ^{e}	124 ^{a}	513 ^{d}	82.0 ^{c}
C.V. %	9.6	24.4	24.1	17.1	76.3	20.2	3.0

plants that survived the drought grew well on the sandy loam. However, their numbers were too few to produce a high biomass.

Liquid manure had a much greater impact on biomass production on the clay loam site than on the sandy loam site which had a history of liquid slurry applications. Liquid manure applications on red clover (treatment 7) tended to depress red clover growth while stimulating cereal regrowth. Oilseed radish responded at least as well or better than the cereal regrowth to the slurry applications at both locations.

The highest biomass producing system in both trials was the treatment with liquid manure + oil radish + cultivation. This system produced 3659 and 3016 kg/ha of dry matter on the clay loam and sandy loam sites respectively. On the clay loam site, two thirds of this biomass was made up of cereal regrowth. The population of the oilseed radish appeared thin which may have been a result of incorporating the oilseed radish too deeply when cultivating after grain harvest.

Fall Weed Biomass

The sandy loam site had more weed growth than the clay loam site in the fall. At the sandy loam site, weed biomass was reduced in systems receiving after harvest cultivation or applications of liquid manure. At the clay loam site an interseeded cover crop or cultivation after harvest (with or without use of a catch crop) significantly reduced weed growth compared to treatments 3 or 12 which received no cover crop or cultivation after harvest.

Table 23. Grain Yield, Biomass Production and Ground Cover of Spring Grain InterseedIng and Catch Crop Systems on a Sandy Loam Soil at the Baechler Farm In 1988.

	At Cereal Harvest			At Fall Harvest			
	Grain Yield t/ha	Forage Biomass kg/ha	Weed Biomass kg/ha	Forage Biomass kg/ha	Weed Biomass kg/ha	Cereal Regrowth kg/ha	Ground Cover %
R.	1.19	13^{b}	709	298^{c}	549^{ab}	722^{cd}	92.3^{abc}
A.	1.10	282^{a}	777	1641^{a}	199^{cd}	173^{d}	96.3^{ab}
B.	1.22	0^{b}	1072	0^{c}	311^{bcd}	808^{cd}	82.3^{bcd}
B.R.	1.33	27^{b}	1092	347^{bc}	637^{a}	708^{cd}	81.3^{cd}
B.V.	0.98	24^{b}	1235	588^{bc}	634^{a}	652^{cd}	93.0^{abc}
B.Cr.	1.07	52^{b}	1138	1052^{ab}	349^{abcd}	840^{cd}	90.3^{abcd}
B.R.M.	1.06	23^{b}	836	177^{c}	108^{d}	2072^{a}	99.3^{a}
B.M.C.	1.19	0^{b}	879	0^{c}	42^{d}	2160^{a}	99.3^{a}
B.O.C.	1.14	0^{b}	897	1373^{a}	28^{d}	1274^{bc}	99.7^{a}
B.M.O.C.	1.25	0^{b}	988	1650^{a}	21^{d}	1346^{bc}	100.0^{a}
B.B.	1.23	0^{b}	1289	0^{c}	58^{d}	1780^{ab}	89.7^{abcd}
Control	1.25	0^{b}	720	0^{c}	430^{abc}	1224^{bc}	76.3^{d}
C.V. %	19.9	101	37.1	66.9	60.7	32.8	8.2

Contrasts

Blind harrow vs. No Blind Harrow *

* Indicates significance at the 5% level of probability

Ground Cover

Fall ground cover in the spring cereal trial was higher than those of the winter wheat study as greater quantities of cereal regrowth occurred in many of the treatments. Relatively low ground cover ratings were obtained in both trials from treatments 3 and 12 which were seeded with cover crops or cultivated after harvest. High ground cover ratings were generally associated with treatments with high biomass production.

Conclusions

The drought severely restricted the growth of the red clover and annual cover crops on the sandy loam site. The introduction of hairy vetch at the time of blind harrowing appeared to put the grain crop at significant risk for combining due to climbing of the vetch. The crimson clover performed relatively well when introduced at the time of harrowing, and produced the second highest biomass among the interseeded cover crops at both sites.

Manure applications stimulated the growth of the oilseed radish and cereal regrowth but suppressed the growth of red clover. The midsummer manure application system using oilseed radish would probably be more suitable after winter wheat as less cereal regrowth occurs than after spring cereals.

3 d) — Interseeded Cover Crops and Mechanical Weeding Systems in Spring Cereals

Following the 1988 spring cereal trials a more extensive study was performed to further evaluate mechanical weeding systems and their compatibility with establishment of red clover and the annual cover crops of crimson clover and hairy vetch. Vetch climbed extensively at harvest in 1988 and it was felt vetch seeding should likely take place 4-6 weeks after the cereal seeding (rather than 1 week as was practiced in 1988). The three mechanical weeding systems that were evaluated were harrowing, rotary hoeing and finger weeding. Harrowing in the 1988 study had no positive effect on weed control and it was believed that the operation might be more aggressive on weeds if it was performed at an early post emergent stage rather than pre-emergent. Rotary hoeing has proven to be a successful technique for removing weeds in soybeans and corn but no trials could be found in which it was used in spring cereals. One of the cooperators, Harry Wilhelm, had used the rotary hoe in the past for weed control in spring grain at the two leaf stage. As well, it is recommended by at least one manufacturer (Case-International) for use in spring cereals. The finger weeder is widely used in Europe and is presently being marketed extensively in Eastern Canada with its main use being for weed control in cereals.

RESULTS AND DISCUSSION

Grain Yield

On the silt loam site several problems occurred with the management of the trial which provided for a relatively high coefficient of variation for grain yield (Table 25). The oats were planted at a seeding rate approximately 40% lower than desired. Wet field conditions existed through the early growth stages of the cereals and the early mechanical weeding processes of harrowing and rotary hoeing appeared to thin grain stands particularly where wheel marks were present. The cooperator commented that the wheel traffic problems would have been reduced if a lighter tractor had been used. Finger weeding appeared to have no affect on plant stands as the activity was performed later on a well established cereal crop. Further problems were created from a mid July storm which created extensive lodging on the plot. No significant yield effects were observed between treatments on this site but this was likely a result of the large experimental error for grain yield.

On the clay loam site, harrowing again had an aggressive action on the cereals but the plants recovered remarkably well. Rotary hoeing appeared to have no effect on plant stand when it was performed under dry soil conditions on the same date. No significant yield affects were observed amongst any of the treatments (Table 24).

Forage Biomass

The extensive grain lodging at the silt loam site likely had a major impact on the low fall biomass production. The red clover appeared to be the least affected by the extensive lodging and produced the highest quantities of biomass. The cereal stubble was closely clipped in swathing the lodged crop at harvest. Field observations on cutting height have indicated that vetch seems sensitive to low cutting height and this restricts its regrowth.

Hairy vetch provided biomass yields approximately twice as high as the other cover crop species tested on the clay loam site (Table 25). There was no significant reduction in fall hairy vetch biomass from drilling vetch six weeks after planting versus the introduction at finger weeding four weeks after planting. The drilled vetch appeared to climb less at grain harvest possibly due to the

EXPERIMENTAL METHODS AND DESIGN

Treatments

Rotary hoeing (R)
Harrowing (H)
Red clover (10 kg/ha Marino)(RC)
Crimson clover (15 kg/ha Tibbee)(CC)
Finger weeding (F)
Rotary hoeing + red Clover (RRC)
Rotary hoeing + crimson clover (RCC)
Harrowing + red clover (HRC)
Harrowing + crimson clover (HCC)
Finger weeding + hairy vetch (25 kg/ha) (FV)
Finger weeding + crimson clover (FCC)
Finger weeding + hairy vetch drilled (FVD)
Control
Control

Statistical Design

Layout	RCBD
Number of Treatments	14
Replications	3

General Information

	Site 1	***Site 2***
Cooperator	Harry Wilhelm	Carl Ruby
Soil Type	Silt loam	Clay loam
Previous Crop	Wheat	Corn
Plot Size	5.0 x 30 m	5.0 x 25 m
Fertilization at seeding	24-24-24	3-11-3 (liquid)
Broadcast Fertilizer	—	37-0-0, June 20
Variety or Mixture	Donald Oats	50% Leger Barley 50% Donald Oats
Seeding rate		
Seeding date	60 kg/ha	100 kg/ha
Clover Seedings, rotary hoeing (2X) and harrowing	May 4 May 27	April 26 May 17
Clover and early vetch seeding + finger weeding	June 6	May 27
Vetch drilling	June 19	June 9
Grain Harvest	1 m^2 quadrat (3), August 2-3	plot combined July 28
Forage and weed harvest	1 m^2 quadrat (3), August 2-3	1 m^2 quadrat (3), July 28-29
Fall Biomass Harvest	1 m^2 quadrat (3), Oct.16-17	1m^2 quadrat (3), Oct. 18-19
Ground Cover Evaluation	October 23	October 24

Table 24. Spring Cereal Weed Control and Interseeding Systems on a Clay Loam Soil at the Ruby Farm In 1989.

	August			October		
Treatment	Grain Yield t/ha	Forage Biomass kg/ha	Weed Biomass kg/ha	Forage Biomass kg/ha	Weed Biomass kg/ha	Ground Cover %
R	3.17	0 ^{f}	150	0 ^{d}	-	88.7 ^{bcd}
H	3.09	0 ^{f}	148	0 ^{d}	-	85.0 ^{cd}
F	3.24	0 f	193	0 ^{d}	-	81.0 d
RC	3.50	100 ^{de}	113	562 ^{c}	64 ^{ab}	98.3 ^{ab}
CC	2.92	117 ^{d}	176	226 ^{cd}	-	96.0 ^{ab}
RRC	3.08	357 ^{ab}	111	1072 ^{b}	54 ^{b}	98.7 ^{ab}
RCC	3.08	192 ^{cd}	96	539 ^{c}	-	95.7 ^{ab}
HRC	3.09	357 ^{ab}	198	1150 ^{b}	68 ^{ab}	99.0 ^{ab}
HCC	3.14	267 ^{bc}	214	439 ^{c}	-	92.3 ^{abc}
FCC	3.20	95 ^{de}	145	498 ^{c}	—	94.3 ^{abc}
FV	2.99	394 ^{a}	134	2110 ^{a}	61 ^{b}	100.0 ^{a}
FVD	3.41	131 ^{d}	41	1990 ^{a}	79 ^{ab}	100.0 ^{a}
Control	2.86	0 ^{f}	237	0 ^{c}	129 ^{a}	89.7 ^{abcd}
Control	3.26	0 ^{f}	126	0 ^{d}	105 ^{ab}	91.7 ^{abc}
C.V. %	14.4	40.2	72.7	33.5	42.2	5.9

2-week delay in planting. Vetch seeded immediately prior to finger weeding was approximately half the height of the spring cereal at harvest and mayhave caused combining problems if cereal harvest was delayed Hairy vetch biomass at grain harvest was reduced by approximately 2/3rds by using the drilling technique.

The shallow incorporation of interseedings with the mechanical weeding techniques acted positively on forage biomass production on the clay loam site. Both rotary hoeing andharrowing provided a doubling of the red and crimson clover biomass production versus broadcast seedings without surface incorporation.

At both sites, biomass production of the crimson clover was very low in 1989 relative to 1988's experiences. The clover was stunted in the fall and biomass increased only marginally between grain harvest and fall harvest unlike 1988. The crimson clover variety was changed in 1989 from Dixie to Tibbee and this may have contributed to the variation between years.

Weed Biomass

On the clay loam soil at the Ruby farm, low weed pressure and a high variability (C.V. of 73%) in weed biomass occurred The control plots produced 237 kg/ha and 126 kg/ha of weed biomass at grain harvest in which the average of all treatments was 148 kg/ha. Contrasts were run between mechanical weeding treatments and the two control plots, but no significant differences were

Table 25. Spring Cereal Weed Control and Interseeding Systems on a Silt Loam Soil at the Wilhelm Farm In 1989.

	August			October	
Treatment	Grain Yield t/ha	Forage Biomass kg/ha	Weed Biomass kg/ha	Forage Biomass kg/ha	Ground Cover %
R	2.76	0 ^{c}	667	-	85.7 ^{d}
H	2.90	0 ^{c}	1025	-	87.3 ^{d}
F	3.70	0 ^{c}	536	-	90.7 ^{b}
RC	3.30	36 ^{c}	693	550 ^{ab}	98.3 ^{a}
CC	3.31	9 ^{c}	645	97 ^{cd}	88.7 ^{cd}
RRC	3.69	42 ^{bc}	448	643 ^{a}	98.0 ^{ab}
RCC	2.54	89 ^{ab}	583	50 ^{d}	92.0 ^{abcd}
HRC	3.09	46 ^{bc}	442	463 ^{ab}	98.7 ^{a}
HCC	2.59	122 ^{a}	756	89 ^{cd}	93.7 ^{abcd}
FCC	3.31	12 ^{c}	396	49 ^{d}	90.0 ^{bcd}
FV	3.29	15 ^{c}	614	334 ^{bc}	97.7 ^{ab}
FVD	3.58	28 ^{c}	600	407 ^{ab}	95.7 ^{abc}
Control	3.24	0 ^{c}	951	-	88.3 ^{cd}
Control	3.25	0 ^{c}	948	--	87.3 ^{d}
C.V. %	22.4	93 5	53.2	46.1	4.6

Contrasts	
Rotary Hoeing Vs. Control	+
Finger Weeding Vs. Control	+
Harrowing vs. Control	N.S.

+ Indicates contrasts significant at the 10% level of probability. N.S. = not significant.

obtained. The high variability likely made identifying differences in weed control between treatments difficult.

On the silt loam soil, weed pressure was much higher but wet weather delayed the timing and likely reduced the effectiveness of the various weed control methods. Contrastsrun between mechanical weeding treatments indicated that the rotary hoeing and finger weeding reduced weed biomass at grain harvest, but only at the 10% level of significance.

In general, the mechanical weeding operations appeared to be performed too late tobe most effective. Rotary hoeing and finger weeding were performed approximately 3 weeks (at the 3 leaf stage) and 1 month (at the 4-5 leaf stage) after grain seeding respectively, at the two sites. Both the finger weeding and rotary hoeing should probably have been performed approximately two weeks after grain planting when the cereal is in the 1-2 leaf stage. The weedings could perhaps be performed again later, if weed pressure wassignificant. Earlier weed control might be particularly useful for controlling mustard as it appeared to have escaped control by the mechanical weedings in the present trial. Given theexperiences with increased weed growth with blind harrowing in 1988, and the aggressive effect of post emergence harrowing on the grain in 1989, this treatment appears to bold lesspotential than rotary hoeing or finger weeding. Both harrowing and finger weeding have constraints for use in corn rotations, because almost any corn stalk residue present in the field plugs the device. The finger weeder exhibited this problem on the clay loam site at theRuby farm where spring grain followed fall moldboard plowed corn.

Conclusions

The mechanical weeding devices were probably used too late for optimal weed control. However, they appreared to be very effective in providing an establishment method for thecover crop species tested. (One of the cooperators, Carl Ruby, broadcasted clover and nitrogen in his 1990 spring grain field at the two leaf stage and rotary hoed). The main disadvantage of the system is that it probably needs to be performed when labour requirements for row crops are high. Following 1988's experiences with hairy vetch climbing in the cereal, the two later methods for introducing hairy vetch in 1989 caused little interference with cereal harvest. Biomass yields from the hairy vetch were approximately twice that of red clover on the clay loam site. On the silt loam site lodging caused low fall plowdown yields.

4 a) — Effect of 1988 Interseeding and Catch Crop Systems in Winter Wheat on Nutrient Cycling and Corn Yield in 1989.

The ability of red clover plowdown to substitute for the majority of the fertilizer N required by corn is well documented in Ontario (Fulkerson 1982; Forrest 1985; Bruulsema and Christie 1987; Alder 1988). In general, most of these studies found red clover plowdown to support corn yields equivalent to those achieved with 90 kg N/ha - 125 kg/ha of fertilizer N. However, current Ontario Ministry of Agriculture and Food recommendations are to reduce nitrogen fertilization levels by 45 kg N/ha, only when the legume stand is thick and over 40 cm high (OMAF 1989). Alder (1988) suggested that the credit given to red clover plowdown be increased to 75 kg N/ha.

Studies in other regions as well as one study in Ontario have found hairy vetch to be a high nitrogen producer (Maitland and Christie 1989; Frye and Blevins 1989). It can supply the nitrogen requirements for corn when an adequate stand has been plowed down (Utomo 1986; Radke *et al.* 1987). In no-tilled systems it provides more efficient nitrogen release and higher corn yields than other cover crops species because of its rapid decomposition and low C:N ratio (Smith *et al.* 1987; Wagger 1987).

Although a great deal of work has focussed on the nitrogen contribution of legumecover crops very little emphasis has been placed on the role of cover crops in mineral cycling. Bauer (1921) found sweet clover, buckwheat and rape to have strong feeding powers and suggested the possibility

EXPERIMENTAL METHODS AND DESIGN

General Information

	Site 1	***Site 2***
Cooperator	Ouentin Martin	Harry Wilhelm
Soil type	Sandy loam	Silt loam
Nitrogen Application	May 6	May 9
Fall Tillage	—	Aerway (1 pass)
Spring Tillage	Moldboard plow and disking May 11	Disking (3X), May 18
Corn Planting	Pioneer 3902	Mixture of Pioneer 3881, Pioneer 3902 and Pride K2204
Seeding Rate	70,000 plants/ha	70,000 plants/ha
Seeding Date	May 17	May 18
Row Width	0 77m	0.92 m
Weed Control	Dual (2.4 l/ha) + 1 row crop cultivation	Atrazine (2 kg/ha in 15 cm band) + rotary hoeing + 2 row cultivations
Soil testing	12 cores per plot to 15 cm June 15	12 cores per plot to 15 cm June 14
5 Leaf Stage Sampling of Corn	16 plants/plot, June 15	16 plants/plot, June 14
Ear Leaf Sampling at silking of Corn	20 leaves/plot, mid 1/3 of leaf	20 leaves/plot, Mid 1/3 of leaf
Corn Harvest	4 metre rows (3 per plot) October 5	4 metre rows (3 per plot) October 4

of growing crops of high feeding power to supply organic matter and available phosphorus in rotations as with plants of low feeding power. Field evaluation of mineral cycling by cover cops has not been well documented to date particularly in temperate climates. The majority of the studies have been performed in the sub-tropics and tropics or the fertilizing values of the legumes have been examined incidental to other observations. No studies could be located which evaluated soil P, cover crop P and main crop P content over several seasons.

In Nigeria, Agboola and Fayemi (1972) found that interseeded legumes in corn prevented soil available P and exchangeable K from being greatly reduced under four years of continuous corn. The authors suggested that legumes might be reducing K leaching and reducing the rate of P fixation by keeping the P in a soluble form and reducing soil contact. In Georgia, Groffman *et al.* (1987) found evidence supporting this concept. An overwintering crimson clover took up (11 kg/ha P and 81 kg/ha potassium) larger amounts of nutrients than a rye cover crop and reduced soil phosphorus and potassium over winter until plowdown in early May. Soil phosphorus and potassium were significantly higher on the crimson clover plots than on the rye plots after spring incorporation. However, the data were significant at P = 0.10 level, the study was performed only for 1 year and the following sorghum crop demonstrated no benefit. Hargrove (1986) found that there was a redistribution of potassium under hairy vetch plots in no-till grain sorghum. Greater potassium levels were found at the soil surface and lower concentrations at the lower soil depths compared to control or rye plots after three years.

Data suggest that P mineralized from legume tissue can be a significant source of plant available P. In Georgia, Touchton *et al.* (1982) found that although the amount of P (11 kg/ha/year) removed in crimson clover tissue was insignificant compared to the total amount of chemical P applied (118 kg/ha), removing clover tissue (versus retaining the cover crop) resulted in decreased P levels in the sorghum leaf in both years.

The objectives of this study were to evaluate nutrient cycling and corn yield following selected cover crops established in the winter wheat interseeding and catch crop experiments in 1988.

RESULTS AND DISCUSSION

The study of the nutrient contribution of the winter wheat interseeding and catch crop systems on corn was not anticipated in 1989. Hence, no chemical analyses of the 1988 cover crops are available. The analysis in Table 26 is from the winter wheat cover *crop* study in 1989 which was on an adjacent field to the 1988 study. The N% *and* P% of the cover crops being evaluated is representative of published data on the species. The potassium content may be an underestimate of what the cover crops contained at the various sites. The buckwheat was sampled after frost had completely killed the vegetation.

The red clover at the silt loam site in 1989 overwintered and regrew considerably before being incorporated prior to corn planting. Thus the estimated shoot nitrogen content is likely underestimated (Table 27).

Table 26. **Nutrient Content of Interseeded Cover Crop and Catch Crops In Winter Wheat on a Silt Loam Soil at the Wilhelm Farm In October, 1989.**

Species	**N %**	**P %**	**K %**	**Ca %**
Red clover (early)	3.41^{c}	0.26^{cd}	2.04^{b}	1.88 a
Red clover (late)	3.32^{c}	0.24^{cd}	1.97^{b}	1.82^{a}
Red clover (drilled)	3.38^{c}	0.24^{cd}	1.50^{c}	1.95^{a}
Nitro alfalfa	3.73^{b}	0.28^{c}	1.74^{bc}	1.99^{a}
Crimson clover	2.83^{d}	0.23^{d}	2.04^{b}	1.24^{b}
Hairy vetch	4.38^{e}	0.35^{b}	1.89^{bd}	1.23^{b}
Oilseed radish	3.23^{c}	0.49^{a}	3.95^{a}	2.19^{a}
Buckwheat	1.31^{e}	0.15^{e}	0.20^{d}	1.35^{b}
C.V. %	5.4	7.8	12.9	11.9

Table 27. **Fall Biomass of the 1988 Interseeded Cover Crops and Catch Crops In Winter Wheat and their Estimated Nitrogen Content.**

Location	***Cover Crop***	Biomass kg/ha	Estimated Shoot N kg/ha
Sandy Loam	Crimson clover	1426	40
	Hairy vetch	2554	112
	Oilseed radish	3654	118
Silt Loam	Red clover	1569	54
	Hairy vetch	3367	148

Effects of Cover Crops on Corn Grain Yields

The effects of cover crops on corn grain yields at the sandy loam site and silt loam site are shown in Table 28. Hairy vetch cover crops appeared to provide the highest yields where no fertilizer was applied as well as the highest mean yield across fertilization treatments. For example, hairy vetch increased corn yields over the control plot by 2.0 and 2.2 t/ha on the silt loam and sandy loam sites with no fertilizer N applied. From Figures 1 and 2, it appears the unfertilized hairy vetch provided corn yields equivalent to corn fertilized with approximately 100 kg /ha fertilizer N at both sites. At the silt loam site, unfertilized red clover appeared to provide the equivalent of 70 kg N/ha while on the sandy loam site the oilseed radish and crimson clover appeared to provide the equivalent of approximately 80 kg/ha.

Corn grain yields may have been limited at the silt loam site by inadequate potassium, particularly on the hairy vetch plots. An analysis of variance for car leaf potassium provided the following results at the 40 kg/ha N fertilization level: F = 6.04 and P < 0.10. The critical ear leaf K content for corn is 1.2% (OMAF, 1989). The hairy vetch had mean potassium ear leaf contents at the 40 and 80 kg/ha nitrogen fertilization rates of 1.07% and 1.04% (Table 29).

Ear Leaf N Content

The concentration of nitrogen in the ear leaf samples taken at silking are shown in Table 30. The % N in the ear leaves during grain filling can be a good indicator of the beneficial effect on corn yield of the N mineralized from the cover crops (Ebalhar *et al.* 1984). Estimates of N release from cover crops are very similar to that of grain yield. The hairy vetch appeared to provide the equivalent of corn fertilized with 100 kg N/ha at both locations (Figures 3 and 4). The red clover on the silt loam appeared to provide the equivalent of approximately 80 kg/ha N fertilizer. The oilseed radish appeared to conserve considerable N as has been reported by others (Derpsch *et al.* 1986). Oilseed radish and crimson clover appeared to provide ear leaf N contents equivalent to corn fertilized with 80 kg N/ha.

Soil and Plant Nutrient Effects

No significant differences were observed amongst the various treatments at either site for pH, extractable P, available potassium or the potassium content of the corn when sampled at the 5 leaf stage. However, significant differences were observed in % P in the corn seedlings among the various treatments.

Table 28. Effects of the 1988 Interseeded Cover Crops and Catch Crops In Winter Wheat on Corn Grain Yield In 1989.

				Nitrogen Rate (in kg/ha)			
Treatment	0	40	80	120	160	200	Mean 0,40,80
				Yield of Corn Grain in t/ha			
Martin Farm — Sandy Loam							
Crimson Clover	5 6^{ab}	7.1	7.0^{ab}				6.6^{a}
Hairy Vetch	6.6^{a}	7.0	7.8^{a}				7.1^{a}
Oilseed Radish	5.9^{a}	6.6	6.3^{bc}				6.2^{a}
Control	4.4^{b}	5.2	5.2^{c}	6.8	6.8	7.1	4.9^{b}
C.V.%	11.1	14.5	10.6				5.2
Wilhelm Farm — Silt Loam							
Red Clover	6.1^{a}	6.5	7.0				6.5^{a}
Hairy Vetch	6.9^{a}	6.6	6.9				6.8^{a}
Control	4.9^{b}	5.7	6 5	7.6	7.2	7.1	5.7^{b}
C.V. %	7.5	7.6	5.9				*7.5*

The estimated quantity of phosphorus taken up over winter in the shoot biomass of the cover crops on the sandy loam site would be equivalent to approximately 3.3 kg/ha for the crimson clover, 5.9 kg/ha for the hairy vetch and 17.9 kg/ha for oilseed radish (based on plant biomass & analyses in Tables 26 and 27). P uptake by plants on the silt loam site would be approximately 4.1 kg/ha and 11.8 kg/ha for the red clover and hairy vetch respectively. The oilseed radish appeared to have the most potential to act as a "sink" for phosphorus over winter, and/or to mobilise phosphorus. When sampling was conducted in mid-June, no significant differences ($P < 0.05$) were observed in soil test at both sites. For the sandy loam site, there was some evidence for increased soil P following cover crops. The analysis of variance for extractable P provided an F value of 4.00 ($P < 0.10$).

At the same time as soil sampling occurred, sampling of corn was performed at the 5 leaf stage to determine P content of the corn plants. Barry *et al.* (1989) found sampling corn seedlings to be more appropriate than sampling ear leaves for assessing P nutrition in corn. Ear leaf sampling usually failed to detect P deficiency.

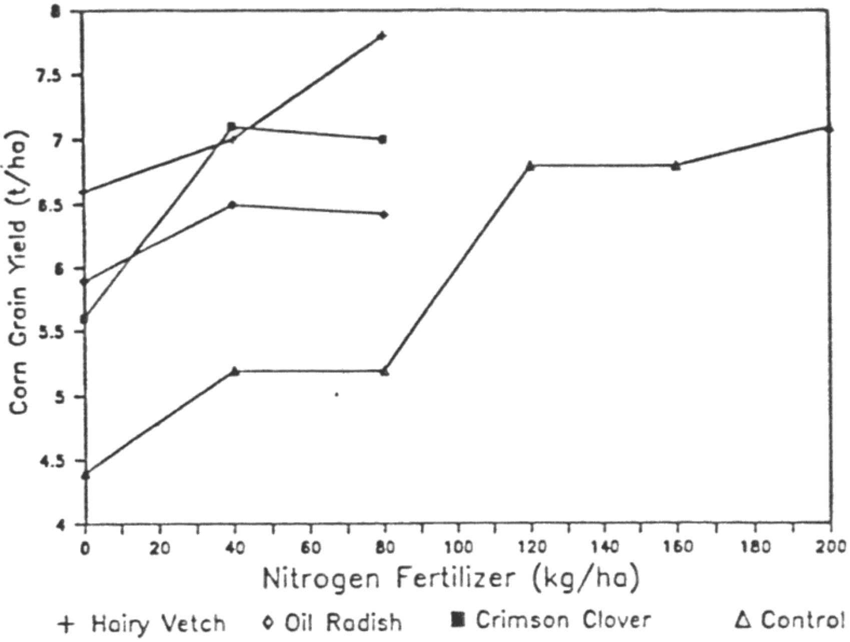

Figure 1. Effect of fertilizer and cover crop on corn grain yield (Sandy Loam, 1989).

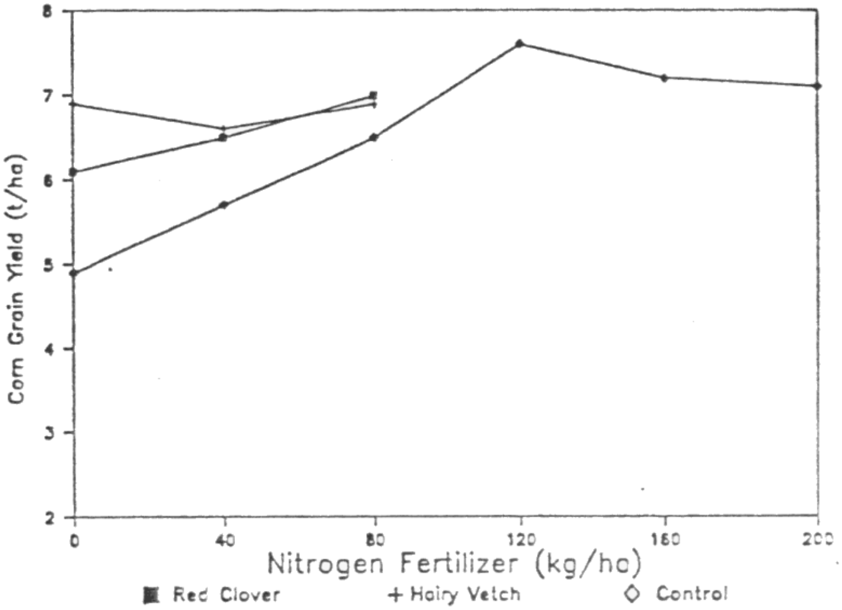

Figure 2. Effect of fertilizer and cover crop on corn grain yield (Slit Loam, 1989).

Table 29. **Effects of 1988 InterseedIng Systems In Winter Wheat on Corn Ear Leaf Potassium Content on a Silt Loam Soil at the Wilhelm Farm In 1989.**

InterseedIng System	**Nitrogen Rate** (in kg/ha) 0	40	80	120	160	200	Mean 0,40,80
				% Potassium			
Wilhelm Farm - Silt Loam							
Red clover	1.23	1.17	1.2				1.19
Hairy vetch	1.15	1.07	1.1				1.09
Control	1.34	1.24	1.1	1.26	1.23	1.14	1.23
C.V. %	7.4	4.1	4.5				5.4

Table 30. **Effects of the 1988 Interseeding Systems and Catch Crop Systems in Winter Wheat on Corn Ear Leaf Nitrogen Content In 1989.**

InterseedIng System	**Nitrogen Rate** (in kg/ha) 0	40	80	120	160	200	Mean 0,40,80
				% Nitrogen			
Martin Farm -Sandy Loam							
Crimson Clover	2.43 ^{a}	2.75 ^{a}	2.87				2.68 ^{a}
Hairy Vetch	2.71 ^{a}	3.02 ^{a}	3.10				2.94 ^{a}
Oilseed Radish	2.54 ^{a}	2.87 ^{a}	2.84				2.75 ^{a}
Control	1.91 ^{a}	2.15 ^{b}	2.46	3.02	3.23	3.00	2.18 ^{b}
C.V. %	9.9	9.4	7.9				5.2
Wilhelm Farm -Silt Loam							
Red Clover	2.96 ^{a}	3.00	3.19 ^{a}				3.05 ^{a}
Hairy Vetch	3.03 ^{a}	3.10	3.12 ^{a}				3.08 ^{a}
Control	2.72 ^{a}	2.85	2.91 ^{b}	3.17	3.23	3.20	2.82 ^{b}
C.V. %	2.8	4.1	2.8				3.8

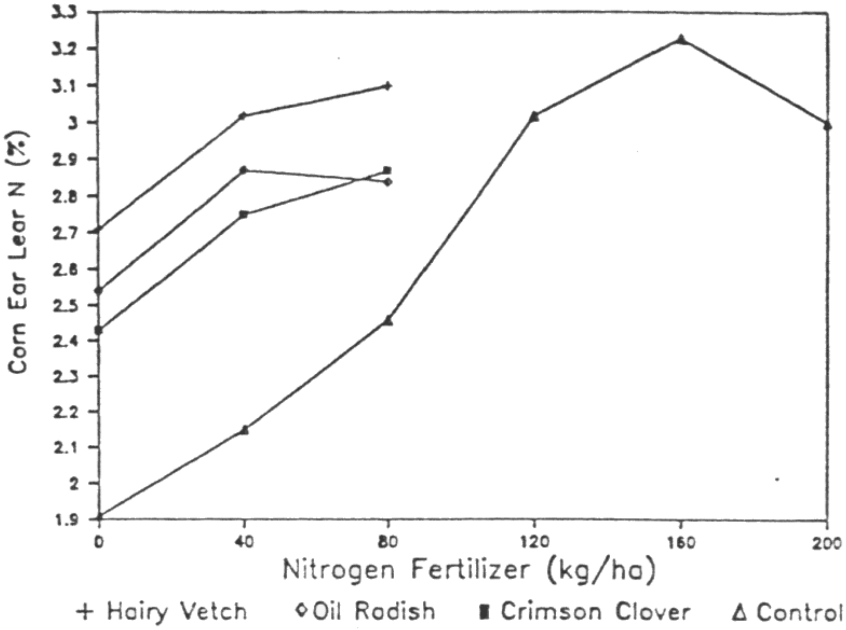

Figure 3. **Effect of fertilizer and cover crop on corn ear leaf N (Sandy Loam, 1989).**

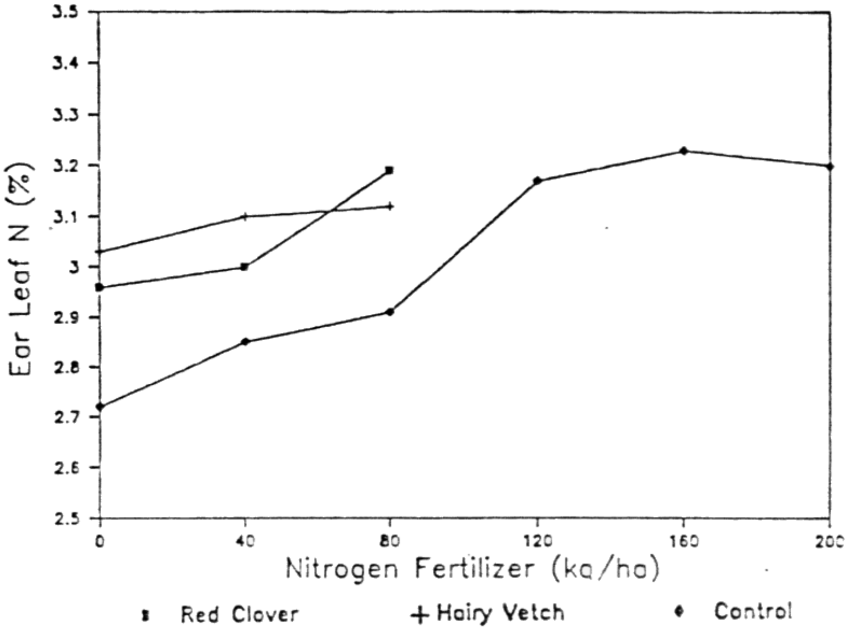

Figure 4. **Effect of fertilizer and cover crop on corn ear leaf N (Silt Loam, 1989).**

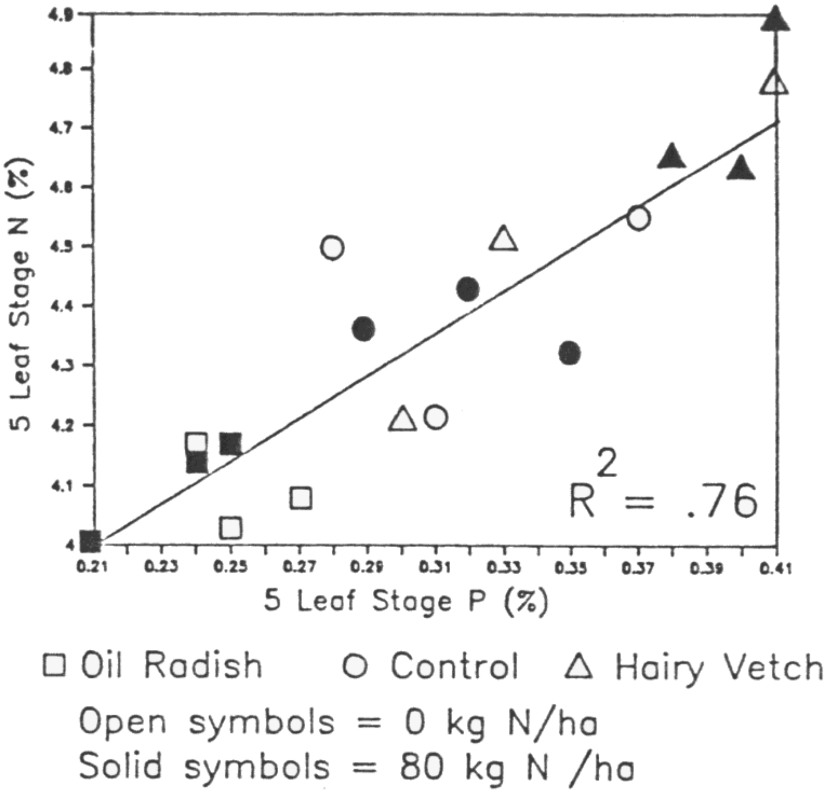

Figure 5. **Effect of cover crop on N and P content of corn at 5-leaf stage (Sandy loam, 1989).**

On the sandy loam site, the oilseed radish had significantly lower N and P content at the 5 leaf stage than the control treatment and the other cover crops. The plant nitrogen concentration was highly correlated with the phosphorus content of the plant (Figure 5). The explanation of the differences may well rest with the cover crops C:N and C:P ratios. Several studies have found that both N and P from cover crop residues are more available to the subsequent crop if low C:N or C:P ratios are present in the residues (Fuller *et al.* 1956; White and Ayoub 1983; Wagger 1989). In the case of phosphorus the differences are less pronounced in soils well supplied with phosphorus than in soils low in available phosphorus (Fuller *et al.* 1956).

Significant differences were obtained in both N and P content of the various corn seedlings at the sandy loam site between the hairy vetch and oilseed radish cover crops. Hairy vetch is a soft, leafy and essentially immature plant with a C:N ratio of approximately 12:1 while oilseed radish has a hard stalk and more cellulose and lignin-like products (no C:N ratio could be located for oilseed radish but white mustard has a C:N ratio of 26:1) (Wagger 1989; Crowther and Mirchandani 1931). Crowther and Mirchandani (1931) studied the effects of vetch and mustard residues and found that vetch liberated its nitrogen extremely rapidly while mustard initially locks up available nitrogen, but that it is later released. This is identical to the response observed in this experiment as early in the season the oilseed radish tied up N and P while the oilseed radish provided considerable nitrogen later in the season (Figure 6).

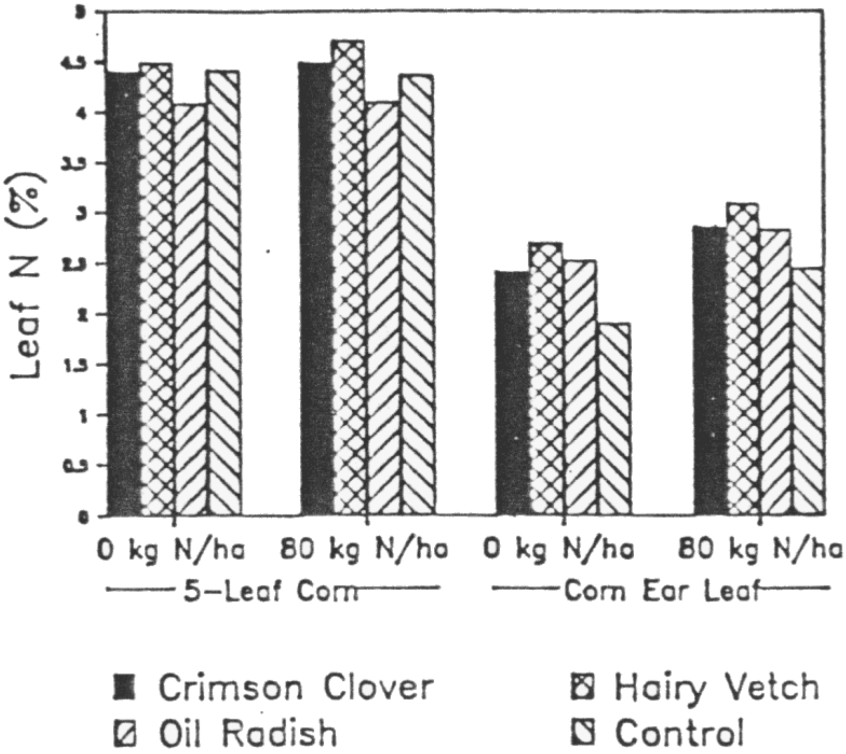

Figure 6. **Effect of cover crop and fertilizer on N content of corn (Sandy Loam, 1989).**

Phosphorus status of the corn recovered on the oilseed radish plot at ear leaf sampling and showed some indications that it may be superior to the control plot (Table 32).

At sampling time in mid June on the silt loam soil, the corn was uneven in growth. This may have been due to several factors. The wet spring caused very slow growth of corn seedlings and it appeared that the cover crop plots which had significant spring regrowth (red clover and to a lessor extent hairy vetch) were more advanced in growth. There also appeared to be some indication that the corn exhibited better growth where the tile drains were running parallel to the blocks of the trial. The effect of the cooperators mixture of three corn hybrids was also evident as purple corn plants existed from one hybrid, and one of the remaining two remaining hybrids appeared to be somewhat taller than the other. No significant differences were found in plant P content. The N contents were erratic. There was a significant cover crop — nitrogen interaction, at the 0 and 80 kg N fertilization level, for the hairy vetch and control plot (Table 31). This is difficult to interpret and may have been related to the tile drain effect on the split plot factor (nitrogen). The data should be interpreted with caution. The data were included because they appeared to support the field observations made in mid June indicating that overall, seedling corn growth following red clover plots was somewhat superior and more uniform than the other treatments. Shortly after the sampling period, the weather improved and the visual differences in corn growth were not present by July 1.

Table 31. **Effect of 1988 Interseeding and Catch Crop Systems In Winter Wheat On Soil and Corn Nutrient Status in 1989. (Average of Two Nitrogen Levels).**

	Soil Analysis			**5 Leaf Stage Analysis**			
Treatment	P ppm	K ppm	pH	N%		P%	K%
Martin Farm - Sandy Loam				0 kg N	80 kg N		
Crimson Clover	18.3	118	7.2		4.46 ^{a}	0.34 ^{a}	4.68
Hairy Vetch	15.7	115	7.1		4.60 ^{a}	0.37 ^{a}	4.48
Oilseed Radish	16.2	118	7.4		4.10 ^{b}	0.24 ^{b}	4.35
Control	12.8	95	7.5		4.40 ^{ab}	0.32 ^{a}	4.16
C.V. %	9.4	8.3	3.2		2.6	10.6	3.9
Wilhelm Farm - Silt Loam							
Red Clover	27.2	103	6.5	4.10 ^{a}	4.27 ^{a}	0.29	3.11
Hairy Vetch	22.2	96	6.6	3.83 ^{b}	3.97 ^{b}	0.25	2.87
Control	22 5	90	6.7	4.09 ^{a}	3.62 ^{c}	0.26	2 23
C.V. %	12.7	7.4	2.4	3.2	3.2	10.5	10.6

The drying effect of the red clover cover crop may have been beneficial in reducing soil moisture, resulting in improved corn development in this unusually wet spring.

Conclusions

Following establishment in a drought year, the cover crop species tested provided 70-100 kg N/ha to the following corn crop on the sandy loam and silt loam sites. As has been found in numerous studies in the U.S., hairy vetch was the most promising N source among the species evaluated. Forage analysis of the various species found oilseed radish, followed by hairy vetch, to possess the highest P contents. When N and P content of 5 leaf corn was determined following the various cover crop species, hairy vetch and oilseed radish appeared to have opposite effects on plant nutrition at the sandy loam site. Oilseed radish exhibited a temporary immobilization of N and P while the legumes appeared to liberate nutrients to the young corn plant. No significant differences were observed in potassium status at this sampling stage among the various treatments. The differences in nutrient content of the corn following the cover crops may be related to the C:N ratios of the species (brassica's possess a high C:N ratio and the legumes a low C:N ratio). Although the nutrient cycling results must be considered as preliminary they are substantiated by the N studies of Crowther and Mirchandani (1931) with vetch and white mustard. It appears that oilseed radish may not be desirable as a cover crop prior to a crop such as corn that is a relatively poor feeder. It may be that mixtures of species such as August seeded oilseed radish and a winter cover crop of hairy vetch would be an effective management system.

Table 32.

Mean Response of Corn Ear Leaf Phosphorus Content Following Cover Crops on a Sandy Loam Soil at the Martin Farm In 1989.

	Nitrogen Rate (kg/ha)		
Cover Crop	0	40	80
	% Phosphorus		
Crimson clover	0.290	0.303 [a]	0.307
Hairy vetch	0.300	0.310 [a]	0.297
Oilseed radish	0.267	0.283 [a]	0.287
Control	0.277	0.247 [b]	0.277
C.V. %	5.9	6.5	8.8

4 b) — Effect of 1988 Interseeded Cover Crop and Catch Crop Systems and August Manure Application on Nutrient Cycling and Corn Yield in 1989

This trial included the same cover crop species as the previous experiments. The major difference in this trial was that liquid manure was applied to several of the treatments. The trial was performed on a clay loam soil that prior to the grain crop in 1988 had been in continuous corn.

RESULTS AND DISCUSSION

As for the winter wheat experiments, no analyses of plant material were conducted in the fall of 1988 on the plots. The estimated nitrogen content in Table 33 does not include nitrogen in the cereal regrowth. The clover treatments overwintered and were approximately 12 cm tall at spring plowdown. The hairy vetch and crimson clover were completely winter-killed while the Nitro alfalfa had approximately 50% winter kill. A considerable quantity of cereal regrowth occurred on plots which had liquid manure applied after harvest. The oilseed radish produced very little biomass as the cover crop may have been incorporated too deeply at planting. The biomass production of the oilseed radish was further reduced from the soil having a low residual soil nitrogen content. The bulk of the biomass on this site was cereal regrowth. The influence of oilseed radish on this treatment was likely minimal. It should essentially be considered as a treatment which had fall cultivation. The control plot received no cultivation after grain harvest.

Corn Grain Yields

The effects of the various treatments on corn grain yield are shown in Table 34. Red clover appeared to provide the highest yields *where* no nitrogen fertilizer was applied as well as the highest average yield across fertilizer treatments. From Figure 7 it appears the unfertilized red clover provided the yield equivalent to corn fertilized with approximately 50 kg N /ha. The treatment with cultivation after

EXPERIMENTAL METHODS AND DESIGN

General Information

Cooperator	Carl Ruby
Soil type	Clay loam
Spring Tillage	Moldboard plow and packing, May 11
Nitrogen Application	May 15
Spring Cultivation	(2X) May 17
Corn Planting	Pioneer 3902; 70,000 plants per ha, May 25
Row Width	0.77 m
Wed Control	Atrazine (8 kg/ha) + rotary hoeing and 2 cultivations
Soil testing	12 cores per plot to 15 cm, June 20
5 Leaf Stage Sampling of	12 plants/plot, June 20
Ear Leaf Sampling at silking of Corn	16 leaves/plot (mid 1/3 of leaf)
Corn Harvest	3 metre rows (4 per pot), October 3-4

Table 33. Fall Biomass of the 1988 Interseed Cover Crops and Catch Crops In Spring Grain and their Estimated Nitrogen Content.

Cover Crop and Catch Crop	Cover Crop Biomass kg/ha	Cereal Biomass kg/ha	Total Biomass kg/ha	Estimated Cover Crop N kg/ha
Red clover	1373	204	1577	47
Harrow + red clover	1300	144	1444	44
Annual alfalfa	1312	102	1414	48
Crimson clover	1790	291	2081	51
Hairy vetch	3446	103	3549	151
Red clover + Aug. manure	1010	917	1927	34
Cultiv. + August manure	0	3031	3031	0
Cultiv. + oil radish	234	1071	1305	8
Oil radish + manure	1153	2506	3659	37
Control (No cultivation)	0	513	513	0

grain harvest which had produced the poor oilseed radish cover crop in 1988 reduced corn yield by approximately 20% (Figure 8). The unfertilized manure treatments (exclusive of the red clover treatment) appeared to have little impact on corn yields in the unfertilized plots compared to the control plot. However, these treatments were also cultivated after harvest. In general, corn yield response from the various cover crop treatments was lower on the clay loam site than the sandy loam and silt loam sites used for the interseeding and catch crop studies in winter wheat.

Leaf Ear N Content

The concentration of nitrogen in ear leaf samples are shown in Table 35. The red clover appeared to provide the equivalent of approximately 50 kg N/ha (Figure 9). In the case of all three treatments containing red clover, the ear leaf N was higher at 0 kg N/ha than the cultivated treatment with the poor growth of oilseed radish at 80 kg N/ha. This treatment appeared to consistently lower the leaf ear N compared to the control plot (Figure 10). Leaching may have been a factor in this, as very wet soil conditions were present throughout the fall of 1988 and spring of 1989. Crowther and Mirchandani (1931) stated that it is necessary to grow good brassica catch crops as a means of locking up nitrogen and liberating it later, because poor (nutrient deficient) crops provide too great an opportunity for loss of nitrate by drainage. The treatments which received cultivation after manure application provided almost identical leaf ear N contents to the control treatment which received no cultivation.

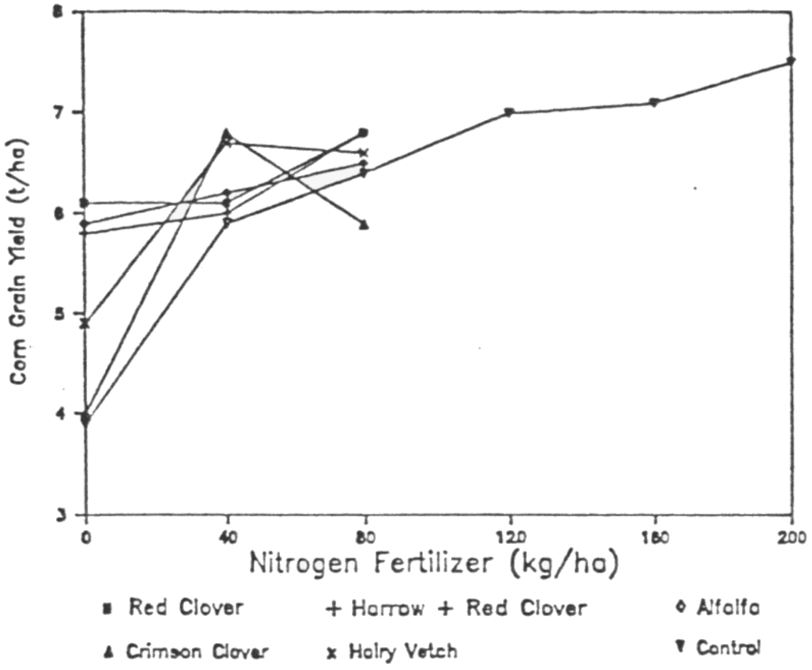

Figure 7. **Effect of fertilizer and cover crop on corn grain yield (Clay Loam, 1989).**

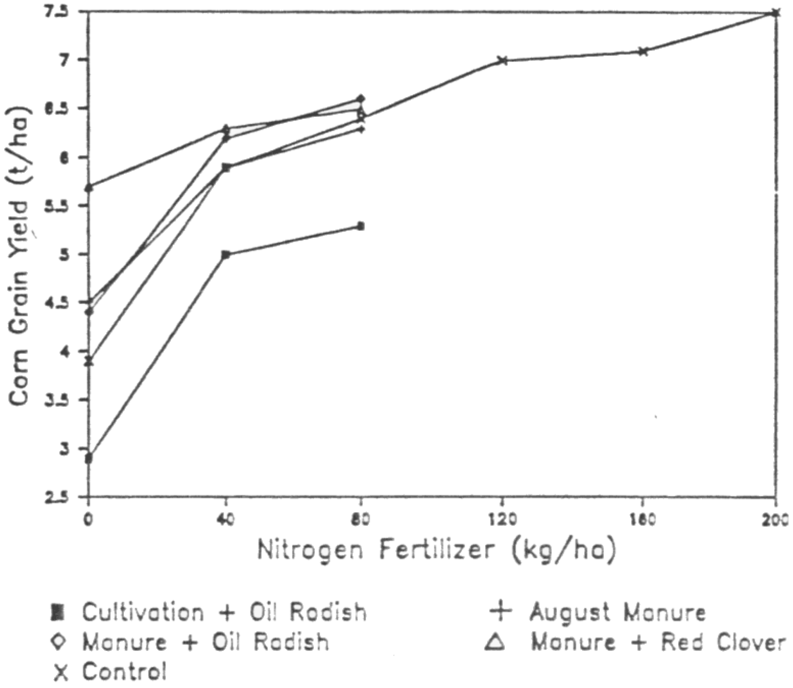

Figure 8. **Effect of fertilizer and cover crop on corn grain yield (Clay Loam, 1989).**

Table 34. Effects of the 1988 Cover Crop and August Applied Liquid Manure Treatments on Corn Grain Yield on a Clay Loam Soli at the Ruby Farm In 1989.

				Nitrogen Rate (in kg/ha)			
Treatment	0	40	80	120	160	200	Mean 0,40,80
				Yield of Corn Grain in t/ha			
Red clover	6.1^{a}	6.1	6.8				6.34^{a}
Harrow + red clover	5.8^{a}	6.0	6.8				6.18^{ab}
Annual alfalfa	5.9^{a}	6.2	6.5				6.23^{ab}
Crimson clover	4.0^{bc}	6.8	5.9				5.54^{ab}
Hairy vetch	4.9^{ab}	6.7	6.6				6.06^{ab}
Red clover + manure	5.7^{a}	6.3	6.5				6.15^{ab}
Fail manure	4.5^{ab}	5.9	6.3				5.56^{ab}
Cultiv. + Oil radish	2.9^{c}	5.0	5.3				4.39^{c}
Oil radish + manure	4.4^{b}	6 2	6.6				5.72^{ab}
Control	3.9^{bc}	5.9	6.4	7.0	7.1	7.5	5.39^{b}
C.V. %	14.0	15.1	9.9				13.5

Given the very high biomass production of the hairy vetch in the fall of 1988 (Table 28), a rather low N supply to corn at ear leaf sampling was experienced relative to the hairy vetch nitrogen release in the winter wheat cover crop studies (i.e. 20 kg N/ha vs approximately 100 kg N/ha). This low N supply may have been the result of excessively rapid nitrification encouraging a considerable loss of N by leaching and denitrification. The vetch was completely winter-killed on the site and the freezing and thawing effect may have released much of the N in early spring. An indication that nitrate levels were high on the vetch plots early in the season can be seen by the high N content of the corn at the five leaf stage on these plots (Table 36). Denitrification would be encouraged by the high soil nitrate levels, waterlogging and poor aeration as a result of a field history of continuous corn production. Other studies have found that rapidly decomposing legume cover crops can be conducive to high rates of denitrification when wet soil conditions are present (Aulakh *et al.* 1983) and that loss of N by leaching over winter of the previous years vetch can be very great (Crowther and Mirchandani 1931).

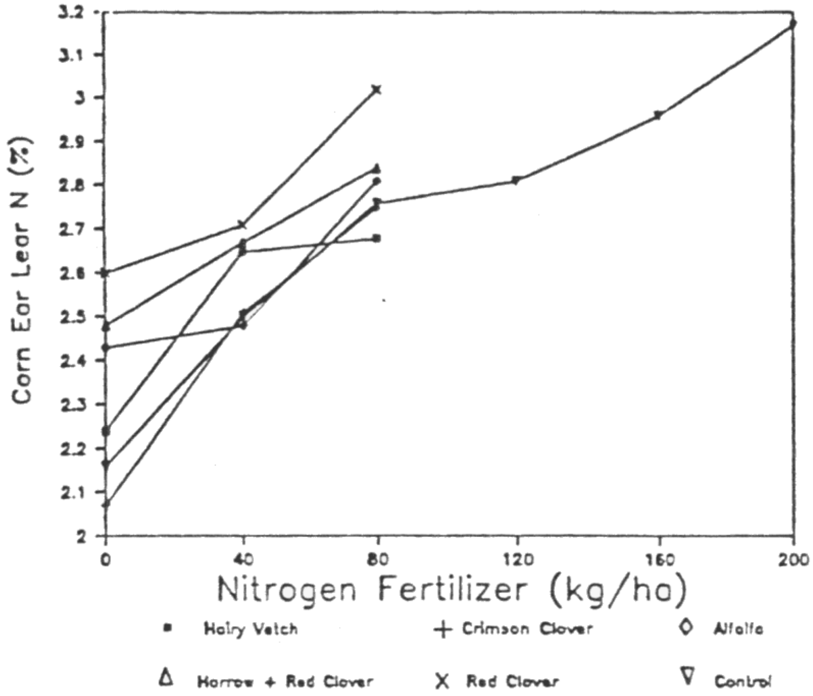

Figure 9. Effect of nitrogen fertilizer and cover crop on corn ear leaf N (Clay Loam, 1989).

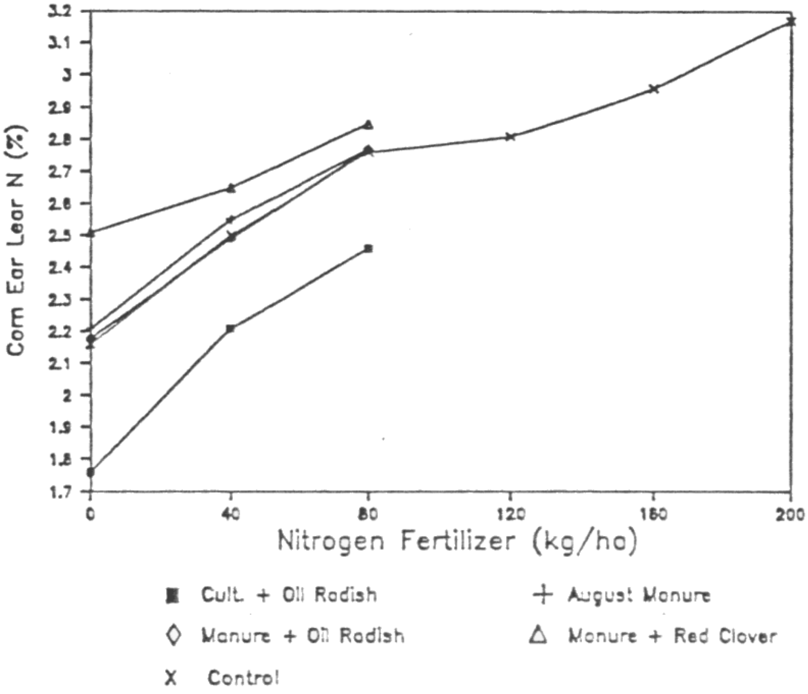

Figure 10. Effect of fertilizer and cover crop on corn ear leaf N (Clay Loam, 1989).

Table 35. Effects of the 1988 Cover Crop and August Applied Liquid Manure Treatments on Corn Leaf Ear N Content on a Clay Loam Soil at the Ruby Farm in 1989.

	Nitrogen Rate (in kg/ha)						
Treatment	0	40	80	120	160	200	Mean 0,40,80
			% Nitrogen				
Red clover	2 60^{a}	2.71	3.02				2.78^{a}
Harrow + red clover	2.48^{ab}	2.67	2.84				2.66^{ab}
Annual alfalfa	2.43^{ab}	2.48	2.81				2.57^{ab}
Crimson clover	2.07^{bc}	2.51	2.75				2.62^{ab}
Hairy vetch	2.24^{abc}	2.65	2.68				2.56^{ab}
Red clover + manure	2.51^{ab}	2.65	2.85				2.67^{ab}
Fall manure	2.21^{abc}	2.55	2.77				2.51^{bc}
Cultiv. + oil radish	1.76^{c}	2.21	2.46				2.26^{c}
Oil radish + manure	2.18^{abc}	2.49	2.77				2.48^{bc}
Control	2.16^{abc}	2.50	2.76	2.81	2.96	3.17	2.47^{bc}
C.V.%	10.4	9.7	6.6				8.0

Soil and nutrient effects

Soil analyses and analyses of corn at the five leaf stage are shown in Table 36. Contrasts indicated that the three treatments that received an August application of liquid swine manure in 1988 had significantly higher soil P ($P < 0.01$) and K ($P < 0.01$) compared to the five legume treatments when measured in mid-June in 1989. Potassium content of the young corn plants was also significantly higher on plots receiving liquid manure application the previous year. However, the manured treatments had no positive impact on P uptake in the young corn plant. The five legume cover crop plots (which had significantly lower soil P levels) had a significantly higher N ($P < 0.01$) and P ($P< 0.05$) content than the three manured plots when corn was sampled at the five leaf stage. These plots exhibited the same N and P relationship as the corn trials following the cover crop systems in winter wheat. In particular, hairy vetch exhibited high nutrient levels at five leaf sampling, significantly increasing N ($P < 0.01$) and P ($P < 0.01$) content compared to the manured treatments.

Sampling at the ear leaf stage indicated that P uptake had changed considerably between treatments. Significantly higher ear leaf P levels were obtained from the manured treatments (which had the high P soil tests) compared to the control treatments ($P < 0.05$)and legume treatments ($P < 0.10$) (Table 37).

Table 36. Effects of the 1988 Cover Crop and August Applied Liquid Manure Treatments on Soil and Corn Nutrient Status on a Clay Loam Soil at the Ruby Farm In 1989 (Sampling performed on the 80 kg N /ha plot).

	Soil Analysis			**5 Leaf Stage Analysis**		
Treatment	P In ppm	K In ppm	pH	N%	P%	K%
Red clover	20.0	101	7.2	3.91	0.33	3.20 ^{abc}
Harrow+ red clover	18.7	96	7.2	4.16	0.35	3.37 ^{abc}
Annual alfalfa	20.7	98	7 2	4.16	0.36	3.13 ^{bc}
Crimson clover	21.0	96	7.3	4.11	0.34	3.19 ^{abc}
Hairy Vetch	20.0	101	7.3	4.27	0.39	2.98 ^{bc}
Red clover + manure	24.7	113	7.2	3.67	0.31	3.56 ^{ab}
Fall manure	25.0	106	7.3	3.93	0.33	3.72 ^{ab}
Cultiv. + oil radish	22.7	94	7.4	3.92	0.34	2.81 ^{c}
Oil radish + manure	26.7	107	7.3	3.93	0.30	3.64 ^{ab}
Control	21.3	105	7.1	3.89	0.32	3.91 ^{a}
C.V. %	14.3	10.0	2.3	5.7	12.2	11.5
Contrasts						
Legume vs Manured	**	**		**	*	**
Legume vs. Control	NS	NS		NS	NS	**
Manured vs. Control	+	NS		NS	NS	NS
Hairy vetch vs. Control	NS	NS		*	+	**
Hairy vetch vs. Manured	*	NS		**	**	**

+, *, ** - Indicates significance at the 10%, 5% and 1% levels of probability. NS - not significant.

Conclusions

The overwintering red clover plots generally had the most positive effects on ear leaf N content and corn yield on the spring plowed, clay loam site. The estimated fall N production from the 1988 hairy vetch cover crop was approximately three times higher than the red clover plots, yet lower N leaf tissue tests and corn yields were experienced compared to the corn following the red clover plots. There was likely significant loss of Nat this site on plots with no living cover in the winter and spring. This is supported by the minimal effect of midsummer manure application on N of the following corn crop and lowering of corn ear leaf N following the treatment with fall cultivation of grain stubble in 1988. Perhaps significantly different results would have been obtained if the site had been fall plowed Comparisons between the 5 legume plots and 3 manured plots indicated that although soil P was higher on the manured plots, N and P content of corn was higher in 5 leaf stage corn following the legume cover crops. The manured plots stimulated cereal regrowth in the fall of 1988.

This may have provided a residue with a relatively high C:N ratio (vs the legume residue with a low C:N ratio). A much more exhaustive study needs to be performed to determine more precisely the factors involved in the liberation of nutrients from cover crops to the following crop.

Table 37

Effects of 1988 Spring Grain Cover and Crop Systems a Liquid Manure on Corn Leaf Ear Nutrient Content on a Clay Loam Soil at the Ruby Farm, 1989 (Sampling performed on the 80 kg/ha plot)

Treatment	**% P**	**% K**
Red clover	0.29	1.75
Harrow + re d clover	0.28	1.65
Annual alfalfa	0 27	1.30
Crimson clover	0.27	1.45
Hairy vetch	0.28	1.60
Red clover + manure	0.31	1.79
Fall manure	0.29	1.89
Oil radish	0.29	1.58
Oil radish + manure	0.30	1.58
Control	0.27	1.71
C.V. %	8.5	8.1
Contrasts		
Legume *vs.* Manured	+	*
Legume vs. Control	NS	NS
Manured *vs.* Control	*	NS

+, *, Indicates significance at the 10% and 5% level of probability. NS . not significant

IV. General Discussion

In these and other studies, cover crops have shown considerable potential for improving ground cover, reducing tillage requirements, fixing or conserving nitrogen and suppressing weeds. When used in a corn -soybean-cereal sequence, they play an important role in the overall development of a more sustainable crop production system. Much of the previous research has focussed on the use of cover crops in monoculture production systems.

The influence of cover crops on P nutrition in the seedling stages of corn may be important to one of SWEEP's main objectives; reducing P loadings into Lake Erie. Cover crops appear to have the potential to reduce soluble P losses in two ways: 1) by reducing soil losses through runoff by increasing ground cover and improving water infiltration; 2) by reducing the need for soluble P fertilizers through improved efficiency of P recycling on farms. The P content of the soil appeared to have little influence on P in the corn plant at the critical, 5 leaf stage. If legume cover crops could provide adequate P to crops such as corn with lower P levels in the soil it may further contribute to reducing losses of soluble P. The negative effect of a high C:N ratio species (e.g. Brassica's) on temporarily immobilizing nutrients available to the following crop may partially substantiate one of the older theories of green manuring: That green manures should be incorporated well before planting of the main crop. However, the opposite may be true for species of low C:N ratio to prevent nutrient loss. The potential for using rapidly growing annual cover crops, such as hairy vetch, to provide an internal nutrient cycle for phosphorus and nitrogen on cash crop farms deserves considerable investigation.

V. Recommendations for Future Research

1. Further Evaluation Of Choice and Management of Cover Crop Species and Varieties

a) Compare white mustard versus oilseed radish for late seeding and rooting depth. European literature suggests that white mustard can be planted later than oilseed radish and does not root as deeply (oilseed radish has been known to plug tile drains).

b) Further evaluate the rotary hoe as a method to provide weed control in grain at various stages while simultaneously shallowly incorporating grass seeds for plowdown or hay.

c) Do a limited screening of other annual cover crops, particularly a clover cover crop such as Berseem which may be suitable for heavy soils.

d) Evaluate various strains of hairy vetch for winter hardiness and N fixation potential.

e) Evaluate crimson clover strains on sandy soils for winter hardiness and N fixation potential.

f) Perform a more extensive evaluation of the mow kill/no-till system for nutrient limitations to yield and to determine mulching methods and rye varieties which are allelopathic and exhibit reduced regrowth upon mowing.

g) Evaluate methods to increase seeding depth in no-till systems into cereals and the effect of seeding depth on possible allelopathic effects from rye cover crops.

h) Evaluate the competitive ability of frost seeded red clover versus hairy vetch drilled in May in winter wheat when grown under various winter wheat N fertilization levels, preferably in a high yielding environment to determine differences in shade tolerance and climbing effects.

2. Nutrient Cycling From Cover Crops

a) Evaluate different cover crop species for their ability to mobilize soil phosphates and/or act as a nutrient relay system for phosphates over winter. Comparisons should evaluate cover crop P content, C:N and C:P ratios of the cover crops, effect on soil P and influence on crop P at varying growth stages. Evaluate the

b) Evaluate different times of incorporation of cover crops and their effect on N and P cycling. Particularly for oilseed radish and May drilled (non-wintering) vs fall sown (overwintering) hairy vetch. C:N ratios should be compared between spring and fall as well as rates of denitrification and leaching on different soil types.

c) Compare over winter and in the following corn crop, the influence of cover crops (hairy vetch vs control) and tillage on N and P dynamics (it may be that P is released slowly from legume residues under no-till management). A cost analysis and energy budget between systems could also be evaluated

d) Evaluate the effect of ryegrass interseedings in com on nitrate leaching.

e) Perform on farm studies or model nutrient flows, energy consumption, and economics of a corn-soybean-winter wheat rotation with reduced tillage and cover crops with conventional crop production systems.

Final Recommendation

The long term contribution of the research can only be measured through its implementation on the farm. A video and/or handbook on cover crop management systems would likely be a valuable asset in ensuring its success.

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