ON-FARM EVALUATION OF CULTIVATION, COVER CROPS AND CHEMICAL BANDING FOR CROP AND WEED MANAGEMENT IN INTEGRATED FARMING SYSTEMS

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ABSTRACT

On- Farm Evaluation of Cultivation, Cover Crops and Chemical Banding for Crop and Weed Management in Integrated farming Systems

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Economic and environmental concerns with the sustainability of high external input systems of crop production are creating interest in more resource efficient farming methods.

Experiments were conducted over two years on selected farms in Southern Ontario to evaluate integrated techniques of crop and weed management in mixed grain, corn and soybeans.

In a mixed grain underseeding study, single and double -cut red clovers showed a trend to suppressing weeds at mixed grain harvest while having no effect on grain yield. After-harvest, red clover cover crops almost completely eliminated weeds while providing a substantial fall plowdown. In 1987, the combination of a relatively dry spring, followed by outstanding crop growth and crop lodging caused little growth of either weeds or interseeded cover crops.

In the second main experiment, corn was grown using various weed control methods and interseeded with ryegrass, red clover, or red clover-ryegrass mixtures. The effects of these treatments were tested in rotation to soybeans grown in 53 cm rows receiving two rotary hoeings and one

cultivation.

When corn followed mixed grain in 1986, two row crop cultivations and a 15 cm herbicide band provided more cost effective weed control than cultivation or herbicide only weed control. When corn followed alfalfa in 1987, two row crop cultivations only was the most cost effective system.

Undersown ryegrass in the herbicide banded treatment in 1986, provided larger quantities of forage biomass than red clover or red clover ryegrass mixtures prior to spring plowdown in 1987. Weed pressure was minimal in all treatments in the soybeans and no effects on crop yield or weed growth were observed. In 1987, interseeded cover crops in corn produced low quantities of biomass when corn grain yields of 13 t/ha. were obtained.

The integrated farming techniques included in these trials reduced preharvest costs by $171.78/ha in corn and $115.60/ha in soybeans compared to conventional recommendations.

RESUME

Evaluation au champs des méthodes de culture, tels que cultures de recouvrement et d'épandage en bandes de produits chimiques dans les systemes de fermes intégrées

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Les problèmes économiques et environnementaux crées par le système de production intensif a stimulé le developpement de méthodes de culture axées sur l'utilisation plus efficace des ressources.

Les expériences ont été effectuées sur des fermes selectionnées dans le Sud de l'Ontario, durant deux saisons. Des techniques intégrées de gestion de cultures et de gestion des mauvaises herbes ont été évalué sur des cultures de mais, de fève soya et des cultures mixtes d'orge et d'avoines.

Dans la culture mixte, le trefle rouge a aidé à réduire les mauvaises herbes sans affecter le rendement. Après la récolte, le developpement du trefle rouge a reduit substantiellement la pousse des mauvaises herbes. En 1987, les faibles précipitations au printemps, la croissance vigoureuse des céréales ainsi que la verse des céréales ont réduit considérablement la présence des mauvaises herbes et des plantes fourragères.

La seconde experimentation consistait a faire pousser du mais en utilisant differentes methodes de contrôle des mauvaises herbes ainsi qu'en intercallant le mais avec des cultures de couvertures telles que l'ivraie, le trèfle rouge, et un mélange de trèfle rouge et d'ivraie. L'année

suivante, l'effet de ces traitements a été évalué sur des fèves soya cultivées sans l'emploi de fertilisants où de pesticides.

En 1986, la culture de mais a suivie la culture de céréales en 1985. Le desherbage méchanique et une application d'herbicide en bandes a permit un contrôle plus économique et aussi efficace que la méthode reposant sur l'utilisation des herbicides ou le desherbage méchanique uniquement. En 1987, quand la culture de mais a succédé à la luzerne, le desherbage mechanique s'est avéré le plus rentable. En 1986, la culture intercallee de l'ivraie et du mais avec une application d'herbicide en bande, a produit la plus grande quantité de biomasse comparativement aux autres traitements durant le printemps 1987. Les cultures de recouvrement de mais ont produit des quantitées inférieures de biomasse en 1987 au moment ou les récoltes de mais étaient de 13 t/ha.

En moyenne, les techniques intégrées ont réduit les coûts de pré-moisson de $171.78/ha pour le mais et de $115.60/ha pour les fèves soya, comparativement aux recommendations conventionnelles.

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1. INTRODUCTION

The continued pursuit of high external input or intensive systems of production is a philosophy of farm management that is facing increasing criticism and challenges. The terms 'high external input' or 'intensive systems' of production are used to describe current farming methods or 'conventional agriculture' in which reliance on high levels of use of chemical fertilizers and pesticides predominate in crop production in industrialized countries.

Critics point to intensive farming methods as the main reason for grain surpluses, low commodity prices, massive government subsidies and large numbers of farmers leaving the land. From an environmental perspective it is claimed that intensive production systems have increased problems of soil erosion, soil degradation, phosphorus eutrophication of lakes, surface water contamination from nitrates and pesticides and damage to the atmosphere from emissions of nitrous oxide (Sargent, 1986; Verijken, 1986; and Wagstaff, 1987).

The adoption of new crop production technologies has occurred rapidly in Canada in the last 15 years. Over an eight year period from 1976-1983, farm input expenses increased by 191% and 110% for pesticides and fertilizers respectively (Samson, 1986). This increased reliance on off-farm resources has meant that farmers have become less self-sufficient and more vulnerable to changes in both input and commodity prices.

Organic farming systems represent a completely different farming philosophy than that of high external input systems of production. Organic farming systems are advocated as systems that promote farmer self-reliance and have fewer negative impacts on the environment. The United States Department of Agriculture has provided a definition for organic agriculture:

'Organic agriculture is a production system which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators and livestock feed additives. To the maximum extent feasible, organic farming systems rely on crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, mechanical cultivation, mineral bearing rocks, and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients and to control insects, weeds, and other pests'(U.S.D.A., 1980).

However, several factors limit the widespread acceptance of organic farming : increased labour requirements , the potential for substantial yield reductions while going through the conversion process (typically 2-3 years), lack of favorable government policies and lack of serious recognition and research support from the scientific community (Peters, 1986; Patriquin, 1988).

The main argument against organic farming is that the increased savings in input costs do not compensate for the reduced yield. The literature suggests that this is true for soil exhausting crops such as potatoes (<u>Solanum</u> <u>tuberosum</u>

L.) (Pimental et al.,1984; Fischer and Richter,1986) and winter wheat (Triticum aestivum L.) (Vine and Bateman, 1981; Lockeretz et al., 1976) particularly under European conditions . However, in the case of much less demanding crops such as grain legumes (Patriquin, 1988; Culik et al., 1983; Roberts et al., 1979; Lockeretz et al., 1976), and legume based forages (Lockeretz et al., 1976; Culik et al., 1983; Karch-Turler, 1983; Murphy,1987) research indicates that organic systems are generally as profitable or more profitable than conventional production systems.

With some crops such as corn (Zea mays L.) (Lockeretz et al.,1984; Peters,1986; Helmers et al.,1986) and spring cereals (Sahs and Lesoing,1985; Lockeretz et al., 1976; Rydberg,1986; Culik et al., 1983) neither conventional or organic systems appear to be consistently superior.

Integrated farming systems which emphasize efficient use of on-farm resources and reduced dependency on off-farm inputs are currently being evaluated as an approach that offers considerable reduction of inputs without loss of income for the farmer. El Titi et al., 1988, defines integrated farming as "a system with the best possible adjustment of farming techniques to fit the natural regulation components on a growing site". Recent farming system reports from Europe (Steiner et al., 1986; Vereijken,1986) indicate that integrated systems are more profitable and less labour intensive than either conventional or organic farming systems.

Integrated farming systems differ from conventional production systems in that energy use is reduced, ground cover is increased and inputs are used to complement, rather than sustain the system. The integrated approach emphasizes organic management techniques such as: crop rotation, mechanical weed control, cover crops, intercropping, disease resistant and weed suppressive varieties, reduced tillage and modified row spacings. It differs from organic systems in that pesticides and fertilizers are used as efficiently as possible when required through techniques such as herbicide and fertilizer banding.

In May of 1984, the author met several farmers in the Tavistock area of Ontario who were practicing integrated techniques but were wishing to develop them further. Several of the farmers were producing higher than average yields at lower than average costs. In May of 1986, on-farm studies were conducted to better identify why the cropping systems were successful and to improve them. Since weed control is regarded as the most difficult aspect of using lower external input systems of production (organic and integrated farming systems) this was the focus of our research (Peters, 1986). The specific objectives were:

1. To evaluate interseeded cover crops as weed suppressants within current row crop and small grain systems on selected farms in Southern Ontario.

2. To identify and evaluate integrated systems of crop and weed management that could produce high yields at a reduced cost in Southern Ontario with reduced environmental impact.

2. LITERATURE REVIEW

"Most research in weed control begins with the assumption that control is economically worthwhile , or that the weed has a negative economic effect" (Altieri, 1988). As a result, much of the research has been directed at the use of herbicides to eliminate crop losses due to weed competition and to provide season long, weed free crops.

In recent years, more effort has been given to the concept of integrated weed management, which extends beyond the idea of the need for removal of all undesirable vegetation. In this approach, weeds are considered part of a crop-weed ecosystem and a variety of measures besides herbicides are used to keep weeds in check. However, since most of todays weed researchers are weed specialists the weed - crop ecosystem concept does not give a balanced approach to both crop and weed management. The researchers emphasis by training will put the importance on the weed or weeds under study and knowledge of crop and soil manipulation to benefit crop performance and reduce weed growth is generally absent. Obtaining a better understanding of the techniques used in crop production and weed management and their interactions may help develop systems that improve crop yield to the detriment of weeds. Manipulating the farming system to benefit crops may not only increase crop yield, but at the same time reduce crop production costs, weed control requirements, and environmental impacts from cropping systems.

This review will focus on crop and weed management systems for corn, spring cereal and soybean (Glycine max L.) production. It will be broken into three sections. The first will examine integrated measures of controlling weeds which emphasizes low cost mechanical weed control systems. The second section evaluates how crops can be manipulated to improve crop growth to the detriment of weeds. Intercrops and cover crop systems are evaluated in the final section with reference to their use as weed suppressants. These green manure systems are also discussed in their short term and long term benefits on the farming system in the effort to improve crop growth and reduce weed growth through better soil management practices.

2.1 Integrated Methods of Controlling Weeds in Row Crops

The majority of studies indicate that the foundation to an economical and effective integrated weed control system is judicious use of cultivation. In its broadest sense the term cultivation refers to all mechanical operations performed on the soil. These include seedbed preparation, intertillage of the crop after it is planted and the tilling of the soil after harvest. This discussion will emphasize the use of cultivation after the crop has been planted as a weed control and a crop management measure.

While many advantages can be realized through the cultivation process, there are several disadvantages. The process of cultivation exposes the soil to oxidation and promotes organic matter breakdown. Extra trips over the field may also increase compaction particularly if heavy tractors and cultivators are used. Methods need to be developed that reduce the number of cultivations required and disturbance of the soil. One such method is ridge tillage where row crop cultivation eliminates the need for primary and secondary tillage. It is receiving considerable attention as a cost effective soil conservation measure (Randall, 1987; Selley and Eisenhauer, 1987).

2.1.1 Non-Weed Control Benefits of Row Crop Cultivation

Through an age when the technology of chemical pesticides has advanced greatly and farmers are often advised not to cultivate, surveys show that most row crop farmers cultivate (Johnson, 1985).

Early studies showed that the practice of cultivation did not usually increase yields. Cates and Cox (1912) tabulated the results of 125 experiments from 1906-1911 and concluded that cultivation was not beneficial to the corn plant except in the removal of weeds. Mosier and Gustafson (1915) covering a period of 8 years, found corn yields were no higher where cultivation was used than where the soil was scraped to remove weeds.

These investigations were done on friable, humus laden soils characteristic of that time period. After 70 years of degradation from intensive row crop production, the soils in some of these areas have changed dramatically. Presently many researchers are finding increased yields from inter-row cultivation even in the absence of weeds and are attributing other benefits to it aside from its value as a weed control measure including increased soil aeration, reduced disease incidence, increased root development, improved fertilizer uptake , improved water infiltration and reduced erosion (Beattie et al., 1985; Coote and Saidak, 1984; Meggitt, 1960; Johnson, 1985).

2.1.1.1 Increased soil aeration

Schriefer (1984) states that on difficult to manage soils, such as those of medium and heavier texture, cultivating row crops should be considered a permanent part of a total tillage system. His reasoning is that with the loss of topsoil and the depletion of soil humus, air management is more difficult in soils with increased soil density. Thus it is important to increase soil aeration for oxygen demanding processes such as the uptake of nutrients, root vigor and microbiological activity.

Meggitt (1960) evaluated the influence of cultivation on corn yields when weeds were controlled by herbicides. Where corn followed two years alfalfa (*Medicago sativa* L.) on a sandy loam soil, there was no significant yield increase due to cultivation. On two seperate loam sites, corn following two years of corn required one cultivation and corn following two years of tomatoes (*Solanum esculentum* L.) required two cultivations to provide maximum corn yields. Meggitt observed that on lighter soil types and in situations such as corn following a meadow crop where the soil is in good tilth, there appears to be no yield advantage from cultivation as long as weeds are controlled by other means.

Chaudary and Prihar (1974) found cultivation to enhance root growth in the upper 15 cm of soil and to increase the lateral spread of roots. The height of 48 day cultivated corn plants was 13 and 34 cm more than that of the control and inter-row compacted plots respectively. Similar results were reported by Prihar and VanDoren (1967).

In a one year study, Coote and Saidak (1984) found surface soil bulk density was lower and air-filled porosity was higher after a single inter-row operation. Grain yields were negatively correlated with bulk density suggesting that some of the yield improvement from inter-row tillage was the result of better soil physical conditions. They suggested that soil structure problems could occur where certain herbicides are used without adequate tillage. Walter (1970) also observed that triazine post-emergent herbicides and pre-emergent (granular soil incorporated) herbicides had measurable negative effects on the top 15 cm. of the soil.

Plant diseases have also been reported to be reduced with the use of cultivation (Beattie et al.,1985). Schriefer (1984) recommends a modest 5-7.5 cm. hill around a bean plant to prevent certain root and lower stem rots in beans that appear in tight anaerobic soil conditions around the plant.

2.1.1.2 Improved fertilizer use efficiency

Hilling can permit corn to increase underground root development by setting extra sets of brace roots. Schriefer (1984) suggests that these upper roots are important because they feed phosphorus to the upper part of the plants late in the season which may enhance maturity, grain fill and weight in corn. Mcleod and Swezey (1979) in their survey of weed problems and management techniques of organic farmers also found producers who claimed that hilling corn not only improves weed control but also covers the adventitious roots on the corn stalks, making the crop more stable, preventing lodging, and providing more covered root surface for nutrient uptake.

Chaudhary and Prihar (1974) state that grain yield increases from cultivated corn having greater lateral spread and root proliferation at shallow depths may be a result of more efficient utilization of the applied nutrients. Lack of roots in the topsoil in widely spaced rows is likely to result in less efficient utilization of surface applied fertilizers, particularly of the non-mobile nutrients like phosphorus.

The process of cultivation may also help reduce nitrogen requirements. Lyon (1922) presented evidence in favour of the assumption that the nitrate content of cultivated plots is higher that that of scraped (surfaced hoed) plots because of the aeration produced by stirring with the cultivator. Call and Sewell (1918), stated that it was through preventing weeds from using nitrates in their growth that the cultivation process had positive effects on soil nitrate levels. Merkle and Irvin (1931) found an increase in only one of four years of the nitrate content of the surface soil from inter-row cultivation. Limited research on the release of nitrogen from cultivation has been performed since these experiments. However, Blevin et al. (1972) found nitrogen stress in corn plants under no-tillage was greater than that of similar treatments under conventional tillage.

Perhaps a more significant role of the row-crop cultivator in reducing nitrogen requirements can be made by using it for nitrogen sidedressing operations. Schriefer (1984) recommends that a cultivator should have the capability of applying a liquid or dry nutrient close to the plants while cultivating. Acccrding to his system, the key to reducing nitrogen requirements and costs by 40% is preventing the over exposure of nitrogen to the entire soil system by locking the mobile nitrate into the zone of updraft (a region approximately 15 cm below and surrounding the base of the corn plant). The zone of updraft is an extremely efficient place to position fertilizers because of the presence of roots and the influence these roots have on soil aeration and the movement of water and nutrients (Schriefer,1984).

2.1.1.3 Increased soil moisture and reduced erosion

Intertillage during a very dry year can help conserve soil moisture. The theory being that it creates a loose dry layer of soil- a soil mulch, which prevents the upward movement of moisture and thereby reduces evaporation of water. Merkle and Irvin (1931) in a very dry year found intertilled plots to contain from two to four percent more moisture in the surface soil than was found on scraped plots.

Johnson (1985) in a review on cultivation states that it has widely been shown in previous research in conventional tillage systems that breaking a soil crust will increase water infiltration and this can increase available soil moisture for crop growth. In addition, breaking a soil crust results in reduced erosion due to increased water infiltration unless an unusually intense long duration of rainfall occurs. Johnson (1985) also states that this holds true under today's systems of conservation tillage.

2.1.2 Row Crop Cultivation and Herbicide Banding

An effective and economical method of controlling weeds that has been supported through the years is herbicide banding combined with row crop cultivating. Band spraying eliminates early weed competition with the crop and the weeds between the bands can be eliminated when the corn or soybeans are large enough to allow high-speed cultivation. This system also saves the time and expense required for the operation of broadcasting herbicides because pesticide applications can be made with the crop planter or cultivator.

2.1.2.1 Soybeans

In wide row soybeans, studies have found that band applied herbicides and cultivation provides as effective or more effective weed control than overall herbicides while reducing chemical weed control costs considerably (Peters et al., 1961; Beattie et al., 1985).

Peters et al. (1961) banded several herbicides in 30-35 cm bands in soybeans grown in 101.6 cm rows and obtained comparable weed control and yield to overall sprays when more than one cultivation was used. Cultivations alone gave poorer weed control and lower yields than combinations of herbicide band treatments and cultivations.

In 75 cm. row soybeans, Beattie et al.(1985) found weed control to be improved considerably in herbicide plus cultivation treatments (94%) as compared to the herbicide only (68%) or cultivation only (66%) treatments. The most economical treatment was a 26 cm. band of a single broadspectrum herbicide (metribuzin (4 -amino- 6 -(1,1-dimethylethyl) -3- (methylthio) -1,2,-triazin-5(4H)-one) at 0.84 kg / ha) plus two cultivations which provided 96% weed control and had a gross margin of $ 273.44 / ha vs. $79.75 / ha for herbicide only treatments.

In ridge till-planted soybeans and corn, List and Kells (1985) testing numerous chemical combinations, found banded herbicide applications along with two cultivations gave equivalent weed control to broadcast herbicide applications and one cultivation. Weed control in these systems were superior to that of a no-herbicide two cultivation system. However, no significant yield differences were observed in either crop from the treatments.

2.1.2.2 Corn

In a two year corn study in India, Gill et al. (1984) showed that both early and late band applications of atrazine at 0.22 and 0.33 kg/ha followed by inter-row cultivation showed the same level of effectiveness as blanket applications of atrazine at 1.0 kg/ha and two hand weedings. Data on grain yields indicated that the dose of atrazine can be reduced to 1/3 by application in a 20 cm band over the crop row (without sacrificing yield in 60 cm row spaced corn).

In 75 cm row corn , Hamill (1983) found a 25 cm band of 1.0 kg / ha atrazine (6-chloro-N-ethyl-N'-(1-methylethyl)-1, 3, 5 - triazine -2,4-diamine) + 2.5 kg/ha alachlor (2-chloro-2', 6'-diethylphenyl)-N-(methoxymethyl) acetanilide) + .5 kg / ha dicamba (3, 6-dichloro-2-methoxy benzoic acid) combined with two row crop cultivations to provide more effective weed control in a four year continuous corn study than broadcast herbicides or two cultivations only. The system with two cultivations only provided weed control similar to the intensive herbicide system at approximately 1/4 the cost. No corn yields were reported.

In another long term continuous corn study, Ammon (1986) evaluated atrazine vs. a band spraying and cultivation timed for when corn most benefitted from weed free conditions (at the 2 to 10 leaf stages). The combination treatment provided more effective and economical weed control over the long term. The continuous corn treatment with atrazine showed an initial increase in field bindweed (Convolvulus arvensis L.) and hedge bindweed (Calystegia sepium L.) followed, after 4 years, by the appearance of horsetail (Echinochloa rusgalli (L.) Beauv.) and yellow foxtail (Setaria verticillata (L.) Beauv.) and, after a further year, by such atrazine resistant species as redroot pigweed (Amaranthus retroflexus L.).

Meggitt (1960) evaluated various widths of herbicide bands in a corn trial that followed two years of tomatoes. A 30 cm. herbicide band and one cultivation was inferior to a 60 cm. band or an overall spray when only one cultivation was used but provided equal yields when two cultivations were used. However, the system with two cultivations and no herbicide band performed similarly.

In a corn study in the Phillipines, banding a herbicide followed by cultivation and one hand weeding reduced weed control costs by 47% compared to an overall herbicide system and one hand weeding and provided more effective weed control (Fisher et al., 1985).

Several other studies have found broadcasting herbicides along with cultivation systems to provide economical and effective weed control in corn. In Russia, integrated systems were found to be superior to herbicides alone in terms of weed control and gave similar yields (Rybka et al., 1986). A premergence harrowing and inter-row cultivation and herbicides was the most economical treatment and also gave the lowest energy consumption/100 kg grains produced. Similar results with corn were reported by Zatuchnyi et al.(1985) in Russia.

Prasad and Mani (1986) found earthing up (hilling soil around the plant base) 25 days after crop emergence to suppress weeds in India. Atrazine at 1.25 kg/ha in combination with earthing up gave the best weed control and the highest two year average corn yields of 6.06 t/ha compared with 5.00 and 2.58 t/ha with atrazine and earthing-up respectively.

2.1.2.3 Control of Problem weeds

Cultivation often helps control problem weeds in row crops more effectively than herbicides. Glaze et al.(1984) reported that yellow nutsedge (<u>Cyperus esculentus</u> L.) increased rapidly in all herbicide programs tested but not in cultivated plots. Velvet leaf (<u>Abutilon theophrasti</u> Medic.) was controlled better by cultivation and herbicide banding or two cultivations alone than a broadcast system of 1.0 kg/ha atrazine + 2.5 kg/ha alachlor + .5 kg/ha dicamba in a four year continuous corn study (Hamill, 1983). Fisher et al.(1985) found <u>Rottboellia exaltata</u>(L.F.), an aggressive annual grass, to be more effectively controlled by two cultivations and one hand weeding or herbicide banding, cultivation and one hand weeding than herbicides overall and one hand weeding.

However, both Hamill (1983) and Glaze et al.(1984)

found pigweed to increase in cultivated systems only. Pigweed was also ranked to be the most frequent weed in row crop situations in a survey of organic farmers in California (Mcleod and Swezey, 1979).

2.1.3 Other Mechanical Weed Control Methods in Row Crops

2.1.3.1 Rotary hoeing

An alternative to herbicides for controlling in-row weeds is the use of the rotary hoe. Patent records indicate that a rotary-hoe type of implement has been in existence since 1839 (Gray, 1929). It destroys annual weeds in the germinating and early seedling stages, since they germinate from shallow depths and have relatively small, shallow root systems as compared to crop plants.

Scientific literature on the use of the rotary hoe, particularly on corn, is limited and recommendations for use are not well defined by published research data. However, several experiments were performed to evaluate its effectiveness on solid seeded and row seeded soybeans in the 1950's.

Lovely et al. (1958) tested combinations of shovel cultivations, chemicals, and rotary hoeings in 102 cm. rows. The use of three timely rotary hoeings plus two cultivations was equal to or superior to all treatments tested. The inclusion of herbicide treatments did not improve weed control except when only one rotary hoeing was used. The researchers cautioned that the use of herbicide treatments may be expected to add considerably to the cost of weed control, barring the development of relatively cheap herbicides. In solid-seeded soybeans, rotary hoeing performed well when weeds were germinating but not emerged. When repeated once or twice at approximately five day intervals rotary hoeing reduced weed infestations 70 to 80% and soybean stands about 10%. When hoeing was delayed until weeds had emerged both weed control and bean yields were reduced 50%. The effectiveness of the rotary hoe was found to be reduced by wet soil conditions before or after hoeing.

In a similar study, Peters et al.(1959), made an additional comparison of the timing of rotary hoeing. Timely rotary hoeings were made when weeds were in the "white" stage, less than 1/2 cm high vs. late rotary hoeings made 7-10 days later. Weed control was more influenced by practicing timely rotary hoeings than by wet or dry soil conditions. In these trials the rotary hoe was less effective in controlling weeds than that reported by Lovely et al.(1958). This may have been due to its slow operating speed at 6.5-8 km/h (vs. 16-19 km/h as used by Lovely et al.(1958)).

In Georgia, Hauser et al.(1972) compared intensive cultivation, herbicides only and herbicides plus cultivation in soybeans. Their data agreed with those of Lovely et al. (1958). Rotary hoeing in combination with a later sweep cultivation controlled annual weeds effectively and economically in soybeans. Costs of weed control ranged from \$20 to \$30 / ha for cultivation only, \$55 to \$73 / ha for herbicides only and from $ 45 to $ 53 / ha for herbicides combined with cultivation.

Rotary hoes are also commonly used by farmers to improve emergence on crusted soils and to enhance herbicide activity particularly during dry seasons. Knake et al.(1965), Peters et al.(1965) and Lovely and Staniforth (1968) reported improved weed control from rotary hoe-herbicide weed control combinations.

The rotary hoe can be used over a considerable range of field conditions, although it has proven less effective for weed control when the soil is excessively wet or extremely dry. Maximum weed control is obtained when the soil is lightly crusted; when weed seedlings are germinating but not yet emerged (in the white); and when the machine is operated at relatively high speeds of 16-24 km/hr (Coleman, 1954; Hull, 1956; Lovely et al., 1958; Peters et al., 1959; and Rea, 1955).

2.1.3.2 Finger Weeder

Several weed control devices have been recently developed in Europe to control weeds in corn. The German firm Rabewerke has introduced the finger or tearaway weeder which is a very versatile instrument that can be used for weeding in row crops, and cereal grains, as well as some vegetable crops. The device is also being built in Holland and sold in Canada by the Lely corporation.

This device is used on a number of field crops successfully on the Lautenbach-Integrated Farming Systems experimental farm in Germany. In the cereal fields it is used with a modified row spacing so that the tractor tires do not run over crop plants (Steiner et al., 1986).

The implement is a spring tined harrow, with numerous long, thin tines spaced at 4 cm. intervals. It has several tension settings for each tine (including moving the tine out of position) which makes the device flexible for different crop growth heights, weed growth stages and soil conditions. The finger weeder can be used both across and along crop rows depending on the stage of crop growth at speeds up to 12 km /hour (Reimann, 1987). The implement has recently been introduced to Canada and is being used by organic farmers primarily in Ontario and Prince Edward Island.

Scientific studies on other methods of mechanical weed control in row crops is limited and exists primarily outside of North America. Vogtmann (1985) reviewed some of the research that has been performed in Europe. In a comparison of costs for chemical and non-chemical weed-control in corn, mechanical methods were found to be less expensive than either thermal or chemical weed control.

2.2. Crop Manipulation to Enhance Crop and Weed Management

In his conclusion on weed control in organic farming systems, Patriquin (1988) states "Non-chemical weed control in organic agriculture differs from that practiced in conventional agriculture mainly in the degree of emphasis on positive measures (making the crop more competitive) as opposed to negative measures (directly suppressing weeds)".

To improve weed control and crop growth while reducing both chemical and cultivation inputs would undoubtedly benefit all farmers as well as be environmentally desirable. Crops can be manipulated in numerous ways to be more competitive with weeds and at the same time increase crop yield. Some of the techniques that can be used include:

- modifying row widths
- adjusting seeding rates
- using aggressive varieties
- crop rotation
- mixed seedings
- changing fertility management

These methods are discussed through the following section with reference to practices that may be relevant to farming systems in Eastern Canada.

2.2.1 Row Widths

Greater flexibility exists in soybeans than in corn or grain with respect to using different row widths (farmers can use conventional grain or corn equipment in its production). Row spacings of approximately 100 cm, were popular before the widespread introduction of herbicides and since that time widths as narrow as 18 cm have been used. Current recommendations in Ontario are for using 18 cm rows in short season areas (Ontario Ministry of Agriculture and Food, 1988) .

According to a review by Johnson et al.(1982), optimal yields are obtained when the row width is sufficiently narrow to close the soybean canopy by the time the plants have begun flowering. Soybeans planted in 15-25cm row widths approximate the ideal pattern of equidistant spacings and should result in maximum yields but lack of effective weed control frequently limits the adoption of narrow rows. In the northern U.S. states, the researchers suggest that the majority of the advantages of narrow rows can be realized in row widths of 37.5-50cm and leaving skips for the tractor wheels.

It has been well documented that narrow-row soybeans provide more shading than wide row soybeans and this can improve control by herbicides. The major difficulty arises with narrow rows when weeds become resistant to the herbicides used and cultivation is not available. McGlamery and Wax (1966) found that a single uncontrolled species such as velvet leaf, can reduce narrow-row soybean yields 70 to 90%. Wax (1972), using a stale seed bed technique, found that even the best treatments failed to provide the weed control necessary to prevent substantial yield reductions. Wax recommended that if soybeans are to be grown in narrow rows without cultivation, they probably should be planted on acreage free of herbicide-resistant weeds and if these areas are not available, row widths should be chosen that enable cultivation. In a later study, Wax et al.(1977) found that where a single herbicide treatment controlled only annual grasses, 76 cm rows (cultivated once) yielded from 0 to almost 50% more than the 18 cm rows. Where combinations of more advanced herbicides were used to effectively control all weeds, soybeans in 18 cm rows averaged up to 9% higher yields than those in the 76 cm. rows. However, the economics of these systems were not compared.

Several studies have been performed which have compared weed control methods in variable row widths. Peters et al.(1965) found that when herbicides were used, soybeans in 50.8 cm and 60.0 cm rows usually required no more than one cultivation, while those in 81.3 cm and 101.6 cm rows usually needed at least one and sometimes two cultivations for good weed control and high soybean yield. Over three years, a system with three cultivations and no herbicides produced approximately 1/2 the weed density in 50.8 cm rows as compared to 101.6 cm rows. Although cultivation was performed carefully in all treatments, root pruning was noted on soybeans in 50.8 cm rows cultivated more than once and in one year this accounted in a yield reduction.

Wax and Pendleton (1968) evaluated crop and weed yields as influenced by mechanical or chemical weed control at four row spacings. Compared to the 101.6 cm row, yield increases of 10, 18 and 20% were shown for 76.2, 50.8 and 25.4 cm rows respectively. Weed control by either trifluralin (2,6-

dinitro -N-N- dfipropyl -4- trifluoromethyl) benzenamine) or cultivation was more effective in the two narrowest row spacings than in the 101.6 cm rows. The authors concluded that the 50.8 cm row spacing, which would allow at least one cultivation was the most effective treatment.

Working in similar row widths in cotton (Gossypium hirsutum L.), Rogers et al. (1976) obtained an excellent response to row spacing and weed free maintenance periods. As little as six weeks of weed free maintenance was required in cotton in 53 cm rows while wider row widths of 79 and 106 cm required 10 and 14 weeks respectively to be weed free for maximum yields.

Lovely and Staniforth (1968) developed a flexible soybean production system using variable row spacing that left 55 cm wide spaces for tractor tires. Either single or paired rows could be planted in relatively narrow rows and cultivated out to leave 76 cm inch spacings if there was a heavy weed infestation. Rotary hoeing, herbicides and paired rows in cultivated treatments improved weed control and yields.

2.2.2 Seeding Densities

Commonly, organic farmers exceed recommended seeding rates by up to 25% to increase competition to weeds and allow for losses during cultivation (Patriquin, 1988). Generally, research trials have proven that this not only helps to reduce weed growth but crop yield is improved.

In 50 field trials in Sweden during 1979-1983, Andersson (1986) found the yields of winter and spring wheat (Triticum aestivum L.) and winter barley (Hordeum vulgare L.) increased with sowing rate up to 25-50% above the normal rates for the country. The weight of weeds decreased both with increased seed rate and with reduced row widths (from 18 to 6 cm).

Barley seeding rates (180 and 90 kg/ha) had a much greater influence on weed competition than two row widths (10 and 20 cm) in a study by Cussans and Wilson (1975). At the low seeding rate, 42% more seeds of wild oats (Avena fatua L.) and 59% more new quack grass (Agropyron repens (L.) Beauv.) rhizomes were produced than at the high seeding rate. The authors stated that the tillering of a cereal crop occurs too late to restrict early weed growth to the same extent as having a high initial crop population. No crop yield data was reported to evaluate the influence on grain yield.

In Norway, Skuterand (1977) found that increasing the seeding rate in oats (Avena sativaL.) from 150 to 300 kg/ha caused about a 50% reduction in quack grass growth, however, grain yield was slightly reduced from 3780 kg/ha to 3660 kg/ha. The researcher cautioned that increasing seeding rates too much could create other problems such as lodging and recommended a sowing rate of 250 kg/ha (30-50 kg/ha higher than average in Norway) if fields are infested with quack grass.

Staniforth and Weber (1956) evaluated the effects of annual weeds on soybeans of various density planted in 102 cm rows. By cultivating between the rows the average yield loss due to weeds over several seasons research was about 10%. Studies on the relationship of soybean stand to weed stand showed reduced yield loss from annual weeds when soybeans were planted at 29-49 plants /m of row than when the soybean stand was 10 plants/m row (Weber and Staniforth, 1957).

Weil (1982) evaluated the effect of planting density and weeds on corn grain yields in unweeded maize in Malawi. As population increased weed dry matter decreased and grain corn yield increased (Table 1).

Table 1. Yield of Grain Corn and Weeds as Affected by Plant Density in Unweeded Corn

Population (plants/ha)	Plant Spacing (cm)	Weed Dry Matter (t/ha)	Grain Corn (t/ha at 15.5% moisture)
20 000	mean	6.47 A	4.92 c
40 000	mean	4.71 B	8.78 b
80 000	mean	2.10 C	10.21 a

Weil (1982)

2.2.3 Crop Varieties

Varieties, particulary with soybeans, differ in their ability to compete with weeds. The majority of trials in soybeans, corn and cereals indicate optimal cultivar characteristics include rapid emergence, a reasonably tall height, slightly later maturity, high yield and possessing allelopathic properties.

McWhorter and Hartwig (1972) evaluated six soybean varieties in competition with common cocklebur and johnsongrass. The variety Bragg, a higher yielding variety competed best with johnsongrass (Sorghum halepense L.) and was also competitive with common cocklebur (Xanthium pennsylvanicum L.). The authors suggested that unidentified varietal characteristics other than height and maturity date influenced its ability to compete with weeds.

In a soybean trial evaluating various systems of weed control, choice of cultivar proved to be as important as row width and method of weed control (herbicide or cultivation) in reducing weed growth. Wax and Pendleton (1968) found weed biomass to be reduced by 65% using the Wayne cultivar compared to the cultivar Harosoy 63. The authors suggested that more rapid canopy closure and increased competition for light in the Wayne canopy was responsible for the improved weed control.

In the most comprehensive study performed to date, Rose et al.(1984), evaluated 280 soybean cultivars to determine competitive ability and also whether allelopathy functions to inhibit surrounding weed growth. Later maturing soybean cultivars tended to compete more effectively with weeds. Competitive cultivars emerged quickly, rapidly formed a canopy, and were able to slow the growth of competing weeds. Allelopathy was identified as one mechanism for competition between soybeans and weeds.

Staniforth (1961) demonstrated differences among corn hybrids in their ability to compete with weeds. A late maturing hybrid experienced a lower yield as weed competition became pronounced at a more vulnerable growth period. He suggested that the early maturing hybrid obtained a higher yield as it was past a critical period in growth before the onset of intense foxtail (Setaria viridis (L.) Beauv.) competition.

Patriquin et al.(1986) evaluated three modern and three traditional oat varieties for their ability to compete with weeds. All three traditional varieties competed well against weeds while only one of the modern varieties was competitive.

Fay and Duke (1977) screened 3000 accessions of Avena spp. germplasm for their ability to exude a naturally occurring compound (scopoletin) shown to have root-inhibiting properties. When one of the 25 high scopoletin varieties identified was grown with wild mustard (Brassica kaber (D C.) L.C. Wheeler), the mustard growth was significantly reduced. Symptoms were indicative of chemical rather than simple competition but analysis of culture solution revealed levels of scopoletin too low to cause the observed effects and the authors suggested that other compounds were involved.

The response of 14 barley varieties used in Sweden to conventional or organic systems was evaluated by Rydberg (1986). Generally, the best performing varieties in the organic systems were late maturing varieties that were high yielding and competitive against weeds. Larger differences in weed biomass were found between growing systems (lower in the case of the organic) than varieties.

Wicks et al.(1986) evaluated the impact of summer annual weeds on 20 winter wheat cultivars in Nebraska. Most cultivars that were 83 cm or taller were good competitors while several cultivars 73-78 cm tall were poor competitors. Two semi-dwarf cultivars which were among the shortest tested (72 and 75 cm) were among the best in competitiveness with weeds. Certain cultivars and related germplasm lines were identified as having either good or poor weed competitiveness. The authors suggested that selection of cultivars that are better competitors to weeds could reduce herbicide, fuel and labour costs.

2.2.4 Crop Rotation

It is well recognized by farmers and researchers that crop rotations can make significant contributions to improving weed control. However, much of the research on crop rotation has focused on yield and economic performance improvements compared to monoculture production systems. Better performance in rotation systems has been attributed to improved insect, disease, soil structure and soil fertility and the successful use of reduced tillage. From a weed control perspective, the majority of studies have focussed on using crop rotation as a means to rotate herbicides to improve weed control with little evaluation of the cultural impacts of rotations themselves on weeds. The most common cultural recommendations in integrated and organic systems include; a rotation of competitive and non-competitive crops, increasing ground cover through the alternation of winter, summer and cover crops, and use of perennial legume based forages which restore soil fertility and enable moving or intensive rotational grazing to control perennial weeds (Patriquin, 1988; Steiner et al., 1986; Peters, 1986; Vogtmann, 1985).

In the majority of crop rotation studies, the diversity of weed species increases while the total number of weeds and weed seeds generally decreases compared to monoculture production systems (Montemurro and Trotta, 1984; Tulikov and Sugrobov, 1984). It is also well documented that perennial weed species such as quack grass invade monoculture systems more easily than multiculture systems (Conn, 1987; Kreuz and Elsner,1986; Walker and Buchanan, 1982). However in Quebec and Ontario, the strategy to reduce quack grass growth for many farmers has been to switch to extended corn monocultures and use atrazine for control. The impact of this approach is that it perpetuates the quack grass problem and degrades the biological efficiency of the cropping system on both cash crop and livestock based farms. An example of how this can have negative impacts on a dairy farm are outlined below.

The economic performance of the corn as well as the forage may decline considerably. Second and third year corn is lower yielding and requires larger quantities of purchased chemical inputs (insecticide and nitrogen fertilizer) than first year corn (Curnoe, 1982; Hicks and Rehm ,1986). Weed control in corn can also become more difficult when extended corn sequences occur and weed control is based on atrazine use (Ammon, 1986). Maintaining the same acreage of crops within the farm, results in the life of the forage stand being lengthened (If corn and alfalfa are grown on 40 % and 60 % of the land base respectively then if the corn rotation is extended to three years the alfalfa would be staying in the field for approximately 4.5 years). This declines both forage quantity and quality as the alfalfa content declines and invasion of perennial weeds such as dandelion (*Taraxicum officinale* Weber.) and quack grass increase with the age of stand (Janke, 1987). As the legume content of the forage declines nitrogen fertilizer may be required on the last several years of hay crops as well as throughout the three years of corn production. This can perpetuate the problem as large quantities of nitrogen fertilizer in the farming system have been found to promote quack grass invasion (Hoogerkamp,1975). The corn-atrazine scenario, that has been created because of the quack grass problem, no doubt has had major negative impacts on soil fertility, crop rotations and the natural competitive advantage that aggressive crop varieties planted in rotation have over weeds.

Replacement herbicides to atrazine such as glyphosate have major limitations for use in quack grass control. Glyphosate (N-(phosphonomethyl) glycine) is a more expensive product than atrazine and farmers find it difficult to use in an effective crop rotation. They can not delay planting to wait for the optimal quack grass growth stage for control by glyphosate (Lang,1986). Quack grass control by glyphosate after harvest is frequently performed by waiting one month after cereal harvest and spraying the quack grass regrowth. However this system also has its disadvantages in that annual weeds have an opportunity to complete their lifecycle prior to chemical kill, and there can be a loss of nitrogen from the system (as opposed to conserving or increasing nitrogen levels by growing cover crops).

With out major reliance on herbicides, a systems approach using crop rotation as the key element is required for the successful suppression of quack grass within a profitable farming system without major reliance on herbicides. Careful selection of a crop rotation that enables judicious use of tillage, the growing of nitrogen depleting species with large root masses near the surface such as ryegrass (<u>Lolium multiflorum</u> Lam., rye (<u>Secale cereale</u>L.) and Brassicaceae (particularly as cover crops during regular periods of crop production), grazing or frequently cutting short rotation perennial grasses in mixtures with forage legumes, and closing the nitrogen cycle as much as possible within the cropping system are all methods that make the crop rotation effective against invasion by quack grass and other weeds (Biniak,1983; Cussans,1972; Cussans and Ayres,1975; Janke,1987; Hoogerkamp,1975; Patriquin,1988). Some of these methods will be discussed further in section 2.4.

2.2.5 Mixed Seeding

Growing mixtures rather than pure stands of barley and oats is a common form of intercropping used in Eastern Canada. Provincial agricultural statistics show that mixed grain consistently outyields pure stands of barley and oats (Ontario Ministry of Agriculture and Food, 1987b). In large plot studies, Fejer et al. (1982) concluded that growing barley and oats in mixtures produce some improvements in yield and protein content when compared with means of pure stands.

Some potential may also exist for mixtures of varieties to provide greater crop yield stability and keep crop competition to weeds high by reducing disease incidence. In Germany , Gieffers and Hesselbach, (1988b) tested mixtures of winter barley in small plots and found disease ratings approximately 30 % lower on average than in pure seedings. Yields were higher in mixtures (1.5 % on average) than in their corresponding pure stands particularly when the epidemics developed early in the season. In spring barley, Gieffers and Hesselbech (1988a) observed greater yield increases from mixtures than in the winter barley studies. In small plots, yields were increased by 4 % on average while in large plot studies increases of 10.5 % were reported.

Simmonds (1962), stated that by reaching values of their higher components, mixtures provide valuable insurance against environmental hazards of year and location thus assuring more stability in production. It is well documented that mixtures reduce disease incidence (Browning and Frey,1969; Wolfe and Minchen,1977; and Clark ,1980) however, few studies have been performed to evaluate the effects of cereal mixtures on weeds.

In New York, Liebman(Alteri and Liebman, 1986) found weed biomass in a barley and pea mixture was 40-60% less than that of a pea (Pisum sativum arvense (l.) Poir.) monoculture and equal to or slightly reduced that of a barley monoculture. Yield advantages were substantial from the barley and pea intercrops as land equivalent ratios of 1.84 and 1.91 were obtained over the two seasons. However, the results obtained were from additive mixtures of the two components for the intercrops.

2.2.6 Mineral Nutrition and Soil Fertility

Walker and Buchanan (1982) reviewed the literature on manipulation of soil fertility to favour the crop and disfavour weeds. They concluded that manipulation of phosphorus and nitrogen offer the most potential for integrated weed management systems. Nitrogen was the more easily managed of the two as it does not accumulate to the same extent as phosphorus does.

An adverse effect from nitrogen in a soybean variety-weed trial was observed by Staniforth (1962). Foxtail growth was increased due to residual nitrogen from a previous years corn crop and this resulted in greater soybean yield reductions.

In a farming systems trial involving a rotation of corn-soybeans-corn-oats(green manure) , soybean yields were compared for an organic system to a fertilizer only system and a herbicide-fertilizer system (Sahs and Lesoing, 1985). The 75 cm row soybeans received two rotary hoeings (pre-emergence and at the 2-3 leaf stage) and at least two cultivations in the no-herbicide treatments and broadcast herbicides in the herbicide-fertilizer treatment. The seven year soybean yield average was 2.08, 2.35 and 2.35 t/ha for each of the organic, fertilizer only, and herbicide fertilizer systems. The authors attributed the lower yield for the organic soybeans to a severe grass weed problem that was particularly bad in the last two years. During the trial soil nitrogen and phosphorus increased significantly from manure applications to corn in the organic treatment. Total nitrogen for the organic treatment was .201% compared to .166% and .169% for the fertilizer only and herbicide-fertilizer systems respectively. Total phosphorus increased by over five fold in the organic system.

Patriquin (1988) in a review of the fertility-weed concept stated that he has observed excessive growth of weeds on organic farms where large amounts of imported manure are applied.

There have been a number of examples where nitrogen and phosphorus have been managed to crop advantage in non-legume crops. In Malawi, in studies of unweeded corn, Weil (1982) observed that corn was favoured over weeds when nitrogen fertilizer was placed where crop roots could easily reach it but weeds could not. In one of his trials using a ridged seedbed system, weeds appeared to reduce grain yield by 24% and 44% in dollop (banded) and broadcast fertilizer treatments respectively. The most effective treatment, produced excellent corn grain yields of 12.12 t/ha on totally unweeded plots where 120 kg nitrogen and 22 kg phosphorus were band applied.

McBreath et al. (1970) and Sexsmith and Russell (1963) investigated the effects of nitrogen and combinations of nitrogen and phosphorus on the growth of wild oats in spring cereals. Although the response was varied, generally it was in favour of wild oats unless the crop established an early competitive advantage.

Thurston (1959) found that wild oats and cultivated cereals benefitted equally from nitrogen fertilizer added to the soil. Pfeiffer and Holmes (1961) suggested that drilling the fertilizer with the desired cereal seed instead of broadcasting may lead to suppression. Reinertsen et al.(1984) evaluated this theory with wild oats in spring wheat. Surface applied fertilizer nitrogen significantly increased wild oat growth compared to the system where nitrogen fertilizer was placed below the seed. In addition banded nitrogen increased total dry weight, nitrogen uptake and grain yields of wheat. The authors stated that these responses indicated that banded fertilizer nitrogen was positionally more available to wheat than was broadcast nitrogen. Surface applied nitrogen stimulated wild oat emergence.

Rice (Oryza sativa L.) has benefitted more than weeds in nitrogen manipulation studies by Smith and Shaw (1966). They found that if nitrogen applications were delayed until after barnyardgrass headed, the crop benefitted more. Smith and Shaw (1966) also produced excellent results with phosphorus manipulation in rice. When phosphorus was applied at planting it stimulated weeds to advantage. When phosphorus was applied to the rotation crop prior to rice, weeds were not stimulated and adequate phosphorus was available for rice growth. Another successful method the researchers found was to place phosphorus several inches below the rice at planting.

The natural fertility of the soil, although difficult to manipulate in the short term is undoubtedly affected by cropping practices. Patriquin et al.(1981) tested how the natural fertility of the soil would influence growth of a fababean (Vicia Faba L.) crop and weeds. The hypothesis was that given the many advantages the crop has over weeds (large seed size, large reserves of nitrogen in the seeds, uniform germination, large leaves, optimal planting time) the higher the natural fertility, the better the crop will do and the fewer the weeds at harvest . The sites with higher total biomass (higher natural fertility) had a ratio of crop:weeds of approximately 8:1 while areas of lower total biomass (lower fertility) had a crop:weed ratio of approximately 2:1. Removing weeds at sites of low total biomass did not significantly improve crop yields. When high nitrogen fertilizer was compared to high natural fertility it was found that the nitrogen fertilizer favoured the weeds or detracted from the natural advantages of the crop (Patriquin, 1988).

2.3 Intercrop and Cover Crop Systems

One of the most under utilized methods of improving both crop production and weed management is the use of interseeded cover crops and fall seeded catch 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, and weed suppression. Lack of use of green manuring 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 weed problems.

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 either continuous spring cereal or continuous corn systems.

2.3.1 Beneficial Effects

2.3.1.1 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.

In Germany, Schäfer (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.

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 undersown maize is the reduction of soil compaction at harvest (Vogtmann, 1985).

2.3.1.2 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).

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.

2.3.1.3 Soil physical properties

Aggregate stability tends to increase more rapidly under grasses than legumes (Clarke et al., 1967; Tisdall and Oades, 1979), particularly grasses such as ryegrass, which has an extensive fibrous root system.

Working with summerseeded 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.

Tisdall and Oades (1979) found that the root system of ryegrass was more efficient than that of white clover (*Trifolium repens* L.) in stabilizing aggregates on a loam soil because ryegrass supported a larger population of vesicular-arbuscular mycorrhizal hyphae in the soil to which clay particles attached firmly.

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 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 (*Brassica hirta* Moench) as the best two green manures for increasing porosity in the soil.

In a one year study, Ampong (1985) found no significant effects on aggregate stability from either undersown red clover or alfalfa. 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.

2.3.1.4 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 addition 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 nitrogen/ha in the first year when water discharge was 400 mm, and 17 kg nitrogen/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 nitrogen/ha being lost in the first and second year respectively.

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. This demonstrates the grass cover crops potential to capture residual soil nitrogen and this could prevent nitrogen leaching after corn silage harvest. If the following crop was a nitrogen fixing legume such as soybeans, the system could be used to advantage without reducing the following crops yield.

2.3.1.5 **Nitrogen production**

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 nitrogen/ha, followed by barley and oats at 122 and 105 kg nitrogen/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 due to lodging at barley harvest which slowed growth of clover seedlings.

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 along stubble of 30 cm.

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 was harvested as grain. When both plowdown species were direct seeded, nitrogen production was similar with red clover and alfalfa (*Medicago sativa* L.) producing 135 and 130 kg N/ha respectively.

Nitrogen production studies from interseeded legume cover crops in corn production systems are just beginning to be published. Scott et al.(1987) over three years 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 nitrogen/ha by spring plowdown.

2.3.2 Interseeded Cover Crops 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 a second crop after cereal harvest.

2.3.2.1 Effect on seeding year grain yield

One of the concerns with interseeded cover crop systems (i.e. undersown or oversown) is that they can compete with the main crop. 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 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.

2.3.2.1 Effect on subsequent crops

Improved crop performance and/or lowered cost for nitrogen can result from using a cover crop. 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 L.) had no significant effect on crop yields. Stockholm 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 similar responses were obtained in the final year with average yield increases across nitrogen levels of 410, 400 and 380 kg/ha respectively for each of fodder rape, red clover and white mustard. 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 (25cm) 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. 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 nitrogen/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 reports that additional trials are currently underway that suggest economic yield increases can be achieved by using small quantities of nitrogen fertilizer along with the plowdown.

2.3.3 Interseeded Cover Crops 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.

2.3.3.1 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.,1988). Alfalfa may be more competitive than red clover when seeded at this time (Ampong, 1985; Tomar et al., 1988).

Studies have also shown that corn yields were not affected by intercrops during the year of establishment provided that corn was .15 to .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.

2.3.3.2 Biomass production

In New York, Scott et al.(1987) performed extensive studies evaluating 18 species and varieties as intercrops and cover crops. When seeding at .15 m - .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 .15-.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 nitrogen/ha by spring plowdown. From these plots ear leaf nitrogen was the same as that of the control receiving 17 kg nitrogen/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 biomasses 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.

2.3.4 Interseeded Cover Crops in Soybeans

The most common interseeded cover crop used in soybean production systems 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 variety should be solid 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 seeding date.

In areas where soybeans are grown in wider 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.

2.3.5 Weed Suppressing Effects of Interseeded 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.

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).

2.3.5.1 Weed Suppression and Crop Suppression

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 centro (Centrosema pubescens Benth) and psopho (Psophocarpus palustris Des.). Corn 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 57 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 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.

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 on farmers fields 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).

3.3.5.2 Suppressing late weed flushes and perennial weeds

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. 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 2).

Table 2. 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	hairy vetch	7.13	72
cultivation)	control-no overseeding	7.49	--
B. 47 DAP	medium red clover	6.96	40
(second	hairy vetch	7.35	27
cultivation)	control-no overseeding	7.13	--

DAP = days after planting Palada et al.(1982)

Other researchers have found a reduction in perennial weed growth and reproduction after harvest from the use of interseeded cover crops. 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 (a site within the sub-plot where individual rhizomes were placed .9m 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

third years of the study used underseeding in both fababeans and barley and found large differences in quack grass growth (Table 3).

Table 3. Effect of Undersown Clover or Ryegrass on Quack Grass Growth when Undersown in Barley or Fababeans

Treatment	1970 Barley	1971 Barley	1971 Fababeans	1972 Barley	1972 Fababeans
	(quack grass dry matter in g / station *)				
No undersowing	4.7	4.0	18.0	0.7	2.5
Italian Ryegrass	1.8	1.9	4.7	0.4	0.8
Red Clover	2.2	.5	3.4	0.5	1.9

(.7g dry quack grass planted per station) Dyke and Barnard, (1976)

* a site within the sub-plot where individual rhizomes were placed .9m apart to prevent rhizome competition)

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 quack grass seeds into the plots of Dyke and Barnard in 1971 and found greater suppression from barley than fababeans and undersown red clover than undersown ryegrass. Shoot dry weight of quack grass was 15.9, 2.4 and .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.

In the first year of a study, Cussans (1972) found Italian ryegrass to reduce quack grass 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.

2.3.5.3 Weed suppression by clover and ryegrass

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.

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.

Reports on the weed suppressing effects of clover species have also been documented. Skeleton weed (Chondrilla juncea L.), a species that reproduces from cut roots, was reported by Groves and Williams (1975) to be reduced in leaf area and root weight by root and shoot competition from subterrannean clover (Trifolium subterranean L.).

In Texas, Evers (1983) found that overseeding subterranean clover in warm season perennial grass pastures was as effective as herbicides in the first season for spring weed control and completely eliminated weeds in the second year of the study. Clover weed control reduced pasture production costs by eliminating the cost of a herbicide and its application, adding symbiotically fixed nitrogen and in addition extended the spring grazing season with high quality forage.

2.4 Conclusions

In evaluating the literature on crop and weed management strategies there is overwhelming evidence that improving cultural techniques reduces weed control requirements through reduced weed growth. This not only enables weed control costs to be reduced but generally improves yield and reduces environmental impacts from crop production.

3. GENERAL MATERIALS AND METHODS

The research involved two main experiments. The first experiment evaluated the effect of underseeding different forage legumes on weed growth and crop yield in mixed grain. The second evaluated the effects of different corn weed control systems and forage interseedings on yield and weed growth in corn and the subsequent effects of these treatments when rotated into soybeans.

3.1 Regional Setting and General Farm Practices

Four farmers , Lloyd Kalbfleisch, Edgar Mckay, Raymond Ruby and Harry Wilhelm participated in the research project with experiments being performed on two of the farmers fields. The farmers resided in Southern Ontario in Oxford county near the town of Tavistock. The area is at a latitude of approximately $43^{\circ}20'$.

The Kalbfleisch farm was the site of the corn trial in 1986 and the site of all three trials (corn, soybeans and mixed grain) in 1987. The sites chosen were on a well drained, stone free, Tavistock silt loam soil of the gray brown podzolic great soil group.

The site chosen for the mixed grain trial on the Ruby Farm in 1986, was an imperfectly drained, stone free, Perth clay loam soil. The weed flora present on these mixed livestock farms was similar, with a diverse group of species being present at rather low levels, rather than one or two predominant weeds at very high levels. At the Ruby farm, weeds generally found in noticeable quantities in the spring cereals included mustard (Sinapsis arvensis L.), wild buckwheat (Polygonum convolvulus L.) and lady's thumb (Polygonum persicaria L.). The farmer generally sprayed MCPA to control these weeds in fields that were not undersown. Undersown fields to alfalfa were generally unsprayed.

At the Kalbfleisch farm, nutsedge, and quack grass were the two most troublesome weeds. Ragweed (Ambrosia artemisifolia L.) was considered to be the worst annual weed on the farm. The farmer mainly sprayed his spring cereals when mustard was present. No other weeds were a concern in the spring cereal crop. In corn, quack grass and nutsedge were the most prominent weeds. Row crop cultivation was considered by the farmer to be effective in getting the crop ahead of these weeds. Both farms had a tradition of falll moldboard plowing. This may have been the reason few winter annual weeds were present on these farms.

The experiments were conducted, as much as possible, in conjunction with normal field operations on the farms of Lloyd Kalbfleisch and Raymond Ruby of Tavistock, Ontario. The farms were mixed livestock farms that traditionally received a rotation of corn, small grains and forages.

Tillage, seeding, fertilizing , spraying and field harvesting were performed by the farmers who provided the land for the trials. Harry Wilhelm performed the planting, rotary hoeing and cultivation of soybeans at the farm of Lloyd Kalbfleisch in 1987. Edgar Mckay provided use of the cultivator/ seeder unit. The only field operations that were not performed by the farmers were the overseeding of the forages in corn and cereals, the two row crop cultivations in the 1986 corn crop, the broadcast nitrogen fertilizer in the 1986 mixed grain crop and the back pack spraying.

3.2 Climatological Data

Weather records for the two year trial period were obtained from the Woodstock research station of Pioneer Hi-Bred Limited. The station is approximately 2 km east of the Kalbfleisch Farm and 5 km south-west of the Ruby farm.

The monthly precipitation totals (Table 4) for May to Oct. in 1986 and 1987 indicate a variation in rainfall between the years. Record amounts of rainfall were recorded in Sept. 1986 which flooded fields and made harvesting conditions difficult.

Rainfall was particularly erratic in 1987. The weather was extremely dry in April (not shown) and also early May after the forages were overseeded on the grain. On May 31,1987, the dry spell was ended by an extremely heavy downpour that forced one of the experiments to be moved and caused some changes in the timing of operations. After the interseedings were performed in the corn another dry period was experienced followed by a more normal pattern of precipitation for the rest of the summer.

The American system of growing degree days is used for recording temperatures at the Pioneer Hi-Bred Station. Monthly accumulated growing degree days for 1986, 1987 and a nine year mean indicate 1987 was a significantly warmer season than 1986 which was near normal (Table 5). After forage interseeding in corn, only 5 days were recorded in 1986 with temperatures above 27° C while the 1987 season had 14 days (not shown).

3.3 Statistical Analysis

Crop yield, weed and forage biomass, and weed and forage plant counts were statistically analyzed in the experiments. An analysis of variance was carried out on this data. When the F-test was significant ($p \leq 0.05$), Duncan's multiple range test was used to compare means.

Table 4. Rainfall Data 1986-1987 at the Pioneer Hi-bred Research Station.

Month	Total monthly precipitation (mm) 1986		1987		9 Yr. AVG.
May	78.0	*(74.2)	72.2	*(27.9)	78.0
June	96.9	**(36.9)	62.5	**(12.2)	85.2
July	61.7		93.9		82.9
August	65.3		84.5		100.7
September	178.5		64.5		102.1
Oct. 1-21	76.7	to Oct. 8	20.4		
***Total	480.4		377.6		448.9

* rainfall within 2 weeks of forage interseeding in grain
** rainfall within 2 weeks of forage interseeding in corn
*** excluding October rainfall
Note: An extremely heavy rainfall of 120 mm was recorded on May 31, 1987 at the Kalbfleisch farm while only 50 mm was recorded at the Pioneer Hi-bred Station.

Table 5. Monthly Accumulated Growing Degree Days 1986-1987 at the Pioneer Hi-bred Research Station.

	1986	1987	9 Yr. AVG.
May	327	372	275
June	721	866	691
July	1312	1525	1270
Aug.	1795	2012	1789
Sept.	2096	2337	2119

4. EXPERIMENTS

4.1 Mixed Grain Underseeding with Legumes

The objective of this experiment was to test the hypothesis that undersown forages suppress weeds without affecting grain yields and also compete extensively with weeds after harvest. The underseeding weed control system was evaluated as an alternative to herbicide spraying when weed infestations were light to moderate. This would provide another conservation and economic benefit to the role of red clover plowdown in addition to improving soil tilth, reducing erosion and fixing large quantities of nitrogen.

4.1.1 Materials and Methods

4.1.1.1 Ruby farm 1986

A site was selected on the farm of Raymond Ruby, of Tavistock , Ontario. The field history in 1983 and 1984 was alfalfa-timothy (*Phleum pratense* L). hay followed by grain corn in 1985. The field was fall moldboard plowed in 1985 and two spring cultivations were made prior to grain seeding.

On April 28th 1986, 114 kg/ha of a Leger barley and Donald oat mixture (0.5:0.5 w/w) were seeded in 17.5 cm rows. At seeding, 6-24-24 fertilizer was band applied at a rate of 185 kg/ha. A randomized complete block design was established on a section of the field with 5 treatments and 4 replications. The entire trial was 30 m in width x 50 m in length which provided an individual plot size of 6.0 m x 12.5 m. The 5 treatments were:

1. undersown alfalfa;
2. undersown single-cut red clover;
3. undersown double-cut red clover;
4. herbicide (no underseeding);
5. control (no herbicide, no underseeding).

On May 10th, when the grain had just begun emerging from the field, common alfalfa, single-cut red clover (a late maturing red clover that does not flower in the seeding year) and double -cut red clover (early maturing) were broadcast with a cyclone seeder at a rate of 8 kg/ha on the three forage treatments. On May 29th, MCPA (4-chloro-2-methylphenoxy acetic acid) 500 g/L was applied using a back pack sprayer at a rate of 1.0 L/ha or 500g MCPA/ha. On June 15th the grain appeared nitrogen deficient and fertilizer was broadcast by hand at a rate of 133 kg/ha of 34-0-0 on all treatments. This brought the actual fertilizer applied to the field to 56.5-45-45 kg/ha of Nitrogen-Phosphate-Potash.

Grain, weeds and forage legumes were harvested on August 1-5 by using hand shears and a 1.0 square metre quadrat. All sampling was performed at least 1 m from the plot edge. From a grid of 12 possible locations, four sites were randomly selected for harvesting each plot . The quadrat was placed over 7 rows of grain at each site. Weeds were removed, counted and classified according to species prior to grain harvest. Each row of mixed grain in the quadrat was hand sheared (at a height above the forage) and harvested in sheaves. Forage legume harvest was obtained by hand shearing at the ground level the same 1.0 metre squared area used for grain and weed harvest. The remaining unharvested plot area was then swathed to a height of approximately 7 cm and removed with a forage harvester (the farmer harvests all his grain and straw in this manner and threshes it in the barn).

Weeds and forage were cleaned of crop debris before oven drying and weighing. The grain was threshed, buffed, cleaned and oven dried and the grain weight adjusted to 14% moisture. In calculating the mixed grain yield the harvest area was adjusted to 1.077 sq. metres as 7 rows of grain required 7.7 additional cm. to be properly centered within the quadrat area. At the end of the growing season, from Oct. 19-21 the forage and weeds were again harvested from 4 different sites within the plots.

4.1.1.2 Kalbfleisch farm 1987

Methodology and materials used in 1987 were virtually identical to those used in 1986. However, the location was changed and some modifications were made. The trial was performed at the farm of Lloyd Kalbfleisch of Tavistock, Ontario. The site chosen was on a well drained silt loam soil that had been in corn in 1986. Fertilization was made before seeding by broadcasting 19.1-19.1-19.1 at a rate of 260 kg/ha which provided a total of 50 kg/ha each of Nitrogen-Phosphate-Potash.

The farmer had cleaned and treated his own seed from the the previous seasons crop of a certified planting of Leger barley and Donald oats (0.5:0.5 w/w). Mixed grain seeding at 114 kg/ha was performed on April 25th. Forage seedings were carried out on May 6th and herbicide spraying on June 2nd. Quadrat harvests of grain weeds and forage were made on July 24-26. Grain moisture levels were taken after threshing and weights adjusted to 14% moisture. No fall harvest data was taken due to lodging of the grain crop and poor forage establishment.

4.1.2 Results

4.1.2.1 Mixed grain yield, weed and forage biomass at cereal harvest in 1986.

The mixed grain yield averaged approximately 4.3 t/ha. The application of MCPA herbicide did not improve crop yield nor did competition from the interseeded cover crops reduce crop yield (Table 6).

The establishment of the interseeded clovers was superior to that of the alfalfa. At harvest, the interseeded alfalfa produced significantly lower biomass yields than the single and double-cut red clovers. No significant differences were found between the single and double-cut red clover seedings. At harvest, the best weed control was obtained in the herbicide treated plot. A trend towards reduced weed biomass in the interseeded single and double-cut red clover plots was also observed. On average the two interseeded clover treatments reduced weed growth by 41 % at grain harvest while having no effect on grain yield. Interseeded alfalfa had much less impact on weed growth than

Table 6. Effect of Interseeded Cover Crops and Herbicide on Biomass Production at Cereal Harvest in 1986.

Treatment	Grain Yield (t/ha at 14 %)	Forage Yield (kg/ha)	Weed Biomass (kg/ha)
Alfalfa	4.39	63 b	166 a
Single-Cut R.C.	4.31	222 a	96 ab
Double-Cut R.C.	4.29	205 a	119 ab
Herbicide	4.28	0 b	50 b
Control	4.35	0 b	181 a
Mean	4.32	98	122
C.V.	7.8 %	62.5 %	43.4 %

* means within a column followed by the same letter are not significantly different at P = .05

other treatments as no significant differences were obtained between undersown alfalfa and the control treatment at cereal harvest (Table 8). The dominant weeds in the trial at cereal harvest were wild buckwheat and lady's thumb. The density of these weeds or combined density of all weeds harvested was not significantly reduced by the interseeded cover crops at the time of grain harvest (Table 7). Application of the MCPA herbicide eliminated the few mustard plants that were present in the trial.

4.1.2.2 Weed and forage biomass at October harvest in 1986

After grain harvest the double-cut red clover produced the largest quantities of shoot biomass. This was significantly greater than that of the single-cut red clover which was significantly better than that of the alfalfa. The double-cut and single-cut clovers produced the lowest quantities of weed biomass after harvest of all treatments (Table 8).

The double and single cut red clover significantly reduced the total number of after harvest weeds compared to other systems. Weeds that were significantly reduced by the double-cut red clover included plantain (Plantago major L.), dandelion, and mustard compared to the control treatment, and annual grasses compared to the alfalfa treatment (Table 9).

Table 7. Effect of Interseeded Cover Crops on Weed Density at Grain Harvest.

Treatment	LT	WB	LQ	Mus	KW	Dn	Ft	**Total
			(Weed	Density	# /	Sq.	M)	
1.Single-cut R.C.	8.8	4.9	.6	.1bc	.6	.2b	.1	16.3
2.Double-cut R.C.	7.4	3.8	.7	.4ab	.7	0b	.1	14.4
3.Alfalfa	18.4	5.3	.4	.3abc	.6	.6a	.1	27.0
4.Control	21.0	4.3	.8	.6a	.1	0b	.6	29.2
5.Herbicide	8.4	2.4	0	0c	.1	.3ab	.6	12.7
Mean	12.8	4.1	.5	.3	.4	.2	.3	19.9
C.V.	108	41	118	85	105	99	211	68.5

* means within a column followed by the same letter are not significantly different at P=0.05

** includes weed species not listed in table due to their low number (Pigweed, hemp-nettle - Galeopsis tetrahit L., plantain, barnyard grass, ragweed, quack grass).

LT - Lady's Thumb
WB - Wild Buckwheat
LQ - Lambs Quarters Chenopodium album L.
Mus- Common Mustard
KW - Prostrate Knotweed - Polygonum aviculare L.
Dn - Dandelion
Ft - Green Foxtail- Setaria viridis L.

Table 8. Weed and Forage Biomass at October Harvest as Affected by Interseeded Cover Crops And Herbicide.

Treatment	Forage yield (kg ha)	Weed Biomass (kg ha)
Alfalfa	819 c	194 abc
Single-Cut R.C.	1428 b	31 bc
Double Cut R.C.	2162 a	14 c
Herbicide	0 d	234 ab
Control	0 d	[illegible] a
Mean	882	171
C.V.	18.5 %	79.2 %

* means within a column followed by the same letter are not significantly different at P=.05

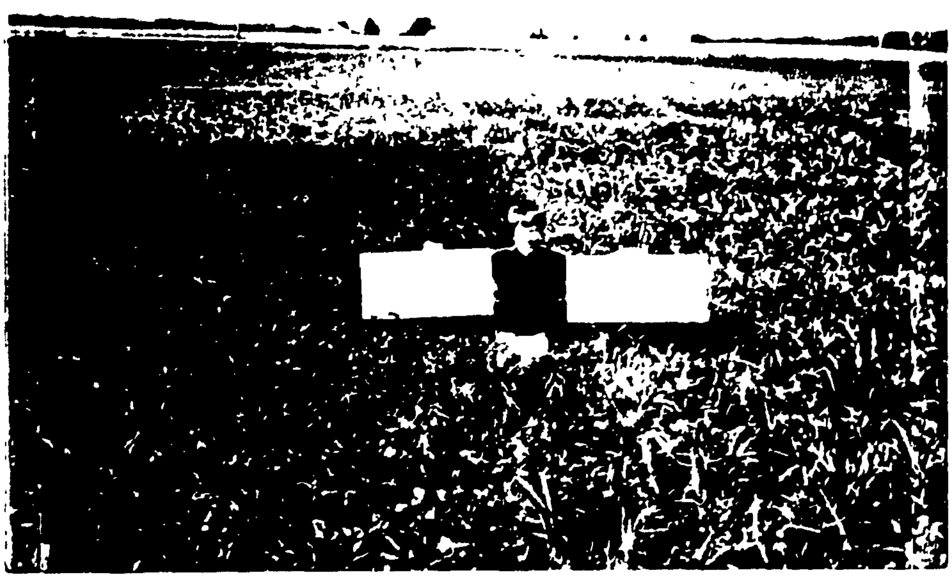

Plate 1. Double-cut Red Clover Almost Completely Eliminated Weeds After-Harvest while Providing an Excellent Fall Plowdown in 1986.

Table 9. **Effect of Interseeded Cover Crops and Herbicide on October Weed Density.**

Treatment	Pl	Dn	Mus	SP	CC	AG	**Total
		(Plants/Sq. Metre)					
1. Single-cut R.C.	.4b	4.8bc	.1b	.3	.4	0b	6.3cd
2. Double-cut R.C.	.4b	2.8c	.1b	0	.2	.1b	3.9d
3. Alfalfa	1.2b	10.8a	.4b	.3	.8	.4a	15.0ab
4. Control	4.3a	9.2a	3.6a	.6	.4	.1b	20.1a
5. Herbicide	1.3b	7.7ab	.1b	.1	.4	.3ab	11.6bc
Mean	1.5	7.34	.9	.3	.4	.2	11.4
C.V.	111	35	135	140	67	102	37

* means within a column followed by the same letter are not significantly different at p = 0.05

** Total includes weed species not in table due to their low number (hemp-nettle, ragweed, and lambsquarters)

Pl Plantain
Dn - Dandelion
Mus Mustard (Wormseed-<u>Erysimum</u> <u>cheiranthoides</u> L. and Common)
SP Shepherds Purse <u>Capsella</u> <u>bursa-pastoris</u> L.
CC Cow Cockle - <u>Saponaria</u> <u>vaccaria</u> Medic.
AG Annual Grasses (Foxtail and Witchgrass <u>Panicum</u> <u>capillare</u> L.)

4.1.2.3 1987 Mixed grain yield, weed and forage biomass at Cereal harvest

In the 1987 season few weeds grew and cover crop establishment was poor. Rainfall was only 27.9 mm in 1987 during the two week period after forage interseeding as compared to 74.2 mm in 1986. This delayed germination of the forage seed and enabled the grain to be well established before forage seedling development occurred. Heavy lodging occurred during the late grain filling period. The grain crop yielded 4.64 t/ha on average at 14% moisture. No significant differences were observed between treatments for grain yield, weed biomass and forage biomass (Table 10). At grain harvest, both the forage biomass and weed biomass were greatly reduced from that of the 1986 trial.

Table 10. Effect of Interseeded Cover Crops and Herbicide on Biomass Production at Cereal Harvest in 1987

Treatment	Grain Yield (t/ha at 14% moisture)	Forage Yield (kg/ha)	Weed Biomass (kg/ha)
1.Single-cut R.C.	4.64	5	22
2.Double-cut R.C.	4.78	9	16
3.Alfalfa	4.69	20	31
4.Control	4.56	0	35
5.Herbicide	4.50	0	17
Mean	4.64	7	24
C.V.	8	137	78

4.1.3 Discussion

4.1.3.1 Effect of interseeding cover crops on grain yield.

In both trials good crop yields were obtained with mean yields of 4.3 and 4.7 t/ha being obtained from the two different locations in two separate years. The forage interseedings in 1986 had no effect on mixed grain yield while providing a substantial fall plowdown. This is in agreement with similar research in Southwestern Ontario that consisted of nine trials over five years (Forrest, 1985). However, in the wet year of 1986, Tavistock area farmers who seeded red clover at about 8 kg/ha or more at grain planting time experienced significant problems with clover interference by the time of grain harvest. They reported losing yield due to both clover competition with the grain and increased combining losses. In moist European climates, some studies have also found red clover to reduce grain yields, unfortunately no climatological data was presented in the studies (Cussans,1974; Stokholm, 1979).

4.1.3.2 Forage establishment and biomass production

In 1986, the alfalfa produced much lower quantities of biomass than the red clover interseedings. This was a substantially greater difference than has been reported in most other plowdown studies (Fulkerson, 1982; Forrest, 1985; Bruulsema and Christie,1987) This may have been due to the combined effect of several factors : the field was imperfectly drained and it was a wet season; alfalfa is a poorer competitor than clovers in low light situations; and an 8 kg/ha seeding rate for all species was used. This latter factor appeared to give a higher plant population to the single cut red clover due to its relatively smaller seed size. This may have been the reason why the single cut red clover produced as much dry matter at grain harvest as the double-cut red clover. The total biomass production after harvest for single cut red clover and double cut red clover was 1428 and 2162 kg/ha respectively in 1986. This was slightly higher than the results obtained by Forrest (1985) in Centralia, Ontario (approximately one hour east of the Tavistock area in a similar heat unit area). Over a five year period, he obtained fall biomass of 1311 and 1740 kg/ha for single and double-cut red clover respectively.

In 1987, a much drier spring was experienced and little forage growth occurred. Gamble (1980) also experienced difficulty in obtaining a stand in a dry season with surface seeding clovers approximately 10 days after planting. The 1987 mixed grain was high yielding and extensively lodged and neither weeds or undersown forage established. These problems have been frequently found to reduce forage establishment in green manure studies in cereals. Dyke and Barnard (1971), found that when barley growth was very vigorous neither undersown clover or weeds grew appreciably. Lodging of a heavy companion crop reduced establishment of undersown legumes in spring cereals in a study by Norris (1981).

A dry period after overseeding, lodging, and a very competitive companion crop appear to be a most deleterious combination for establishment of forage seedlings. The previously mentioned researchers experienced problems in one of these three areas. In the 1987 cereal underseeding study, all these factors were present which explains the poor performance of the underseedings. Suggestions for reducing these problems could include :

1. Using an equally high yielding cereal crop of Rodeo Barley and Ogle oats (cultivars of shorter stature and greater lodging resistance) would likely have improved plowdown crop establishment. The traditional approach for forage establishment purposes is to reduce the seeding rate and nitrogen level but this may not be economical if the clover is being grown for plowdown purposes.

2. A system that might be more compatible with a dry spring would be to reduce the seeding rate to 4-6 kg/ha and seed clover at planting. This would reduce seeding costs, the time and expense of making an additional pass for plowdown overseeding and possibly the risk of forage competition with the grain in a moist season.

4.1.3.3 Weed control from interseeded clover

More than 50 % of the time, herbicides do not economically increase yield in grain fields in Eastern Canada (Samson, 1986). However, many farmers spray to keep weed seeds out of the grain and to prevent weed problems in future years. It may be possible that clovers can be an effective alternative to herbicides in this situation by improving weed control while providing other economic benefits from its use (rather than being a preventative cost as is experienced by applying a herbicide at a low weed infestation level).

From the data obtained at grain harvest, there was a trend towards reduced total weed biomass at harvest with the use of undersown single or double-cut red clover compared to the control treatment or undersown alfalfa. Although there were no significant differences between the single and double-cut red clovers in weed biomass produced (96 vs. 119 kg/ha per ha), the single-cut red clover appeared to possess a more dense mulch than the double-cut red clover due to greater numbers of seedlings established.

In the case of weed density there was no significant differences between clover systems and that of the check. This may suggest that the clovers are not affecting weed establishment up to grain harvest but are reducing weed growth by competing with weeds once the grain canopy opens. Visually there appeared to be a 'race' between a late flush of weeds and the underseeded clovers for the light area opened up by the maturing cereal crop. This ability of undersown clovers to 'keep weeds out of the grain' has frequently been stated by farmers (Lang, 1986; Lapointe, 1986) but has received very little research attention. The herbicide treatment appeared to eliminate most of the early weeds but enabled a late flush of weeds to be present at harvest. A combination treatment of MCPB herbicide and red clover underseeding may have almost completely eliminated weed growth. This approach would probably be useful in situations where greater weed pressure was experienced than in the present study. Mechanical weed control measures such as the use of blind harrowing, rotary hoeing or finger weeding could likely be substituted for the use of herbicide if a non-chemical method of weed control was desired for control of early weed infestations (Patriquin et al., 1986; Steiner et al.,1986). Seeding of the clover could then take place either immediately before or immediately after the shallow cultivation process. This delayed seeding technique may also reduce the chances of too much clover competition at cereal harvest.

After harvest, both the single and double-cut red clover formed an excellent mulch against weed growth. However, due to its more aggressive growth after harvest, the double cut red clover showed a trend to greater suppression of weed density compared to the single-cut red clover treatment (Table 8). On average, the two species suppressed after harvest weed growth by 94 %. With only the competition from some volunteer grain in the herbicide and non treated plots, weeds had a greater opportunity to set seed in these plots. The main species that appeared to be setting seed in the trial were wormseed mustard, shepherd's purse, cow cockle, plantain, foxtail and witchgrass.

Several studies have been performed in England to evaluate the effect of undersown red clover in spring barley on quack grass growth both before and after harvest (Cussans, 1972; Dyke and Barnard, 1976; Williams, 1972). The studies showed quack grass growth to be greatly restricted by the barley crop until the crop began to mature. In plots not underseeded, rhizome weight increased dramatically during grain maturation and after the barley crop was harvested. Over a three year study period, Dyke and Barnard (1976) found undersowing with red clover to reduce quack grass growth by 57 % on average compared to plots not undersown. They concluded that undersowing spring cereals can appreciably retard the spread of quack grass and prevent its rapid spread after harvest if cultivation or spraying is delayed.

In addition to suppressing weeds, improving soil tilth, and reducing soil erosion, the major benefit of red clover plowdown is its nitrogen fixation potential. The double cut red clover plowdown in 1986 with a shoot biomass of 2160 kg/ha dry matter (and accompanying root biomass produced under a short stubble grain harvest of 7cm) would fix approximately 160 kg/ha of N or replace approximately 100 kg/ha of fertilizer N for the following years corn crop (Fulkerson, 1982; Bruulsema and Christie, 1987; and Forrest, 1985).

4.2 Evaluation of Corn Weed Control Methods and Interseedings for Use in a Low External Input Corn-Soybean Sequence.

Corn followed by soybeans is a very common crop sequence in Southern Ontario. However, few studies have evaluated this sequence within the context of developing a low external input system of management. The objectives of this study were to:

1. evaluate various corn weed control methods to provide the highest economic return to corn grown in a rotational system.

2. evaluate different methods of weed control and interseeded species in corn on interseeded forage establishment and dry matter production.

3. test the effects of the different corn weed control methods and forage interseeding species on weed growth and yield in soybeans grown the following year.

4. evaluate if high yields could be produced at a low cost using integrated farming methods.

4.2.1 Materials and Methods

4.2.1.1 1986 Corn and 1987 Soybean Site

A two hectare site was selected on a silt loam soil in Oxford county. The site had been in corn for two of the previous seasons. In 1985, the field had been in mixed grain (barley and oats) with red clover seeded for plowdown.

In the spring of 1986, the cover crop was plowed on May 11 and the field cultivated twice. On May 13 the field was seeded to Pioneer 3790 corn at 70,000 seeds per ha in 0.77 m rows. No insecticide was used on the field. Fertilizer was applied at 260 kg/ha of 19-19-19, 8 cm off the row, providing 50 kg/ha of nitrogen, phosphate and potash respectively. The weed control and interseeding treatments were:

0 - Check - no herbicide, cultivation or forage;
1 - Herbicide overall;
2 - Cultivated twice;
3 - Cultivated twice and herbicide banded;
4 - Cultivated twice and red clover;
5 - Cultivated twice and ryegrass;
6 - Cultivated twice, red clover and ryegrass;
7 - Cultivated twice, herbicide banded and red clover;
8 - Cultivated twice, herbicide banded and ryegrass;
9 -Cultivated twice, herbicide banded, red clover and ryegrass.

A randomized complete block design was used with three replications. Plot size was 12.3 m x 52.6 m. The entire trial size was 123 m x 157.8 m. On May 27, 1986, cyanazine (2-((4-chloro-6- (ethylamino) -1,3,5-triazin- 2 -yl-)amino)-2-methylpropanenitrile) herbicide (Bladex 80 WP) was applied 2.25 kg/ha overall in treatment 1 and applied in a 15 cm band over the corn row in treatments 3, 7, 8, and 9 with a back-pack sprayer to simulate a herbicide banding with the seeder or cultivator. Two row crop cultivations were made on the corn 21 days (with rolling shields) and 37 days (with no rolling shields) after planting on the cultivated treatments. At the time of second cultivation

June 20 (37 days after planting), a cultivator / seeder unit was used to seed red clover (8 kg/ha of Tristan) and ryegrass (11 kg/ha of a 50:50 Lemtal annual and Bastien perennial ryegrass mixture) and 10 kg/ha of a 50:50 mixture of the red clover and ryegrass seedings. The forage seed was incorporated slightly with drag chains on the cultivator / seeder unit to improve seed-soil contact (Plate 2). Forage plant counts were performed with a 0.25 sq. m. quadrat between rows of corn on July 26 (early count) and August 26 (late count).

On October 18-19, weeds were counted and weed and forage biomass were measured four times for each plot. This was done at random locations over the corn row using a one square metre quadrat (0.77 m wide x 1.30 m to fit exactly over one corn row). Corn ears were hand harvested on October 20, 1986, from two rows of 5 m in length from the centre of each plot. The entire field was then combined and the corn stalks left on the surface unchopped.

A grain/ear weight ratio and moisture percentage from each plot was determined from shelling 10 cobs from each plot. Corn grain yields were determined using the following formula:

Grain corn Yield/ha =

$$\text{Harvested ear wt.} \times \frac{\text{grain wt.}}{\text{ear wt.}} \times \frac{100-\text{ moisture reading}}{100-14} \times \frac{10{,}000}{5\text{m} \times 1.54\text{m}}$$

The following spring, weeds and forage were again harvested over the row using the 0.77 m x 1.30 m quadrat on May 8,

1987. On May 9, 1987 the field was plowed and subsequently disced and cultivated twice prior to seeding. On May 25, the entire field was planted to Pioneer 0877 soybeans seeded at 85 kg/ha in 0.53 m rows using a grain drill with every third run open. Grip brand inoculant was used at triple rate as the field had not been sown to soybeans previously. No fertilizer, herbicide or additional seed protectant was applied on the field. The entire field was rotary hoed two times June 11 when the soybeans were approximately 7 cm high. A mid mounted beet and bean cultivator was used to cultivate soybeans at a height of approximately 17 cm on July 2,1987. On October 3, 1987, a quack grass shoot harvest and total weed harvest was taken at four randomly selected locations per plot using a one sq. m. quadrat (0.96 m x 1.06 m) to fit exactly over two soybean rows. On October 5, 1987, soybeans yields were obtained by hand harvesting a single 5 metre row from the centre of each plot. Soybean samples were threshed, cleaned and oven dried and weights adjusted to 14% moisture.

4.2.1.2 1987 Corn Site

As a result of a severe rain on May 31, 1987 (120 mm in 2 hours) the initial site chosen in 1987 was abandoned due to flooding and burial of corn seedlings. This caused some modifications in the timing of operations, herbicide selection, trial location and size as compared to the 1986 season. An adjacent site was selected that had been planted to corn on May 3 using the same cultivar, tillage, seeding and fertilizer practices as in 1986. The field had been in alfalfa for the past two seasons and was moldboard plowed in the fall of 1986. Plot size was 6.2 m x 24 m and the trial size was 62 m x 72 m. A mixture of bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) at .28 kg/ha and atrazine at 1.5 kg/ha was applied in a 15 cm band over the row on June 4. On June 11 the broadcast herbicide treatment was applied using the same mixture and rate. Tractor spraying was delayed one week, initially due to soil conditions too wet to support a tractor followed by cold weather warnings for spraying and high winds. The first cultivation was made on June 5 with rolling shields on a damp soil and the second cultivation the following day in a drier soil without rolling shields. The cover crops were also seeded on June 6 (34 days after planting) using a hand driven broadcast-seeder as the plots were reduced in size. To simulate similar conditions to the previous year, the drag chains were removed from the cultivator/seeder unit and manually dragged over interseeded plots. Plant counts were performed on July 15 (early count) and August 11(late count), 1987. The corn was hand harvested on September 28 and the cover crops and weeds on Sept. 29 and 30.

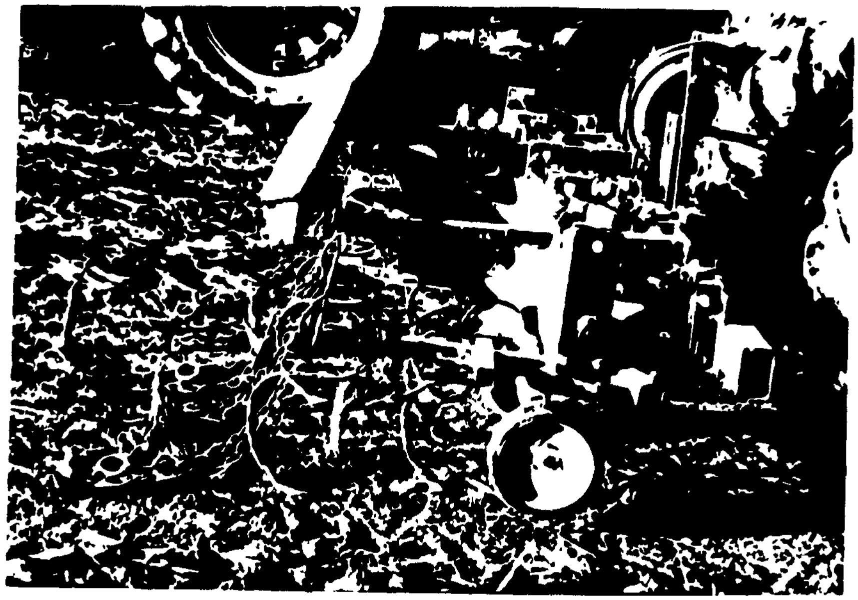

Plate 2. Cultivator / Seeder Unit for Interseeding Cover Crops in Corn at Time of Second Cultivation.

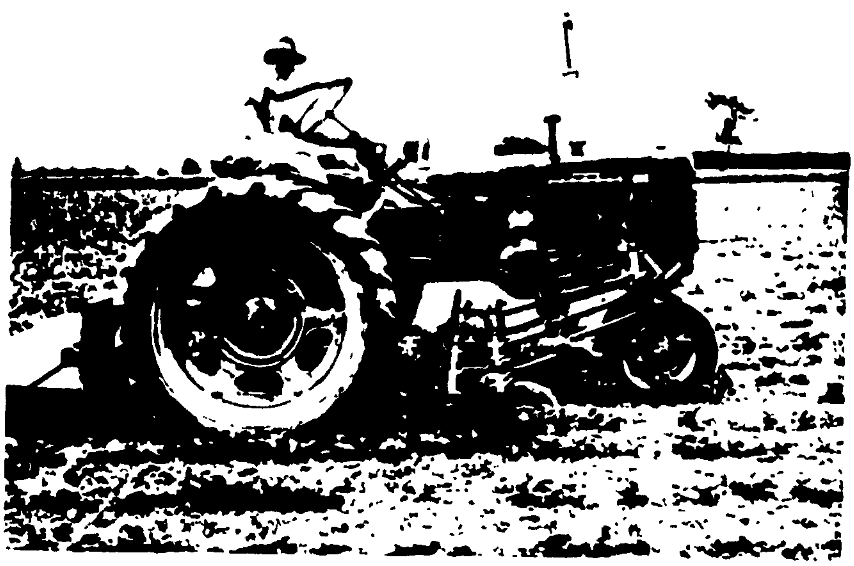

Plate 3. Midmounted Beet and Bean Cultivator used for One Time Cultivation of Soybeans in 53 cm. Rows.

4.2.2 Results

4.2.2.1 1986 Corn yield, weed and forage biomass and 1987 spring forage and weed biomass

Crop growth was excellent in 1986 with a mean corn yield of 8.92 t/ha being produced across the ten different treatments (Table 11). The only significant yield difference was from the control treatment (no herbicide, cultivation, or forage) which was significantly lower than the other nine treatments.

Weed growth was influenced both by cultivation and herbicides, while cover crops had no significant effects on weed biomass production in the corn. The treatments with overall herbicide or herbicide banded with two cultivations performed similarly. The herbicide systems provided superior weed control to that of two cultivations only, however, corn yields were not significantly different. The system with no herbicide or cultivation produced the largest quantities of weeds and significantly reduced yields (Table 11).

Forage biomass was significantly higher on the ryegrass treatment which included a herbicide band compared to the system with two cultivations only. The ryegrass- red clover treatment with a herbicide band also showed a trend towards greater biomass than the ryegrass-red clover established with two cultivations only. Forage biomass was significantly higher for both treatments containing pure ryegrass compared to red clover. The two ryegrass- red clover mixtures also showed a trend towards increased forage biomass compared to those of the pure red clover (Table 11). Red clover was

Table1 . 1986 Corn Grain Yield, Weed and Forage Biomass

Treatment	Corn Yield (t/ha at 14%) Moisture	Weed Biomass	Forage Biomass
		(kg /ha Dry Matter)	
No Weed Control	7.72 b	1146 a	0 d
Herbicide	9.15 a	54 cd	0 d
Cultivation (2X)	8.84 a	182 bc	0 d
Herb. Banded + Cult.	9.54 a	9 d	0 d
Cult. + Red Clover	8.73 a	188 bc	20 cd
Cult. + Ryegrass	9.15 a	242 b	53 b
Cult. + R.C.-Rye.	8.97 a	158 bcd	50 b
H.B.+ Cult. + R.C.	8.77 a	56 cd	20 cd
H.B.+ Cult. + Rye.	9.23 a	64 cd	123 a
H.B.+ Cult. + R.C.-Rye.	9.12 a	61 cd	38 bc
Mean	8.92	216	30
C.V.	6	39	45

* means within a column followed by the same letter are not significantly different at p = 0.05

Cult. - Cultivation
R.C. - Red Clover
Rye. - Ryegrass
H.B. - Herbicide Band

damaged heavily by slug feeding in the wet fall. In general, forage biomasses were relatively low regardless of treatment.

The following spring none of the treatments had a significant effect on the above-ground weed biomass harvested on May 8, 1987. The herbicide banded plus ryegrass system continued to provide the greatest quantities of above-ground biomass followed by the ryegrass mixture treatments and pure ryegrass treatment established without a herbicide band. In the spring the only significant effect of herbicide band on increased forage biomass was on the pure ryegrass treatment (Table 12). The two clover systems experienced poor spring regrowth. Forage production from the clover was particularly poor in the wheel marks where the combine had passed the previous fall as compared to the ryegrass treatments.

4.2.2.2 Effect of 1986 Corn Treatments on 1987 Soybeans.

Soybean yields were not significantly different following any of the corn treatments in 1986. The hand harvested yield averaged 4.04 t/ ha at 14% moisture. The farmer reported an average combine harvested yield of 3.56 t/ha (at 14% moisture) which he considered to be an excellent crop. The total above-ground weed biomass and above ground quackgrass biomass were not significantly different amongst any of the treatments. Mean weed biomass of only 10.4 kg/ha for quack grass and 47.1 kg/ha for all weeds were obtained in the trial.

Table 12. 1987 Spring Forage and Weed Biomass Prior to Plowdown for Soybeans

1986 Corn Treatment	Weed Biomass (D.M. kg/ha)	Forage Biomass (D.M. kg/ha)
No Weed Control	22	0 d
Herbicide	11	0 d
Cultivation (2X)	13	0 d
Herb. Banded + Cult.	7	0 d
Cult. + Red Clover	8	23 c
Cult. + Ryegrass	10	137 b
Cult. + R.C.-Rye.	13	94 b
H.B.+Cult. + R.C.	13	28 c
H.B.+Cult. + Rye.	16	277 a
H.B.+Cult. + R.C.-Rye.	8	100 b
Mean	12	66
C.V.	115	43

* means within a column followed by the same letter are not significantly different at P = 0.05

Cult. - Cultivation
R.C. - Red Clover
Rye. - Ryegrass
H.B. - Herbicide Band

Table 13. 1987 Soybean Yield , Quack Grass Shoot Biomass and Total Weed Biomass following 1986 Corn Interseeding Systems.

1986 Corn Treatment	Soybean Yield (t/ha at 14 %)	Quackgrass Biomass (Dry Matter kg / ha)	Total Weed Biomass
No Weed Control	4221	6.0	13.8
Herbicide	3673	10.9	110.0
Cultivation (2X)	4062	1.1	56.2
Herb. Banded + Cult.	4083	39.6	42.8
Cult. + Red Clover	4314	7.9	74.4
Cult. + Ryegrass	4305	1.6	84.7
Cult. + R.C.-Rye.	3631	6.5	21.4
H.B.+Cult. + R.C.	4030	13.6	27.7
H.B.+Cult. + Rye.	4251	0.0	16.0
H.B.+Cult. + R.C.-Rye.	3835	17.2	23.8
Mean	4041	10.4	47.1
C.V.	13	158	131

Cult. - Cultivation
R.C. - Red Clover
Rye. - Ryegrass
H.B. - Herbicide Band

Plate 4. Soybeans grown in 53 cm rows using two rotary hoeings and one cultivation provided relatively high soybean yields and low total weed biomass.

Plate 5. Two row crop cultivations eliminated almost all weeds except those directly over the corn row.

4.2.2.3 1987 corn yield, weed and forage biomass

In 1987 corn growth was outstanding and no significant differences were recorded amongst any of the treatments. The corn grain yields averaged 12.93 t/ha across treatments (at 14 % moisture) and this was the highest yielding field the farmer had ever harvested. The only significant difference in weed growth was that of the treatment receiving no herbicide or cultivation which had a higher weed biomass than other treatments. Forage biomass was low in all treatments and no significant differences were recorded amongst interseeded treatments (Table 14).

4.2.2.4 Interseeding plant counts in corn 1986 and 1987

The early and late plant counts of red clover in 1986 showed significant seedling loss in both treatments where ryegrass was sown with red clover. The pure red clover seeding established without a herbicide band also showed a trend towards reduced plant numbers at the late count. None of the ryegrass treatments showed a trend towards reduced plant numbers at the late plant count in 1986 (Table 15).

In 1987, early plant counts were generally lower than those obtained in 1986, particularly in the case of ryegrass. Plant losses were much higher between early and late counts in 1987 with much larger losses in ryegrass. The ryegrass system established with a herbicide band in 1987 showed significantly higher plant counts than the treatment with no herbicide band (Table 16).

Table 14. 1987 Corn Grain Yield, Weed and Forage Biomass.

Treatment	Corn Grain Yield (t/ha at 14%) Moisture	Weed Biomass (kg/ha Dry Matter)	Forage Biomass (kg/ha Dry Matter)
No Weed Control	12.43	442 a	0 b
Herbicide	12.64	176 b	0 b
Cultivation (2X)	13.42	101 b	0 b
Herb. Banded + Cult.	13.01	56 b	0 b
Cult. + Red Clover	12.92	125 b	7 a
Cult. + Ryegrass	12.59	70 b	8 a
Cult. + R.C.- Rye.	13.08	135 b	9 a
H.B.+Cult. + R.C.	12.86	16 b	10 a
H.B.+Cult. + Rye.	13.10	22 b	13 a
H.B.+Cult. + R.C.-Rye.	13.27	11 b	9 a
Mean	12.93	115	6
C.V.	4	77	69

* means within a column followed by the same letter are not significantly different at P = 0.05

Cult. - Cultivation
R.C. - Red Clover
Rye. - Ryegrass
H.B. - Herbicide Band

Table 15 1986 Corn Interseeding Plant Counts (plants/Sq.M.) of red clover and ryegrass.

Treatment	Red Clover Early Count	Red Clover Late Count	Ryegrass Early Count	Ryegrass Late Count
Cultivation + R.C.	148ab	108b	-	-
Cultivation + Rye.	-	-	189a	175a
Cult. + R.C.-Rye.	87b	66c	87b	80b
Herb. Band + Cult. + R.C.	175a	148a	-	-
Herb. Band + Cult. + Rye.	-	-	170a	156a
H.B. + Cult. + R.C.-Rye.	92b	49c	81b	80b
Mean	126	93	132	123
C.V.	26	12	26	21

* means within the column followed by the same letter are not significantly different at P = 0.05

Table 16. 1987 Corn Interseeding Plant Counts (Plants/Sq.M.) of red clover and ryegrass

Treatment	Red Clover Early Count	Red Clover Late Count	Ryegrass Early Count	Ryegrass Late Count
Cultivation + R.C.	123a	82	-	-
Cultivation + Rye.	-	-	118a	50b
Cult. + R.C.-Rye.	99ab	66	45b	27c
Herb. Band. + Cult. + R.C.	128a	81	-	-
Herb. Band. + Cult. + Rye.	-	-	105a	71a
H.B. + Cult. + R.C.-Rye.	80b	52	49b	22c
Mean	108	70	79	43
C.V.	26	12	15	20

* means within the column followed by the same letter are not significantly different at P = 0.05

4.2.3 Discussion

4.2.3.1 Economics of weed control systems in corn

In the first year of the study, the combination system of narrow herbicide banding and two row crop cultivations provided the highest economic return to weed control performed (Table 17). In the second year, the row crop cultivation only system provided a higher economic return when weed pressure was lower (Table 18). In both years herbicides only were the highest cost system of weed control and provided the lowest economic return.

In 1987, the yield advantage from the best performing weed control system on average (herbicide banding plus two cultivations) compared to the check treatment was only 5 % (which when statistically analyzed was not significantly different). As a result the economic response to weed control measures was low in 1987 compared to 1986 (Table 18). Several factors were likely responsible for this:

1. The field had previously been sown to alfalfa for the past two seasons and a short term alfalfa stand is well known by farmers to reduce weed problems (Brusko, 1985). Meggitt (1960) found yield reductions in corn when no weed control was performed of 37 % and 47 % following row crops and 17 % following alfalfa in three separate fields studies.
2. Reduced quantities of fertilizer were applied to the field (following legume plowdown) and this fertilizer was banded near the crop row. Weil (1982) and Reinertsen et al. (1981) found crops took advantage of fertilizer more than weeds when placed near the crop row.

Table 17. Economics of Weed Control Systems in Corn 1986

	Check	*Cultivation (2X)	Herbicide Overall	*Herb. Band + Cult. (2X)
Corn Yield (t/ha at 14%)	7.72	8.92	9.15	9.17
Weed Biomass (kg/ha)	1150	190	50	50
Weed Control (%)	0	83.5	95.7	95.7
Weed Control Cost ($/ha)	0	16.10	42.85	25.60
Economic Returns to Weed Control Measure ($/ha)	0	$ 103.90	$ 100.15	$ 119.40

* average of four treatments
Cost of one cultivation = $ 8.05/ha
Cost of herbicide overall (cyanazine at 2.25 kg/ha)= $35.00/ha
Cost of applying herbicide = $ 7.85/ha
Cost of herbicide band = $ 7.00/ha
Cost of applying herbicide band = $2.50/ha
Corn at $ 100.00/tonne and labour at $ 8.00/hr.

Cost of mechanical weedings and herbicide applications was adapted from Fisher (1985) using a labour charge of $ 8.00/hour.

Herbicide costs were determined from purchase invoices from Yantzi Feed and seed limited Tavistock, Ontario.

Economic returns to weed control measure was determined by:

Increase in corn yield from weed control practice vs. check	X $100/tonne (corn value)	-	Cost of Weed Control Measure ($ /ha)

Table 18. Economics of Weed Control Systems in Corn 1987

	Check	*Cultivation (2X)	Herbicide Overall	*Herb. Band + Cult. (2X)
Corn Yield (t/ha at 14%)	12.43	13.00	12.64	13.06
Weed Biomass (kg/ha)	440	110	180	30
Weed Control (%)	0	75.0	59.1	93.2
Weed Control Costs ($/ha)	0	16.10	31.10	23.25
Returns to Weed Control Measure ($/ha)	0	$ 40.90	$ (-10.10)	$ 39.75

* average of four treatments
Cost of one cultivation = $ 8.05/ha
Cost of herbicide overall (bromoxynil at .28 kg/ha and atrazine at 1.5 kg/ha) = $ 23.25/ha
Cost of herbicide application = $ 7.85/ha
Cost of herbicide band = $ 4.65/ha
Cost of applying herbicide band = $ 2.50/ha
Corn at $ 100/tonne and labour at $ 8.00/hr.

Cost of mechanical weedings and herbicide applications was adapted from Fisher (1985) using a labour charge of $ 8.00/hour.

Herbicide costs were determined from purchase invoices from Yantzi Feed and seed limited Tavistock, Ontario.

Economic returns to weed control measure was determined by:

Increase in corn yield from weed control practice vs. check	X $100/tonne (corn value)	-	Cost of Weed Control Measure ($ /ha)

3. A rapidly emerging, high yielding, later maturing, "stay green" hybrid was planted at a relatively high population in 75 cm rows. These are all desirable features for increasing plant competition to weeds as reported by Weil (1982), Walker and Buchanan (1982), and Rose et al. (1984).

4. The trial was on one of the most productive fields of a well managed farm on class 1 land. Weed growth has been found to be reduced in environments of high natural fertility favorable to high biomass production (Patriquin, 1981).

The two cultivations alone provided approximately 80 % weed control over the two years with 83.5% in 1986 and 75 % in 1987 when the two cultivations were within two days. The weed escapes were observed to be almost entirely over the 15 cm area over the crop row, which is the 20 % of the field uncontrolled by the cultivator (Plate 5).

The herbicide band over this 15 cm area appeared to be effective in reducing weed biomass but only the weed biomass in 1986 showed significant reductions (Table 11). Most research on herbicide banding and cultivation has evaluated wider herbicide bands of approximately one/third the row spacing in continuous corn systems (Ammon, 1986; Hamill, 1983; and Gill et al., 1984). If precision row cultivating can be performed to control 80 % of the weeds a wider herbicide band would likely only increase the weed control cost particularly if weed populations were reduced through cultural management techniques. With current development of cultivators with improved stability and enhanced guidance systems including electronic systems and mirrors the need for a wide herbicide band could be further reduced.

The overall herbicide treatments were poorer performing economically than the cultivation and herbicide banding treatments in both seasons which is consistent with all research studies reviewed. However , the weed control of the overall herbicide treatment in 1987 was impaired by the one week delay in application (due to a series of unstable weather events) compared to the herbicide banding system. The annual grasses had passed the two leaf stage in that week and escaped control from the overall herbicide application. Weed biomass in overall herbicide treated plots was relatively low in both years with 50 kg/ha in 1986 and 180 kg/ha in 1987 .

If the economic analysis was performed at the same yield level as the cultivation based treatments it would remain less economical due to the low cost of mechanical weed control. Over the two years these results appear to indicate that a system of using narrow herbicide band of 15 cm along with two row crop cultivations can be a more cost effective weed control system than broadcasting herbicides when good cultural techniques are used to grow the corn.

If the suggested cultural manipulations (good crop rotation, reduced fertilizer use and efficient placement, weed suppressive cultivar, relatively high population) can be utilized during a season conducive to outstanding crop growth (such as experienced in 1987), it may be possible to reduce control measures such as the need for a herbicide band or cultivation(s). The few weeds that do grow would cause little yield reduction and act as a soil and nitrogen conserving cover crop as suggested by Weil (1982) and Patriquin (1988).

4.2.3.2 Effect of weed control method and interseeded species on forage establishment and dry matter production

The pure ryegrass treatment established with a herbicide band provided larger quantities of biomass at fall and spring harvest in 1986-1987. Four suggestions on why this treatment was superior to other systems in 1986-1987 are;

1. The herbicide band reduced weed populations in the row and this reduced competition to the forage seedlings compared to the cultivation only establishment method. This is shown in Table 15 where significantly greater quantity of established red clover plants were obtained at the late count date in the herbicide banded treatment compared to the cultivated treatment.

2. The extremely wet field conditions in September 1986 (178.5 mm rainfall occurred) appeared to impair red clover growth which was further reduced by substantial feeding by slugs.

3. The red clover was heavily damaged by wheel traffic from the combine and the biomass was greatly reduced in these areas which would represent almost half the field (since little forage growth appears in the corn row and a 4 row

combine was used for harvest).

4. Grasses such as ryegrass generally grow better at cooler soil and air temperatures than legumes. The main growth period for interseeded cover crops in corn is during cool periods of the year in late fall and early spring.

In the 1987 corn interseeding trial, biomass production was extremely low and there were no significant differences amongst interseeded treatments. Four factors were likely responsible for the poorer establishment and biomass production compared to the 1986 corn interseeding trial:

1. For two weeks after the forage interseeding in 1987 only 12.2 mm of rainfall was received compared to 36.9 in 1986 (Table 4). This was most likely the reason why plant counts taken at the first date were reduced in 1987 (Table 16) compared to 1986 (Table 15).

2. The summer was much warmer in 1987 than 1986. After forage interseeding in corn, fourteen days were recorded in 1987 with temperatures above 27° C compared to only five in 1986. A particularly hot dry eight day period was experienced between forage counts in 1987 in which little rainfall occurred and daily high temperatures reached at least 27° C. This may explain why the loss of forage seedlings between counts was much higher in 1987 than in 1986. The pure ryegrass treatments appeared to be particularly vulnerable to the hot dry period with a seedling loss of 46 % in 1987 compared to only 7% in 1986. The average red clover plant losses in pure seedings were 36

% in 1987 and 27 % in 1986 (Tables 15 and 16).

3. The corn crop was extremely high yielding in 1987 with an average yield on interseeded treatments of 13.04 t/ha compared to 9.05 tonne/ha in the 1986 season. This would increase competition to the undersown forage through intense shading and greater competition for soil moisture and nutrients.

4. The forage biomass was harvested by an earlier date in 1987 (Sept. 30 vs. Oct. 19 in 1986) due to an earlier planting date and a record warm season. This may have affected the quantity of forage biomass obtained as the corn canopy had not yet opened because heavy frosts had not occurred. In 1986 it was observed that significant growth of the interseeded forage occurred only after the canopy opened after several frosts. This could explain why the mean fall forage biomass was reduced approximately 80 % in 1987 compared to 1986 while the late forage interseeding counts were only approximately halved in 1987 compared to those of 1986.

In general it would likely be necessary to produce greater quantities of biomass production than was obtained in 1986-1987 or 1987 if the interseeding technique is to be widely accepted for corn grain management systems. Biomass production from the interseeded treatments in 1986 1987 could likely have been increased in several ways:

- by increasing the seeding rate of red clover , red clover and ryegrass and pure ryegrass treatments from 8, 10 and 11 kg/ha to 12, 16 and 20 kg/ha and running tubes off the grass seed box to the inter-row area to avoid seed landing on the herbicide band.

- the forage interseedings being made at the 15 cm height in corn 30 days after planting (instead of at the 30cm height, 34-37 days after planting) if grown in a high yielding environment.

- by planting corn earlier and not using a " stay green" corn hybrid 150 heat units longer than the area.

- by incorporating the cover crop immediately prior to soybean planting on May 25 rather than tilling it in on May 9th.

4.2.3.3 Effect of 1986 Corn Treatments on Soybean yield and Weed Biomass.

Both soybean yield and weed control across all treatments were excellent. The soybean crop and weed management system of planting the crop in a row width of 53 cm rows and using two rotary hoeings and one cultivation for weed control was very effective (perhaps too effective to demonstrate differences in total weed growth from the previous corn treatments). Significant research exists that suggests that this system should optimize crop yield with low cost and effective weed control (Lovely et al., 1958; Peters et al., 1965; Wax and Pendleton, 1968; Hauser et al.,1972; Johnson et al., 1982). The fact that soybean yield was not significantly influenced by the previous corn treatments is consistent with most research following plowdown of grass type cover crops before soybeans. However, yields have been found to increase following rye and ryegrass cover crops with improved weed control being frequently cited (Cole and Witt, 1983; Wrucke and Arnold, 1981). Yield reductions have also been reported in soybeans following rye cover crops in a dry spring (Hammond, 1984). Although the ground was dry in 1987, adequate rainfall was received after planting to prevent this from being a problem.

During the course of the experiment it became evident that the potential existed for the interseeded ryegrass cover crops to suppress quack grass growth. Unfortunately the natural stand of quack grass was sporadic in growth in the field and caused high co-efficients of variation for this measurement. There is a great deal of information that suggests that corn interseeding with ryegrass could make a very effective integrated crop and weed management system in a corn-soybean sequence. Quack grass is a serious concern of soybean growers and ryegrass has been found to reduce or delay the spread of quack grass due to its extensive root system (Cussans, 1972; Dyke and Barnard, 1976; Bann Hofman and Ennik, 1982). As well, excessive residual nitrogen from corn has been found to increase annual weed growth in soybeans as well as be an environmental threat due to seepage into groundwater (Staniforth,1962). Extensive studies by Scott et al. (1987) found ryegrass interseedings in corn to provide high biomass production and reduce nitrogen availability. Low nitrogen levels are generally desirable when planting grain legumes such as soybeans as they stimulate nitrogen fixation. Studies by Cussans (1973) and Hoogerkamp (1975) also found that lower soil nitrogen levels help control quack grass growth.

4.2.3.4 Economics of Integrated versus Conventional Corn and Soybean Production

Average corn yields of 9.17 and 13.06 t/ha were obtained in 1986 and 1987 respectively, from crops whose only chemical inputs were herbicide and fertilizer bands. Using legumes as the main nitrogen source and row crop cultivation as the main weed control method enabled a substantial reduction in corn input costs (Table 19). Hicks and Rehm (1986) in a review on reducing corn production costs concluded that for maximum profit corn growers should use recommended levels of all production inputs. However within the article they stated (summarized points):

- that only in the areas of herbicide and fertilizer is there major opportunity to reduce costs without reducing yields (by using herbicide banding and cultivation for weed control and fertilizer banding, legume plowdown or manure to supply crop nutrients);
- that corn yields are 10-15% higher when corn is grown following other crops;
- cash costs are reduced in first year corn as no rootworm insecticide is needed.

These were many of the methods used in the present study that made the integrated corn production system a high producing low cost system (Table 19).

Table 19. Input Cost Comparison between Integrated and Conventional Corn Production System (1986-87)

	Integrated System (Cost $/ha)	Conventional Recommendations (Cost $/ha)
Tillage	57.25	57.25
Seeding	15.41	15.41
Seed	70.00	70.00
Fertilizer	78.15	184.33
Fertilizer Application	-	5.93
Herbicide	5.88	60.25
Herbicide Application	2.50	7.85
Insecticide	-	16.05
Row Crop Cultivation (2X)	16.10	-
Pre-harvest Costs	$ 245.29	$ 417.07

Field operation costs adapted from Fisher, 1985 to include labour charge at $ 8.00/hr
Fertilizer and herbicide recommendations average of Ontario Ministry of Agriculture and Food 1987b, Publication 60 and Ministere de l'Agriculture, des Pecheries et de l'Alimentation du Quebec 1985, Mais Grain, Agdex 111/821

The average crop yield in soybeans of 4.04 t/ha at 14 % moisture was an excellent crop particularly as no fertilizer, or herbicide was applied. This would result in substantial savings due to lower input costs and elimination of broadcast application costs for fertilizer and herbicide. The area of greatest savings in soybean production is on weed control. The mechanical weed control system of two rotary hoeings and one cultivation compared to a conventional soybean weed control system of a broadcast tank mixture of a grass and broadleaf herbicide would cost approximately $22.61/ha compared to $83.29/ha (Table 20).

Reduction in chemical weed control costs through the substitution of mechanical weed control was one of the main areas for savings in both corn and soybeans. This difference could be even more important when it is recognized that frequently, cultivation increases crop yield (Johnson,1985), while very widely used herbicides (such as bromoxynil and dicamba in corn) decrease crop yields in the absence of weeds (Lanini, 1986).

The current study is in agreement with integrated farming systems reports from Europe which have shown that substantial reduction in input costs can occur with the use of integrated methods (Steiner, 1986; Vereijken 1986). What is of particular interest in this study is the level of productivity that was achieved along with the reduced costs. In 1987, yields of 13.0 t/ha corn and 4.0 t/ha soybeans were achieved without the use of herbicides on the Kalbfleisch farm. In 1987, provincial yields for corn and soybeans averaged 7.4 t/ha and 2.8 t/ha respectively while Oxford county yields for corn and soybean averaged 8.0 t/ha and 2.9 t/ha (Ontario Ministry of Agriculture and Food, 1987a)

Table 20. Input Cost Comparison between Integrated and Conventional Soybeans

	Integrated System Cost $/ha	Conventional Recommendations Cost $ / ha
Tillage	57.25	57.25
Seeding	15.41	15.41
Seed	42.00	42.00
Inoculant (1st Yr.)	12.50	12.50
Fertilizer	-	48.99
Fertilizer Application	-	5.93
Herbicide	-	75.44
Herbicide Application	-	7.85
Rotary Hoeing (2X)	14.56	-
Row Crop Cultivation	8.05	-
Total Preharvest Cost $ / ha	$ 149.77	$ 265.37

Field operation costs adapted from Fisher, 1985 to include labour cost at $8.00/hour
Seed, fertilizer and herbicide costs from Ontario Ministry of Agriculture and Food, 1987b, Publication 60.

5. GENERAL DISCUSSION

Through the course of the study the system that was identified by the participating farmers and the researcher as an alternative to high external input systems was one which included:

- Crop Rotation
- Cultivation
- Cover Cropping
- Chemical Banding

In this system: crop rotation was used to eliminate the need for insecticides and to help provide crop nutrients; cultivation equipment, consisting of rotary hoes and row crop cultivators, is used not only for effective and economical weed control, but to improve soil aeration, reduce crusting and establish ryegrass intercrops; cover crops are used to improve soil fertility, reduce tillage, suppress weeds and increase ground cover preventing nutrient leaching and erosion; chemical banding, rather than broadcasting fertilizers and herbicides, enables smaller quantities of chemical inputs to economically enhance the systems weed control and fertility. The system emphasizes the use of resources within the farm to lower production costs, maintain high crop yields and reduce chemical input use in crop production.

Although alfalfa was grown prior to corn in the second year of the study, the system could work in exclusively cash grain systems but likely not perform as well as if forage was included in the rotation. In cash grain systems, winter wheat overseeded with red clover prior to the corn-soybean sequence may be more effective than mixed grain and red clover (as was used in 1986). It would provide a higher value cash grain, fix greater quantities of nitrogen (Norris, 1981) and increase ground cover as it would provide winter cover after soybeans. This potential low input cash grain system is outlined below:

Table 21. Potential Low Input Cash Grain System

	Year 1	Year 2	Year 3
Main Crop	Corn	Soybeans	Winter Wheat
Cover Crop	Ryegrass	Winter Wheat	Red Clover

The winter wheat would be aerially seeded at soybean leaf yellowing or direct drilled after harvest in longer season areas. Red clover would be frost seeded in late winter as practiced by Norris (1981). In short rotations such as this, the ability of interseeded ryegrass in corn and overseeded red clover in cereals to suppress weeds could be important as there is little to no opportunity for excessive tillage or persistent herbicides between crops.

It should be stated that almost all the techniques used in the experiments have been scientifically proven to be successful for at least 25 years and many of the techniques were mainstream farming methods in corn, soybean, and small grain production before the widespread introduction of herbicides. The techniques of clover underseeding in grain and ryegrass interseeding in corn were prevalent in the past (Stevensen, 1955) and may be again in the future. The Ontario Ministry of Agriculture and Food is currently promoting these farming practices with grants for first time adoption of cover crop interseeding in corn and cereals.

The herbicide banding technique in corn combined with row crop cultivation is well documented to provide more effective and economical weed control than broadcast herbicides over many years and environments. However, almost all the existing studies have used wider herbicide bands than the one-fifth the row width area used in the present study. The idea of the narrow herbicide band came from one of the participating farmers, Harry Wilhelm. He has used the 15 cm herbicide band plus two cultivations successfully for the past 14 years on a 60 hectare farm in which corn is grown in a corn- mixed grain -white bean -winter wheat rotation. If weed pressures were more intense than in the present study a wider herbicide band may be necessary.

For the past eight years, Harry Wilhelm has also been using the mechanical weed control system of two rotary hoeings and one to two cultivations for weed control in 53 cm. row white beans and soybeans. Exclusive use of rotary hoeing and cultivation for weed control in soybeans has also been documented to provide more cost-effective weed control than herbicide only or herbicide cultivation system in U.S. studies (Hauser et al., 1972; Lovely et al., 1958). In extremely wet seasons, where weed seed banks are large, or where residual fertilizer is present in large quantities this system will not likely be adequate to control weeds particularly if soybeans are grown in wide rows of 75-102 cm (Peters et al., 1959; Sahs and Lesoing,1985). In these cases herbicide bands could likely be used economically to improve weed control and crop yield. It is likely that use of mechanical weed control systems will increase in the future. The Ontario Ministry of Agriculture and Food has recently announced a major program to reduce herbicide use by 50% over the next 15 years.

The major question remaining is can systems of crop rotation, cultivation, cover cropping and chemical banding be used consistently and profitably on much of our crop acreage of corn, soybeans and small grains. What would the impact of the techniques used in the experiments be on larger farms, on more moderately productive soils with greater weed seed banks and in years with less favorable weather conditions. It seems likely that greater levels of inputs might be required and lower yields would be achieved under these conditions. In particular, farms that have had intensive cash crop production for the past 20 years may require a more gradual reduction in inputs than those tested (a slower period of chemical weaning). However, even if yields were slightly lower, the reduction in production costs would more than offset small yield reductions particularly when commodity prices are low. The interesting feature of the farmers participating in this study is that they can consistently achieve average to above average yields with reduced chemical input requirements.

The reduction in chemical input requirements is simply not a matter of dropping inputs from the system. Farming with less chemicals means that the biological efficiency of the farm must be improved (if the aim is to maintain or increase productivity and profitability over the long term). The more we understand, improve and promote practices that enhance the resource base of the farm , the more we will move into an agriculture that relies on less chemicals.

6. SUMMARY AND CONCLUSIONS

Interactions between weeds, crops and cover crops were examined to identify and develop crop and weed management systems that reduce crop production costs and chemical input use.

Integrated farming techniques used by the farmers in the immediate area of the research were evaluated by following normal farming operations as much as possible. Conclusions from the experiments include the following:

1. Interseeded double cut red clover in grain and ryegrass in corn were the most suitable interseedings for optimizing dry matter production.

2. Interseeded cover crops of single and double cut red clover in mixed grain appear to influence weed growth at cereal harvest but their major role is in suppressing weeds after harvest. Interseeded ryegrass holds potential as a weed suppressant in corn in a corn - soybean sequence but weed pressure present in the trials was not adequate to determine this.

3. A narrow herbicide band (15cm) over the corn row improved establishment and dry matter production of forage interseedings compared to cultivation only systems. Herbicide banding in corn improved the economics of herbicide use and reduced application costs compared to broadcast herbicide systems.

4. Integrated farming techniques decreased preharvest costs while producing high crop yields. Substitution of mechanical weed control for chemical weed control in corn and soybean was a major component of this reduction.

5. High yielding crops of corn and mixed grain were associated with poor growth of weeds or interseeded forage. This suggests the need for modifications of weed control practices and of interseeding rates and timing for these high yielding systems.

7. SUGGESTIONS FOR FUTURE RESEARCH IN INTEGRATED CROP AND WEED MANAGEMENT SYSTEMS

1. Test effect of mixed cereals and underseeding on crop and weed yields in spring cereals.

Evaluate a barley, oats and peas replacement series with and with out underseeding of a mixture of single and double cut red clover. Evaluate the influence of these practices on wild oats and lady's thumb weeds.

2. Evaluate combinations of mechanical weed control and cover crops for moderate -heavy annual weed infestations in cereals.

Compare blind harrowing, rotary hoeing and finger weeding with/without use of interseeded red clover, interseeded hairy vetch, interseeded crimson clover, after harvest cultivation and after harvest cultivation and seeding of oilseed radish (*Raphanus sativus*).

3. Mechanical weed control trials in corn.

Study the economics of rotary hoeing, row crop cultivation, disc hilling and use of the finger weeder in various combinations vs. banded herbicides and two row crop cultivations.

4. Mechanical weed control trials in soybeans.

Study the economics of rotary hoeing, row crop cultivation and use of the finger weeder in various combinations vs. standard herbicide treatments in 35 cm and 53 cm row soybeans.

5. **Manipulation of soil nitrogen to reduce weed growth in a corn - soybean sequence.**

Evaluate broadcasting and banding various N levels in corn and interseeding ryegrass or fall seeding rye and determining the effects on nitrogen leaching and annual and perennial weed growth in soybeans.

6. **Ability of cover crops to suppress quackgrass.**

Compare species and cultivars of annual ryegrass, perennial ryegrass, winter rye, winter triticale, oilseed radish, white mustard, fodder rape, buckwheat and red clover. Evaluate the influence of the cover crops root mass on quack grass rhizome development.

7. **Crop and weed management in rotational farming systems.**

Perform a long term study comparing crop yields, weed control and impacts on soil quality of a three year rotation of corn soybeans and wheat, with/without cover crops and with /without herbicides.

8. **Manure application in cover crop systems.**

Evaluate different manure sources (liquid, aerated liquid, semi-solid, solid, and compost) in cereal management systems. The manure could be soil incorporated after cereal harvest with/without seeding of oil radish, or surface applied to grain stubble with/without red clover underseeding. Test the effects on nitrogen requirements and weed growth in the subsequent corn crop.

9. Corn -ryegrass interseeding variety trials.

Determin. cultivars of annual and perennial ryegrass which are heat tolerant, shade tolerant, winter hardy and provide good weed suppression, ground cover and dry matter production.

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9. Appendix: Abbreviated Analysis of Variance Tables

Appendix 1. Analysis of Variance for Grain Yields, Forage Biomass, And Weed Biomass in 1986 Cereal Expt.

Source	Degrees of Freedom	Mean Squares	F Value
Grain Yield			
Replication	3	.030485	1.43
Treatment	4	.001660	0.08
Model	7	.014013	0.66
Error	12	.021389	
Corrected Total	19		
Forage Biomass at Cereal Harvest			
Replication	3	.001012	1.67
Treatment	4	.007619	12.58**
Model	7	.004787	7.90**
Error	12	.000606	
Corrected Total	19		
Weed Biomass at Cereal Harvest			
Replication	3	.000566	1.25
Treatment	4	.001816	4.01*
Model	7	.001280	2.83
Error	12	.000452	
Corrected Total	19		
Fall Forage Biomass			
Replication	3	.007428	1.74
Treatment	4	.559376	131.30**
Model	7	.322827	75.78**
Error	12	.004260	
Corrected Total	19		
Fall Weed Biomass			
Replication	3	.005044	1.91
Treatment	4	.015640	5.60**
Model	7	.010770	4.07*
Error	12	.002647	
Corrected Total	19		

*, ** denote significance at the 5% and 1% level, respectively

Appendix 2. Analysis of Variance for Weed Density at Cereal Harvest in 1986

Source	Degrees of Freedom	Mean Square	F-Value
Lady's Thumb			
Replication	3	5049.6500	1.67
Treatment	4	2546.4500	0.84
Model	7	3619.2500	1.20
Error	12	3017.3170	
Wild Buckwheat			
Replication	3	41.5166	0.91
Treatment	4	85.4250	1.87
Model	7	66.6071	1.46
Error	12	45.7250	
Lambs Quarters			
Replication	3	2.1833	.38
Treatment	4	6.6750	1.15
Model	7	4.7500	.82
Error	12	5.8083	
Mustard			
Replication	3	2.5833	3.26
Treatment	4	3.4250	4.33*
Model	7	3.0642	3.87*
Error	12	0.7911	
Knotweed			
Replication	3	13.5333	4.28*
Treatment	4	4.9250	1.56
Model	7	8.6142	2.73
Error	12	3.1583	
Dandelion			
Replication	3	2.3333	2.95
Treatment	4	4.3250	5.46**
Model	7	3.4714	3.47*
Error	12	0.7917	
Foxtail			
Replication	3	15.2000	2.37
Treatment	4	4.6750	0.73
Model	7	9.1857	1.43
Error	12	6.4083	
Total Weeds			
Replication	3	6151.9167	2.22
Treatment	4	3529.8250	1.27
Model	7	4653.5785	1.68
Error	12	2774.4583	

*, ** Denote significance at the 5% and 1% levels, respectively

Appendix 3. Analysis of Variance for Weed Density at Fall Harvest in 1986 Cereal Trial

Source	Degrees of Freedom	Mean Square	F Value
Plantain			
Replication	3	1340.0500	2.85
Treatment	4	167.4250	3.67*
Model	7	151.4071	3.32*
Error	12	45.5917	
Dandelion			
Replication	3	766.9833	7.74**
Treatment	4	673.5000	6.80**
Model	7	713.5643	7.20**
Error	12	99.0667	
Cow Cockle			
Replication	3	4.6667	3.20
Treatment	4	2.9250	2.01
Model	7	3.6714	2.52
Error	12	1.4583	
Shepherd's Purse			
Replication	3	0.9333	0.47
Treatment	4	3.8750	1.96
Model	7	2.6142	1.32
Error	12	1.9750	
Mustard			
Replication	3	28.5333	1.39
Treatment	4	149.5750	7.28**
Model	7	97.7214	4.76**
Error	12	20.5416	
Annual Grasses			
Replication	3	0.6666	1.78
Treatment	4	1.5750	4.20*
Model	7	1.1871	3.16*
Error	12	0.3750	
Total Weeds			
Replication	3	1963.2667	6.92**
Treatment	4	2745.8750	9.68**
Model	7	2410.4714	8.49**
Error	12	283.8083	

*, ** Denote significance at the 5% and 1% level, respectively

Appendix 4. Analysis of Variance for Grain Yield, Forage Biomass and Weed Biomass in the 1987 Cereal Expt.

Source	Degrees of Freedom	Mean Square	F-Value
Grain Yield			
Replication	3	.005738	0.32
Treatment	4	.063256	0.35
Model	7	.006074	0.34
Error	12	.017857	
Forage Biomass			
Replication	3	.000009	0.68
Treatment	4	.000044	3.13
Model	7	.000029	2.08
Error	12	.000014	
Weed Biomass			
Replication	3	.000081	1.43
Treatment	4	.000047	0.82
Model	7	.000062	1.08
Error	12	.000057	

Appendix 5. Analysis of Variance of Corn Yield, Forage Biomass and Weed Biomass in 1986 Corn Experiment and 1987 Spring Regrowth

Source	Degrees of Freedom	Mean Square	F-Value
Corn Yield			
Replication	2	.612930	2.05
Treatment	9	.709964	2.38
Model	11	.692321	2.32
Error	18	.298420	
Corrected Total	29		
Forage Biomass at Corn Harvest			
Replication	2	.000449	1.48
Treatment	9	.000719	23.73**
Model	11	.000596	19.69**
Error	18	.000030	
Corrected Total	29		
Weed Biomass at Corn Harvest			
Replication	2	.002017	1.78
Treatment	9	.053987	47.54**
Model	11	.044538	39.22**
Error	18	.011357	
Corrected Total	29		
Forage Biomass at Spring 1987 Harvest			
Replication	2	.000122	0.97
Treatment	9	.003839	30.40**
Model	11	.003163	25.05**
Error	18	.000126	
Corrected Total	29		
Weed Biomass at Spring 1987 Harvest			
Replication	2	.000030	0.99
Treatment	9	.000091	0.30
Model	11	.000013	0.43
Error	18	.000030	
Corrected Total	29		

** Denotes significance at 1% level

Appendix 6. Analysis of Variance of Corn Yield, Forage Biomass and Weed Biomass in 1987 at Corn Harvest

Source	Degrees of Freedom	Mean Square	F-Value
Corn Yield			
Replication	2	.150040	0.50
Treatment	9	.299453	0.99
Model	11	.272287	0.90
Error	18	.301973	
Corrected total	29		
Forage Biomass			
Replication	2	.000007	2.66
Treatment	9	.000013	5.11**
Model	11	.000012	4.66**
Error	18	.000003	
Corrected Total	29		
Weed Biomass			
Replication	2	.000510	0.41
Treatment	9	.007793	6.25**
Model	11	.006469	5.18**
Error	18	.001247	
Corrected Total	29		

** Denotes significance at the 1% level

Appendix 7. Analysis of Variance of Plant Counts for Interseedings in Corn in 1986

Source	Degrees of Freedom	Mean Square	F-Value
Early Ryegrass Counts			
Replication	2	786.5833	0.68
Treatment	3	9276.5555	8.03*
Model	5	5880.5667	5.09*
Error	6	1155.1384	
Corrected total	11		
Late Ryegrass Counts			
Replication	2	327.0000	0.48
Treatment	3	7490.9722	11.05**
Model	5	4625.3833	6.82*
Error	6	678.2222	
Corrected Total	11		
Early Red Clover Counts			
Replication	2	1975.5833	1.82
Treatment	3	5550.4444	5.10
Model	5	4120.5000	3.79
Error	6	1087.3611	
Corrected Total	11		
Late Red Clover Counts			
Replication	2	1001.2159	9.20*
Treatment	3	4767.2272	43.81**
Model	5	3260.8227	29.97**
Error	6	108.8136	
Corrected Total	11		

*, ** Denote significance at the 5% and 1% level, respectively

Appendix 8. Analysis of Variance for Plant Counts in 1987 Corn Interseedings

Source	Degrees of Freedom	Mean Square	F-Value
Early Ryegrass Counts			
Replication	2	385.5833	2.62
Treatment	3	4287.4167	29.18**
Model	5	2726.6833	18.56**
Error	6	146.9167	
Corrected Total	11		
Late Ryegrass Counts			
Replication	2	47.0909	0.58
Treatment	3	1406.7828	17.34**
Model	5	862.9060	10.64*
Error	6	81.1303	
Corrected Total	11		
Early Red Clover Counts			
Replication	2	148.5833	0.70
Treatment	3	1483.4167	6.99*
Model	5	949.4833	4.47*
Error	6	212.2500	
Corrected Total	11		
Late Red Clover Counts			
Replication	2	108.5833	0.44
Treatment	3	561.6388	2.27
Model	5	380.4167	1.54
Error	6	247.1388	
Corrected Total	11		

*, ** Denote significance at the 5% and 1% level, respectively

Appendix 9. Analysis of Variance for 1987 Soybean Yield, Total Weed Biomass and Quack Grass Biomass

Source	Degrees of Freedom	Mean Square	F-Value
Soybean Yield			
Replication	2	.016273	1.01
Treatment	9	.010024	0.64
Model	11	.011339	0.71
Error	18	.016037	
Corrected Total	29		
Total Weed Biomass			
Replication	2	6.2950	0.01
Treatment	9	526.3662	0.86
Model	11	431.8078	0.70
Error	18	613.1255	
Corrected Total	29		
Quack Grass Biomass			
Replication	2	89.5210	2.08
Treatment	9	65.1402	1.51
Model	11	69.5730	1.61
Error	18	43.1263	
Corrected Total	29		