University of Alberta

Clovers in Cropping Systems

by

Shirley Marilyn Ross ©

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Top) Clover plots at Edmonton. Bottom) Meeting of project participants, from left to right: Michael Radzick, Larry Bogart, Lois Burger, Wubshet Kassa, Dorothy Melnychuk, Lauren Zaychuk, Joe Melnychuk, Shirley Ross, Ron Bowick, César Izaurralde. Photo taken by Jane King.

University of Alberta

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Clovers in Cropping Systems** submitted by **Shirley Marilyn Ross** in partial fulfillment of the requirements for the degree of Master of Science in Plant Science.

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Date: January 25, 1999

DEDICATION

For all the farmers in my family -

past and present,

and

for those who are working to achieve

sustainability in agriculture.

Abstract

The potential of annual clovers was tested in cropping systems in north-central Alberta. Four annual clover (*Trifolium*) species, [balansa (*T. michelianum* Savi var. *balansae* Boiss.), berseem (*T. alexandrinum* L.), crimson (*T. incarnatum* L.), and persian (*T. resupinatum* L.)] were compared with three perennial clovers [alsike (*T. hybridum* L.), red (*T. pratense* L.), and white Dutch (*T. repens* L.)] and fall rye (*Secale cereale* L.). Species were grown as annuals, on Black Chernozemic and Gray Luvisolic soils. Brown mustard (*Brassica juncea* (L.) Czern.) was used as a model weed. Suppression of weeds was greatest by clovers with high growth rates and long stems. The effect of mowing on clover/weed balance varied with species, soil fertility and timing. Annual and perennial clovers had similar shoot N yield, N fixation and impact on subsequent grain yield. Berseem clover had the best combined biomass production, weed suppression and soil benefit.

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Chapter 1

Introduction

OVERVIEW

THE PROBLEM

New annual legume crops offer the potential to diversify crops and improve cropping systems in Alberta. In addition to their product value, legumes bring benefits to cropping systems of improved soil quality, fertilizer replacement and rotational value. The use of legumes in north-central Alberta is largely confined to small-seeded perennial legumes (alfalfa, red, alsike and white clovers) and large-seeded annual legumes (field peas). There is a need for alternate annual legumes to fit with the rotations of cereals and oilseeds. The potential of small-seeded annual legumes (clovers, medics) has largely been untested in north-central Alberta. The soils and climate of the parkland and low boreal regions of Alberta offer some unique agricultural opportunities and challenges; higher rainfall than on the Brown and Dark Brown soils and the high fertility of the Thick Black soils give a boost to both crop and weed growth. Farming on Gray Luvisols requires a long-term strategy to build up organic matter in the soil. In any cropping system, the potential benefits of legumes may be lost due to heavy weed competition. New legume species for north-central Alberta should therefore be tested for their impact on soil and their ability to compete with weeds.

OBJECTIVES

Hypothesis: With proper management, annual clovers may be used in cropping systems in north-central Alberta to improve soil, increase yields and aid weed control.

In this study, four annual clovers (balansa, berseem, crimson and persian) were compared with three perennial clovers (alsike, red and white Dutch), and a non-legume "check" species (fall rye) on six sites in 1996 and 1997.

The objectives of the study were to:

- investigate clover/weed interaction, using either brown mustard (as a model weed) or natural weed populations;
- determine the effect of mowing on clover/weed interaction;
- assess N fixation and N yield of clovers;
- measure the impact of clover/fall rye plowdown on soil NO_3-N and subsequent crop yield;
- compare results on Chernozemic and Luvisolic soils;
- test the use of annual clovers in organic farming systems.

The project also tested a model of collaboration between farmers and university researchers.

LITERATURE REVIEW

The remainder of this chapter is organized as a review of some of the relevant literature for the topics:

- annual clovers,
- benefits of legumes,
- soil quality,
- crop/weed interaction, and
- sustainable cropping systems.

There are four chapters in this thesis. Chapter Two addresses the abilities of the clover species to suppress weed growth. Chapter Three addresses the impact of the clover species on soils and subsequent crops. Chapter Four is a synthesis of the research findings and implications.

ANNUAL CLOVERS

The genus *Trifolium* is one of the most important genera of the Fabaceae, in terms of its agricultural value and because of its large number of species (about 240 species) (Zohary and Heller, 1984). The *Trifolium* genus is closely related to the genera of *Trigonella*, *Medicago* and *Melilotus*. The proportion of annual species to perennial species is about two to one (Zohary, 1972). Clovers have three main centers of diversity: the Eurasian center, predominantly the Mediterranean, with 150 to 160 species; the American center, predominantly California, with 60 to 65 species; and the African center, south of the Sahara, with 25 to 30 species (Zohary and Heller, 1984; Taylor, 1985). Clovers generally inhabit temperate regions, and prefer cool, moist climates or seasons.

Although the beneficial effects of clovers have been appreciated for centuries, an understanding of nitrogen fixation and clover-*Rhizobium* symbiosis is relatively recent - within the past 100 years (Taylor, 1985). As early as 1663, Yarranton (cited by Pieters and Hollowell, 1937) stated in *The Great Improvements of Lands by Clover*:

> "for I perceive the land doth receive wonderful advantage by these leaves and branches, so the root doth very much contribute towards the enriching of the land."

A 1913 publication describes the benefits of green manuring and the importance of humus to the soil (Taylor, 1913). It cites a study by Vaelcker in England, who found that one acre of clover roots and stubble contained one hundred pounds of nitrogen which had been gathered from the air. Beneficial effects of red clover on soil, attributed to its extensive root system, were described as: furnishing a large amount of humus and nitrogen; improving the physical condition of soil, loosening compacted soil and making it more permeable to water and air; ease of tillage; deeper root growth of following crops. In contrast to current emphasis on reduced tillage, the John Deere publication by Taylor (1913) recommended that:

> "humus in time becomes dead, especially if thorough tillage is not practiced", and

"humus must be renewed from time to time, for it becomes worthless in soil which has been repeatedly cropped with the same crop or like crops. It can be supplied, renewed and kept active by application of barnyard manure, green crops plowed under and rotation of crops. Intensive methods of tillage are also factors in keeping humus active".

Another early publication described the benefits of the root system of clovers to soil (Boss and Arny, 1918, cited by Taylor, 1985):

- makes the soil mellow and suitable for the best development of roots of other plants,
- makes it possible for a greater number of the lower forms of plant life to live and work in the soil,
- increases the water-holding capacity of the soil,
- assists in keeping light soil from blowing and washing, and heavy soils from baking, and,
- deepens the soil and aids in drainage.

The list of benefits from clovers is mainly based on the use of perennials such as red and white clover. The benefits may be less with annual clovers, due to a smaller root mass. Most annual clovers have a simple root structure consisting of a central tapering main root, which has a number of branching fibrous roots (Gillett, 1985). Because they have a short life cycle and survive mainly by seed, an elaborate root structure is not necessary. The roots of perennial clovers are often thickened and woody. Compared to drought tolerant legumes like alfalfa and sweetclover, the root systems of white and alsike clover are more fibrous and shallow, with smaller taproots (Sheaffer et al., 1993). A few perennial clovers have rhizomes (e.g. kura clover) and a few, like white clover, spread by stolons.

Clover use in Canada is almost exclusively perennial species. In the U.S., the production of perennials far out-weighs the use of annual clovers. Taylor (1985) put the U.S. acreage seeded to red and white clover at about 9 million hectares, plus varying amounts of white clover in 43 million hectares of pastureland, compared to about 200,000 hectares of annual clovers.

In forage trials with annual legumes, Fraser (1995) identified some annual clovers with forage potential for Alberta. These included balansa, berseem, crimson and persian clovers.

Balansa clover, *Trifolium michelianum* Savi. var *balansae* Boiss., is an annual, cross-pollinated pasture species, native to the region between Bulgaria and Turkey (Rogers and Noble, 1991; Snowball, 1993). The cultivar Paradana was released by the South Australian Department of Agriculture in 1985 for forage use. Its main attributes in Australia are high tolerance to clover scorch (*Kabatiella caulivora*), prolific seed production, of which approximately 70% are hard seeds, and tolerance of waterlogging. Balansa clover has slow growth during the fall and winter, but is highly productive in the spring. It is mainly used in irrigated or high rainfall areas for pasture, hay or silage. In South Australia, it flowers in late September to mid-November. A study of salt tolerance in balansa clover, found that established stands of balansa may be able to withstand high concentrations of NaCl, but it had poor seedling vigor under both saline and non-saline conditions (Rogers and Noble, 1991). There has been limited testing of the cultivar Paradana in more northerly latitudes because of the belief that it is suited only to wet, southern regions (Snowball, 1993). Researchers would like to develop a later maturing line of balansa clover, to help match the maturity of companion grasses for hay or silage.

Berseem clover, *Trifolium alexandrinum* L. originated in Syria and is also known as Egyptian clover (Knight, 1985). It is grown extensively throughout the Mediterranean, Middle East, India and Near East (Dunn, 1991). Egypt is the world's largest producer of berseem (about four million acres) where it is grown as a winter forage crop and precedes cotton or vegetables in rotation systems. There are no reported cases of bloat in ruminants feeding on berseem. It has been grown in the U.S. since the early 1900s and has mainly been used as a winter forage in the southern States. Berseem is an upright-growing legume with oblong leaflets and hollow stems. It produces self-sterile, yellowish-white florets and short taproots. It is not well adapted to hot weather and prefers cool temperatures. Berseem is similar to alfalfa in drought tolerance but can tolerate more soil moisture than alfalfa. It grows well on a variety of soils, but prefers a medium loam soil that is slightly alkaline. It is a high yielding, nutritious forage crop and may be used for green-chopped forage or pasture. Berseem forage has a crude protein of 28 to 30%, which is slightly higher than that of crimson clover and alfalfa. After the last cutting, it is generally plowed under as green manure or cut for seed. Trials in Montana report a maximum berseem herbage plowdown nitrogen (N) yield of 125 to over 200 kg N ha^{-1} (Westcott et al, 1995). With a two cut harvest and plowdown of regrowth, forage yield was 5.5 to 6 Mg ha^{-1} and plowdown nitrogen was 45 to 78 kg N ha^{-1} on two irrigated sites. Berseem is moderately tolerant of saline conditions and is often one of the first crops planted on reclaimed saline areas in Egypt (Kaddah, 1965). 'Bigbee' berseem, a cultivar with improved cold tolerance, was developed in Mississippi and registered in 1985 (Knight, 1985). Use of berseem in Canada has consisted of a few research trials in B.C., Alberta and the Maritimes. Results indicate potential for use as a high yielding annual forage, when grown alone or in a mixture with grain. Under Central Alberta conditions, berseem is very late flowering, which is an advantage for forage production.

Crimson clover, *Trifolium incarnatum* L., is a winter annual, native to southern Europe and the Caucasus (Gillett, 1985). It was introduced into the USA in the early 1800's and has been used in the southern U.S. as a winter cover crop, green manure and forage (Knight, 1985). As a green manure, it will produce as much corn as with 75 to 100 kg N ha^{-1} of commercial fertilizer. In a 1913 publication for farmers, it was described as "a splendid fertilizing crop if sown between the rows of corn" (Taylor, 1913). Crimson is the main annual clover grown in the U.S., and the amount of use peaked around 1950 (Taylor, 1985). Hofstetter (1993) reports that crimson clover grows best under cool, moist conditions. Extended periods of hot, dry weather may stall growth. It won't tolerate inadequate drainage or alkaline soils. Plant tissue N levels are usually around 2.5%, somewhat lower than for most clovers, but it is capable of producing large amounts of phytomass.

Persian clover, *Trifolium resupinatum* L., is a winter annual, native to central and southern Europe, all Mediterranean countries and southwest Asia, occurring in wet meadows and on shores (Gillett, 1985). It is cultivated in many temperate countries and in the south-central U.S. The plant forms low rosettes during the winter and in spring stems develop rapidly (Knight, 1985). One variety has medium-sized, mostly-solid stems, that reach a height/length of 20 to 60 cm and another variety type has hollow stems, 0.64 cm in diameter, that reach a length of 90 cm. Persian clover is best suited to low-lying areas with heavy, moist soils. Persian grows best on alkaline soils. In the USA it is often seeded into grass sods and used for grazing, but can also be used for hay and silage. Green manure crops yield as much as 33.6 Mg ha^{-1} of green matter.

BENEFITS OF LEGUMES

Legumes have been long known as soil building crops. When properly managed in cropping systems, legumes can be used to improve many aspects of soil quality: nitrogen levels, organic matter, reduced erosion by wind and water, water-holding capacity, tilth, aeration, and biological activity. (Green and Biederbeck, 1995).

Some of the benefits of legumes are associated with increases in soil organic matter. When plant residues and manure are added to soil, the reserves of organic matter are built up in the soil. Organic matter increases nutrient availability, and improves the physical qualities of soil (such as water infiltration, moisture storage capacity, aggregate stability, and resistance to erosion) (Jensen and Jans, 1993).

The cultivation of prairies soils has depleted reserves of organic matter and nutrients. Prairie soils which originally had the potential to release up to 140 kg ha^{-1} (125 lb a^{-1}) of mineral N each year, may now only deliver as little as 10 kg ha^{-1} (9 lb a^{-1}) each year (Jensen and Jans, 1993). The practice of summerfallowing has contributed to the erosion and depletion of soils. Summerfallowing of Gray Luvisolic soils has been especially destructive, because reserves of organic matter were initially low (Ellert, 1995). Even in Black soils, which are naturally high in organic matter, nitrogen is often deficient when the soils have been intensively farmed for decades.

Some benefits with legumes may relate to their use as cover crops. Advantages of cover crops include: nutrient enhancement (particularly with legume cover crop), soil nutrient capture, soil moisture retention, and long-term soil stabilization (Teasdale, 1996). A living mulch (cover crop) will inhibit germination and emergence of weeds more effectively than a desiccated residue mulch, because of effects on light transmittance and soil temperature. Cover crops may also have disadvantages: additional management and expense, soil moisture depletion, and cooler soil temperatures.

NITROGEN FIXATION

The nitrogen yield of legumes is affected by soil fertility, length of growing season, climate, management practices and environmental factors. Fixation of nitrogen from the atmosphere by *Rhizobium* spp., requires favourable conditions for a symbiotic relationship between the legume and the rhizobia. (Rice, 1980) found that N fixation varied considerably between years, and was affected by moisture stress, above average precipitation, and soil heat units. Soil conditions that are either too dry or too wet will reduce N fixation. Nitrogen fixation in lentil, flatpea, chickling vetch and feed pea was severely limited by dry growing conditions (Biederbeck et al., 1993). If initial soil N levels are high, nodule formation will be inhibited. If soil N levels are very low, plant growth may be reduced. It takes approximately a month from the time of seedling emergence (or onset of forage regrowth) for nodules to form on the legume and for N fixation to begin (Green and Biederbeck, 1995). Nitrogen fixation is affected by phenological development. Rice (1980) observed that N fixation activity in perennial clovers commenced in May, increased to a maximum about the time of flower initiation (mid-June), and then decreased. Weed competition may reduce the N yield of legumes (Panciera and Sparrow, 1995). Defoliation of clovers results in decay of root tissue and sloughing of nodules (Butler et al., 1959).

Given all the factors that can affect N fixation, it is not surprising that there is a wide variation in reported N yields of legumes. Heichel (1987) reported that with clovers, the annual amount of N fixed was: white 129 to 202 kg N ha^{-1}; red 67 to 129; and crimson 72. On a Gray Luvisol, annual N fixed by alsike was 20 to 143 kg N ha^{-1} and for red clover was 15 to 77 kg N ha^{-1} (Rice, 1980). A general range for N fixed by clovers in temperate climates is: 56 to 336 kg N ha^{-1} (50 to 300 lb a^{-1}) per year (Tisdale et al., 1985). Crimson clover may fix 50 to 120 kg N ha^{-1} (Torbert et al. 1996). In 6 - 8 weeks of growth at six sites in Alberta, annual legumes were capable of fixing 40 to 100 kg N ha^{-1}(Jensen, 1992). N fixation by annual legumes (flatpea, lentil and alfalfa) was low, 16 kg N ha^{-1}, in a Peace River study (Rice et al., 1993). Panciera and Sparrow (1995) reported an average N yield for berseem of 140 kg N ha^{-1}, 130 kg N ha^{-1} for red, and 38 kg N ha^{-1} for crimson in an Alaska study. Maximum N yield for berseem was 125 to over 200 kg N ha^{-1} in a Montana study (Westcott et al., 1995).

Biederbeck et al. (1995) estimated that the total atmospheric N fixed by major legume crops, across all six soil climatic zones of the Prairies, was 250 million kg N in 1994. This was equal to 24% of the sum of all types of fertilizer N sold in 1994, and was valued at $213 million, using fertilizer prices at that time. The estimate was based on 2.4 million hectares of legume crops and implies an average fixation rate of 104 kg N ha^{-1}. The proportion of fixed N remaining after harvest, as N credit, varied among legume crops: green manures (100%), forage crops for seed (67%), hay (30-45%), chickpeas (35-40%), field peas (15-25%), lentils (10-20%), and beans (0%).

IMPACT ON SOIL NITROGEN

The processes of decomposition and mineralization of legume N are influenced by the composition of the legume tissues. Free amino acids, certain sugars and simple proteins are the first compounds that will be taken up by soil microbes (Sarrantonio, 1991). Complex proteins go next, and the N associated with the structural materials of cellulose and hemicellulose is released more slowly. The N associated with resistant materials, like lignin, may take many years to be released. The rate of mineralization of legume residue is affected by soil temperatures and moisture. Little mineralization occurs under cold or very dry conditions. Immobilization of N may occur if the C:N ratio of plant residues is over 20:1. Most non-woody legume residues have C:N ratios between 10:1 and and 15:1, so immobilization is unlikely to occur with legume residues. There can be N losses from the soil due to leaching, denitrification and/or ammonia volatilization. Losses due to denitrification occur under anaerobic conditions in flooded soils. Losses of legume N from soil varied from about 1% at a Dark Brown soil site to about 30% at a Luvisolic site, in a study by Jensen (1992).

The amount of legume N present in the soil mineral N pool is not static. There is a flux of N between pools of phytomass N, mineral N, and non-microbial organic N. Most of the nitrogen in soils is contained in inactive forms of organic matter, and is unavailable to plants. (Janzen et al. 1990) found that the relative contribution of green manures to the stable organic N reserves in the surface soil layer was approximately twice that of the contribution to the inorganic N pool. In a study of the fate of N from green manured field peas on

Dark Brown and Gray Luvisolic soils, Jensen (1992) determined that 75-80% of the N from the legume residue became incorporated into soil organic matter. The amount of residue N that shifted into the mineral N pool varied with time and with the physiological (bloom) stage of the peas. A maximum of 20-25% of residue N became present in the mineral N pool. The N from residue of early bloom field peas moved more rapidly into organic N pools than did residue of full bloom field peas. Only 11-27% of lentil and flatpea green manure N was recovered by a subsequent wheat crop on a Dark Brown Chernozemic soil (Janzen et al. 1990).

Using legumes in rotations may not necessarily increase soil N. In a eight year study of a lupin-wheat rotation, total soil N declined 33%, similar to the decline in total soil N under a continuous wheat system (Mason and Rowland, 1990, cited by Chalk, 1998). The decline in total soil N in the lupin-wheat rotation was attributed to exploitation of the N benefits by the cereal, so that N benefits of the legume were removed with the subsequent wheat crop.

IMPACT ON YIELD

Legumes often have beneficial effects on subsequent crop yields. In an example from the early 1900's in Germany, the effect of unfertilized, crimson clover green manure on subsequent cereal grain yield was an increase of 1011 kg ha^{-1} (cited by Jensen and Jans, 1993). Torbert et al. (1996) reported that corn grain yields, following crimson clover, increased by 65% compared to fall rye, and by 30% compared to fallow. Studies on Black and Gray soils in northeastern Saskatchewan found that using fababeans, field peas or lentils in rotations with cereals improved subsequent cereal quality and yield. A 21% increase in barley yield occurred in the first year following the legume crop, and a 12% increase in wheat yield occurred in the second year (Green and Biederbeck, 1995).

Green manures and legume rotations do not always increase subsequent crop yields. In a study of the effects of green manure crops on subsequent barley yields in the Peace River region, Rice et al. (1993) found that barley grain yields varied with legume species, year, and timing of incorporation. In some cases, barley grain yields were higher with green manures and in other cases they were lower, compared to check treatments. In situations of limited soil moisture, green manuring may reduce subsequent crop yields, compared to fallow (Jensen, 1992). On a site where available soil N was already high, green manuring had little effect on subsequent wheat yields (Battle River Research Group, 1996).

Sometimes the impact of legumes on crop involves increased crop quality instead of increased yield. In a Montana study with variable amounts of alfalfa and berseem green manure phytomass, increasing the green manure phytomass resulted in increased N concentrations in subsequent barley grain, but did not necessarily increase barley grain yields (Westcott et al., 1995). Limited grain yield response was attributed to differential N allocation within the plant. Nitrogen is not the only determinant of grain yield, and the yield may have been limited by factors other than N. In some cases, crop yield and crop quality are both improved by legume green manures. An Alaska study of seven species of legume green manures, concluded that legume green manures usually resulted in higher barley dry matter yield, higher plant N concentration and higher N uptake, than with green manuring of non-legume crops (Sparrow et al. 1995)

Growing legumes with cereals may increase yield and quality of forage crops and may increase the quantity of N returned to the soil. Izaurralde et al. (1990) reported that intercropping barley with peas resulted in increased N production in grain and straw over sole cropping. Research has been conducted on legume-grass or legume-cereal mixtures, to determine if there is a direct "feeding" of N to the non-legume from the legume. Izaurralde et al. (1992) conducted research on barley-pea mixtures, and found no evidence of direct N transfer between peas and barley in the mixture. Intercropped field peas fixed a greater proportion of their N than sole-cropped peas, even under conditions of high soil N supply. Competition for soil and fertilizer N between cereal and the legume increased the proportion of pea shoot N derived from N fixation from 60 to 84%. The benefit of intercropping with legumes may be in increased N yield from the crop, and increased N in shoot and root residue for the subsequent crop.

ROTATIONAL EFFECTS

Some studies have concluded that the benefits from legumes on subsequent crops are not only due to added N, but that positive 'rotational effects' also occur (Green and Biederbeck, 1995). The benefits of rotational effects may lie in disease suppression and improvement of the soil physical quality. Rotation effects could confound the fixed-N effects by increasing both N utilization and fertilizer N efficiency (Torbert et al., 1996). Improved soil structure may increase soil water infiltration and storage, resulting in more effective rooting. Better soil physical conditions could promote root growth, and thereby increase utilization of soil N and fertilizer N. Also, healthier plants due to rotation effects could produce more phytomass with the same amount of nitrogen.

Some claim that the measurement of legume benefits is greatly affected by the choice of the crop that is used as a reference criterion (Chalk, 1998). In addition to factors of pest and disease cycles, phytotoxic and allelopathic effects of different crop residues have been implicated in yield responses. Some dispute that rotational effects exist. Westcott et al. (1995) concluded that legume contributions to subsequent crops were quantitatively attributable to N availability rather than undefined rotational benefits. Others have concluded that rotational benefits may be as evident with non-legume green manures as with legumes. Torbert et al. (1996) studied the effects of crimson clover and fall rye cover crops on corn yields. Besides soil N availability there was very little difference, if any, between the beneficial effects of crimson clover and fall rye cover crops to corn. Without added fertilizer N, the rye cover crop produced lower corn phytomass than either clover or fallow (rye had a negative effect on N-benefit). Corn yield was reduced following rye due to immobilization of N. At approximately 40 kg fertilizer N uptake ha^{-1}, corn phytomass production was the same with either rye or clover. At 70 kg fertilizer N ha^{-1} uptake level, rye produced approximately 1.6 and 3.7 Mg ha^{-1} additional phytomass compared with crimson clover and fallow cover crops, respectively. The beneficial effects of legumes on soil and subsequent crop are not automatic. Effects will vary with climate, choice of legume, management of the legume crop, and soil characteristics.

SOIL QUALITY

During the past decade, a great deal of useful work has been done to define soil quality and to develop standardized ways of assessing soil quality. The challenge still exists to develop low-cost, appropriate tools to assess and monitor soil quality.

DEFINING SOIL QUALITY

In 1992, Arshad and Coen concluded that the lack of accepted, scientific criteria to evaluate soil quality was an obstacle to effective design and evaluation of soil management programs. Establishing criteria required that "soil quality" be defined.

Arshad and Coen defined soil quality as: "the sustaining capability of a soil to accept, store and recycle water, minerals and energy for production of crops at optimum levels while preserving a healthy environment". They situated soil quality within an inter-related framework of:

- soil attributes (physical, chemical and biological properties),
- land (vegetation, terrain, geology, drainage, runoff),
- human socio-economic factors (land use, management practices, ownership, cost of inputs, marketability, farm policy), and
- climate (rainfall, temperature, storms).

Others have defined soil quality on the basis of soil functions in the ecosystem (Warkentin, 1995, 1996):

- cycling of materials for organic synthesis,
- storage and release of ions and molecules at controlled rates,
- partitioning of water into runoff and infiltration,
- buffering capacity,
- partitioning of radiation energy at the soil surface,
- maintaining habitat diversity and stability.

As part of the process of defining soil quality, soil quality indexes have been developed. A soil quality index provides a systematic way to assess soil quality and provides a basis for monitoring soil condition over time. Doran and Parkin (1994a) proposed the following Soil Quality Index:

SQ = f(SQE1, SQE2, SQE3, SQE4, SQE5, SQE6)

where:

SQE1 = food and fiber production,

SQE2 = erosivity,

SQE3 = groundwater quality,

SQE4 = surface water quality,

SQE5 = air quality, and

SQE6 = food quality.

Weighting factors would be attached to the various components, determined by geographical considerations, societal concerns and economic constraints. They also proposed that each SQE element consisted of a functional relationship of five soil functions. For example:

SQE1 = f(SF1, SF2, SF3, SF4, SF5)

where:

SF1 = ability to hold, accept, and release water to plants, streams and subsoil (water flux),

SF2 = ability to hold, accept, and release nutrients and other chemicals (nutrient and chemical fluxes),

SF3 = promote and sustain root growth,

SF4 = maintain suitable soil biotic habitat,

SF5 = respond to management and resist degradation

ASSESSING SOIL QUALITY

A major study of soil health in Canada, the Canadian Soil Health Inventory, was conducted by the Centre for Land and Biological Resources Research, Agriculture and Agri-Food Canada (Acton and Gregorich, eds., 1995). Broad-scale information on soil, landscapes and climate was combined with agriculture census information to assess soil quality for generalized large areas. An index of inherent soil quality (ISQ) ranked soils according to four elements which determined their ability to produce crops:

- soil porosity (providing air and water for biological processes);
- nutrient retention (retaining nutrients for plants);
- physical rooting conditions (promoting root growth due to physical characteristics); and

- chemical rooting conditions (promoting root growth due to chemical characteristics).

The ISQ index rated the four soil properties as: good, good to moderate, moderate to poor, or poor. Areas with ISQ ratings better than poor were considered suitable for annual crops. Another index, soil quality susceptibility (SQS), was used to identify agricultural areas that were at risk of declining soil quality due to various land use and management practices.

At benchmark sites across the country, extensive testing was conducted to measure chemical, physical, biological and mineralogical properties of soils. Soil properties were classified as:

- Sensitive - could change significantly in less than 10 years (e.g. organic C, total N, dry aggregate size distribution),
- Moderately sensitive - may change over decades (e.g. soil moisture retention, cation exchange capacity),
- Nonsensitive - not likely to change significantly in 100 years (e.g. particle-size distribution, clay mineralogy).

Findings of the Canadian Soil Health Inventory for the Prairie Provinces included:

- one-quarter of the total land area of the Prairie Provinces meets minimum soil and climatic requirements for annual cropping.
- areas under intensive summerfallow faced the greatest risk of declining soil quality.
- soil organic matter (OM) levels have stabilized in much of the region, after losses of 15 to 30% of OM from uneroded soils since the land was first cultivated. For eroded soils, the decline in OM has been much more dramatic - with losses of 80% or more of the original OM level.
- about 46% of cultivated Alberta soils have a high-to-severe inherent risk of wind erosion if the soils are left bare.
- about 5% of cultivated land is at risk of water erosion at levels exceeding tolerable limits.
- significant reduction in wind and water erosion risks occurred between 1981 and 1991 due to practices such as reduced

summerfallowing, conservation tillage and conversion from annual cropping to perennial forage production.

- irrigation of some soils results in nitrate and pesticide entry into groundwater.
- compaction is not a major problem because most field operations take place when the soil is dry.
- summerfallowing, overfertilization and applying manure at high rates can result in significant nitrate leaching.

THE MINIMUM DATA SET

To provide a standard approach to measuring soil quality, various "minimum data sets" (MDS) of soil attributes have been proposed. These data sets differ in the soil functions measured, general or technical descriptors and prescribed or unprescribed method of assessment. Arshad and Coen (1992) proposed 10 key physical and chemical attributes of soil as indicators of soil quality. Specific methods of measurement were also proposed. The soil indicators were:

- soil depth
- water holding capacity and water retention characteristics
- structural type/aggregate stability
- hydraulic conductivity and infiltration rate
- bulk density/penetration resistance
- organic matter
- cation exchange capacity
- pH and base saturation
- electrical conductivity
- exchangeable sodium percentage

Other soil scientists (Karlen et al., 1992; Parr et al., 1992; Kennedy and Papendick, 1995) added indicators of soil biological activity to soil quality criteria. Although it is more difficult to quantify and predict soil biological behaviour, they considered biological properties to be as important as the chemical and physical properties of soil. They suggested that indicators such as respiration and potentially mineralizable N could be used as indicators of microbial activity. Less emphasis was placed on standardizing the method of measurement, and more emphasis on establishing a framework of indicators. A MDS for soil quality from Kennedy and Papendick (1995) lists 11 factors:

- aggregation
- bulk density
- depth to hardpan
- electrical conductivity
- fertility
- infiltration
- mineralizable N potential
- organic matter
- pH
- respiration
- water-holding capacity

A study of how 100 Wisconsin farmers assess soil quality found that they relied almost exclusively on sensory observations to judge a soil's health (Romig et al., 1995). Numerical descriptions were emphasized, to varying degrees, for only five properties (organic matter, pH, yield, grain test weight and topsoil depth). The top 10 soil health properties, ranked from most to least important, were:

1. organic matter
2. crop appearance
3. erosion
4. earthworms
5. drainage
6. tillage ease
7. soil structure
8. pH
9. soil test
10. yield

Doran et al. (1994b) state that indicators chosen for a MDS must be holistic rather than reductionist, must be measurable by as many people as possible (especially managers of the land), and should define the major ecological processes in soil. Dr. John Doran, a soil microbiologist in Nebraska, has developed a soil quality test kit to help producers, researchers, conservationists, environmentalists and consultants assess the health and quality of soil. The intention is to use tests which are simple to perform, require little in the way of expensive equipment, give rapid results and are meaningful to producers' understanding of soil and soil processes (Doran et al. 1996). The kit includes tests for: bulk density, soil water content, water-filled pore space, electrical conductivity, pH, nitrate-N, water infiltration, water holding capacity and soil respiration. The kit has been tested by researchers, extension educators, environmental monitors and producers at locations in the US, Australia, Canada, Cuba, Honduras, India, Poland and Russia. Results suggest that the kit may be useful to specialists, but the overall procedures are too complicated and time consuming for practical use by farmers. Technological advances may help to simplify some of the tests developed by Doran. Technology could play a role in developing user-friendly soil assessment monitoring devices and also in helping producers to access computerized databases such as those compiled in the Canadian inventory of soil health.

CROP/WEED INTERACTION

Annual legumes are generally considered to be non-competitive plants, but what does that mean? Can a group of clover species be effectively tested to predict their ability to suppress weeds? Is mustard a good choice of "model" weed to grow with annual legumes?

TERMS

The predominant framework for assessing interaction between crop species and weed species is one of "competition": plants are viewed as "competing" with each other for resources; plant species may be described as competitive or non-competitive; many factors have been identified as influencing crop/weed competition.

Some prefer to use the word "interference" to describe crop/weed interaction. "Interference" is an ecological term and is less common than the agronomic term "competition" (Vanden Born, 1995). Some distinguish between competitive and noncompetitive crop/weed interaction and use the term interference to include both types of interaction (Zimdahl, 1990). Zimdahl defines competition as "a component of interference and results from the removal or reduction of a required ingredient by one plant to the detriment of another". He points to a 1929 definition (Clements et al.) of plant competition as being more comprehensive than many definitions of competition:

> "Competition arises from the reaction of one plant upon the physical factors about it and the effect of the modified factors upon its competitors. In an exact sense, two plants, no matter how close together, do not compete with each other so long as the water content, the nutrient material, the light , and the heat are in excess of the needs of both. When the immediate supply of a single necessary factor falls below the combined demands of the plants, competition begins."

This definition qualifies the use of "competition" as applied to plants and emphasizes the need to look beyond plant-plant interaction to plant-environment interaction. Regardless of terms, most weed scientists situate crop/weed interaction within a wider framework than one of narrowly defined crop/weed rivalry. "The most useful studies of interference are those that characterize the limiting resource(s) or environmental conditions and examine the biological (plant) and proximity factors that influence crop/weed interactions" (Radosevich, 1988).

BIOLOGICAL FACTORS IN COMPETITION

Early weed science researchers investigated plant biology to explain competitive abilities of weeds and crops. Early concepts of competition were based on observation of natural forest and grassland communities, and systematic research of competition began with Clements in 1903 (Pavlychenko and Harrington, 1934). Classical studies, such as those on root systems conducted by T. K. Pavlychenko at the University of Saskatchewan in the 1930's and 1940's, provided foundational principles for weed science (Bubar and Morrison, 1982). Some findings from the classical studies of Pavlychenko and Harrington (1934, 1935):

- Five days after emergence, wild mustard (*Sinapsis arvensis* L.) had a root system 87 cm (34.7 inches) in length, and at 21 days after emergence the length was 12,055 cm (4747 inches). This root system at 21 days was larger than the roots of 11 cereals and eight other weeds.
- When grown to maturity in mixtures, the root system of wheat was 30 times larger than that of wild mustard (although wild mustard depressed wheat yield up to 40%). More severe yield reduction of wheat yield occurred with wild oats, which had a root area four times greater than wheat.
- At five days after emergence, the assimilation surface, mainly cotyledons, of wild mustard contained many more stomata than a number of cereals and common weeds. Numbers of stomata per plant were: wild mustard 79,800, Hannchen barley 64,300, Prolific spring rye 63,700, Banner oats 43,200, Marquis wheat 40,300, wild oats 30,300, and redroot pigweed 9,600. They suggested that a high number of stomata on young seedlings facilitates physiological activities and gives a plant a competitive advantage at early stages of growth. At blooming, the number of stomata in a wild mustard plant was about 490 million.
- Of the 11 cereals and nine weeds examined, fall rye (*Secale cereale* L.) was the most competitive cereal and wild mustard, wild oats and stinkweed were the most competitive weeds. In addition to high numbers of stomata, their competitive success was attributed to:

1. Ready and uniform germination under adverse soil moisture conditions.
2. Ability to develop a large leaf assimilation surface in the early seedling stage of growth.
3. A large mass of fibrous roots close to the soil surface and deeply penetrating main roots.

Patriquin (1988) draws upon the work of Clements et al. (1929) and explains some of the biological factors which give grain crops a strong competitive advantage over their wild relatives: large seed size (allowing crop seeds to germinate deeper in the soil than weeds), large reserves of N in the seeds (making crops initially less dependent on soil N), uniform germination, and large leaves (resulting in rapid canopy closure). Early germination is an advantage but not if the crop grows slowly and has to compete with later-germinating but faster-growing weeds (Zimdahl, 1990). Differences in growth rate during early growth stages are important in determining the outcome of competition (Cussans, 1968). Berkowitz (1988) states that high intrinsic resource use rates and absolute growth rate, especially during early growth, are good indicators of competitive ability. The first 0.01 ounce of a seedling of a large-seed crop (e.g. corn) is mainly created by mobilization of seed reserves, whereas the first 0.01 ounce of a small-seed weed (e.g. redroot pigweed) seedling must be created by photosynthesis, which requires construction of substantial leaf area beyond the cotyledons (Mohler, 1996).

A large seed size and high initial absolute growth rate in a crop species gives a crop a potential competitive advantage which can be exploited for weed management. However, small-seeded annual weeds may surpass large-seeded crop species in phytomass, because of higher relative growth rates (measured in ounces per ounce per day) and because their growth rates decline less quickly as they grow. This high relative growth rate comes at a cost, - extreme reduction in growth in response to stress. In particular, annual weeds are highly sensitive to shade. Plant attributes that aid competition for belowground resources include: high net assimilation rate, high root growth rate, high root/shoot ratios at low nutrient levels and increased root activity in response to low nutrient status (Baldwin, 1976).

Radosevich (1988) summarizes the key biological factors in crop/weed interaction as: emergence time, seed size, seedling size, canopy architecture, reproductive strategy, genetic variation, physiological efficiency, phenology, growth rate, allelochemicals, life history, and growth form.

COMPETITION FOR RESOURCES

The physiology and morphology of plants influence access to light, water and nutrients. Competition for water and nutrients differs from competition for light. Water and nutrients can be translocated within a plant. Also, nutrients taken up early in the season can be redistributed later within the plant, e.g. some cereals can accumulate up to 90% of their final nutrient content when they have reached only 25% of their final size (Willey and Roberts, 1976). Factors other than total root length (e.g. root volume, density, placement) contribute to root physiology and affect belowground competition for water and nutrients (Berkowitz, 1988). Idris and Milthorpe (1966) attributed the success of barley in competing with mustard to superiority of barley roots in extracting soil nutrients.

Light cannot be redistributed or stored in a plant. Competition for light occurs between leaves rather than between plants (Donald, 1963; Weiner, 1985). An upper leaf may shade and cause the death of a lower leaf, whether the lower leaf is part of the same plant or a different plant. A plant which displays its leaves above a neighboring plant has an obvious competitive advantage. A positive relationship was found between height and competitive ability in variety studies of some crops (Berkowitz, 1988). Cover crops with high leaf:stem ratios are better suited to weed suppression because of greater interception of light (Teasdale, 1996). Clovers have small seed size, slow establishment and lack seedling vigor (Lee, 1985). Aggressive annual and perennial weeds, which quickly establish a canopy, may severely shade clovers and limit their growth. An experiment with subterranean clover compared growth using small and large seeds (Black, 1958). Large seed produced large seedlings and the smaller seedlings from small seeds were suppressed, receiving only 2% of full sunlight. However, if the stems of shaded plants continued to grow more than their neighbors, subsequent leaves had improved light status. Shading reduces the carbohydrate supply to the root system and results in reduced root growth, premature senescence and decay of root tissue, and sloughing of nodules (Butler et al., 1959). Loss of roots and nodules due to shading was greater in white clover than in red clover. Red, white (ladino), alsike and subclovers respond as "sun" species and their relative growth rate decreases rapidly as a result of slight shading of full sunlight (Kendall and Stringer, 1985). Maximum growth of clover plants as swards is attained only with full sunlight. With increasing light intensity, there is an increase in white clover leaf production, leaf size, and plant weight but a decrease in leaf longevity. Tolerance to shade may vary among clover species and cultivars. Clonal lines of red clover differ in their response to reduced light. Hofstetter (1993) describes crimson clover as being tolerant of shade and refers to findings that growth of crimson did not appear to be affected when it grew in the shade of a corn canopy.

Explanations of competition can best be done by moving toward whole plant or community concepts (Zimdahl, 1990). Studies of single limiting factors, where one aspect of competition is studied in isolation, are rarely adequate to explain competitive effects. For example, a heavily shaded plant suffers reduced photosynthesis leading to poorer growth, a smaller root system, and ultimately a reduced capacity for water or nutrient uptake. Understanding is needed of the interactions between factors.

HIERARCHIES

Some studies have been conducted to place weeds and crops in hierarchies of competitive ability. Blaser et al. (1956) ranked the aggressiveness of clover seedlings as: high - red and crimson; medium - alsike and ladino white; low - white clover. They cautioned that the classification should not be considered as absolute because temperature and moisture affect seedling performance. Studies have concluded that wild mustard is more competitive than many other plants (Pavlychenko and Harrington, 1934; Idris and Milthorpe, 1966; Blackshaw and Dekker, 1988). Blackshaw and Dekker (1988) ranked the competitive ability of wild mustard > rapeseed > lamb's quarters, based on dry matter and seed yield. They concluded that relative rate of development was important to competitive ability, and that the strong ability of wild mustard to compete for soil moisture and nutrients was probably related to early development of an extensive root system. Haizel and Harper (1973) studied barley, white mustard and wild oats and rated their aggressiveness. They found that ratings of aggressiveness varied with target species: against mustard - mustard > barley > wild oats; against barley - barley > wild oats > mustard; against wild oats - barley > mustard > wild oats.

Growth ability measurements (e.g. net assimilation rate, leaf area ratio, plant height, relative growth rate, dry weight) can be useful in assessing competitive ability of different plant species, but cannot be used to predict competitive ability because of variability with environment (Radosevich and Roush, 1990). Climate, location and management activities influence competitive relationships and cause hierarchies among plant species to be inconsistent. Zimdahl (1990) cautions against definitive ratings of competitive abilities of various species because they have not been adequately tested and do not take into account the complexity of competition.

PROXIMITY

Proximity is an important factor in crop/weed interaction. Plant growth is usually "plastic" in response to available resources (Radosevich, 1988). At low plant densities, the resources available to each plant may be high and the few plants may quickly grow to a large size. At high plant densities, the resources available to each plant may be quite low, resulting in plants that grow more slowly and do not get as large. The greater the plasticity of a plant, the greater the variation of plant size with changes of density and resource availability.

Intraspecific competition (between plants of the same species) increases with increasing density. At high densities, self-thinning (or density dependent mortality) may occur, with mortality of the smallest, weakest plants (Weiner, 1985). Self-thinning occurs at increased rates in higher fertility soils. The formation of a very pronounced plant size hierarchy precedes the process of self-thinning. High soil fertility accelerates the processes of hierarchy development and self-thinning.

Competition between different species (interspecific competition) is more complicated than intraspecific competition. Species differ in resource requirements and patterns of growth, they respond differently to environmental conditions, and they modify the environment for each other (Firbank and Watkinson, 1990). Plants of *Bromus sterilis* showed less variation in size, in the presence of wheat, than they did in monoculture. Annual ryegrass (*Lolium multiflorum* Lam.), the dominant species when grown with crimson clover (*Trifolium incarnatum* L.), showed less size inequality in mixture than in monoculture, whereas the clover plants, the suppressed species, usually developed a greater degree of inequality (Weiner, 1985).

Plants with high plasticity (e.g. oats, mustard) are more competitive than plants with low plasticity (e.g. flax, green foxtail). The lower the proportion of wild mustard in a mixture (with lamb's quarters and rapeseed), the greater the per plant yield (Blackshaw and Dekker, 1988). Wild mustard appeared to be well adapted to growing in mixtures with other species, a characteristic contributing to its widespread success as a weed.

OTHER FACTORS

Associations between plants are not always negative. Symbiotic associations occur and certain plants may be beneficial to soil and crop health. In some traditional peasant agroecosystems, weeds may be considered to be useful elements and may be deliberately left in association with crops (Gliessman, 1988). In southeastern Mexico, farmers did not view non-crop plants as weeds, but distinguished between good and bad plants. Good plants: had beneficial impacts on crop development; improved soil through shading, loosening or providing nutrients; were easy to manage; were used for food or medicinal purposes; provided feed for domesticated animals. Bad plants: had detrimental impacts on crops or soil, such as smothering of crops or compacting of soil; were hard to pull, cut or kill; and could not be used for food or feed. In many cases, plants were said to be good or bad, depending upon the circumstances.

Goldberg (1990) describes six types of indirect interaction among plants which may have beneficial or detrimental effects. "Exploitation competition", "negative facilitation" and "positive facilitation" involve resource acquisition. "Apparent competition" and "apparent facilitation" involve natural enemies. The sixth type of interaction is allelopathy.

Neighboring plants can have a number of indirect effects on plant resource uptake or status: light quality (increased far-red wavelengths at lower depths of canopy, inhibiting germination, stimulating shoot elongation), temperature (e.g. lower air temperatures due to shading), evaporative demand (e.g. higher leaf water potential in shaded plants), altered soil nutrient dynamics (e.g. uptake of N by nonlegumes may stimulate N-fixation by legumes), altered soil water dynamics (e.g. transfer of water from wet to dry zones), altered soil flora (e.g. mycorrhizal associations may increase availability of P), and allelopathy (Berkowitz, 1988).

Other noncompetitive plant factors, such as senescence and seed bank dynamics, also influence crop/weed interaction (Radosevich and Roush, 1990).

MYCORRHIZAE

Associations of clover roots with vesicular-arbuscular mycorrhizae (VAM) can enhance the capacity of clovers to compete with grasses for P, under low soil P concentrations (Hall, 1978; Buwalda, 1980). The roots of grasses are usually more effective than those of clovers in taking up P from the soil (Kendall and Stringer, 1985). In low-P soils, clovers may undergo considerable P stress in mixtures with grasses. Hall (1978) found that the presence of perennial ryegrass (*Lolium perenne* L.) decreased the P concentration of white clover compared to clover in monoculture. Buwalda (1980) grew white clover and ryegrass in pots with a range of soil P and N levels. The ryegrass was dominant in all but the lowest two N treatments. At low N and P levels, N levels in white clover were aided by N-fixing *Rhizobium* nodules and P levels in clover were aided by VAM associations.

ALLELOPATHY

The term allelopathy was first introduced in 1937 by H. Molisch in Germany, and it refers to biochemical interactions among plants, including those mediated by micro-organisms (Weston, 1996). The mechanism of allelopathy involves release of sufficient quantities of plant-produced phytotoxins into the rhizosphere to cause an affect on neighboring plants. Chemicals with allelopathic potential are present in virtually all plants and in most plant tissues (leaves, stems, flowers, roots, seeds and buds).

Allelopathic properties have been identified in many clover species. A soil condition known as "clover sickness" or "clover failure" has been known in Europe since the 17th century (Knight, 1985). With clover sickness, land ceases to produce satisfactory yields of clover. Problems occurred with repeated red clover plantings in the US in the early 1900's, and the clover sickness was believed to be due to accumulation of toxic substances (Fergus and Valleau, 1926). The phenomena was later observed in Japan. In one study, nine isoflavonoids were isolated from red clover herbage but none could be isolated from the soil (Tamura et al., 1969). A study of soils with severe clover sickness with persian (*Trifolium resupinatum L.*) and berseem (*Trifolium alexandrinum L.*) clovers, found that the nematode count was high in the persian clover and low in the berseem (Katznelson, 1972). Persian causes soil sickness for berseem, but berseem does not cause soil sickness for persian. It is probable that insects and soil-borne pathogens, such as *Sclerotinia*, *Fusarium* and *Collectotrichum*, allied with allelopathic agents and unfavourable soil conditions to produce clover sickness (Leath, 1985).

Aqueous and volatile extracts of sweetclover (*Melilotus* spp.), berseem clover and crimson clover have been shown to reduce germination and early seedling growth in bioassay studies (McCalla and Duley, 1948; White et al., 1989; Bradow and Connick, 1990). White et al. (1989) found that sensitivity to allelochemicals (derived from crimson clover) varied among species: the negative effect on radicle development was greater in two broadleaf weed species (wild mustard and pitted morning glory) than in corn. In field experiments, Dyck and Liebman (1994) concluded that decreased emergence and growth of sweet corn and lamb's quarters, in the presence of crimson clover residue, could not be attributed to low availability of N. The suppressive effects of the clover residue were thought to be due to either allelochemicals or stimulation of pathogens such as *Pythium* spp.

Weston (1996) summarizes some of the allelochemicals that have been identified in crops: rye (*Secale cereale* L.) - phenolic acids and benzoxazinones

(BOA and DIBOA); clovers (red, white, sweetclover) - isoflavonoids and phenolics; black mustard (*Brassica nigra* (L.) Koch) - allyl isothiocyanate and other water-soluble inhibitors. She observes that northern growers have noted the weed suppressive properties of the *Brassica* spp., particularly the mustards. Rye has been used for centuries as a "smother crop" and there are numerous papers indicating that rye interferes with the growth of other plants (Putnam 1986, 1988). Roots are more toxic than tops. Residues of rye are generally more toxic to annual broadleaf weeds, moderately toxic to annual grasses, and have little or no effect on perennial weeds (Barnes and Putnam, 1983). Allelochemicals are less active than synthetic herbicides by an order or two of magnitude, but they may be produced in relatively high quantities, e.g. rye might produce as much as 14 kg ha^{-1} of DIBOA (Putnam, 1988). Weston (1996) notes that in the field it may be difficult to distinguish between the effects of allelopathy and the effects of competition for resources. Rye produces a dense canopy that competes effectively with weeds for light, moisture and nutrients. Mwaja et al.(1995) found that the phytotoxicity of rye is influenced by soil fertility. Concentrations of BOA and DIBOA were higher in shoot tissues of rye grown under low or moderate fertility than in shoots grown under high fertility. Ether extracts of dried rye shoots were less inhibitory when grown under high fertility.

WEED THRESHOLDS

Early studies of crop yield losses due to weeds did not necessarily quantify the density of weeds. For example, Anderson (1956) reported average yield reductions due to "dense" infestations of wild mustard in wheat, oats and barley as 53%, 63% and 69% respectively, over a 9 year period at Regina. However, Burrows and Olsen (1955) measured the density of weeds and reported nearly a 50% yield loss in wheat with 239 wild mustard m^{-2}. Over the years, many research studies have used an additive model of research to determine that "x" numbers of a certain weed will reduce the yield of a certain crop by "y" percent. The additive model simulates the agricultural situation where at least one weed species invades an area already occupied by a fixed density of crop species (Radosevich, 1988). Two or more species are grown together, and the density of one is held constant, while the density of the other is varied.

Some studies varied the densities of both crop and weed plants, to look at the effect of crop seeding rate on weed biologic and economic thresholds. For wheat seeded at 67 kg ha^{-1}, the critical wild mustard density to justify spraying was 59 plants m^{-2} (Burrows and Olsen, 1955). For wheat at 134 or 200 kg ha^{-1}, the critical wild mustard densities were 237 and 474 plants m^{-2}, respectively.

Crop/weed responses in additive experiments serve as indicators of the relative aggressiveness of the species. The poor competitive ability of some legume crops has been demonstrated by marked yield reductions with relatively light weed infestations. Soybean yields were reduced 50% by the in-row presence of 8 wild mustard per foot of row (Radosevich, 1988). Yields of field peas (*Pisum sativum* L.) were reduced by 2 to 35% at 20 wild mustard plants m^{-2} (Wall, 1991). Yields of navy beans (*Phaseolus vulgaris* L.) were reduced by 30 to 35% at 10 wild mustard plants m^{-2}, and by 57% and 46% at 20 mustard m^{-2} (Wall, 1993).

Four general methods have been used to study crop/weed interaction: additive, substitutive/replacement, systematic, and neighborhood (Radosevich, 1988; Radosevich & Roush, 1990). Additive experiments are somewhat problematic because proximity factors (density, spatial arrangement, proportion) are variable. Substitutive and systematic methods provide better quantification of competition in agricultural systems, because proximity factors are constant or consistent. Influences of intraspecific competition can be separated from interspecific competition.

Haizel and Harper (1973) claim that "ecologists have often followed Darwin in generalizing that intraspecific stress is greater than interspecific", but they found that wild oats were more sensitive to interspecific competition (from mustard and barley) than intraspecific competition (from wild oats). They conducted substitutive experiments with white mustard, wild oats and barley to differentiate between the effects of intraspecific and interspecific competition.

Neighborhood or sphere of influence approaches study the relationship between the performance of individual plants of a target species (usually the crop) and the abundance/proximity of neighboring species (usually weeds) (Radosevich, 1988). The focus is on the response of individual target plants, rather than a population of plants. Radosevich and Roush (1990) conclude that process-based models are needed to provide a framework to define and organize ecological processes or factors that influence crop-weed dynamics.

O'Donovan (1996) lists research in Canada where 45 different weed/crop combinations have been studied to determine the relationship between weed density and crop yield. Despite numerous quantitative weed/crop studies and the development of improved equations to predict economic weed thresholds, there have been shortcomings in putting them into practical use. Many factors other than weed density need to be considered (e.g. crop density, multiple weed species, seed production by uncontrolled weeds, environmental factors such as precipitation and growing degree days). Computer models show some promise in integrating information on various crop, weed and environmental factors to provide user-friendly decision support systems for rational weed management.

ENVIRONMENT

Crop/weed interaction within a plant community is influenced by environmental factors, such as: availability of resources (light, water, oxygen, carbon dioxide, nutrients), temperature, soil compaction, pathogens, insects and other predators (Radosevich, 1988; Radosevich & Roush, 1990). Wall (1991) found that the effect of wild mustard interference on field pea yield was influenced by the amount of precipitation received, with the greatest yield losses occurring in seasons with normal to high rainfall.

SOIL FERTILITY EFFECTS

Studies of the effect of soil N on weeds/crop have produced diverse results. Some conclude that increasing N will favor the crop, while others conclude that the weed will be favored. Of 40 weed-crop data sets, 35 exhibited trends of increasing percent crop values with increasing total phytomass (Patriquin, 1988). With high soil fertility, the crop plants exceeded weed plants in height and phytomass, and weeds formed an understory in the crop. Exceptions to the trends were attributed to: very high initial numbers of weeds, type and timing of fertilization, inhibition of cereals by phytotoxins, predominance of perennial weeds, weeds that were larger than the crop, and sparcity of crop plants. Effects of N application will vary with timing and placement of fertilizer. From a study involving fababean-weed interaction and an organic farm in Nova Scotia, Patriquin (1988) concluded that higher levels of "natural" fertility favored the crop, but use of N fertilizer favored the weeds, or detracted from the natural advantages of the crop.

The effects of N on competition between barley/pea mixtures and mustard (wild mustard and white mustard) have been studied (Liebman 1986, Liebman 1989; Liebman and Robichaux, 1990). Suppression of mustard growth by the crop (barley/pea) species was greater under conditions of low soil N availability. Shading of mustard by barley-pea intercrops was greatest when N fertilizer was not applied. Shading can affect not only production of photosynthate, but also root growth, uptake of N from the soil and N metabolism. Application of N fertilizer greatly increased mustard's fraction of total leaf area in canopies of crop-weed mixtures. Mustard had a much larger height growth response to N fertilizer than did either of the crop species. There was a correlation between above-ground phytomass of white mustard and net photosynthesis rates of single upper canopy leaves measured under ambient conditions weeks or months before final harvest. A hierarchy in the strength of responses by mustard to N deficits was observed. In terms of percentage reductions, the relative magnitude of mustard's responses to N deficits was: leaf N concentration < leaf photosynthetic rate < photosynthetic surface area. For example, in one experiment, mustard in -N treatments had 21% lower leaf N concentration, a 48% lower photosynthetic rate and 60% less green surface area, than +N mustard. This suggests that conservation of physiological function may have priority in plants over conservation of physical structure.

ORIGIN AND EVOLUTION OF WEEDS

Three primary origins for weeds have been identified: wild species may adapt to the recurrent disturbances and concentrated resources of agroecosystems and become weeds; cultivated species may escape domestication and persist as weeds; and new weeds may appear due to hybridization and introgression between crop and wild species (Salisbury, 1961; Baker, 1974; di Castri, 1989). The evolution of weeds depends upon the interaction of biological selection with a disturbed habitat and social selection for the value of the species (Ghersa et al. 1994). The development of rye (*Secale cereale* L.) as a crop is an example of interaction between biological and social selection. When wheat and barley were being domesticated as crops in the Middle East, rye was a wild species that grew in these crops and was considered a weed. As cultivation of wheat and barley moved to higher latitudes and altitudes, climatic and edaphic conditions favored the rye over the wheat and barley. In harsh conditions, the rye weed became valued as a good crop and was planted independently (Sakamoto, 1982).

In early agriculture, recurrent selective pressures created conditions that were suitable for development of weedy syndromes, such as: discontinuous germination, longevity of seed, rapid seedling growth, short vegetative condition before flowering, long continuous seed production, plasticity, and ability to compete (Baker, 1974).

MUSTARD SPECIES AS MODEL WEEDS

Liebman (1986, 1989) has used both wild mustard and white mustard (*Brassica hirta* Moench) as model weeds in competition studies of mixtures. He concluded that the two mustard species were similar in their yield responses to crop competition, and notes that the two are morphologically and phenologically quite similar. Wild mustard was used in greenhouse experiments but white mustard was preferred for field experiments. White mustard's more synchronous pattern of germination allowed easier establishment of even-aged populations in field experiments.

Wild mustard (*Sinapsis arvensis* L., *Brassica kaber* (DC.) Wheeler, charlock, moutarde des champs) is a serious weed of cultivated land in Canada, and has been responsible for reductions in crop yields, dockage losses and costly chemical and cultural control measures (Mulligan and Bailey, 1975). Wild mustard is an example of a weed that is very well adapted to the agricultural practice of recurrent cultivation. Germination is sporadic and there is evidence that dormancy of buried seeds is related to low amounts of oxygen beneath the soil surface. Seeds can remain viable for up to 60 years (Evans, 1962). In early stages of growth, wild mustard seedlings outgrow the seedlings of other plants (Pavlychenko and Harrington, 1935). It is an annual plant that requires 2.5 to 3 months to reach maturity (Mulligan and Bailey, 1975). The seed is contained in pods that usually split when a crop is harvested. In Canada, wild mustard plants produce 2,000 to 3,500 seeds per plant. Seeds may fall to the ground and/or be taken up with the crop as impurity. Seeds may cause serious illness in livestock if ingested in large quantities.

Wild mustard was one of the first weeds introduced to Canada by the early settlers (Hunter et al. 1990). By 1881 it was a major problem in the settled areas and it spread rapidly across the prairies. By the early 1930's, wild mustard infestations had reached epidemic proportions, termed the "yellow scourge", and threatened the continuation of agriculture in areas such as the Regina Plains (which mainly produced wheat at that time). The situation changed with the introduction of 2,4-D in 1946. Wild mustard was easily killed by 2,4-D and could be effectively removed from cereal crops. By 1962, 75% of the cereal crops on the Prairies were being sprayed for control of broadleaf weeds. It has been suggested that effective control of wild mustard was responsible for the rapid and widespread acceptance of selective weed control by farmers of the Canadian prairies (Mulligan and Bailey, 1975). By 1975, wild mustard was still classified as a noxious weed in Nova Scotia, Quebec, Manitoba, Saskatchewan and Alberta, but it had been deleted from the noxious weed lists in Ontario and B.C. because of effective control measures. Surveys of weeds in cereal and oilseed crops in Alberta, Saskatchewan and Manitoba in the late 1970's found that easily killed weeds, lamb's quarters, wild mustard and stinkweed, continued to be ever-present problems (Hunter et al. 1990). Due to untimely application of postemergent herbicides, wild mustard frequently escapes control in field peas (Wall, 1991). Following herbicide application, wild mustard numbers in field pea crops averaged 19 plants m^{-2} in a 1985 survey in Saskatchewan.

Without the use of herbicides, organic farmers must use other methods to control wild mustard. An Alberta government publication (Vaillancourt, 1994) provides information on cultural control of wild mustard. Because the main flush of germination is in early spring, with sporadic germination during the summer, early tillage can be used. Seedlings are easily killed with cultivation: summer fallow, pre-seeding tillage, post-seeding tillage, and fall tillage if weeds emerged late. Early seeding helps the crop to compete with emerging mustard. Wild mustard requires high light intensity to grow well and does not compete well with heavily seeded, well-fertilized cereal crops. Mowing prevents seed set or can be used in place of tillage in the fall to destroy weeds.

MANAGING THE CROP/WEED BALANCE IN AGROECOSYSTEMS

The crop/weed balance in agroecosystems is determined by physical (climate and soil), biological, and cultural management factors (Altieri and Liebman, 1988). In order to influence the crop/weed balance, it is essential to determine site-specific factors, such as resource limitations, germination, and growth rates. The manipulation of one or two management factors (e.g. crop density, rate of applied N) can favorably shift the crop/weed balance. In its simplest form, weed management consists of exploiting the understanding of the relationships between physical, biological and cultural factors. Although crop/weed interactions may be "site specific", the ecological mechanisms underlying such interactions are not. An understanding of ecological mechanisms can be applied to a variety of crop/weed species and across geographical zones. O'Donovan (1996) recommends that weed ecology studies in Canada should focus more on the effects of the crop on the weed, rather than the effects of the weed on the crop. Altieri and Liebman (1988) conclude that weed ecologists could make major contributions to weed management by: determining ecological factors governing weed abundance; discerning the conditions and times under which weeds would be most vulnerable to management tactics; and providing information for accurate prediction of the responses of weeds to various control practices and cropping patterns. A greater understanding of the biological and ecological mechanisms in crop/weed interaction will aid the development of improved systems to manage weeds in cropping systems.

CULTURAL CONTROL OF COVER CROPS

Clipping or grazing is recommended to control certain weeds in new clover plantings (Lee, 1985). Timing of mowing is important. It is recommended that weeds should be 30 to 45 cm high when clipped. If clipped when they are too small, branches and stems may develop from lateral buds and the weeds may compete more effectively for light than if they had not been clipped. The clover plants regrow from crown buds and are usually not injured by close clipping. Mowing is useful to avoid shading during living mulch establishment and has not been reported to suppress living mulches (Teasdale, 1996). Weston (1996) states that mowing, grazing, or herbicide application at low rates are ways to maintain clover cover crops as living mulch, while minimizing competition with a row crop.

CHANGING PARADIGMS

Approaches to weed management have changed over the years. Ecological models and integrated pest management have become popular in recent years, while others look to biotechnology for new forms of control. Weed science necessitates complex integration of many factors. Radosevich and Ghersa (1992) depict weed science as comprising six disciplines: physiology/ morphology, genetics, chemistry, economics, ecology and sociology. Zimdahl (1990) is critical of an agronomic paradigm which assumes that all plant associations are detrimental, and that weeds must be eliminated. He advocates greater emphasis on biological understanding and raises the question, "Can agriculturalists work with weeds rather than against them?" (Zimdahl, 1994). He claims that the evidence from studies of mulches, cover crops and allelopathy suggest that the answer is yes for many cropping systems.

Ghersa et al. (1994) state that weed management practices are increasingly uncoupled from biological feedback in the ecosystem and have become more linked to social and economic feedback. The lack of feedback from the biological system to weed management is evident by the findings of Forcella and Harvey (1983) that: despite the enormous efforts to control weeds, the relative and absolute abundance of weed flora has increased steadily since 1900. Ghersa et al. (1994) state that "the old paradigms of Newtonian science, with its assumptions of reductionism, linearity, and objectivity, are yielding to a post-industrial paradigm that emphasizes holism, circuitry, and connections". They advocate a process of healthy "coevolution" between agroecosystems and weed management. This goes beyond agronomic techniques. It requires the involvement of social institutions to find ways to minimize the use of energy (inputs and fuel power) and maximize the use of information (about moral responsibility, values and biotic interactions) to design weed management strategies.

SUSTAINABLE CROPPING SYSTEMS

Before low-cost synthetic fertilizers were available, farmers relied on legumes and manure to renew soil fertility. It is anticipated that interest in legumes will return as the reserves of fossil fuels decline. Power (1987) predicts that the direct monetary advantages of fertilizer-N over biologically fixed N, that have been predominant in the past, will not be so great in the future. Costs of synthetic fertilizers will increase as reserves of fossil fuels are depleted. Some experts are predicting a permanent decline of world oil production within the next 20 years. Hatfield (1997) warns that development of alternative sources of energy is a Herculean task that requires time, gigantic capital investment and innovative technology; and it is unlikely that alternatives to petroleum will be in place by the time they are needed, by 2010 to 2015. Interest in nutrient cycling and legumes is also likely to grow in response to global warming. The popular press took interest in a recent report from the Rodale Institute stating that use of organic fertilizer could reduce greenhouse gases, because organic farming may use 50% less energy than conventional farming methods (Drinkwater, 1998).

Scientists and farmers have debated whether substance-based systems, dependent on high inputs like chemicals and fertilizers, could be replaced by knowledge-based systems (Ellert, 1995). Knowledge-based systems are more complex than substance-based systems; they incorporate the knowledge of farmers, and account for site-specific differences. A debate about the sustainability of different cropping systems, led to the establishment of the Hendrigan Plots in 1980 at Breton. Lou Hendrigan, a local farmer, believed that the best agricultural system for the Gray Luvisolic soils was a continuous forage system, using a fescue-white clover mixture. The Hendrigan plots were designed to compare three cropping systems: continuous barley; continuous fescue-white clover forage; and an eight year agroecological rotation of barley-fababeans-barley-fababeans-barley-forage-forage-forage (where the forage is a brome-red clover mixture). While the continuous forage system involves a relatively closed system and little soil disturbance, the agroecological system incorporates both annual and perennial cropping. In both cases, legumes are an important component of the systems.

In reviewing findings from Breton, and from other cropping system and tillage research in Alberta, Izaurralde et al. (1995) concluded that:

- tillage frequency, nutrient additions and crop sequences are critical research components for developing sustainable cropping systems,
- soil organic matter not only can be maintained but also improved with sustainable cropping practices, and
- closed nutrient cycles are essential for maintaining environmental quality.

With current emphasis on reduced tillage, plow down of legume green manures may be viewed as a questionable practice. A three-year study by Arshad and Gill (1996) compared three crop production systems: conventional (CNV, tilled fallow with conventional tillage); chemical (CHM, chemical fallow with zero tillage); and alternative (ALT, green manure with reduced tillage). Fallow systems were followed by a wheat crop in the second year, and a canola crop in the third year. Research was conducted on a Solodized Solonetzic soil and field peas were used as the green manure. Neither tillage nor herbicides provided an effective control across weed species. With reduced tillage in the CHM system, the wet aggregate stability of the soil improved. The green manure in the ALT system significantly increased soil NO_3-N. The ALT system was considered to be better than the other two systems, because it resulted in higher crop production, economic benefit and improved soil fertility.

There are many different definitions of sustainable agriculture. I think that a description of regenerative agriculture by Doran, Sarrantonio and Liebig (1996) provides a valuable guide to sustainable agricultural practices. Key elements include:

- replenishment of soil organic matter is the cornerstone to regenerating soil health,
- plant residues, animal manures and/or community food waste should be returned to the soil,
- living cover should be maintained throughout all or most of the year, to cycle nutrients, protect against erosion, support soil organisms, and increase inputs to soil organic residue,

- diversity is critical at every level: in crops, in soil microbial and faunal communities.
- crop rotations are based on progressions of plants with complementary water and nutrient needs, pest susceptibilities, and root system types,
- inorganic fertilizers and pesticides should be reduced or eliminated,
- tillage should be minimized.

As pressures increase to find alternatives to cropping systems that are dependent on fossil fuels, legumes will be looked to as valuable resources and vital components of sustainable cropping systems.

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Chapter 2

Abilities of seven clover species and fall rye to suppress weed growth, with mustard as a model weed.

INTRODUCTION

Legume crops are a key component of sustainable cropping systems. Pressures to conserve soil resources, to maintain environmental quality and to replace input-intensive agriculture with knowledge-intensive agriculture have contributed to a renewed interest in legume crops. New annual legume crops offer the potential to diversify and improve Alberta cropping systems.

Trials have been conducted in Alberta to assess a variety of annual legumes for use as green manure or forage crops. Some annual clovers produced promising forage yields in southern Alberta trials (Fraser, 1995). Organic producers of horticultural crops are interested in annual legume crops which can be used to provide ground cover, suppress weeds and improve soil quality (Sustainable Agriculture Association, 1995). Farmers may have various reasons for looking at cover crops as an alternative method of weed control (concerns about soil erosion, cost and environmental impact of herbicides, increased incidence of herbicide resistant weeds).

Research studies in Alberta have assessed a number of annual legumes for yield, water use, potential N contribution, and impact on subsequent crop (Jensen, 1992; Rice et al., 1993; Fraser, 1995). Weed competition has been raised as a concern in using annual legumes, but this area has not been adequately studied. In an Alberta study of five legumes for annual plowdown to replace cultivated fallow, it was observed that "If weed competition is so severe that the legumes do not grow well and the weeds make up the dominant composition of the plants on the field there is little benefit to green manuring" (Jensen, 1992). Basic requirements of a legume used for green manure should include an ability to compete well with weeds (especially broadleaf weeds) and provide adequate ground cover to protect against soil erosion. (Jensen and Jans 1993). If weed levels in a green manure crop are low to moderate, weed control measures are not recommended, because the weeds will not have set seed at the time of plowdown (seven to eight weeks of growth). The Battle River Research Group in Camrose tested the yield potential of 19 annual legumes (BRRG, 1995). Weed competition was strong and the plots had to be hand weeded to prevent yield losses. They noted that weed competition should be of concern to farmers in growing annual legumes because registered herbicides were not available for most of them. A study of 12 cover crops (including four annual clovers) interseeded with corn in Quebec found that "in a number of cases in our data, weed development interfered with cover crop establishment, and the cover crops provided little or no weed control" (Abdin et al., 1998). In contrast, Galloway and Weston (1996) found that white ladino clover and crimson clover were extremely weed suppressive, when used as a glyphosate-suppressed mulch with no-till corn. A 1994-1995 Nova Scotia study evaluated many new and old cover crops for use in organic vegetable production (Wallace and Scott, 1996). The farmers controlled weeds in the clover cover crops by hand-pulling or mowing the weeds until the clovers became established. They observed that mowing helped to give cover crops a competitive edge over weeds. The vigor of cover crop regrowth was reduced if the cover crops were in flower, if they were mowed too close to the soil surface or if growing conditions were unfavourable.

Little information is available on the relative abilities of various annual legumes species to compete with weeds. We chose to focus on small-seeded legumes and to investigate weed suppression abilities of annual clovers. The objectives of this study were to:

a) test the ability of four annual clovers to suppress weeds;
b) compare annual clovers with perennial clovers and fall rye regarding their ability to suppress weeds;
c) investigate the effect of mowing on clover/weed interaction;
d) compare the growth of annual clovers on Luvisolic and Chernozemic soils in north-central Alberta; and
e) test the use of annual clovers in organic cropping systems.

MATERIALS AND METHODS

Trials were conducted in 1996 and 1997* at six sites in North/Central Alberta, with two to seven species of clover and fall rye at each site. Research sites (identified on a map in Appendix 1) were chosen to compare growth on Black Chernozemic soils with Gray Luvisolic soils. Chernozems and Luvisols are the two main soil orders cultivated for agricultural production in Alberta and represent two extremes of natural fertility. The three locations on Luvisolic soils were: Bowicks (grain/forage/livestock farm near Barrhead); Burgers (grain/forage/livestock farm near Breton); and the University of Alberta Breton Plots. The three locations on Chernozemic soils were: Melnychuks (grain farm near Redwater); Radzicks (fruit farm near Spruce Grove); and the University of Alberta Edmonton Research Station. The four farms are organic producers and members of the Sustainable Agriculture Association.

The six research sites were chosen to provide a range of soil characteristics and fertility. The initial soil test results (Appendix 2) confirmed that the sites differed in levels of macro-nutrients, micro-nutrients, pH and organic matter. Soil N levels were generally higher in the Chernozemic soils than in the luvisolic soils. The Luvisolic soil at the University of Alberta site at Breton represented the extreme low end of soil fertility, with deficient levels of NPKS, and organic matter of about 3%. The University of Alberta site at Edmonton (Malmo soil series) provided the opposite extreme of soil fertility, with the highest overall NPKS levels and organic matter of over 10%. The soil fertility levels of the two Luvisolic farms and the two Chernozemic farms were intermediate between the U of A sites. The soil N levels of the four farm sites were fairly similar, with the exception of much higher soil N levels at the 1996 Radzick site. The majority of the soils were phosphorus deficient.

No nitrogen fertilizer was added to research plots, but some P and K was applied. The site at Breton (U of A), received P at 22 kg ha^{-1} as P_2O_5 and K at 50 kg ha^{-1} as KCl. In keeping with acceptable organic amendments, rock phosphate was used as a P source on the farm plots. Based on a rate of 100 lbs rock phosphate $acre^{-1}$ at Burgers and Radzicks, and 200 lbs $acre^{-1}$ at Melnychuks, the actual P applied was 10 and 20 kg P ha^{-1}, respectively. The rock phosphate was 21.34% P_2O_5 and 9.18% P. Rock phosphate is a slow release form of P fertilizer and it takes about three years for the P to become available.

Four annual clover (*Trifolium*) species, [balansa (*T. michelianum* Savi var. *balansae* Boiss.), berseem (*T. alexandrinum* L.), crimson (*T. incarnatum* L.), and persian (*T. resupinatum* L.)] (Plate 2-1) were compared with three commonly-used perennial clovers [alsike (*T. hybridum* L.), red (*T. pratense* L.), and white Dutch (*T. repens* L.)]. Fall rye (*Secale cereale* L.) was grown as a "check" species in order to compare the clovers with a non-legume crop, and because fall rye is known to compete well with weeds. Commercial seeding rates were used as listed in Table 2-1. Clover seeds were inoculated with appropriate strains of *Rhizobium leguminosarum biovar trifolii*, broadcast onto the soil surface by hand and then incorporated by hand raking. Fall rye was seeded in 17.8 cm or 20 cm (7-8 inch) rows. The experimental design at each site was a randomized complete block (RCB) with four replicates and individual treatment plot size varied from 10 to 24 m^2.

Table 2-1: Common names, scientific names, cultivars and seeding rates ($kg\ ha^{-1}$) of species grown.

Common name	Scientific name	Cultivars	Seeding rate ($kg\ ha^{-1}$)
Alsike clover	*Trifolium hybridum L.*	Aurora	8
Balansa clover	*Trifolium michelianum* Savi. *var. balansae* Boiss.	Paradana	8
Berseem clover	*Trifolium alexandrinum L.*	Bigbee	15
Crimson clover	*Trifolium incarnatum L.*	Au Robin	15
Persian clover	*Trifolium resupinatum L.*	Felix, Ciro	12
Red clover	*Trifolium pratense L.*	Altaswede	12
White Dutch clover	*Trifolium repens L.*	common	8
Fall rye	*Secale cereale* L.	Kodiak	70

At the Breton and Edmonton University sites, brown mustard (*Brassica juncea* (L.) Czern.) was used as a model weed and was added to all plots, including mustard-only control plots. Mustard was broadcast onto the soil surface at 15 seeds m^{-2}, and then incorporated by hand raking. In 1996, mustard numbers were left as they randomly occurred in the quadrats. In 1997, mustard numbers were set at 12 plants m^{-2} in quadrats. In 1996 at Breton, thistles and dandelions were removed from quadrats and volunteer oats were removed from the 0.25 m^2 subquadrats. In 1996 at Edmonton, weeds were left in the quadrats, with the exception of a few large redroot pigweed. In 1997, all weeds (except mustard) were removed from the areas to be sampled. At the University sites, nine species were tested under mowed and unmowed treatments in a split-plot design. Plot size was 2 by 6 m in 1996 and 2 by 5 m in 1997. Mowing was applied to half of the plots, using a sickle-bar mower in 1996 and a flail mower in 1997. Plots were mowed to a height of 7 to 10 cm (3 to 4 inches) and the cut material was removed.

Details of species grown, seeding dates, mowing, and sampling are summarized by site and year in Table 2-2.

Table 2-2: Locations, species tested and dates for seeding, mowing, and sampling for six research sites in north-central Alberta for 1996 and 1997.

Site	Location	Species tested	Seeded	Mowing date	Sample dates (weeks)	
					Mowed	Unmowed
1996						
Breton U of A	Breton	A, Ba, Be, C, PF, R, W, FR	7-Jun	at 10 weeks	10 & 14	14
Edmonton U of A	Edmonton	A, Ba, Be, C, PF, R, W, FR	4-Jun	at 10 weeks	10 & 16	16
Burger	Breton	Be, C, PC, FR	11-Jul	none	n a	9
Bowick	Barrhead	Be, C, PC, FR	12-Jun	none	n a	12
Melnychuk	Redwater	Be, C, FR	11-Jun	none	n a	12
Radzick	Spruce Grove	Be, C, PC	3-Jul	none	n a	9
1997						
Breton U of A	Breton	A, Ba, Be, C, PF, R, W, FR	9-Jun	at 7 weeks	7 & 15	15
Edmonton U of A	Edmonton	A, Ba, Be, C, PF, R, W, FR	30-May	at 7 weeks	6 - 7 & 14	14
Burger	Breton	Be, C, PC, FR	10-Jun	none	n a	12
Bowick	Barrhead	berseem-oat mixture	June	August	7	n a
Melnychuk	Redwater	Be, C, FR	12-Jun	August	8 & 14	n a
Radzick	Spruce Grove	Be, C, PC, FR	4-Jul	August	7 & 11	n a

Notes: Species tested: A= alsike clover, Ba= balansa clover, Be= Berseem clover, C= crimson clover, PC= persian "Ciro" clover, PF= persian "Felix" clover, R= red clover, W= white Dutch clover, FR= fall rye. Breton and Edmonton U of A sites had both mowed and unmowed treatments, while farms had either unmowed or mowed. "na" = not applicable.

Each of the four farms tested two or three clovers and fall rye. Natural weed populations were used as competitive factors on the farms. In 1997, Bowicks conducted a field-scale (10 acre) trial of a berseem/oat mixture for feed and plowdown, rather than clover-weed trials.

DATA COLLECTION

One 1 m^2 quadrat, with a 0.25 m^2 subquadrat, was permanently marked in each plot (Plate 2-2A). The quadrats were intentionally placed away from the margins of the plots and in spots where the growth of clover/rye/mustard was fairly uniform. Plant numbers were counted within the 0.25 m^2 subquadrats to estimate emergence of the clover species and for later calculation of per plant yields of clover and fall rye. Quadrats were harvested by hand, cutting the plants at a height of approximately 5 to 7.5 cm (2 to 3 inches) above ground level. Sampling dates (by weeks after planting) are listed in Table 2-2. At the University sites, mustard numbers were recorded for all quadrats harvested. Clover, fall rye and weeds/mustard were separated, put in bags, dried for 72 hours at 52 °C and then weighed. In 1996 at Breton, volunteer oats in the quadrats were also separated, counted, dried and weighed. In this paper, "phytomass" refers to the dry weight of the above-ground plant matter.

In 1996, clover growth characteristics (leaf number, stem number, flowering) were noted at the time of plant counts and first sampling. Maximum height of mustard and average height of clover were measured at time of sampling in 1996.

Analysis of variance was performed on data for phytomass (g m^{-2}), mustard phytomass (g $plant^{-1}$) and height of mustard (cm) using SAS version 6.11 (SAS Inst., 1995). There were some differences in methodology between 1996 and 1997 (mowing at an earlier stage in 1997 than in 1996, at University plots), and effects of location and year were significant, so data are presented separately for each year and each location. Significant differences between species and between mowed and unmowed treatments were determined using an F-test. For University sites, results for clover phytomass (g m^{-2}), mustard (g m^{-2}) and mustard per plant phytomass (g $plant^{-1}$) were transformed to square root values before F-test and means separation analysis. Means separation was done using Fisher's LSD values where the F-test denoted significance ($P \leq 0.05$).

RESULTS AND DISCUSSION

CLIMATE CONDITIONS

Monthly mean temperatures and precipitation totals for the growing seasons of 1996 and 1997 are summarized for Edmonton and Breton in Appendix 3. Most plots were seeded in June. Seasonal rainfall was higher than average in both years, particularly in June, resulting in a few delays in seeding. Compared to the June norm of about 80 mm of precipitation, Edmonton received 118 mm in 1996 and 133 mm in 1997, and Breton received 127 mm in 1996 and 108 mm in 1997. Some of the farms received even higher amounts of rainfall than Edmonton and Breton. In 1996, Bowicks reported receiving about 125 mm (5 inches) of rain in the week after the plots were seeded. In Melnychuk's area, many fields were affected by waterlogging and flooding in 1996 and 1997. Low-lying areas of the Edmonton plots were under water for several days in both years, following heavy rains.

For our main growing season (June to August), monthly mean temperatures were near average. Spring 1996 was cooler than usual, with lower mean temperatures than average in May and June. Normally, Breton has lower mean temperatures, fewer frost-free days, and higher rainfall than the Edmonton area (Izaurralde et al., 1993). For 1996 and 1997, mean temperatures at Breton were lower than at Edmonton, but precipitation varied. For June to August, Breton had higher precipitation than Edmonton in 1996 (Breton - 312 mm, Edmonton - 256 mm), but in 1997 precipitation was lower at Breton than at Edmonton (Breton - 248 mm, Edmonton - 264 mm).

Environmental conditions were generally favourable for growth in both 1996 and 1997. Moisture was adequate or more than adequate. With the exception of cooler than average temperatures in June 1996, seasonal temperatures in 1996 and 1997 were near normal.

BRETON

At the University of Alberta Breton site, the clover and mustard plants were slow to establish and initial growth was sparse. This may be attributed to the low soil fertility (soil NO_3-N of 1 to 3 ppm, organic matter of about 3%) of the site (Appendix 2). Dandelions (*Taraxacum officinale* Weber) and thistles (*Cirsium arvense* (L.) Scop.) were the predominant forms of initial growth. In 1996 and 1997, quadrats were hand weeded to reduce interference from natural infestations of perennial and annual weeds. In 1996, volunteer oats emerged after the clovers and mustard. The late emergence of the oats may have been due to cooler than average temperatures in May and June of 1996. The oats were numerous and were evenly distributed over the entire plot area. Rather than attempting to remove all the oats, they were left in the plots to be part of the "weed" flora. The experiment was designed to compare the phytomass of mustard (kg ha^{-1} and g $plant^{-1}$) grown without competition from other species, with the phytomass of mustard grown in conjunction with clover species and fall rye. In 1996, the measure of mustard (kg ha^{-1}) was replaced by a "weed" phytomass, consisting of mustard and oats. In 1997, only mustard plants were left in the quadrats as weeds.

Emergence and establishment was good for all of the clovers except persian (Table 2-3). Emergence of persian was 34% in 1996 and 36% in 1997, compared to the clover average of 69% in 1996 and 65% in 1997. Early plant size (g $plant^{-1}$ at seven weeks in 1997) reflected seed size: crimson > berseem > red > persian ≥ balansa > alsike ≥ white Dutch (Table 2-3 and Table 2-4). The same pattern was evident in 1996, when plants were sampled at 10 weeks, with the exception of larger relative plant size with persian: crimson > persian > berseem > red > balansa > alsike > white Dutch. The annual clovers had higher number of leaves per plant and were taller than the perennial clovers at 6-7 and 10 weeks in 1996 (Table 2-5). At 14 weeks, maximum stem length was approximately: 35 cm for white and red, 50-70 cm for alsike, balansa and crimson, 90 cm for berseem and 100 cm for persian. By 14 weeks in 1996 and 15 weeks in 1997, crimson still had the largest plant size (about 2 g $plant^{-1}$) and berseem and persian were either second or third in size, with about 1.4 g $plant^{-1}$. Perennial clovers had smaller plant size than crimson, berseem and persian. White Dutch plants were smallest at about 0.4 g $plant^{-1}$. Per plant weights were based on counts at 5-7 weeks, and do not account for interim mortality of plants. Balansa had flower buds at six weeks, crimson was in flower by 10 weeks, and white, alsike and persian were in flower at 14 weeks. Berseem and red did not have flowers by 14 weeks.

The density of clover plants averaged about 400 plants m^{-2} in both years, ranging from about 200 plants m^{-2} with crimson to about 650 plants m^{-2} with white (Table 2-4). In 1996, berseem had the largest phytomass (kg ha^{-1}) of the clovers at 10 weeks (1880 kg ha^{-1}, compared to the mean clover phytomass of 1420 kg ha^{-1}) (data not presented). At 7 weeks in 1997, crimson had the largest phytomass (330 kg ha^{-1}, compared to the clover mean of 210 kg ha^{-1}).

The seven clover species and fall rye significantly suppressed weed/mustard growth at Breton in 1996 and 1997 (Tables 2-6 and 2-7). The split-plot ANOVA statistics are summarized in Appendix 4. The presence of the clover and fall rye reduced the overall weed/mustard phytomass (kg ha^{-1}) by 49% and the mustard phytomass (g $plant^{-1}$) by 52%. The suppression of weed/mustard phytomass tended to be higher in unmowed treatments (54%) than in mowed treatments (47%), but the difference was not significant.

In the four tests at Breton (mowed and unmowed treatments in 1996 and 1997), all of the clover species, except persian, significantly reduced weed/mustard phytomass (kg ha^{-1}) in three or four of the tests (Table 2-6). The poorer competitive ability of persian may be partly explained by the lower rate of emergence and establishment than the other clovers.

Significant effects on weed/mustard phytomass were fairly consistent between data sets using weed/mustard kg ha^{-1} and mustard g $plant^{-1}$, except for the unmowed treatments in 1996 (Tables 2-6 and 2-7). The 1996 mustard phytomass (g $plant^{-1}$) result for mustard unmowed treatments (7.4 g) was considerably lower than that in 1997 (11.8 g $plant^{-1}$). In 1996, the mustard phytomass (g $plant^{-1}$) was affected by competition from clovers/rye and volunteer oats. The 1996 values for the "mustard" treatments did not represent the possible phytomass of mustard if it had been grown alone. The oat density was fairly uniform (averaged 33 oat plants per quadrat), but the unmowed "mustard" treatment quadrats had the highest number (average of 69) of oat plants (data not presented). The mustard phytomass (g $plant^{-1}$) result for the "mustard" unmowed treatment in 1996 was lower than it would have been without interspecific competition, and it provided an inaccurate reference against which to measure significant suppression by the clovers. This may explain why there was less significant difference with the clovers in 1996 than in 1997, using the mustard phytomass (g $plant^{-1}$) results.

The 1997 results for mustard phytomass (g $plant^{-1}$) should be more reliable than the 1996 results (Table 2-7). In 1997, mustard numbers were thinned to 12 plants in a 1 m^2 quadrat, and all other plant growth was removed. The mustard plants were thinned to evenly space the mustard within the quadrat. Adjusting the proximity of mustard plants was done to make intraspecific competition more uniform among treatments. In 1997, significant effects on mustard phytomass were nearly the same for mustard kg ha^{-1} and g $plant^{-1}$ data sets.

Fall rye was the most competitive species and it reduced the weed/mustard phytomass by an average of 85% (Tables 2-6 and 2-7). The suppression of mustard by fall rye cannot be accounted for by physical interference. The growth of the fall rye was short and sparse, leaving much of the ground bare (Plate 2-3D). In 1996, at 10 weeks after planting, the height of the fall rye plants (with the leaves held upright) was 14 cm (Table 2-5). At this same time, the mustard height was 72 cm (Table 2-8). For the tests at Breton, the average phytomass for fall rye was only about 25% (710 kg ha^{-1}) of the average for the seven clovers and rye (2540 kg ha^{-1}) (Table 2-6). While the phytomass (g $plant^{-1}$) of the clovers continued to increase between 10 and 14 weeks in 1996, the fall rye phytomass did not increase during this time (Table 2-4).

In contrast to fall rye, the suppression of weeds/mustard by the clovers may be partly explained by phytomass and physical competition. The clovers did not have a height advantage over the mustard but they did have an advantage in total phytomass. In 1996, clover plant height averaged 30 cm at 10 weeks, and stem length averaged over 60 cm at 14 weeks (Table 2-5). Mustard mean height was 92 cm at 10 weeks, and 108 cm at 14 weeks (Table 2-8). In 1996, the clover phytomass (kg ha^{-1}) was about twice that of the weeds (oats and mustard), and in 1997 the clover phytomass was about five times that of the mustard (Table 2-6). The annual clovers (balansa, berseem, crimson and persian) had higher phytomass (kg ha^{-1}) than the perennials (alsike, red and white Dutch) in most cases. Phytomass results do not include roots, and it is likely that root phytomass would have been higher for the perennials than for the annual clovers. The annual clovers had higher numbers of leaves $plant^{-1}$ and taller/longer stems than the perennial clovers. The differences in growth characteristics between the annual and perennial clovers were not substantial enough to produce significant differences in weed/mustard suppression.

EDMONTON

Persian had a lower rate of emergence and establishment than the other clovers at Edmonton: 16% in 1996 and 63% in 1997, compared to clover averages of 48% in 1996 and 84% in 1997 (Table 2-3). The lower emergence/ establishment rates for all clovers in 1996, compared to 1997, were probably due to the effects of heavy rainfall in June 1996. Following seeding on June 4, 36 mm of rain fell within 48 hours. Later in the month, 66 mm of rain fell on June 18-19. Plant counts were made on July 15-17. The high clay content of the Malmo series soil impeded drainage and resulted in pools of standing water on the plots after heavy rainfall. Seedlings may have failed to establish due to surface exposure, waterlogging and/or crusting of the soil surface. As a result of poorer emergence, the average plant density of clovers was lower in 1996 (360 plants m^{-2}) than in 1997 (620 plants m^{-2}) (Table 2-4).

Among the six research sites, the highest clover and weed (mustard) yields occurred at the University of Alberta Edmonton site. The vigorous growth at Edmonton may be attributed to high soil fertility (soil NO_3-N of 20 and 39 ppm, organic matter over 10%) (Appendix 2). The location of the 1996 field trials was fairly "clean" and weeding was only required to remove a few patches of redroot pigweed (*Amaranthus retroflexus* L.). The 1997 site required weeding to remove a variety of annual weeds from the quadrats.

The early growth of clovers was less dependent on seed size, than at Breton. Relative plant size (g $plant^{-1}$) at 6-7 weeks in 1997 (with relative seed size, using "1" as largest, in brackets) was: berseem (2) $\geq$ crimson (1) > balansa (5) > red (3) $\geq$ persian (4) > alsike (6) > white Dutch (7) (Table 2-3 and Table 2-4). The relatively larger plant sizes for berseem and balansa suggest higher growth rates, or may represent greater response to high fertility and high moisture.

The seven clover species and fall rye significantly suppressed mustard growth in at least one of the four tests (mowed and unmowed treatments in 1996 and 1997) at Edmonton (Table 2-9, Table 2-10, and Appendix 4). The greatest mustard suppression (68%) occurred in the mowed treatments of 1997, with significant reduction of mustard phytomass by all clovers and rye. The overall reduction of mustard phytomass by clover and rye was 38% for kg ha^{-1} and 36% for g $plant^{-1}$. Mustard suppression was higher in mowed treatments (49% reduction of mustard phytomass) than in unmowed treatments (24%). In 1997, mowing was applied at 6-7 weeks, as compared to 10 weeks in 1996. The earlier mowing in 1997 helped the clovers to compete with the mustard. The least suppression of mustard (17%) occurred in the 1996 unmowed treatments.

Berseem clover and fall rye significantly reduced mustard phytomass (kg ha^{-1}) in all of the four tests at Edmonton (Table 2-9). Alsike, balansa and crimson significantly reduced mustard phytomass (kg ha^{-1}) in three of the four tests. Fall rye was <u>not</u> the most competitive species. Suppression of mustard phytomass by berseem was significantly greater than by fall rye in one test, and numerically greater in two other tests. There were also cases where mustard phytomass was numerically lower with alsike and persian than with fall rye. White, red and persian were generally less competitive than the other clovers.

In the early stages of growth, balansa may have provided the mustard plants with greater competition for light than the other clovers. Balansa responded well to the high soil moisture conditions, whereas the mustard plants had poorer growth in the waterlogged areas of the plots. Balansa quickly established a ground cover (Plate 2-2A). Balansa had more leaves and stems at six and 10 weeks than the other clovers (Table 2-5). At the first sampling of the mowed plots, balansa had the largest phytomass (kg ha^{-1}) of the clovers. At 10 weeks in 1996, the phytomass of balansa (2610 kg ha^{-1}), was the same as that of fall rye and much higher than the clover average (1500 kg ha^{-1}) (data not presented). At 6-7 weeks in 1997, the phytomass of balansa (1300 kg ha^{-1}), was higher than fall rye (790 kg ha^{-1}) and twice the clover average (600 kg ha^{-1}). The higher phytomass of balansa was a combination of growth rate and plant density. Crimson had a larger per plant phytomass than balansa but was seeded at a lower plant density because of its much larger seed size (1000 seed weight of crimson was 5.1 g, versus 0.8 g for balansa) (Table 2-3). While the early growth of balansa was quite competitive, it was not very competitive at later stages. Balansa had flowers at six weeks after planting (much earlier than the other clovers) and growth slowed with the switch from vegetative to reproductive growth. Also, the growth habit of balansa is prostrate, so it was overgrown and overshadowed when the mustard formed a closed canopy.

At 10 weeks in 1996, the relative plant size (with relative seed size in brackets) was: crimson (1) > persian (4) > balansa (5) > berseem (2) > alsike (6) > red (3) > white Dutch (7). The influence of competition from the mustard plants would have affected the growth of the clovers by this stage. At 14 to 16 weeks in 1996 and 1997, berseem had the largest plant size (2.6 g $plant^{-1}$) and persian and crimson were either second or third in size. Perennial clovers had smaller plant size than crimson, berseem and persian. White Dutch plants were smallest at about 0.1 to 0.3 g $plant^{-1}$. Per plant weights for clovers were based on counts at 4-6 weeks, and do not account for interim mortality of plants.

In the absence of mowing, most of the clovers provided the mustard with very little competition for light after the mustard established a closed canopy. In 1996, at 10 weeks after planting, the mustard plants were very large and leafy, with an average canopy height of 117 cm and phytomass of 35.6 g $plant^{-1}$ (Tables 2-8 and 2-10). In contrast, the average height of the clovers and fall rye was about 50 cm, and mean phytomass (g $plant^{-1}$) was 0.55 g for clovers and 2.9 g for fall rye (Table 2-5). In 1996 at 16 weeks after planting, the average mustard canopy height was 141 cm, and mean phytomass was 70.4 g $plant^{-1}$ (Tables 2-8 and 2-10). The average maximum stem length of the clovers was 108 cm, and mean phytomass (g $plant^{-1}$) was 1 g for clovers and 2.8 g for fall rye. At 10 weeks, white clover had the lowest standing height (28 cm) and berseem had the highest (75 cm). At 16 weeks, the maximum stem length for white clover was 40 cm and for berseem was 164 cm (Plates 2-2B and 2-3C). The stems of berseem probably caused some shading of the mustard. Berseem was the only species that had a higher phytomass (kg ha^{-1}) than mustard in the mixture at 16 weeks (6740 kg ha^{-1} of berseem with 4480 kg ha^{-1} of mustard) (Table 2-9). Berseem was the only clover which had higher phytomass in the unmowed plots than the mowed plots in both years (Table 2-10).

The high, closed canopy of the mustard likely excluded a large amount of the light from the shorter clovers and fall rye. The clovers with longer, erect stems (alsike, berseem, persian) would have been able to access some light and their phytomass (g $plant^{-1}$) continued to increase between 10 and 16 weeks (Table 2-5). The phytomass (g $plant^{-1}$) of balansa, crimson, red, white and fall rye did not increase between 10 and 16 weeks, possibly due to shading by the mustard. At Breton, the phytomass (g $plant^{-1}$) of balansa, crimson, red, white and fall rye increased substantially between 10 and 14 weeks.

Although the individual clover plants were very small in comparison to the mustard plants, the density of the clover plants would have contributed to competition for light and soil nutrients. In 1996, with average densities of 360 plants m^{-2} for clovers, the mean phytomass of clovers/fall rye (2500 kg ha^{-1}) was 33% of the mean mustard phytomass (7670 kg ha^{-1}) at 16 weeks (Tables 2-4 and 2-9). In 1997, with average densities of 620 plants m^{-2} for clovers, the mean phytomass of clovers/fall rye (4040 kg ha^{-1}) was 62% of the mean mustard phytomass (6530 kg ha^{-1}) at 14 weeks. Higher densities of clover in 1997 may account for greater suppression of mustard phytomass (31% reduction of unmowed mustard phytomass) than occurred in 1996 (17% reduction).

BRETON AND EDMONTON

The differences in soil fertility between Breton and Edmonton produced large differences in mustard phytomass. In 1997, the mean unmowed mustard phytomass at Edmonton was 10 to 11 times greater than the corresponding mustard phytomass at Breton: 6530 kg ha^{-1} and 54.6 g $plant^{-1}$ at Edmonton versus 610 kg ha^{-1} and 5.26 g $plant^{-1}$ at Breton (Tables 2-6, 2-7, 2-9 and 2-10). The competition provided by the mustard plants at Edmonton would have been much greater than that at Breton.

With the effects of low soil fertility at Breton and high mustard competition at Edmonton, there were relatively small differences in clover phytomass between the two sites. In 1996, the mean unmowed phytomass of the clovers and fall rye (kg ha^{-1}) at Edmonton was 9% less than that at Breton, and it was 37% greater at Edmonton than Breton in 1997 (Tables 2-6 and 2-9). The higher clover phytomass at Edmonton in 1997 may have been due to higher plant densities. The clover phytomass represented a much higher portion of the total unmowed phytomass at Breton than at Edmonton. Clover phytomass was 77% of the total unmowed growth at Breton and 31% at Edmonton, based on the two year average. The higher relative growth of clovers at Breton can be attributed to the comparative advantage of N-fixing legumes on low fertility soil.

When mustard competition was reduced by early mowing (at 6-7 weeks) in 1997, there were greater differences in clover phytomass between Breton and Edmonton. The mean mowed phytomass of the clovers and fall rye (kg ha^{-1}) at Edmonton was more than twice the size of that at Breton (Tables 2-6 and 2-9).

There were some differences in the clover plant characteristics observed at Breton and Edmonton in 1996. At six weeks, there were similar numbers of leaves on the clover plants, with the exception of balansa, which had higher numbers of leaves at Edmonton (Table 2-5). At 10 weeks, the clovers at Edmonton had somewhat lower numbers of leaves and higher stem heights than those at Breton. At 14 weeks, the mean maximum stem length of the clovers at Edmonton (108 cm) was much greater than that at Breton (64 cm), but the mean per plant phytomass was similar (1 g $plant^{-1}$). Elongation of stems and slower leaf production may have occurred in response to shading by the mustard plants at Edmonton. In crimson clover, stem and petiole elongation are directly related to stand density (Knight, 1985). Among the species, berseem and persian had the tallest stems and white Dutch was the shortest. Balansa had the largest number of stems per plant, and the largest number of leaves at six and 10 weeks, while red clover had the lowest number of leaves.

EFFECTS OF MOWING

The effects of mowing differed between Breton and Edmonton. At Breton, there was a trend of reduced mustard/weed phytomass with mowing, but it was not significant (Table 2-11). At Edmonton, mowing significantly reduced mustard phytomass. The effect of mowing at this site was less significant in 1996 than in 1997. In 1996, the effect of mowing on mustard phytomass (kg ha^{-1}) was significant at $p \leq 0.05$, and effect on mustard phytomass (g $plant^{-1}$) was significant at p value = 0.07. In 1997, the effect of mowing on mustard phytomass (kg ha^{-1} and g $plant^{-1}$) was significant at $p \leq 0.01$.

In 1996, mowing occurred at 10 weeks after planting, in mid-August. By this time, the mustard plants in Edmonton were very large and leafy, with a canopy at a height of 117 cm, and mean per plant phytomass of 35.6 g (Tables 2-8 and 2-10). The mustard plants were mature enough to have pods and secondary branching. At Breton, the mustard plants had few branches and few leaves. They did not form a closed canopy, plant height was about 92 cm, and mean per plant phytomass was 3.1 g. The purple color of some stems indicated nutrient deficiencies. Some pods were forming. At both locations, the mustard did not regrow after being mowed in 1996.

In 1997, mowing occurred at six to seven weeks after planting, at initiation of flowering of the mustard (Plates 2-2C and 2-2D). Most of the mustard plants regrew, but their growth was considerably set back compared to the unmowed mustard.

At Breton, mowing had a detrimental effect on clover phytomass (kg ha^{-1}). In both years, mowing significantly reduced total clover phytomass ($p \leq 0.05$) (Table 2-11). Generally, the amount of regrowth after defoliation was less than the continued growth of the unmowed clover. The reduction in growth rate may be explained by reduced leaf area. This may have reduced production of photosynthate, increased sloughing off of N-fixing nodules and roots, and reduced capacity to provide N and other nutrients. Removal of the relatively small amount of mustard phytomass probably had a fairly negligible effect on competition for light, water and soil nutrients. Mowing at 10 weeks in 1996 had a greater impact on total clover phytomass (reduction of 1200 kg ha^{-1} compared to unmowed), than mowing at seven weeks in 1997 (reduction of 500 kg ha^{-1}).

The effects of mowing also varied with species and with timing of mowing. Generally, mowing decreased clover phytomass production compared to unmowed treatments, but there were exceptions. Red clover phytomass production (kg ha^{-1}) was largely unaffected by mowing (Table 2-6). In 1997, the total phytomass (g $plant^{-1}$) of alsike and white clover was slightly higher in the mowed than the unmowed treatments (Table 2-4 and Plate 2-3B). White clover had greater regrowth phytomass (920 kg ha^{-1}) than the other clovers in 1996. This may have been due to the low growth of white clover and greater retention of leaf area following defoliation, than the clovers with more erect growth. The perennial clovers likely had greater root reserves than the annual clovers to support regrowth. Averaged over the two years, the per plant phytomass production of the perennial clovers was less affected by defoliation than the annual clovers: average mowed phytomass (g $plant^{-1}$) of alsike, red and white clover was 80 to 89% of unmowed phytomass (g $plant^{-1}$); average mowed phytomass (g $plant^{-1}$) of balansa, berseem, crimson and persian clover was 51 to 72% of unmowed phytomass (g $plant^{-1}$).

Mowing was more detrimental to the phytomass production of clovers that were flowering than those that were still in vegetative growth. Crimson and balansa were flowering when cut at 10 weeks in 1996, and they produced smaller amounts of regrowth (kg ha^{-1}) than the other clovers (Table 2-12). When plots were mowed at seven weeks in 1997, crimson was not flowering, and crimson produced the largest phytomass (kg ha^{-1}) of regrowth at Breton.

At Edmonton, the response to mowing also varied with timing and species. Mowing at 10 weeks in 1996 had no significant effect on clover phytomass (Table 2-11). However, mowing at seven weeks in 1997 significantly increased clover phytomass ($p \leq 0.05$). Total mowed clover phytomass was 6230 kg ha^{-1}, versus unmowed clover phytomass of 4250 kg ha^{-1} in 1997.

In 1996, at 10 weeks after planting, the mustard phytomass was such that many of the clovers were heavily shaded at Edmonton. Under shaded conditions, growth rate would be low, and there would be very little photosynthate to support the growth of roots, leaves and stems. After mowing in 1996, the amount of regrowth (kg ha^{-1}) of alsike, balansa, crimson, red and white clovers was similar to the amount of regrowth at Breton (Table 2-12). However, berseem and persian produced much higher amounts of regrowth (kg ha^{-1} and g $plant^{-1}$) at Edmonton than at Breton. This suggests that the effects of low fertility at Breton and shading at Edmonton were such that the majority of the clover species were in a similar condition to respond to defoliation. The long, erect stems of berseem and persian enabled them to continue to access light within the mustard canopy at Edmonton, and they were better able to take advantage of the high fertility at Edmonton to support regrowth. Except for cases with alsike and berseem, the unmowed phytomass (g $plant^{-1}$) of clovers was less than the total mowed phytomass (g $plant^{-1}$) (Table 2-4). White and red clover may have been most susceptible to the effects of shading. White and red clover had the highest percent increase of phytomass (g $plant^{-1}$) with mowing. The total mowed phytomass (g $plant^{-1}$) of white clover was 215% higher than the unmowed phytomass, and unmowed phytomass of red was 178% higher than the unmowed phytomass, using the two year average.

When plots were mowed at 6-7 weeks in 1997, the mustard plants were not yet big enough to cause substantial shading of the plot area. The mustard phytomass of the first cut ranged from 420 kg ha^{-1} (with rye) to 1020 kg ha^{-1} (mustard alone), with means of 580 kg ha^{-1} and 5.2 g $plant^{-1}$ (data not presented). The clover/rye phytomass cut at 6-7 weeks averaged 620 kg ha^{-1} and ranged from 200 kg ha^{-1} for white clover to 1300 kg ha^{-1} for balansa. The phytomass of the first cut was a small part of the total clover phytomass for mowed plots (about 10% of total) (Table 2-12). Berseem and persian produced the largest amount of regrowth, with 8440 kg ha^{-1} and 6500 kg ha^{-1}, respectively (Plate 2-3A).

SUMMARY - MUSTARD SUPPRESSION

In the mowed and unmowed treatments at Breton and Edmonton in 1996 and 1997, all the clovers demonstrated some ability to suppress mustard phytomass, but there were differences among species. Results, based on suppression of mustard kg ha^{-1} are summarized in Table 2-13. Fall rye suppressed mustard phytomass in all eight tests. The results for fall rye confirm its ability to suppress weeds and support our choice of fall rye as a "check" species. Alsike, balansa, berseem and crimson suppressed mustard phytomass in seven of the eight tests. White Dutch suppressed mustard phytomass in five tests, red in four tests and persian in three. A study of legume green manures in Alberta (Jensen, 1992) found that red clover was slow to establish and produced significantly less phytomass than other legumes (i.e. lentil, Tangier flatpea, field pea and sweet clover).

Suppression of mustard g $plant^{-1}$ was also measured and those results are summarized in Table 2-14. The 1997 results for suppression of mustard (g $plant^{-1}$) are consistent with results for mustard phytomass (kg ha^{-1}), but the 1996 results for suppression of mustard g $plant^{-1}$ and kg ha^{-1} are not consistent. There are similar trends (e.g. significance of suppression by fall rye) in the 1996 results for mustard g $plant^{-1}$ and kg ha^{-1}, but the g $plant^{-1}$ results indicate fewer cases of significant suppression by the clovers. Mustard numbers were not set in 1996, and this variability made it more difficult to separate variation in mustard phytomass (g $plant^{-1}$) due to changes in density from variation due to suppression by clover. Mustard has a very "plastic" growth habit, and it is very sensitive to intraspecific competition. In 1996 at Edmonton, the mustard phytomass in the unmowed white clover plots averaged 10990 kg ha^{-1}, considerably higher (but not significantly different) than the mustard alone phytomass of 9060 kg ha^{-1}. The result might lead one to conclude that white clover had a beneficial effect on mustard phytomass. But, the high mustard phytomass result was likely due to higher numbers of mustard in the white clover quadrats. The average number of mustard plants m^{-2} in the white clover quadrats was 18 m^{-2}, compared to an average of 11.5 m^{-2} in the mustard-alone quadrats.

In 1997, the mustard density was set within quadrats and proximity was adjusted (where possible) to have a more uniform distribution of mustard within the quadrat. The consistency of the 1997 mustard g $plant^{-1}$ and kg ha^{-1} results would indicate that setting density and proximity factors helped to separate the effects of interspecific competition from those of intraspecific competition.

In 1996, data on mustard height was gathered by measuring the maximum height of the mustard plants within quadrats. This was not a very accurate measurement of mustard suppression, but there are some points worth noting. The results for suppression of mustard height are summarized in Table 2-15, based on the data in Table 2-8. Fall rye significantly suppressed mustard height in all four tests. The height of mustard plants growing with fall rye at Breton were an average of 32 cm shorter than plants in mustard only plots. At Edmonton, the mustard growing with fall rye were an average of 16 cm shorter than the plants in mustard only plots. This was consistent with phytomass results which found that fall rye had a significant suppressive effect and that the suppression was greater at Breton than at Edmonton. Results for suppression of mustard height by the clover species were not consistent with the results for phytomass, but it is interesting that the five cases where mustard height was significantly suppressed by clovers were all at 10 weeks, with no significant effect of clover on mustard height at 14-16 weeks. This suggests that if the clovers had an effect on mustard height, it was more likely to occur in early stages. The suppressive effects of fall rye on mustard were maintained over time, and may be further evidence that the suppression by fall rye was due to allelopathy.

FARMS

Farmers from four organic farms participated in the study and they grew berseem, crimson and persian clovers and fall rye as cover crops/green manures. Weed populations ranged from very high to very low among the farms. The weed suppression by fall rye was used as a reference to assess the weed suppression abilities of the clover species.

The clover/fall rye/weed phytomass results for the two farms on luvisolic soils are summarized in Table 2-16. Berseem, crimson and persian clovers compared favorably with fall rye in their ability to suppress weeds. Weed suppression by the clovers was equal to or better than fall rye in all cases except the crimson at Bowicks in 1996. The major weeds at the Bowick site were wild mustard and volunteer rapeseed (not canola). Ron Bowick said that the growth of the wild mustard and rapeseed was more prolific than usual in 1996 because it was a cool spring and they emerged later than usual. Weed suppression results varied between sites and years, so few overall conclusions can be drawn from the tests at these sites. The plots at Bowicks were on the side of a hill and there were some differences in fertility between the top and the bottom of the slope. There was also a part of the plot area that had poorer growth, which had previously been a gateway area. Variability in growth also occurred at Burgers. Part of the 1996 plot area had been a holding pen for cattle at one time and it had higher growth, presumably due to manure inputs. The 1997 plots at Burgers were grazed by deer and they seemed to prefer the persian and berseem clovers over the crimson. The areas of the 1997 plots next to the fenceline had more weeds than the plots that were further away from the fence.

On the two Chernozemic farm sites, there were few differences in weed yields among plots (Table 2-17). Weed suppression by fall rye was greater than with crimson at Melnychuks in 1997. Weed numbers were very low at Radzicks and soil fertility was high. The land had been a hayfield for many, many years before being developed for fruit crops. The 1996 plot area had been worked, summerfallowed and a buckwheat plowdown had been used in 1995 to prepare the land for planting rows of raspberries. Buckwheat plowdown is valued by organic farmers for its weed suppressive qualities and researchers have identified some of its allelochemicals (Weston, 1996). Clovers were planted between the rows of raspberry seedlings in 1996. Fall rye was planted in one strip between raspberry rows, but it was not included in the four strips of randomized blocks of clovers, so results for fall rye could not be compared with the clovers. The 1997 site was in a summerfallowed area that was being prepared for future planting of strawberries. The site was on a gentle slope with a noticeable variation in soil organic matter (O.M.). The sandy soil had lower O.M. on the upper slope and O.M. gradually increased going down the slope, which ended in a depressional area. Radzicks was the only site where rye phytomass exceeded that of the clovers. The sparse weed numbers may not have provided a vigorous test of weed competition for the clovers, but they did demonstrate the important role of land management practices in affecting "natural" weed populations.

Weed pressures were high at the Melnychuk site. Wild mustard and wild oats were the major weeds. Joe Melnychuk is a semi-retired, part-time farmer, who grows only cereal crops. Continuous cereal cropping has provided the wild mustard and wild oats with excellent conditions for proliferation. The wild mustard problem has developed in the past several years and Joe believes that it was introduced with construction of an oil lease road through the field. Variability occurred among the plots, with poorer growth in low lying areas that were waterlogged after heavy rains. Mowing in 1997 helped to reduce weed phytomass without affecting total clover phytomass.

WEED SUPPRESSION COMPARED TO FALL RYE

Two measures of competitive ability were used in our experiments:

1) suppression of mustard phytomass by clovers, and
2) weed suppression by clover compared to weed suppression by fall rye.

Results for weed suppression by berseem, crimson and persian clovers, compared to fall rye, at all six sites, are tabulated in Table 2-18. Weed suppression by berseem was equal to or better than fall rye in 10 of 14 tests (71%). The four tests where weed suppression by berseem was less than fall rye were all at Breton. Weed suppression by berseem was equal or better than fall rye at the other five sites. Results for persian and crimson clover varied among sites, but totals were similar: weed suppression was equal or better than fall rye in 43% of the tests for crimson and 50% of the tests for persian.

The approaches used in this study of crop/weed interaction were rather atypical. The majority of weed competition studies are modeled to assess the impact of variation of density, proximity or species of weeds on the yield of a crop species. In the additive model, two or more species are grown together, and the density of one (usually the crop) is held constant, while the density of the other (usually the weed) is varied (Radosevich, 1988). The crop serves as an indicator of the relative aggressiveness of the weed. Our experiments could be viewed as a variation of the additive approach: i.e. two species were grown together, and the density of weeds (mustard or natural weed population) was assumed to be constant, while the species (not the density) of the crop was varied. The mustard/weed phytomass served as an indicator of the relative aggressiveness of the clover/fall rye species.

Our experiments were affected by a weakness of additive experiments: variability of proximity factors (density, spatial arrangement, proportion) (Radosevich, 1988). In 1996, we assumed that there was a uniform density of mustard plants in the plots. Variability in mustard plant density made it difficult to differentiate between interspecific and intraspecific competition. Substitutive, systematic and neighborhood methods of studying weed competition address this problem by making proximity factors constant or consistent. By thinning the mustard plants to set the number and spatial arrangement within quadrats in 1997, proximity factors were more consistent than in 1996.

With set proximity factors and measurement of effects on individual mustard plants, our experimental design in 1997 might be viewed as a variation of a neighborhood experiment. Neighborhood experiments study the relationship between performance of individual plants of a target species (usually the crop) and the abundance/proximity of neighboring species (usually weeds) (Radosevich, 1988). The focus is on the response of individual target plants (versus a population of plants, as in additive experiments). O'Donovan (1996) recommends that more studies should focus on the effects of the crop on the weed, rather than the effects of the weed on the crop. We focused on the response of individual mustard plants and varied the "neighborhood" with different species of clover and fall rye.

In addressing the question, "What is the affect of clover species on weeds?", it could **not** be assumed that the clovers would suppress weed growth. Annual legumes are generally considered to be poor competitors. The clovers might have virtually no affect on weed growth. It is also possible, given the

N-sparing properties of clovers, that they might have a beneficial effect on weed growth by improving the availability of soil N.

As a model annual weed, brown mustard, provided many of the attributes that make plants competitive: rapid early growth, large leaves, good height, high plasticity, early seed set. Although brown mustard was used as a domesticated substitute for wild mustard (*Sinapsis arvensis* L.), *Brassica* crop species can also become weeds (as we saw with the volunteer rapeseed at Bowicks). Liebman (1989) has used both wild mustard and white mustard (*Brassica hirta* Moench) as model weeds in competition studies of mixtures. He concluded that the two mustard species were similar in their yield responses to crop competition were quite similar in morphology and phenology.

Wild mustard was so successfully adapted to the early annual cropping systems of the Prairies that, prior to the introduction of herbicides, infestations reached epidemic proportions - termed the "yellow scourge" (Hunter et al., 1990). For organic farmers such as Joe Melnychuk, the presence of wild mustard infestations can still be a "yellow scourge". Studies using wild mustard have concluded that: it is more competitive than many other plants (Pavlychenko and Harrington, 1934; Idris and Milthorpe, 1966); the lower the proportion of wild mustard in a mixture, the greater the per plant yield (Blackshaw and Dekker, 1988); wild mustard is more sensitive to intraspecific competition than to interspecific competition from wild oats and barley (Haizel and Harper, 1973); relatively light infestations of wild mustard can markedly reduce yields of legume crops such as soybean, field peas and navy beans (Radosevich, 1988; Wall, 1991, 1993).

Clover species are viewed as having many attributes that make them non-competitive: small seed size, lack of seedling vigor, slow establishment, small leaves, low height, high sensitivity to shading. Our experiments found that these attributes are not absolute in clover species and there is considerable variation among species.

Seed size influences seedling establishment. Direct relationships between seed size and seedling vigor have been identified in clover species (Black, 1958;

Knight, 1985). The relative size of young clover plants at Breton corresponded to seed size. Similarly, the ranking of the aggressiveness of clover seedlings by Blaser et al. (1956) was consistent with seed size: high - red and crimson; medium - alsike and ladino white; low - white clover. Blaser et al. noted that this was not an absolute hierarchy, but would be affected by temperature and moisture. Soil fertility and soil moisture likely influenced seedling establishment at Edmonton. Mustard seed is about the same size as crimson clover. The small seed size of mustard has not been a great disadvantage to its competitive ability and has aided its dispersal.

The larger-seeded clovers likely had an advantage in initial competition with mustard seedlings for light. Black (1958) found a direct relationship between seedling size and seed size in subterranean clover. Larger seedlings had an advantage in early intraspecific competition for light. At Breton, the final unmowed largest/smallest plant sizes were the same as the largest/smallest seed size: crimson - largest (over 2 g $plant^{-1}$) and white - smallest (less than 0.5 g $plant^{-1}$).

The clover species differed in rate of establishment and flowering date. Balansa established ground cover more quickly than the other six clovers, but it began flowering by six weeks and then growth slowed. The annual clovers (balansa, berseem, crimson and persian) had higher growth rates than the perennial clovers (alsike, red and white Dutch), as indicated by higher numbers of leaves and taller stems. It has been suggested that crimson clover is poorly suited for use as a forage in northern climates because daylengths longer than 12 hours stimulate flowering and the flowering response is accelerated when seeds germinate at low temperatures (Knight, 1985; Panciera and Sparrow, 1995).

At Edmonton, competition for light was likely a major factor in clover/mustard competition. Clovers respond as "sun" species and their relative growth rates decrease rapidly as a result of shading (Kendall and Stringer, 1985). After mustard formed a closed canopy at Edmonton, the clovers with longer, erect stems (alsike, berseem, persian) continued to grow, while the shorter plants (balansa, crimson, red, white and fall rye) stopped growing. In response to shading of clovers at Edmonton, clovers produced longer stems and fewer leaves than the unshaded clovers at Breton.

Low soil fertility was the main limiting factor for growth at Breton. Clover/fall rye growth caused greater reduction of mustard phytomass on the low fertility soil at Breton (mustard g $plant^{-1}$ reduced by 52%) than on the high fertility soil at Edmonton (mustard g $plant^{-1}$ reduced by 36%). Clover phytomass was a much higher portion of the total unmowed phytomass at Breton than at Edmonton. The N-fixing capabilities of clovers gives them an advantage on low fertility soil compared to mustard. This advantage does not occur right away. It is estimated that it takes about a month from the time of seedling emergence for the nodules to form on legume roots and begin to fix N (Green and Biederbeck, 1995). Suppression of mustard growth by a barley/pea mixture was greater under conditions of low soil N availability (Liebman and Robichaux, 1990). Shading of mustard by barley-pea intercrops was greatest when N fertilizer was not applied.

The amount of regrowth of heavily shaded clovers (alsike, balansa, crimson, red and white) at Edmonton in 1996 was similar to the amount of regrowth at Breton, after mowing. The clovers that were less affected by shading at Edmonton (berseem and persian) produced much higher amounts of regrowth at Edmonton than at Breton. This suggests that the effects of shading at a high fertility site were similar to the effects of low soil fertility. Shading can affect not only production of photosynthate, but also root growth, uptake of N from the soil and N metabolism (Liebman, 1989). Reduced supply of carbohydrates to the root system results in reduced root growth, premature senescence and decay of root tissue, and sloughing of nodules (Butler et al., 1959). White clover had the highest percent increase of phytomass (g $plant^{-1}$) in mowed treatments at Edmonton, compared to unmowed treatments. Butler et al. (1959) found that loss of roots and nodules due to shading was greater in white clover than in red clover.

Clovers are adapted to grazing and some of the clover characteristics that are viewed as disadvantageous in annual crops (low height, small leaves) are advantageous under grazing. Mowing is recommended as a method to control weeds during establishment of clovers (Lee, 1985; Weston, 1996). Mowing significantly reduced mustard phytomass at Edmonton and there was a trend towards reduced mustard/weed phytomass with mowing at Breton. Timing of mowing is important. When Edmonton plots were mowed at 6-7 weeks, the mustard plants regrew, but total clover phytomass in mowed treatments was significantly greater than that in unmowed treatments. When Edmonton plots were mowed at 10 weeks, the mustard plants did not regrow, but there was no significant gain in clover phytomass.

In the absence of weed competition, it would be expected that defoliation of vegetative clover would reduce phytomass production, compared to clover that had not been defoliated (as occurred at Breton). The addition of heavy weed competition (as occurred at Edmonton) complicated the response to defoliation. In the presence of weed competition, it would be expected that reduction of the weed phytomass would enhance the phytomass production of the clovers. It appears that when the clover plots were mowed at 10 weeks in Edmonton, the detrimental impact of defoliation was counter-acted by the beneficial impact of reduced weed competition. The net result was that mowed and unmowed clovers had similar phytomass production. When the weed competition was removed at an earlier stage of growth (at 6-7 weeks in 1997), the balance tipped, and the beneficial impact of reduced weed competition far exceeded the detrimental impact of defoliation. Although mowing did not have a beneficial effect on the clover crop at Breton, it did have the benefit of preventing/ reducing seed set of the weeds (mustard).

There might have been a point between seven and 10 weeks, when mowing at Edmonton would have produced better clover/mustard results (i.e. removal of mustard soon enough to have a beneficial impact on clover growth, but late enough so that mustard plants would not regrow). Lee (1985) recommends that weeds should be 30 to 45 cm high when mowed. If the weeds are mowed when they are too small, branches and stems may develop from lateral buds and the weeds may compete more effectively for light than if they had not been mowed. Clover plants regrow from crown buds and are usually not injured by close mowing. Altieri and Liebman (1988) state that weed ecologists could make major contributions to weed management by discerning the conditions and times under which weeds would be most vulnerable to management tactics.

The mustard suppression by fall rye cannot be explained by physical competition for light and resources by the fall rye phytomass. It is presumed that allelopathy was a factor in mustard suppression. The allelopathic properties of fall rye have been documented in numerous papers (Barnes and Putnam, 1983; Putnam 1986, 1988; Weston, 1996). Greater suppression of the mustard phytomass by fall rye occurred at Breton than at Edmonton, and this is consistent with findings of Mwaja et al. (1995) that the phytotoxicity of rye is higher under low or moderate fertility than under high fertility. The actual dynamics of allelopathy were probably quite complex in our plots, as allelochemicals have also been identified in clover and mustard species (Weston, 1996).

All seven clover species demonstrated some ability to suppress mustard/weed phytomass, but there were differences among the sites, mowing treatments and species. Overall mustard suppression ability was: fall rye > alsike, berseem and crimson > balansa > white Dutch > red > persian. Using weed suppression by fall rye as a benchmark, weed suppression by berseem was greater than that by crimson and persian. In a Nova Scotia study of cover crops, crimson had the lowest weed growth (Wallace and Scott, 1996). It is not possible to establish a definitive hierarchy of competitive ability among various species. Some of the factors that shaped these results (e.g. plant height, growth rate, allelopathy) are useful in understanding competitive ability, but many other factors (e.g. poor emergence of persian clover, density of clover plants, timing of mowing) influenced the results. Factors such as climate, location and management activities influence competitive relationships and cause hierarchies among plant species to be inconsistent (Radosevich and Roush, 1990).

The results of our experiments are relevant beyond weed control in green manure crops. Clovers have been used in mixtures and intercropped with row crops. The goal may be to find a legume that helps to control weeds, but does not reduce crop yield. Various experiments have looked at interseeding corn with legumes. Wall et al. (1991) found that intercropping silage corn with red clover can provide protection against soil erosion without significant effect on silage yield. Galloway and Weston (1996) tested white ladino clover and crimson clover as glyphosate-suppressed mulches with no-till corn. The clovers were extremely weed suppressive (reduced weed phytomass up to 90%), but they regrew after glyphosate treatment and reduced corn yield by up to 50%. In studies of legume/cereal mixtures: a mixture of field peas and barley had lower weed counts than barley alone (Izaurralde et al., 1993); intercropping annual medic with semi-dwarf barley reduced fall weed phytomass by an average of 65% compared with barley monoculture, but medic also reduced barley grain yield on 3 of 4 sites (Moynihan et al., 1996).

CONCLUSIONS

The crop/weed balance in agroecosystems is determined by physical (climate and soil), biological, and cultural management factors (Altieri and Liebman, 1988). By determining site-specific factors, identifying resource limitations, and understanding biological factors, it is possible to favorably shift the crop/weed balance through manipulation of management factors.

All clover species demonstrated some ability to suppress weed phytomass. In eight tests (mowed and unmowed treatments, Breton and Edmonton, 1996 and 1997), mustard phytomass was significantly suppressed by: fall rye in eight tests; alsike, berseem and crimson in seven tests; balansa in six; white Dutch in five; red in four; and persian in three. Weed suppression by berseem was equal to or better than fall rye at five of six sites, in 10 of 14 tests (71%). Weed suppression by persian and crimson was equal to or better than fall rye in 43-50% of tests. The weed suppression by persian clover, may have been influenced by poor emergence and establishment. Brown mustard was a very competitive model annual weed, with rapid early growth, large leaves, height advantage, and high plasticity.

Biological characteristics of clover species (growth rate, stem length, and flowering date) affected competitive ability. Clovers with upright growth habit were more competitive than low-growing species. Clover species are viewed as having many attributes that make them non-competitive: small seed size, lack of seedling vigor, slow establishment, small leaves, low height, and high sensitivity to shading. Our experiments found that these attributes are not universally true for clover species and there is considerable variation among species.

The effect of mowing on clover/weed balance varied with species, soil type and timing of mowing. Mowing had a beneficial impact on the clover/mustard balance at Edmonton (high soil fertility site), with greater benefit when mowing was applied at 6-7 weeks than at 10 weeks. At Breton (low soil fertility site), mowing did not have a beneficial impact on the clover/mustard balance, but mustard seed set was reduced. Clovers are adapted to grazing and some of the characteristics that are viewed as disadvantages in annual crops (low height, small leaves) are advantageous under grazing. Mowing may give clovers an advantage over weeds in cases where the weeds are more vulnerable to mowing than clovers.

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Table 2-3: Thousand seed weight (g), seeding rate (kg ha^{-1}), number of live seed 0.25 m^{-2}, and emergence (count 0.25 m^{-2} and %) for seven clover species at Breton and Edmonton in 1996 and 1997.

	1000 seed weight	Seeding rate	Live seed	Emergence							
				1996				1997			
				count 0.25 m^{-2}		%		count 0.25 m^{-2}		%	
	grams	kg ha^{-1}	no. 0.25 m^{-2}	Bret.	Edm.	Bret.	Edm.	Bret.	Edm.	Bret.	Edm.
Alsike	0.809	8	235	143	136	62	59	138	164	56	67
Balansa	0.830	8	241	168	92	70	38	138	219	57	91
Berseem	2.877	15	130	113	76	87	59	113	119	87	92
Crimson	5.098	15	74	61	47	83	64	69	78	94	106
Persian	1.230	12	242	82	38	34	16	89	153	36	63
Red	1.763	12	170	131	83	77	49	109	153	64	90
White	0.674	8	297	199	146	67	49	190	231	64	78
Mean						69	48			65	84
Weeks				6-7	6			5-6	4		

Table 2-4: Plant numbers (no. m^{-2}), plant weight (g $plant^{-1}$), mowed plant weight as percent of unmowed plant weight for clover and fall rye at Breton and Edmonton in 1996 and 1997.

	1996						1997						Mowed g $plant^{-1}$ as % of unmowed g $plant^{-1}$ (%)		
	Plant number m^{-2}		Plant weight (g $plant^{-1}$)				Plant number m^{-2}		Plant weight (g $plant^{-1}$)						
			Mowed			Un mow			Mowed			Un mow			
	Mow	Un mow	1st cut	2nd cut	total	1 cut	Mow	Un mow	1st cut	2nd cut	total	1 cut	1996	1997	2 yr ave.
BRETON															
Alsike	530	400	0.21	0.13	0.34	0.67	340	440	0.03	0.59	0.63	0.58	51	109	80
Balansa	680	490	0.26	0.07	0.33	0.72	590	350	0.05	0.32	0.37	0.65	46	56	51
Berseem	450	300	0.42	0.21	0.63	1.34	330	390	0.09	1.17	1.25	1.54	47	81	64
Crimson	220	160	0.71	0.07	0.78	2.27	230	230	0.17	1.74	1.91	2.19	34	87	61
Persian	220	250	0.46	0.41	0.87	1.47	310	320	0.05	1.15	1.20	1.43	59	84	72
Red	450	290	0.32	0.22	0.54	0.76	370	360	0.06	0.50	0.55	0.57	71	96	84
White	740	580	0.15	0.16	0.31	0.46	620	700	0.03	0.39	0.42	0.38	68	110	89
Average	470	360	0.36	0.18	0.54	1.10	400	400	0.07	0.84	0.90	1.05	49	86	68
Rye	80	80	0.72	0.34	1.06	0.73	60	50	0.52	0.93	1.45	1.13	146	128	137
EDMONTON															
Alsike	600	560	0.29	0.11	0.40	0.53	670	700	0.07	0.83	0.90	0.66	75	137	106
Balansa	340	330	0.76	0.07	0.84	0.75	1010	880	0.11	0.60	0.71	0.51	111	139	125
Berseem	330	260	0.72	0.72	1.44	2.63	460	390	0.15	1.85	2.00	2.65	55	76	65
Crimson	120	260	0.84	0.13	0.97	0.79	320	310	0.15	1.65	1.79	1.29	122	139	131
Persian	130	90	0.82	1.42	2.24	1.97	800	420	0.08	0.80	0.87	0.81	114	109	111
Red	270	540	0.25	0.28	0.52	0.31	560	590	0.08	0.85	0.93	0.50	170	185	178
White	570	600	0.16	0.22	0.38	0.13	960	680	0.03	0.39	0.41	0.30	294	136	215
Average	340	380	0.55	0.42	0.97	1.02	680	560	0.10	0.99	1.09	0.96	96	114	105
Rye	90	120	2.87	1.05	3.93	2.77	90	70	1.00	6.01	7.01	3.88	142	181	161
Sampled (weeks)			10	14-16					6-7	15-16					

Table 2-5: Plant characteristics in 1996 at Breton and Edmonton for seven clover species and fall rye.

	Initial			At first harvest				At second harvest				
	Number per plant			Number per plant			Ave. Plant height	Mowed			Unmowed	
	Leaves		Sec. stems	Leaves		Sec. stems		Weight per plant			Max. Stem length	Per pt. weight
								Before mowed	Re-growth	2 cut total		
	Min	Max	Max	Min	Max	Max	cm	g	g	g	cm	g
	BRETON											
Alsike	2	14	2	5	24	4	24	0.21	0.13	0.34	57	0.67
Balansa	3	17	3	7	41	5	27	0.26	0.07	0.33	60	0.72
Berseem	3	20	3	6	46	4	42	0.42	0.21	0.63	91	1.34
Crimson	3	18	3	7	34	4	41	0.71	0.07	0.78	72	2.27
Persian	3	17	2	6	28	3	34	0.46	0.41	0.87	101	1.47
Red	3	11	1	4	20	3	25	0.32	0.22	0.54	34	0.76
White	3	12	2	10	28	5	18	0.15	0.16	0.31	33	0.46
Average	2.8	15.3	2.2	6.5	31.4	4.0	30.1	0.36	0.18	0.54	64	1.10
Rye	3 to 13 tillers			4 to 12 tillers			14	0.72	0.34	1.06	23	0.73
	EDMONTON											
Alsike	3	15	2	4	23	4	47	0.29	0.11	0.40	115	0.53
Balansa	5	35	5	16	50	7	38*	0.76	0.07	0.84	134	0.75
Berseem	4	17	3	5	29	4	75	0.72	0.72	1.44	163	2.63
Crimson	5	17	2	9	28	4	52	0.84	0.13	0.97	109	0.79
Persian	5	19	3	7	26	3	51	0.82	1.42	2.24	149	1.97
Red	3	7	0	4	14	3	35	0.25	0.28	0.52	49	0.31
White	3	15	2	4	17	4	28	0.16	0.22	0.38	40	0.13
Average	3.9	17.8	2.4	6.9	26.4	4.0	52.3	0.55	0.42	0.97	108	1.02
Rye	7 to 26 tillers			5 to 14 tillers			50	2.87	1.05	3.93	76	2.77
Weeks	6-7 weeks			10 weeks				14 to 16 weeks				

* Balansa standing height was 38 cm, but stem length was 77 cm.

Table 2-6: Clover, weed and mustard phytomass (kg ha^{-1}) on a Luvisolic soil at the University of Alberta Breton plots in 1996 and 1997.

BRETON	Phytomass (kg ha^{-1})							
	1996				1997			
	Mowed		Unmowed		Mowed		Unmowed	
Species	Clov	Weeds	Clov	Weeds	Clov	Mustard	Clov	Mustard
Mustard	0	1250 a*	0	2350 a	0	800 a	0	1370 a
Alsike	1660	720 bc	2720	850 d	2130	410 b	2520	510 b
Balansa	2030	820 bc	3540	1010 cd	2160	410 b	2300	720 b
Berseem	2550	950 abc	4000	1220 bcd	4080	370 b	6040	500 b
Crimson	1670	670 bc	3670	1150 bcd	4390	340 b	5120	560 b
Persian	1720	1030 abc	3680	1600 b	3770	550 ab	4620	680 b
Red	2250	920 abc	2230	1330 bc	2020	360 b	2070	680 b
White	2030	1160 ab	2670	870 d	2560	480 b	2650	480 b
Rye	870	200 d	560	340 e	920	140 c	510	150 c
Mean	1810	820	2740	1130	2650	410	2960	610
Sampled	10 & 14 weeks		14 weeks		7 & 15 weeks		15 weeks	

Notes: "Mowed" yields are totals from 2 cuts; "Unmowed" yields are from 1 cut.* Means within weed/mustard phytomass columns followed by the same letter are not significantly different at the 0.05 level of probability using Fisher's LSD test. Clover yields are presented for information only and significant differences have not been indicated.

Table 2-7: Phytomass (g $plant^{-1}$) of mustard plants, grown in association with clover species and rye, on a Luvisolic soil at the University of Alberta Breton plots in 1996 and 1997.

BRETON	Mustard phytomass (g $plant^{-1}$)			
	1996		1997	
Species	Mowed	Unmowed	Mowed	Unmowed
Mustard	5.8 a*	7.4 a	6.8 a	11.8 a
Alsike	2.9 b	3.6 b	3.5 b	4.2 c
Balansa	2.4 bc	3.6 b	3.4 b	6.1 bc
Berseem	3.9 ab	5.2 ab	3.2 b	4.2 c
Crimson	2.4 bc	5.0 ab	3.0 b	4.5 c
Persian	3.7 ab	5.6 ab	4.6 ab	5.6 bc
Red	3.4 ab	4.7 ab	3.1 b	6.9 b
White	3.1 b	3.0 b	4.0 b	4.1 c
Rye	1.0 c	0.9 c	1.2 c	1.6 d
Mean	3.1	4.1	3.5	5.3
Mustard density: no. m^{-2}	14.2	10.6	11.8	11.4
Mustard density: std. dev.	4.7	4.4	1.2	1.8

Notes: "Mowed" yields are totals from 2 cuts; "Unmowed" yields are from 1 cut.
* Means within mustard phytomass columns followed by the same letter are not significantly different at the 0.05 level of probability using Fisher's LSD test.

Table 2-8: Height (cm) of mustard plants, grown in association with clover species and rye, on Edmonton and Breton University of Alberta plots in 1996.

Species	Mustard plant height (cm)			
	Breton		Edmonton	
	Mowed	Unmowed	Mowed	Unmowed
Mustard	107 a*	111 a	125 a	142 ab
Alsike	93 abc	113 a	111 bc	146 ab
Balansa	76 de	104 a	124 ab	139 abc
Berseem	101 abc	115 a	121 abc	140 abc
Crimson	85 cde	108 a	109 c	151 a
Persian	106 ab	115 a	116 abc	136 bc
Red	91 bcd	113 a	125 a	145 ab
White	95 abc	111 a	114 abc	140 abc
Rye	72 e	83 b	108 c	128 c
Average	92	108	117	141
Measured at	10 weeks	14 weeks	10 weeks	15-16 w'ks

Notes: "Mowed" heights were measured prior to mowing. * Means within mustard height columns followed by the same letter are not significantly different at the 0.05 level of probability using Fisher's LSD test.

Table 2-9: Clover and mustard phytomass (kg ha^{-1}) on a Chernozemic soil at a University of Alberta Edmonton site in 1996 and 1997.

EDM.	Phytomass (kg ha^{-1})							
	1996				1997			
	Mowed		Unmowed		Mowed		Unmowed	
Species	Clov	Mustard	Clov	Mustard	Clov	Mustard	Clov	Mustard
Mustard	0	5450 a*	0	9060 ab	0	5590 a	0	9280 a
Alsike	2080	3870 abc	2990	5290 de	6060	1230 de	4580	6440 bcd
Balansa	2850	3930 abc	2490	7190 bcd	7180	1940 cd	4460	6500 bcd
Berseem	4530	3140 cd	6740	4480 e	9210	950 de	10230	2830 e
Crimson	1140	3120 cd	2050	9380 ab	5680	2470 bc	3950	6410 cd
Persian	2710	3730 abcd	1710	9350 ab	7020	630 e	3380	7380 abc
Red	1440	5410 ab	1660	8220 abc	5180	1830 cd	2940	7950 abc
White	1850	3370 bcd	770	10990 a	3970	3410 b	2060	8830 ab
Rye	3700	2120 d	3400	6290 cde	6360	1280 de	2730	4610 d
Mean	2420	3720	2500	7670	6250	1940	4040	6530
Sampled	10 & 16 weeks		15-16 weeks		6-7 & 14 weeks		14 weeks	

Notes: "Mowed" yields are totals from 2 cuts; "Unmowed" yields are from 1 cut.* Means within mustard phytomass columns followed by the same letter are not significantly different at the 0.05 level of probability using Fisher's LSD test. Clover yields are presented for information only and significant differences have not been indicated.

Table 2-10: Phytomass (g $plant^{-1}$) of mustard plants, grown in association with clover species and rye, on a Chernozemic soil at the University of Alberta Edmonton plots in 1996 and 1997.

EDMONTON	Mustard phytomass (g $plant^{-1}$)			
	1996		1997	
Species	Mowed	Unmowed	Mowed	Unmowed
Mustard	46.5 a	84.6 ab	48.0 a	77.1 a
Alsike	30.2 a*	72.5 abc	11.4 de	52.4 bc
Balansa	39.8 a	61.3 bc	17.7 cd	54.3 b
Berseem	29.6 a	47.4 c	9.3 de	24.8 d
Crimson	32.0 a	100.6 a	22.0 bc	53.8 bc
Persian	38.7 a	72.7 abc	5.6 e	60.4 ab
Red	44.0 a	87.3 ab	15.9 cd	67.8 ab
White	36.8 a	65.9 abc	30.3 b	74.1 a
Rye	25.8 a	49.9 c	10.9 de	38.1 c
Mean	35.6	70.4	17.3	54.6
Ave. must. no. m^{-2}	11.0	11.5	11.3	12.0
Std. dev., must. no. m^{-2}	4.4	4.0	0.6	1.1

Notes: "Mowed" yields are totals from 2 cuts; "Unmowed" yields are from 1 cut. *Means within columns followed by the same letter are not significantly different using Fisher's LSD test.

Table 2-11: Effect of mowing on mustard (kg ha^{-1}, g $plant^{-1}$) and clover phytomass (kg ha^{-1}) for Breton and Edmonton sites for 1996 and 1997.

	Breton					
	Mustard				Clover	
	kg ha^{-1}	g $plant^{-1}$	kg ha^{-1}	g $plant^{-1}$	kg ha^{-1}	
	1996		1997		1996	1997
Mowed	820 ns	3.07 ns	410 ns	3.45 ns	1980 b*	2980 b
Unmowed	1130	4.09	610	5.26	3190 a	3470 a
p value	.1729	.2331	.1718	.1635	.0278	.0109
	Edmonton					
	Mustard				Clover	
	kg ha^{-1}	g $plant^{-1}$	kg ha^{-1}	g $plant^{-1}$	kg ha^{-1}	
	1996		1997		1996	1997
Mowed	3720 b	35.6 ns	1940 b	17.3 b	2260 ns	6230 a
Unmowed	7670 a	70.4	6530 a	54.6 a	2390	4250 b
p value	.0263	.0679	.0026	.0035	.8068	.0119

Notes: "Mustard" data is based on results for mustard from 9 species plots (7 clover species, fall rye and mustard-only). "Clover" is based on results from 7 clover species plots. Plots were mowed at 10 weeks in 1996 and at 7 weeks in 1997. "Mowed" yields are totals from 2 cuts; "Unmowed" yields are from 1 cut. "p values" are for the significance of mowing, using the Type III mean square values for Rep x Mow as the error term.
* Means within columns and location followed by the same letter are not significantly different at the 0.05 level of probability using Fisher's LSD test. "ns" = not significant.

Table 2-12: Clover regrowth (kg ha^{-1}) after mowing, total (kg ha^{-1}) of two cuts and regrowth as % of total clover phytomass at Edmonton and Breton in 1996 and 1997.

Clover	Breton						Edmonton					
	1996			1997			1996			1997		
	DM kg ha^{-1}		%	DM kg ha^{-1}		%	DM kg ha^{-1}		%	DM kg ha^{-1}		%
	RG	Total	RG	RG	Total	RG	RG	Total	RG	RG	Total	RG
Alsike	550	1660	33	2020	2130	94	500	2080	23	5630	6060	93
Balansa	320	2030	15	1480	2160	87	280	2850	10	5880	7180	82
Berseem	680	2550	26	3860	4080	94	2260	4530	49	8440	9210	91
Crimson	100	1670	6	4070	4390	92	120	1140	10	5250	5680	92
Persian	720	1720	41	3670	3770	96	1650	2710	60	6500	7020	92
Red	810	2250	36	1850	2020	90	770	1440	53	4730	5180	91
White	920	2030	45	2450	2560	94	940	1850	50	3820	3970	95
Mean	580		29	2770		93	930		38	5750		91
Mowed	10 weeks*			7 weeks			10 weeks			7 weeks		
Growth - weeks	4	14		8	15		6	16		7	14	

Notes: "RG"= regrowth of clover. "DM"= dry matter. * weeks after planting.

Table 2-13: Mustard/weed phytomass (kg ha^{-1}) significantly suppressed by clover or fall rye compared to mustard-alone, for Breton and Edmonton plots in 1996 and 1997.

	BRETON				EDMONTON				
	1996		1997		1996		1997		
			MOW	UN	MOW	UN	MOW	UN	Total
Alsike	√	√	√	√		√	√	√	7
Balansa	√	√	√	√			√	√	6
Berseem		√	√	√	√	√	√	√	7
Crimson	√	√	√	√	√		√	√	7
Persian		√		√			√		3
Red		√	√	√			√		4
White		√	√	√	√		√		5
Rye	√	√	√	√	√	√	√	√	8

Notes: "√"= mean mustard yield (kg/ha), grown in conjunction with clover or fall rye, was significantly less than the mean mustard yield of mustard-alone treatments within the same location, year and mowed or unmowed treatment, using Fisher's LSD test at the 0.05 level of probability. "MOW"= mowed treatments. "UN"= unmowed treatments.

Table 2-14: Mustard/weed phytomass (g $plant^{-1}$) significantly suppressed by clover or fall rye compared to mustard-alone, for Breton and Edmonton plots in 1996 and 1997.

	BRETON				EDMONTON				
	1996		1997		1996		1997		
Species	MOW	UN	MOW	UN	MOW	UN	MOW	UN	Total
Alsike	√	√	√	√			√	√	6
Balansa	√	√	√	√			√	√	6
Berseem			√	√		√	√	√	5
Crimson	√		√	√			√	√	5
Persian				√			√		2
Red			√	√			√		3
White	√	√	√	√			√		5
Rye	√	√	√	√		√	√	√	7

Notes: "√"= mean mustard per plant phytomass, grown in conjunction with clover or fall rye, was significantly less than in the mustard-alone treatments within the same location, year and mowed or unmowed treatment, using Fisher's LSD test at the 0.05 level of probability. "MOW"= mowed treatments. "UN"= unmowed treatments.

Table 2-15: Mustard height significantly suppressed by clover or fall rye compared to mustard-alone, for Breton and Edmonton plots in 1996.

Species	BRETON 10 weeks	BRETON 14 weeks	EDMONTON 10 weeks	EDMONTON 15-16 weeks	Total
Alsike			√		1
Balansa	√				1
Berseem					0
Crimson	√		√		2
Persian					0
Red	√				1
White					0
Rye	√	√	√	√	4

Notes: "√"= mean mustard height, grown in conjunction with clover or fall rye, was significantly less than in the mustard-alone treatments within the same location, and mowed or unmowed treatment, using Fisher's LSD test at the 0.05 level of probability. 10 weeks = mowed treatments prior to mowing. 14-16 weeks = unmowed treatments.

Table 2-16: Clover and mustard phytomass (kg ha^{-1}) on Luvisolic soils on two farm sites in 1996 and 1997.

	Burger farm				**Bowick farm**	
	Phytomass (kg ha^{-1})				P'mass (kg ha^{-1})	
	1996		1997		1996	
Species	Clov	Weeds	Clov	Weeds	Clov	Weeds
Berseem	1500	480	1740	820 ab*	3640	2360 ab
Crimson	1510	590	2200	890 ab	2550	3820 a
Persian	1780	420	1750	510 b	2740	1870 b
Rye	830	380	470	1100 a	2480	1240 b
Average	1410	470	1540	830	2850	2320
p value		ns		.0945		.0327
Sampled	9 weeks		12 weeks		12 weeks	

Notes: * Means within weed phytomass columns followed by the same letter are not significantly different at the 0.10 level of probability using Fisher's LSD test. "ns" = not significant. Clover yields are presented for information only and significant differences have not been indicated.

Table 2-17: Clover and mustard phytomass (kg ha^{-1}) on Chernozemic soils at two farm sites in 1996 and 1997.

	Melnychuk farm				Radzick farm			
	Phytomass (kg ha^{-1})				Phytomass (kg ha^{-1})			
	1996		1997		1996		1997	
Species	Clov	Weeds	Clov	Weeds	Clov	Weeds	Clov	Weeds
Berseem	1180	2040	1160	1110 b*	2930	170	2190	120
Crimson	330	2520	460	1470 a	3930	130	2840	110
Persian	n a	n a	n a	n a	3570	100	2620	190
Rye	260	2410	330	1150 b	n a	n a	4710	40
Average	590	2320	650	1240	3480	130	3090	120
p value		n s		.028		n s		n s
Sampled	12 weeks		8 & 14 weeks		9 weeks		7 & 11 weeks	

Notes: * Means within weed yield columns followed by the same letter are not significantly different at the 0.05 level of probability using Fisher's LSD test. "ns" = not significant. Clover yields are presented for information only and significant differences have not been indicated.

Table 2-18: Suppression of weed/mustard phytomass by berseem, crimson and persian clovers as compared to suppression of weed/mustard phytomass by fall rye for six sites in North/Central Alberta in 1996 and 1997.

Location	Year	Mow/Un	Berseem	Crimson	Persian
Luvisolic soils					
Breton U of A	96	mow	<	<	<
	96	unmow	<	<	<
	97	mow	<	<	<
	97	unmow	<	<	<
Burger	96	unmow	=	=	=
	97	unmow	=	=	>
Bowick	96	unmow	=	<	=
Chernozemic soils					
Melnychuk	96	unmow	=	=	n a
	97	mow	=	<	n a
Radzick	97	mow	=	=	=
Edmonton U of A	96	mow	=	=	=
	96	unmow	=	<	<
	97	mow	=	<	=
	97	unmow	>	=	<
Total of tests with "=" or ">"			10 of 14	6 of 14	6 of 12
% of tests with "=" or ">"			71%	43%	50%

Notes: "=" weed/mustard yield (kg/ha) was not significantly different with clover than with fall rye within the same location, year and mowed or unmowed treatment, using Fisher's LSD test. "<" weed suppression was significantly less with clovers than with fall rye. ">" weed suppression was significantly greater with clover than with fall rye. "na"= not applicable.

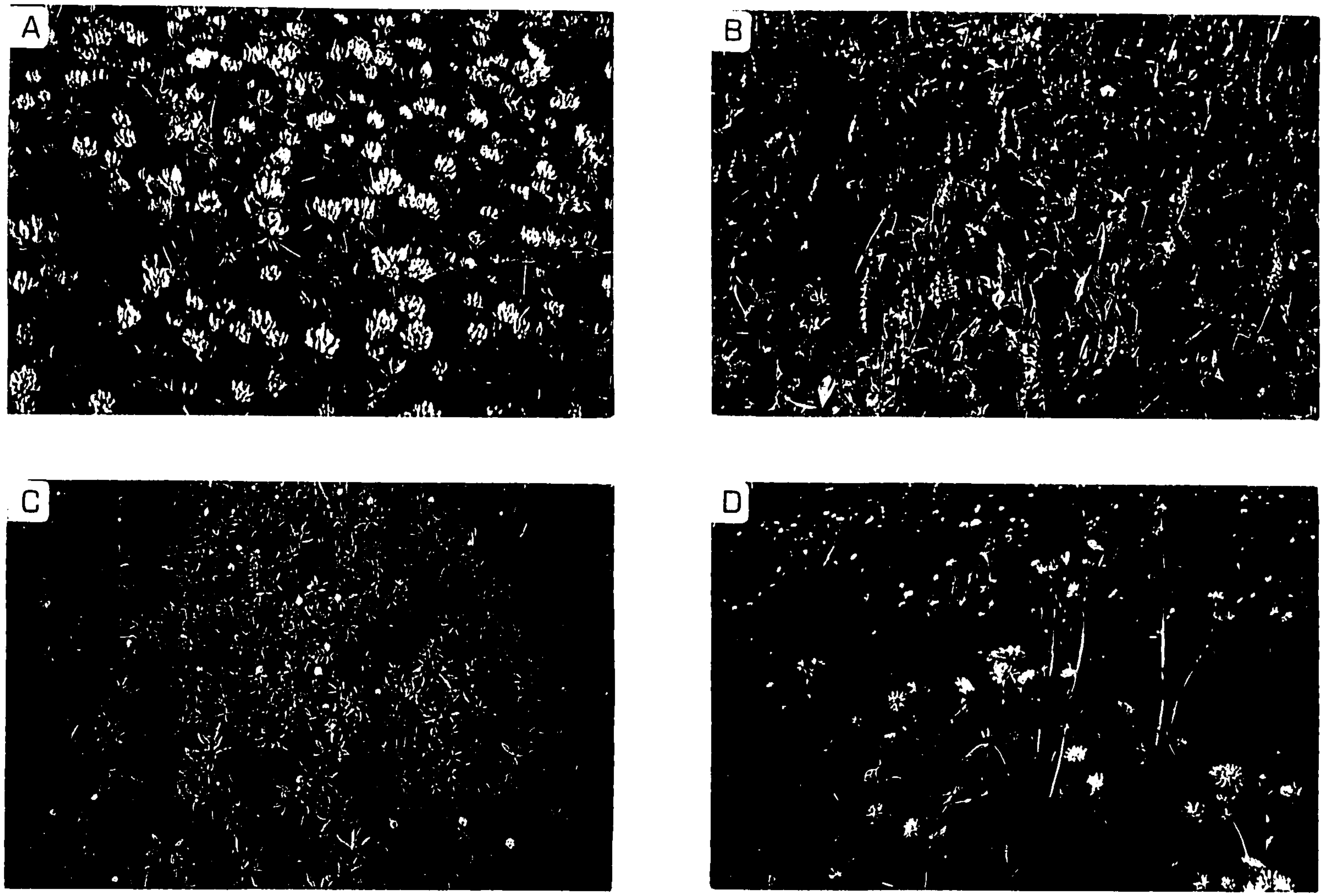

Plate 2-1: Annual clover (*Trifolium*) species. A) Balansa (*T. michelianum*). B) Crimson (*T. incarnatum*). C) Berseem (*T. alexandrinum*). D) Persian (*T. resupinatum*).

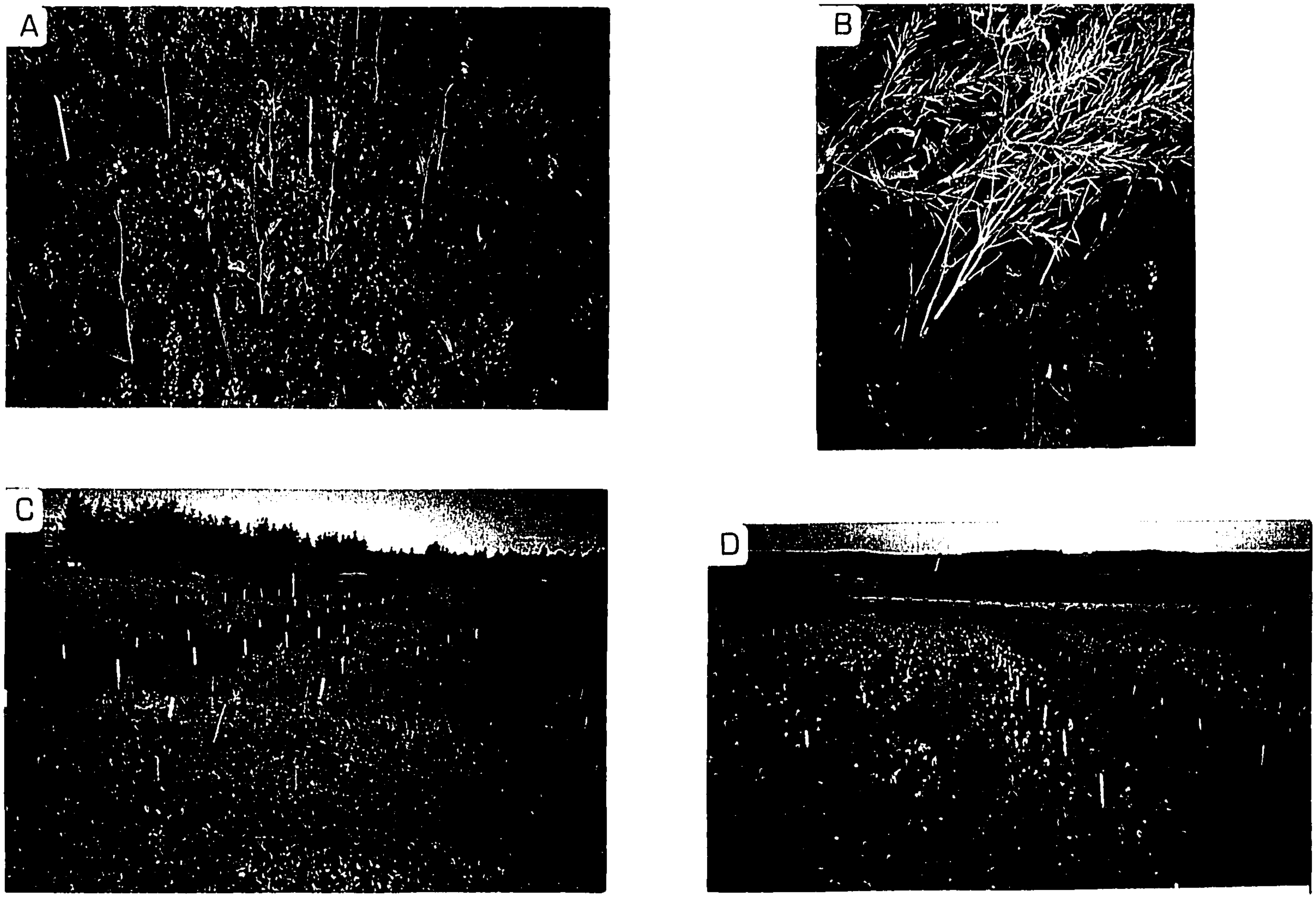

Plate 2-2: A) Early growth of balansa clover with mustard in quadrat at Edmonton. B) Late growth of white clover with unmowed mustard at Edmonton. C) View of mowed and unmowed Edmonton clover plots, following mowing in 1997. D) Breton 1997 clover plots, prior to mowing.

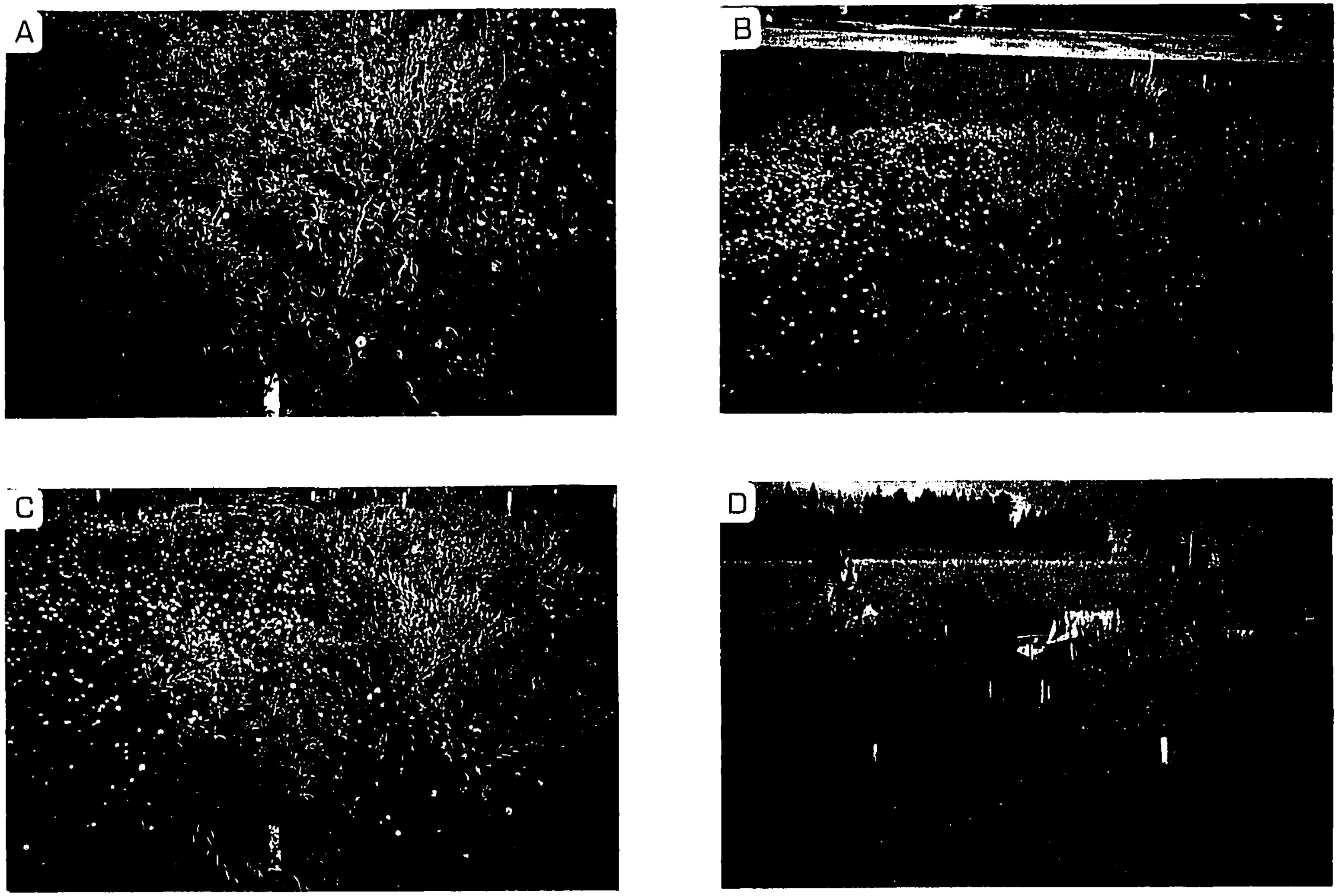

Plate 2-3: A to C - Clover growth with mustard at Edmonton in 1997. A) Berseem (left) and crimson (right) in mowed plots. B) Alsike (l) and red (r) in mowed plots. C) Berseem (l) and white Dutch (r) in unmowed plots. D) Growth of berseem (l), fall rye (centre) and balansa (r) with mustard in mowed 1996 plots at Breton.

Chapter 3

Impact of seven clover species and fall rye on soils in north-central Alberta.

INTRODUCTION

Legume crops are a key component of sustainable cropping systems. When properly managed in cropping systems, legumes can be used to improve many aspects of soil quality: nitrogen levels, organic matter, reduced erosion by wind and water, water-holding capacity, tilth, aeration, and biological activity (Green and Biederbeck, 1995). New annual legume crops offer the potential to diversify and improve economic returns of farmers. Farmers have various reasons for using legume crops to replace or supplement commercial fertilizers (costs, environmental concerns, long-term soil benefits). Pressures to conserve soil resources, to maintain environmental quality and to replace input-intensive agriculture with knowledge-intensive agriculture have contributed to a renewed interest in legume crops.

Research studies in Alberta have assessed a number of annual legumes for yield, water use, potential N contribution, and impact on subsequent crop. Many of the Alberta and Saskatchewan studies of annual green manures have focused on large-seeded legumes such as peas, lentils and fababeans (Janzen et al., 1990; Jensen, 1992; Jensen and Jans, 1993; Biederbeck et al., 1993; Izaurralde et al., 1993; Rice et al., 1993; Green and Biederbeck, 1995). These studies have sometimes included small-seeded perennials (alfalfa, red clover, alsike clover) or biennials (sweetclover) for comparison. The green manure potential of small-seeded annual legumes (clovers, medics) has largely been untested in Alberta. Some annual clover species (berseem, persian, crimson and balansa) produced promising forage yield results in southern Alberta trials (Fraser, 1995).

The information available in Alberta and Saskatchewan on green manures is mainly oriented to zones where heat is adequate but moisture is a limitation to agriculture. The water use of legume green manures is a major concern.

Sweetclover works very well as a green manure in these areas. By contrast, the north-central region of Alberta (Aspen Parkland and low Boreal ecoregions) receives adequate precipitation but heat is a limitation to agriculture. With higher precipitation, the prolific growth of sweetclover can be difficult to manage as a green manure. Red clover, alsike clover and alfalfa are preferred in north-central Alberta for their combined forage and green manure use. While the benefits of perennial legumes are substantial, there is a need for more annual legumes to fit with the rotations of cereals and oilseeds.

The soils of north-central Alberta are mainly Black Chernozems and Gray Luvisols. These soils represent two extremes of natural fertility. Gray Luvisols are acidic, leached, degraded soils with an eluviated horizon (Izaurralde et al., 1993). They have a low organic matter content and form hard surface crusts upon drying. Surface crusting causes management problems such as water runoff and poor seedling emergence. Cultivated Gray soils are deficient in nutrients because they are low in organic matter and because high moisture has leached away many nutrients. The soils are most deficient in nitrogen, but sulphur, phosphorous and potassium may also be limiting (Ellert, 1995). Gray Luvisols developed under boreal forest vegetation. In the low Boreal (deciduous and mixed wood) ecoregion, where the University of Alberta Breton plots are located, the vegetation is dominated by aspen, with some white spruce (Ellert, 1995).

The Thick Black Chernozemic soils are the most fertile of the prairie soils. The fertility of these soils is due to high organic matter, high nutrient and base status, and good structure. "Edmonton lies at the northern fringe of the Black Soil Zone. The deep root systems of tall grasses and forbs of the Aspen Parkland plant communities added large amounts of organic matter to the surface soil, where it is continuously altered to humus by soil micro-organisms. The humus is incorporated within the mineral material to form highly fertile granular and friable soils." (Pawluk, 1993) The Thick Black soils formed in the Transitional Grassland (Aspen Parkland) ecoregion, the region of transition between prairie and forest (Ellert, 1995). The vegetation consists of a mixture of grasses (such as fescue), shrubs and bluffs of aspen trees.

In this study, we focus on annual clovers and their impact on soils. The objectives of the study were to:

a) assess the ability of four annual clovers to fix N from the atmosphere;
b) assess the impact of plowdown of clovers on soil NO_3-N and subsequent crop;
c) compare annual clovers with perennial clovers and fall rye;
d) compare the growth of annual clovers on Chernozemic and Luvisolic soils in north-central Alberta;
e) test the use of annual clovers in organic farming systems.

MATERIALS AND METHODS

RESEARCH DESIGN

Trials were conducted in 1996 and 1997 at six sites in north-central Alberta, with two to seven species of clover and fall rye at each site. Research sites (identified on a map in Appendix 1) were chosen to compare growth on Black Chernozemic soils with Gray Luvisolic soils. The four farms that participated in the project are organic producers and members of the Sustainable Agriculture Association (of Alberta) (see Plates 3-2 and 3-3 for pictures from the farms). The three locations on Gray Luvisolic soils were: Bowicks (grain/forage/ livestock farm near Barrhead); Burgers (grain/forage/ livestock farm near Breton); and the University of Alberta Breton Plots. The University of Alberta Breton site is located approximately 110 km southwest of Edmonton (53° 07'N, 114° 28' W). The soil is an Orthic Gray Luvisol, mapped as Breton loam series, and developed under boreal forest vegetation on glacial till parent material. The three locations on Black Chernozemic soils were: Melnychuks (grain farm near Redwater); Radzicks (fruit farm near Spruce Grove); and the University of Alberta Edmonton Research Station. The Edmonton site is in south Edmonton (53° 25' N, 113 ° 33' W) on an Orthic Black Chernozemic soil mapped as Malmo silt loam series. The soil was formed on glaciolacustrine sediment and has a high clay content.

The six research sites were chosen to provide a range of soil characteristics and fertility. Soil samples (depths 0-15 cm and 15-30 cm) were taken in the spring of 1996 and 1997 at each site and tested for NPKS, O.M., Na, pH and E.C. by the AAFRD Soil and Crop Diagnostic Centre. The 1997 soil samples were also tested for micro-nutrients Zn, Cu, Mn and Fe. The initial soil test results (Appendix 2) confirmed that the sites differed in levels of macro-nutrients, micro-nutrients, pH and organic matter. Soil nitrogen levels were generally higher in the Chernozemic soils than in the Luvisolic soils. The Luvisolic soil at the University of Alberta site at Breton represented the extreme low end of soil fertility, with deficient levels of NPKS, and organic matter of about 3%. The University of Alberta site at Edmonton provided the opposite extreme of soil fertility, with the highest overall NPKS levels and organic matter of over 10%. The soil fertility levels of the two Luvisolic farms and the two Chernozemic farms were intermediate between the U of A sites. The soil N levels of the four farm sites were fairly similar, with the exception of much higher soil N levels at the 1996 Radzick site. The majority of the soils were phosphorus deficient.

Four annual clover (*Trifolium*) species, [balansa (*T. michelianum* Savi var. *balansae* Boiss.), berseem (*T. alexandrinum* L.), crimson (*T. incarnatum* L.), and persian (*T. resupinatum* L.)] were compared with three commonly-used perennial clovers [alsike (*T. hybridum* L.), red (*T. pratense* L.), and white Dutch (*T. repens* L.)]. Fall rye (*Secale cereale* L.) was grown as a "check" species in order to compare the clovers with a non-legume crop. The clovers and fall rye were grown as annuals in 1996 and 1997. Species, cultivars and seeding rates are listed in Table 3-1.

Table 3-1: Common names, scientific names, cultivars and seeding rates (kg ha^{-1}) of species grown.

Common name	Scientific name	Cultivars	Seeding rate (kg ha^{-1})
Alsike clover	*Trifolium hybridum* L.	Aurora	8
Balansa clover	*Trifolium michelianum* Savi. var. *balansae* Boiss.	Paradana	8
Berseem clover	*Trifolium alexandrinum* L.	Bigbee	15
Crimson clover	*Trifolium incarnatum* L.	Au Robin	15
Persian clover	*Trifolium resupinatum* L.	Felix, Ciro	12
Red clover	*Trifolium pratense* L.	Altaswede	12
White Dutch clover	*Trifolium repens* L.	common	8
Fall rye	*Secale cereale* L.	Kodiak	70

Table 3-2: Soil type, fertilizer added, species tested, seeding dates, plowdown, and subsequent crop for six research sites in north-central Alberta for 1996 and 1997.

Site	Soil type	Fertilizer (kg ha^{-1})	Species tested	Seeding date	Plowdown	Subseq. crop
		1996				**1997**
Breton U of A	Luvisol	P - 22 K - 50	A, Ba, Be, C, PF, R, W, FR	7-Jun	Mustard removed; clover & rye plots rototilled on Sept. 13.	barley
Edmonton U of A	Chernozem	none	A, Ba, Be, C, PF, R, W, FR	4-Jun	Mustard removed; clover & rye plots rototilled on Sept. 26.	barley
Burger	Luvisol	P -10 rock P	Be, C, PC, FR	11-Jul	Plots cut with flail mower and plowed down Fall '96.	oats
Bowick	Luvisol	none	Be, C, PC, FR	12-Jun	Plots cut and baled in Sept., then cultivated.	oats
Melnychuk	Chernozem	P - 20 rock P	Be, C, FR	11-Jun	Plots left standing over winter, then plowed down Spring '97.	barley
Radzick	Chernozem	P - 10 rock P	Be, C, PC	3-Jul	Left as ground cover over winter, then plowed down in late Spring '97.	n a
		1997				**1998**
Breton U of A	Luvisol	P - 22,K - 50 in 1996	A, Ba, Be, C, PF, R, W, FR	9-Jun	Mustard removed; clover & rye plots rototilled on October 16.	barley
Edmonton U of A	Chernozem	none	A, Ba, Be, C, PF, R, W, FR	30-May	Mustard removed; clover & rye plots rototilled on October 20.	barley
Burger	Luvisol	P -10, rockP	Be, C, PC, FR	10-Jun	-	-
Bowick	Luvisol	none	berseem-oat mixture	June	One cut of hay in Aug., then berseem regrowth used as plowdown.	-
Melnychuk	Chernozem	P -20, rockP	Be, C, FR	12-Jun	-	-
Radzick	Chernozem	P -10, rockP	Be, C, PC, FR	4-Jul	-	-

Notes: Species tested: A= alsike clover, Ba= balansa clover, Be= Berseem clover, C= crimson clover, PC= persian "Ciro" clover, PF= persian "Felix" clover, R= red clover, W= white Dutch clover, FR= fall rye.

Clover seeds were inoculated with appropriate strains of *Rhizobium leguminosarum biovar trifolii*, broadcast onto the soil surface by hand and then incorporated by hand raking. Fall rye was seeded in 17.8 cm or 20 cm (7-8 inch) rows. At most sites, growth of clover/fall rye was followed by a cereal crop (barley and oats) in the subsequent year. Table 3-2 summarizes information for the six research sites: clover species grown, seeding, mowing, harvesting, plowdown of plots, and subsequent cereal crop.

At the Breton and Edmonton University sites, brown mustard (*Brassica juncea*) was used as a model weed and was added to all plots, including mustard-only control plots. Nine species were tested under mowed and unmowed treatments in a split-plot design. In the fall, mustard phytomass was removed from the plots by hand and the remaining growth of clover and fall rye was worked into the soil by rototilling to a depth of about nine cm. Plots were rototilled with care, to avoid mixing between plots. Plot areas were seeded to barley in 1997 and 1998 (Plates 3-1A and 3-1B).

Each of the four farms tested two or three clovers and fall rye. Plots were not weeded. In 1997, one farm (Bowicks) conducted a field-scale (10 acre) trial of a mixture of berseem clover and oats, with one cut used for feed and the regrowth used for plowdown. Plowdown of clovers was not necessarily applied. At three of the farms (Bowick, Burger and Melnychuk), the area that was seeded to clovers/fall rye in 1996 was seeded to a cereal crop in 1997. Bowicks and Burgers grew oats as a subsequent crop to clovers/fall rye, and Melnychuks seeded barley. At the fruit farm, Radzicks, the area that was seeded to clovers/fall rye in 1996 was between rows of raspberry seedlings. The clovers/fall rye were left as winter cover and then cultivated/plowed down in late spring 1997. The areas between the raspberry rows were then seeded to grass.

The experimental design at each site was a randomized complete block (RCB) with four replicates and individual treatment plot size varied from 10 m^2 to 24 m^2. No nitrogen fertilizer was added to research plots, but some P and K was applied prior to seeding clovers/fall rye. The site at Breton (U of A), received P at 22 kg ha^{-1} as P_2O_5 and K at 50 kg ha^{-1} as KCl. In keeping with acceptable organic amendments, rock phosphate was used as a P source on the farm plots. Based on a rate of 100 lbs rock phosphate $acre^{-1}$ at Burgers and Radzicks, and 200 lbs $acre^{-1}$ at Melnychuks, the actual P applied was 10 and 20 kg P ha^{-1}, respectively. The rock phosphate was 21.34% P_2O_5 and 9.18% P. Rock phosphate is a slow release form of P fertilizer which takes about three years for the P to become available.

PLANT NITROGEN

A one m^2 quadrat was marked in each of the clover/fall rye plots in 1996 and 1997. In August/September, quadrats were harvested by hand, cutting the plants at a height of approximately 5 to 7.5 cm (2 - 3 inches) above ground level. Clover and fall rye plants were separated from weeds, put in bags, dried for 72 hours at 52 °C and weighed. Clover and fall rye samples from three replicate blocks of unmowed plots at Breton were finely ground (using a two step grinding process), and were then analyzed for atom % ^{15}N abundance and plant %N using an ANA SIRA (Automatic Nitrogen Analyzer, Stable Isotope Ratio Analyzer) 10 mass spectrometer (VG Isogas, Middlewich, England) in the soils laboratory of the Department of Renewable Resources. Methods based on natural abundance of ^{15}N (equation 1) and the classical difference method (equation 2) were used to calculate the percentage of clover plant N derived from the atmosphere (Ndfa) by biological dinitrogen fixation (Rennie and Rennie, 1983). The ^{15}N natural abundance technique has been shown to be accurate when compared with ^{15}N-enriched techniques in the field for determination of %Ndfa of soybeans, field beans, clover and alfalfa (Bardin et al., 1977; Domenach et al., 1979; Rennie, 1982; Rennie and Kemp, 1983; cited in Rennie and Rennie, 1983).

To calculate the % Ndfa using ^{15}N results, the natural abundance of atmospheric ^{15}N was taken as 0.3663 (atom%), and the following equation was used:

$$\%\ \text{Ndfa by } ^{15}N = [1 - (\text{atomic natural abundance of } ^{15}N \text{ in clover} - 0.3663)/ (\text{atomic natural abundance of } ^{15}N \text{ in fall rye} - 0.3663)] \times 100. \quad [1]$$

The equation is based on the premise that if a legume derives 100% of its N from the atmosphere, the amount of ^{15}N in the plant material will be 0.3663. The amount of ^{15}N in the non-legume represents the natural abundance level of ^{15}N in the soil (which is greater than 0.3663). Soils in western Canada have an average ^{15}N enrichment of 8.8 ± 1.2%, compared to ^{15}N enrichment of 0.0% for the atmosphere (Rennie and Rennie, 1983). With biological dinitrogen fixation, the natural abundance level of plant ^{15}N decreases as compared to plants that derive N from the soil.

To calculate the % Ndfa using difference (D method), we used the equation:

$$\% \text{ Ndfa by difference} = [1 - \text{total N (g m}^{-2}\text{) of fall rye/ total N (g m}^{-2}\text{) of clover]} \times 100. \quad [2]$$

One sample of berseem clover and fall rye was similarly analyzed from each of the other five research locations. The potential N contribution of the plowdown material was also calculated.

SOIL NITROGEN

At the University sites, clovers and fall rye were plowed down in the fall of 1996 and 1997. The following spring, soil samples were taken to assess the impact of the plowdown on soil N. Soil samples (depths 0-15 cm and 15-30 cm) were taken from three replicate blocks of the nine unmowed species treatments (seven clovers, fall rye, mustard alone). In the spring of 1997, soil samples were also taken at each farm: from one plot that had grown berseem in 1996; and from one plot that had grown fall rye in 1996. All samples were analyzed for NO_3-N.

BARLEY AND OATS

At the University sites, a one m^2 quadrat of barley was sampled in 1997 and 1998 from each of the nine unmowed species treatments (seven clovers, fall rye, mustard alone) of three replicate blocks. On the farms, barley/oats samples were collected in 1997 from one m^2 quadrats of two or three species treatments for three replicate blocks. Cereal plant numbers and tiller numbers were counted for each quadrat. Cereal plants were put in bags, cured if necessary, then dried for 72 hours at 52 °C and weighed. Plant material was threshed to separate seed grain, and the weight of grain was measured. In 1997, cereal grain samples were ground and analyzed for plant %N, using the Kjeldahl procedure.

STATISTICAL ANALYSIS

Crop and soil data were statistically analyzed according to the randomized complete block design. Analysis of variance was performed on data for soil NO_3-N, barley and oat dry matter and grain yields (kg ha^{-1}, g $plant^{-1}$, g $tiller^{-1}$), tillers $plant^{-1}$, and grain %N using SAS version 6.11 (SAS Inst., 1995). Where possible, two years of data were combined for analysis. Two year data for barley yields at Edmonton and soil NO_3-N at Breton could not be combined due to lack of homogeneity of variance, significant differences between years, and/or significant year x species interaction. Significant differences between species treatments were determined using an F-test. Means were separated by using Fisher's LSD values when the F-test denoted significance ($P \leq 0.05$).

RESULTS AND DISCUSSION

CLIMATE CONDITIONS

Annual precipitation for the province of Alberta was 24 mm above average in 1996 and 15.8 mm above average in 1997 (AAFRD, 1998). For April to August of 1998, precipitation for Central Alberta was near normal and mean temperatures were 1.5° C above average. Annual mean temperatures were 2.1° C below average in 1996 and 1° C above average in 1997.

Rainfall in June of 1996 and 1997 was much higher than average at Breton and Edmonton (Appendix 3). Breton normally has higher rainfall than the Edmonton area: average annual precipitation of 547 mm at Breton and 455 mm at Edmonton. In 1997, precipitation was lower at Breton than at Edmonton (Breton - 248 mm, Edmonton - 264 mm). Some of the farms received even higher amounts of rainfall than Edmonton and Breton. In Melnychuk's area (Redwater), many fields were affected by waterlogging and flooding in 1996 and 1997. Higher than average precipitation in 1996 and 1997 caused a few delays in seeding and resulted in short-term waterlogging of some plots.

Normally, Breton has a severe to moderate heat limitation, with a growing season of about 80 frost-free days; while Edmonton has a slight to moderate heat limitation with a growing season of 90 to 110 frost-free days. Temperatures in 1998 were well above normal, with summer-like weather in

April and May. Seasonal precipitation was near normal, but dry conditions in some locations (including Edmonton) in late May/early June caused stress in emerging crops (AAFRD, 1998). Growing degree day totals were about three to four weeks ahead of normal in Alberta, contributing to early crop maturity.

NITROGEN FIXATION

In order to test the potential of the clovers to derive N from the atmosphere through biological dinitrogen fixation, we chose to analyze plant samples from the site with the lowest levels of soil N (Breton). Plant samples, taken from unmowed Breton plots at the end of the season (14 weeks after planting in 1996 and 15 weeks in 1997), were analyzed for ^{15}N and plant %N.

All seven clover species, grown at Breton, derived the majority of their N from the atmosphere (Table 3-3). Results for %Ndfa (% nitrogen derived from the atmosphere) of clover shoot growth ranged from 59% to 93%. There were no consistent differences in %Ndfa between clover species. Average values for %Ndfa calculated by D method (using N yield differences from non-legume fall rye) were higher than values calculated by ^{15}N method (using natural abundance ^{15}N differences from fall rye). Average %Ndfa was 89% by D method and 76% by ^{15}N method. A limitation of the D method of %Ndfa is in finding a non-fixing reference species which has a similar pattern of soil N use as the legume. Estimates of %Ndfa using the D method may have over-estimated N fixation. The N yield of above-ground phytomass of the reference species (fall rye) may have been lower than that which would have accumulated in a non-N-fixing clover. Fall rye plants may differ from clovers in their pattern of soil N uptake or may partition a greater amount of N to root tissues. Using differences in herbage N yield to estimate %Ndfa in annual medics, Zhu et al. (1998) obtained similar results using either noninoculated *Medicago* species or annual ryegrass (*Lolium multiflorum* L.) as reference species. When root N yield was used to estimate %Ndfa of medic root tissues, negative values of %Ndfa were obtained using ryegrass roots as reference, versus 50% Ndfa using the noninoculated *Medicago* species as reference. Ryegrass roots had higher N yield than the medic roots.

Results for %Ndfa by ^{15}N method were more variable than results by D method. Standard deviations for %Ndfa were higher with the ^{15}N method (16.2% and 13%) than with the D method (3.3% and 3.6%). The accuracy of the natural abundance ^{15}N method is limited by the capability of instruments to detect very small amounts of ^{15}N and the variability of soils. Significant changes in the natural abundance levels of atom % ^{15}N occur at the point of maximal precision of most mass spectrometers (Rennie and Rennie, 1983). Differences in natural abundance ^{15}N occur at 0.0001 atom% ^{15}N, and the precision of the SIRA 10 mass spectrometer ranges from $\pm$ 0.0001 to $\pm$ 0.0005 atom% ^{15}N depending upon the method of sample preparation. The technician operating the machine notes that the error factor for atom% ^{15}N analysis is higher with heterogeneous samples like soils than with uniform samples such as crystals.

Clover plant %N ranged from 1.9% to 3.2% in 1996 and 1.6% to 3.0% in 1997 (Table 3-3). Fall rye %N was 1.5% in 1996 and 1.6% in 1997. The %N of the perennial clovers (white Dutch, red and alsike) was higher than %N of the annual clovers (crimson, balansa, berseem and persian), while dry matter (kg ha^{-1}) of the annual clovers was higher than that of the perennial clovers. In Kirchmann's study (1988), there were fewer differences in shoot %N values between annual and perennial clovers. For samples taken at 101 days after planting (similar to sampling date for Breton), Kirchmann's results for shoot %N were: white clover - 3.1%, red clover - 2.6%, berseem - 2.5%, and persian - 2.2%.

In 1996 at Breton, the average N yield of the clover growth was 80 kg N ha^{-1}, and ranged from 71 to 90 kg N ha^{-1} (Table 3-3). The average N yield of the clover growth was 74 kg N ha^{-1} in 1997. Greater variability in dry matter resulted in a wider range of N yield in 1997, with a low of 44 kg N ha^{-1} for balansa and a high of 110 kg N ha^{-1} for berseem. Assuming 80% Ndfa and using an average N yield of 77 kg N ha^{-1}, the average amount of N fixed by the clovers was 62 kg N ha^{-1}. This compares well with the annual N fixation by perennial clovers on a similar soil and with other studies of green manures in Alberta. Annual N fixation on a Gray Luvisolic soil in the Peace River region was 15-77 kg N ha^{-1} for red clover and 20-143 kg N ha^{-1} for alsike (Rice, 1980).

In 6-8 weeks of growth at six sites in Alberta, annual legumes were capable of fixing 40 to 100 kg N ha^{-1}(Jensen, 1992). Nyborg et al. (1995) calculated that the Breton loam soil releases an average of about 20 kg N ha^{-1} $year^{-1}$. If it is assumed that 20 kg N ha^{-1} of the plant N yield was obtained from the soil, and the remainder of the plant N was obtained from the atmosphere, the average N fixation would be 60 kg N ha^{-1} in 1996 and 54 kg N ha^{-1} in 1996. This would represent 75% Ndfa in 1996 and 73% Ndfa in 1997. On this basis, the results obtained using the ^{15}N method (76% and 75% Ndfa) may be a more accurate measure of %Ndfa than the results by D method (90% and 88% Ndfa).

The estimated C:N ratios for the clovers ranged from 12 for white to 21 for crimson (Table 3-3). The C:N ratios of the perennial clovers (white Dutch, red and alsike) were lower than those of the annual clovers (crimson, balansa, berseem and persian). The higher C:N ratios in the annual clovers may be explained by greater stem growth and higher lignin content of stem tissue than leaf tissue. Also, the crimson and balansa plants were more mature (going to seed) than the other clovers when samples were gathered in September. A C% value of 37% was used to calculate C:N ratios, based on the average %C results of Kirchmann (1988) for red, white, persian and berseem clovers (sampled at 101 days) in a field study conducted in Sweden. Results compare with Kirchmann's C:N ratios for clover shoots of: berseem 16.7 (C:N = 16.7:1), persian 15.8, red 13.7, and white 10.7. The estimated C:N ratios for crimson at Breton (C:N = 21) is higher than Ranells and Wagger (1996) finding of a C:N ratio of 17 for crimson clover (grown as a winter cover crop). The C:N ratio of fall rye, grown in the same study, was 38 to 42. Carbon-to-nitrogen ratios of 25:1 to 30:1 have been suggested as the threshold between net mineralization and immobilization of N (Allison,1966). Sarrantonio (1991) suggests that when the C:N ratio of plant residues exceeds 20:1, immobilization is likely. One would expect immobilization of N to occur with rye residue but not with the clover residue.

Rannells and Wagger (1996, 1997) suggest that the low C:N ratios of legumes residues may not always be advantageous compared to residue with higher C:N ratios. The rates of N release from grass-legume biculture residues were 6% to 15% less than those of legume monoculture residue, in four to eight weeks after corn planting. They suggest that the higher C:N ratios in grass-legume bicultures may moderate the release of cover crop N to a subsequent corn crop and enhance N-use efficiency.

We did not measure the phytomass and N yield of roots. Perennial clovers have greater root phytomass than annual clovers. Kirchmann (1988) found that the root/shoot ratio of white clover was much higher (42.3%) than that of persian clover (2.5% to 5%), at 20 weeks of growth. The C:N ratio of root tissues was 15 to 25, compared to 10 to 17 in shoot tissue. He concluded that the risk of N losses may be lower with green manure crops which accumulate considerable amounts of N in their root system, because root residue of clovers would release N more slowly than shoot tissue.

SOIL NITRATE

To test the potential of the clovers to improve the N status of soils, plots at Edmonton and Breton were cleared of mustard plants and the phytomass of clover and fall rye was plowed down. The following spring, soil samples were taken at 0-30 cm and analyzed for NO_3-N. Some of the perennial clover plants survived rototilling/cultivation and regrew in plots at Edmonton and Breton. A few crimson clover plants grew from seed in the plowdown. The fall rye and mustard plots provided "checks" to compare with the clovers. Because mustard plants were removed before plowdown, mustard plots represent a no-above-ground-phytomass plowdown check. The fall rye plots provided a non-legume comparison plowdown.

For Breton, a significant year x species interaction occurred for soil NO_3-N and differences between years were almost significant ($P = 0.06$), so data is presented by year (Table 3-4). Soil NO_3-N means were somewhat higher in 1997 than 1998, which may have been due to earlier plowdown in 1996 (Sept. 13) than in 1997 (Oct. 16). Soil NO_3-N in the rye and mustard plots remained close to the initial levels of 1 mg kg^{-1}. With clover plowdown, there was evidence of increased available soil N. In 1997, plowdown of white Dutch, persian, berseem, crimson and alsike significantly increased soil NO_3-N, compared to rye and mustard plots. In 1998, soil NO_3-N was significantly higher in crimson and white Dutch plots than in rye and mustard plots. Soil

NO_3-N levels were higher in the 0-15 cm soil depth than in the 15-30 cm soil depth, but the clovers caused significant increases in NO_3-N in both depths (data not shown).

At Edmonton, the initial soil NO_3-N levels (29 mg kg^{-1}) were much higher than at Breton. With the growth and removal of large amounts of mustard phytomass, soil NO_3-N declined in all plots. Plowdown of the accompanying clover and fall rye phytomass in unmowed plots produced variable results. Plowdown of white Dutch, fall rye, persian, berseem, balansa and alsike resulted in significantly higher soil NO_3-N than the no-phytomass plowdown in mustard plots. White Dutch plots had the highest soil NO_3-N results (16 mg kg^{-1}), and significantly higher NO_3-N levels than the other clovers. Fall rye plots had significantly higher NO_3-N than berseem, balansa, alsike, red and crimson clover plots. In 1997, the significant differences in soil NO_3-N occurred in the 15-30 cm soil depth, while in 1998 the significant differences were in the 0-15 cm depth. Earlier plowdown in 1996 (one month earlier than in 1997) and higher precipitation in 1996/97 may account for greater infiltration of NO_3-N into the soil profile. In 1996, the plots were plowed down on September 26, and 18 mm of rain fell in the next three days. In mid-April of 1997, 30 mm of rain fell on the plowdown plots, and soil samples were taken on April 29. Soil NO_3-N levels were lowest in the areas that had been waterlogged in the spring of 1996. Due to periods of heavy rainfall, the soil NO_3-N levels in the 1996/97 plots at Edmonton were likely affected by leaching and denitrification.

At the time of sampling, soil NO_3-N levels were higher with white Dutch plowdown than with plowdown of the other clovers. The greater soil NO_3-N contribution of white Dutch clover cannot be accounted for by greater shoot phytomass or shoot N yield. Higher %N in white clover tissues and lower C:N ratio may have contributed to greater soil NO_3-N levels, but red and alsike clovers had similar %N and C:N ratios. Greater N yield of white clover root tissue may account for the higher soil NO_3-N levels. Kirchmann (1988) found that white clover contained higher amounts of N in roots (7.5 g N m^{-2} of root) than four other clovers. In a study comparing plowdown of berseem and alfalfa, soil N availability was consistently greater for alfalfa, although herbage plowdown N was higher for berseem (Westcott et al., 1995). It was concluded that the higher soil N availability with alfalfa was due to a greater root N contribution from alfalfa.

The NO_3-N results at Edmonton indicate that plowdown of a non-legume crop (fall rye) may provide as much soil N benefit as legume plowdown, on high N soils. Because the clovers and fall rye were not grown as monocultures, but were grown in conjunction with significant amounts of mustard phytomass, removal of soil nutrients by the mustard contributed to soil N dynamics. Higher soil NO_3-N results in fall rye plots may be partly explained by lower mustard phytomass in the previous year's rye plots. Mustard phytomass in unmowed, fall rye plots in Edmonton was lower than in the majority of clover plots, but some clover plots had lower amounts of mustard phytomass than in the rye plots. Total phytomass in the 1997 unmowed rye plots was lower than in other plots (7300 kg ha^{-1} compared to 9300 - 13,100 kg ha^{-1}) but the total phytomass in the 1996 unmowed rye plots was similar to other plots (data not presented). When the fall rye plants were plowed down, the plant %N of the rye may have been as high or higher than the plant %N of the clovers. The amount of rye phytomass plowed down in unmowed plots in 1996 (3400 kg ha^{-1}) was greater than the phytomass in clover plots, except for berseem. Root phytomass was not measured, and root mass of fall rye may also have contributed considerable amounts of N to the soil. Sainju et al. (1998) concluded that fall rye had greater root density and scavenged more soil NO_3-N early in the season than crimson clover or hairy vetch.

There are limitations in interpreting NO_3-N results from a single soil sampling and much more sampling would have been required to follow the fate of the plowdown N in the soil. In a study of the fate of N from green manured field peas on Dark Brown and Gray Luvisolic soils, Jensen (1992) determined that 75% to 80% of the N from the legume residue became incorporated into soil organic matter. The amount of residue N that shifted into the mineral N pool varied with time and with the physiological (bloom) stage of the peas. A maximum of 20% to 25% of residue N became present in the mineral N pool. There was a flux of N between pools of legume residue, biomass N, mineral N, and non-microbial organic N. Losses of legume N from soil varied from about 1% at the Dark Brown site to about 30% at the Luvisolic site.

Our measurements of soil NO_3-N following clover/rye plowdown provide a "snapshot" of the fate of residue N in soils, but are a small part of a larger, changing picture.

BERSEEM CLOVER AND FALL RYE COMPARISONS

Plant and soil samples were collected from all six sites, in order to compare N results for one of the annual clovers (berseem) with a non-legume (fall rye). Results for initial soil NO_3-N (mg kg^{-1}), phytomass (kg ha^{-1}), plant %N, total N (kg N ha^{-1}), % Ndfa and soil NO_3-N (mg kg^{-1}) after plowdown are summarized in Table 3-5. Because many of the results are based on only one sample, there are limitations in analyzing the results. Treating the data as replicates across sites and years, some trends can be identified. Berseem %Ndfa was higher (about 60% to 90% Ndfa) on sites with low initial soil NO_3-N than on sites with high initial levels of soil NO_3-N (30% to 55% Ndfa). The plant %N of fall rye was lower on sites with low initial soil NO_3-N than on sites with higher soil NO_3-N levels. Berseem plant %N was often higher than fall rye %N on sites with low soil NO_3-N. Berseem plant %N results varied among sites and were not necessarily higher on sites with high initial soil NO_3-N levels. Younger berseem phytomass (e.g. 9 weeks after planting or 4-6 weeks regrowth) had higher plant %N than older phytomass (e.g. 12 - 16 weeks). The berseem N yield (potential fertilizer contribution of plowdown) ranged from 23 to 193 kg N ha^{-1}. The total N fixed was highest at Edmonton (about 100 kg N ha^{-1} derived from the atmosphere) and lowest at Melnychuks (about 20 kg N ha^{-1} Ndfa). The N yield (kg N ha^{-1}) of berseem was higher than that of rye at 5 of 6 sites. On the four sites with low initial soil NO_3-N (Breton, Burger, Bowick and Melnychuk), plowdown of berseem resulted in higher soil NO_3-N than plowdown of fall rye. On the two sites with high initial soil NO_3-N (Radzick and Edmonton), plowdown of berseem resulted in similar or lower soil NO_3-N than plowdown of fall rye.

The response to higher soil N of increased phytomass and N yield, was greater with fall rye than with berseem. (Torbert et al. 1996) found that without added fertilizer N, phytomass production of fall rye was lower than for crimson clover. With applications of 67 to 134 kg N ha^{-1}, rye phytomass exceeded crimson clover phytomass. At a level of 70 kg fertilizer N ha^{-1} uptake, a winter cover crop of rye produced higher subsequent corn phytomass than did a crimson clover cover crop.

Nitrogen fixation occurred with the berseem clover at all six sites (Table 3-5). In the majority of cases, results for %Ndfa determined by D method compared well with results determined by ^{15}N. In some cases, results for %Ndfa by D method were lower than results by ^{15}N. At Radzicks, high %N and high phytomass for fall rye resulted in negative % Ndfa values for berseem by D method, versus 32% and 58% Ndfa using ^{15}N results. Zhu et al. (1998) concluded that D methods of %Ndfa could substitute for the more expensive isotope methods, particularly when relative ranking of Ndfa is the primary concern. Isotope methods were preferable on soils with high N content.

SUBSEQUENT BARLEY CROPS AT BRETON AND EDMONTON

Plowdown of clovers had significant effects on subsequent barley crops at Breton. White Dutch, persian, alsike, red, berseem and crimson clover plots had significantly higher barley yields than balansa, fall rye and check (mustard) plots for 1997 and 1998 (Table 3-6). Differences between species treatments were consistent for many aspects of barley yield: DM (dry matter) kg ha^{-1}, DM g $plant^{-1}$, DM g $tiller^{-1}$, grain kg ha^{-1}, grain g $plant^{-1}$, grain g $tiller^{-1}$, and tillers $plant^{-1}$. With the exception of persian treatments, grain yields were somewhat higher on perennial clover treatments than on annual clover treatments. Grain yields on clover treatments, as % of those on check plots, were: white 170%, alsike 164%, red 157%, persian 167% berseem 154%, crimson 153% and balansa 118%. There were no significant differences in harvest index (grain kg ha^{-1} as a percent of total dry matter yield) and grain %N, but barley grown on fall rye and mustard plots had somewhat higher harvest index and grain %N values. Although the %yield increases are impressive, the actual grain yields (about 40 to 45 bushel $acre^{-1}$) were low by farmer standards.

Edmonton data for barley yields are presented by year due to significant differences between years. Yields were lower in 1998 than in 1997, which may have been due to above average temperatures and lack of moisture during early establishment and grain fill stages in 1998. The only significant difference in barley yields at Edmonton was with grain yields (kg ha^{-1}) in 1997 (Tables 3-7). Plowdown of alsike and fall rye significantly increased grain yields (kg ha^{-1}), compared to plowdown of balansa, crimson, persian, red and white clover. There were no significant differences in other yield indicators (dry matter kg ha^{-1}, g $tiller^{-1}$ and tillers $plant^{-1}$) to substantiate the differences in grain yield (kg ha^{-1}). It appears that plowdown of clovers/ rye did have a beneficial effect on grain yield in some cases. Compared to grain yield (kg ha^{-1}) on mustard plots, grain yield was 115% on alsike plots and 113% on fall rye plots in 1997. In 1998, grain yield (kg ha^{-1}) was 119% on berseem plots, 116% on white plots, and 113% on fall rye plots, compared to yield on mustard plots (Table 3-8). There were differences among clover treatments at Edmonton, but no consistent trends.

Many studies of green manures have demonstrated beneficial impacts on subsequent crops, but results do vary. Studies on Black and Gray soils in northeastern Saskatchewan found that fababean, field pea and lentil improved subsequent cereal quality and produced a 21% increase in barley yield in the first year and a 12% increase in wheat yield in the second year (Green and Biederbeck, 1995). Following crimson clover, corn grain yields increased by 65%, compared to fall rye (Torbert et al. 1996). In a study of the effects of green manure crops on subsequent barley yields in the Peace River region, Rice et al. (1993) found that barley grain yields varied with legume species, year, and timing of incorporation. In some cases, barley grain yields were higher with green manures and in other cases they were lower, compared to check treatments. An Alaska study of seven species of legume green manures, concluded that legume green manures usually resulted in higher barley dry matter yield, higher plant N concentration and higher N uptake, than with green manuring of non-legume crops (Sparrow et al. 1995). In a Montana study, increasing the amount of alfalfa and berseem green manure phytomass had a greater impact in increasing subsequent barley grain N concentrations than increasing barley yields (Westcott et al., 1995). In situations where moisture was limited, green manuring reduced subsequent crop yields, compared to fallow (Jensen, 1992). Where moisture was adequate, green manuring resulted in equal or higher grain yields than on fallow. On a site where available soil N was already high, green manuring had little effect on subsequent wheat yields (Battle River Research Group, 1996).

SUBSEQUENT CROPS ON FARMS

The impact of clover on subsequent cereal crop was measured at three farms in 1997. At the Burger farm (located near Breton), plowdown of clovers significantly increased oat yields (Table 3-9). Oat grain yield (kg ha^{-1}), dry matter yield (kg ha^{-1}) and grain %N were significantly higher with berseem, crimson and persian clover plowdown, than with plowdown of fall rye. Oat dry matter yield (kg ha^{-1}) was significantly higher with persian plowdown, than with crimson plowdown. Grain yields (kg ha^{-1}) were 139% on persian plots, 134% on berseem plots and 122% on crimson plots, compared to yields on fall rye plots. The oat yields on the clover plots would be considered very good for the region, with bushel equivalents of 120 to 135 bushels $acre^{-1}$ (using Alberta Agriculture benchmarks for the area of 75 bu. $acre^{-1}$ as average and 100 bu. $acre^{-1}$ as very good).

Growth of crimson, berseem and persian clovers and fall rye was not plowed down at the Bowick site in 1996. In September, plot growth was cut and baled to use for livestock feed. The plot area was cultivated and then seeded to oats the following spring. In the spring of 1997, Ron Bowick noted visible differences in oat growth among plots, but poorer initial growth was not linked to any particular clover/rye species. There were no significant differences in oat yields at Bowicks in 1997 (Table 3-10). Grain yields (kg ha^{-1}) were slightly higher on the crimson plots (106%) and berseem plots (105%), compared to yields on the fall rye plots. There was a significant difference in harvest index. Vegetative growth of oats was significantly higher on the berseem plots (harvest index of 48%) than on the rye plots (harvest index of 53%). Oat dry matter yields (kg ha^{-1}) were 13% higher on berseem plots than on fall rye plots. Oat yields were lowest on persian plots, but %N of grain from persian plots was higher than on rye and crimson plots (significant at $P \leq 0.10$). It would appear that effects on N allocation within the oat plants varied due to differences in the residue characteristics of the clover species.

With the harvest of the annual clovers for hay at Bowicks, it appears that the remaining clover root matter provided some impact on soil, but not enough to significantly increase oat yields. Green and Biederbeck (1995) reported than when sweetclover, red clover and alfalfa were harvested and only the stubble was turned over as green manure, less than one-third of the legume dry matter and nitrogen was retained by the soil. With annual clovers, the amount of residue retained in roots would be less than one-third of the legume dry matter. Differences between replicate blocks were significant for oat yields at Bowicks. The plots were located on a hillside and there was additional variation in soil due to an area which had been previously used as a gateway. The plot area had been growing alfalfa prior to 1996, so there were also other legume residues in the soil to potentially influence growth.

At the Melnychuk farm, barley grain yield (kg ha^{-1}) was 25% higher on berseem plowdown than on fall rye plowdown, but the differences were not significant (Tables 3-11). Only berseem, crimson and fall rye were tested at Melnychuks. Barley yields on crimson plots were similar to those on fall rye plots. Grain yields at Melnychuks were the lowest of the five test sites. Although the soil is Chernozemic, it is very sandy and has been depleted of nutrients. The soil $N0_3$-N was 6 ppm, P was below detection limit, and K was about 30 ppm (Appendix 2). The soil P and K levels were lower than at any other site. Weed pressures were also very high at this site.

The fourth farm, Radzicks, is a U-Pick fruit farm. It was not appropriate to look at impact on a subsequent crop, because the clovers/rye were used as ground cover between rows of raspberries. The clover/rye growth was left over winter and then cultivated in the late spring of 1997 and seeded to grass. Michael Radzick noted that the grass established more rapidly in the row that had been seeded to fall rye, than in the rows seeded to annual clovers. He suspected that the rye cover retained more soil moisture than the clovers. Given the high potential N yield of the rye phytomass at Radzicks (222 kg N

ha^{-1}), plowdown of the rye may have provided large amounts of N to the soil to stimulate growth of the grass (Table 3-5).

SUMMARY OF IMPACT ON SOIL MINERAL N AND GRAIN YIELD AT FIVE SITES

In the majority of cases at Breton and Edmonton, fall plowdown of clovers resulted in increased soil NO_3-N levels (measured the following spring), as compared to check plots (Table 3-12). Increases of soil mineral N were most evident with white clover and least evident with red clover. Plowdown of a non-legume (fall rye) significantly increased soil NO_3-N on a high fertility soil (Edmonton), but not on a low fertility soil (Breton).

Clover plowdown significantly increased subsequent grain yields on two low fertility soils (Breton and Burger), but did not significantly increase subsequent grain yields on three sites: a high fertility soil (Edmonton), a site where growth was removed as hay (Bowick), and a site with low soil P and K and high weed pressures (Melnychuk). All clover species, except balansa, significantly increased grain yields at Breton. Barley grain yields at Breton were an average of 55% higher on clover plowdown than on check plots (Table 3-13). Oat grain yields at Burgers were an average of 32% higher on berseem, crimson and persian plowdown than on check plots. On a high fertility soil (Edmonton), barley grain yields were higher with plowdown of fall rye (113% of check) than with clover plowdown (average of 102% of check).

The relative soil NO_3-N results were reasonably good indicators of potential grain yield, but there were some inconsistencies. Although soil NO_3-N levels were relatively low in red clover plots, the grain yields were similar to yields with other clovers. The soil NO_3-N levels may have been lower in red clover plots at the time of sampling due to differences in rates of residue breakdown and partitioning between various N pools. Unlike most of the other clovers, the red clover was not flowering when it was plowed down in the fall. The high percentage of leaf matter in the phytomass may have meant that the residue decomposed rapidly and the N moved more rapidly from the phytomass N pool, to the mineral N pool, to the organic N pool. Jensen (1992) found that, in the spring following plowdown of peas, soil NO_3-N levels were higher with full bloom stage plowdown, than with early bloom plowdown, while organic N levels were higher with the early bloom plowdown than the late bloom plowdown. He concluded that delaying green manuring until full bloom resulted in slower release of N from the legume tissue. The N from the red clover residue was less evident in the inorganic pool at the time of sampling, but it appears that the amount of N made available during barley growth was similar to that in other clover plots.

Significant differences in soil NO_3-N were a better predictor of increased grain yield at Breton than at Edmonton. The addition of clover/rye residue at Breton represented a large addition to the existing N pools and organic matter. At Edmonton, the clover/rye residue represented a relatively small addition to existing N pools and organic matter. Variations in soil NO_3-N content, following various green manure treatments, did not substantially affect yields of barley, on a Black Solod soil in the Peace River region (Rice et al., 1993). It was suggested that the amount of green-manure N available to the subsequent barley crop may not have been large enough to affect barley yield.

The perennial clovers tended to have somewhat greater impact on grain yield than annual clovers. Using numeric values for average grain yield increases across years at Edmonton and Breton, the impact on grain yield was: alsike and white > berseem and persian > red and crimson > balansa.

CONCLUSIONS

All seven clover species fixed significant amounts of nitrogen from the atmosphere, when grown on a Gray Luvisolic soil at Breton. The average %Ndfa of clovers was 89%, when calculated by D method, and was 76% by ^{15}N method. There were no consistent differences in %Ndfa among clover species. The %N of the perennial clovers (white Dutch, red and alsike) was numerically higher than that of the annual clovers (crimson, balansa, berseem and persian), while dry matter (kg ha^{-1}) of the annual clovers was numerically higher than that of the perennial clovers. The average N yield of clover above-ground growth was 77 kg N ha^{-1} at Breton, with about 80% being derived from the atmosphere.

On high fertility Chernozemic soils, the %Ndfa by berseem was lower (30% to 55% Ndfa) than on low fertility soils, but the total N fixed was sometimes higher. For the six test sites, the N yield of berseem clover phytomass ranged from 23 to 193 kg N ha^{-1}, with about 20 to 100 kg N ha^{-1} derived from the atmosphere. The lowest N yield of berseem occurred on a Chernozemic soil that had very low levels of P and K.

In the spring, following plowdown of clovers at Breton and Edmonton, increases of soil mineral N were most evident with white clover and least evident with red clover. Plowdown of a non-legume (fall rye) significantly increased soil mineral N on a high fertility soil, but not on a low fertility soil.

Clover plowdown significantly increased subsequent grain yields on two Luvisolic soils, with grain yield increases of 55% and 32% compared to check plots. Plowdown of balansa clover failed to increase subsequent grain yield at Breton. Perennial clovers tended to have somewhat greater impact on grain yield than annual clovers. For the annual clovers, grain yield increases were numerically higher with plowdown of berseem and persian clovers than with crimson and balansa clovers. On a high fertility Chernozemic soil, plowdown of fall rye resulted in barley grain yields that were equal to or higher than grain yields with clover plowdown.

The benefits of legume green manuring were more evident on Luvisolic soils (where the clover residue represented a large addition to the existing N pools) than on high fertility Chernozemic soils (where clover residue represented a small addition to existing N pools). The effects of clover plowdown on soil NO_3-N and subsequent crop may have been different if we had grown the clovers in monoculture on the University sites. By adding mustard to the University test plots, we tested the green manure benefits of clovers grown in mixtures, rather than clovers alone. In taking only one measurement of soil NO_3-N after clover plowdown, we were not able to assess the impact of the clovers on other components of soil N or to assess changes in NO_3-N over time. Janzen et al. (1990) found that the relative contribution of green manures to the stable organic N reserves in the surface soil layer was approximately twice that of the contribution to the inorganic N pool.

Annual clovers could be used in cropping systems in north-central Alberta to improve soil and increase yields. Green manuring of annual clovers would be particularly beneficial on Gray Luvisols, to build up levels of available N and organic matter in the soil. With proper management, annual clovers could be used in cropping systems of both Luvisolic and Chernozemic soils to replenish stable organic N reserves and improve soil quality.

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Table 3-3: Dry matter yield (kg ha^{-1}), dry matter N (%N), N yield (kg N ha^{-1}), percent nitrogen derived from the atmosphere (%Ndfa), and estimated C:N ratio for seven clover species grown at Breton in 1996 and 1997.

Species	1996					1997					Est. ave C:N
	DM	DM N	N Yld	% Ndfa		DM	DM N	N Yld	% Ndfa		
	kg ha^{-1}	%N	kg N ha^{-1}	by D	by ^{15}N	kg ha^{-1}	%N	kg N ha^{-1}	by D	by ^{15}N	
Rye	565	1.5	8	-	-	524	1.6	8	-	-	-
Alsike	2745	3.0	83	90	68	2531	2.5	64	87	64	14
Balansa	3566	2.0	72	89	84	2306	1.9	44	82	89	19
Berseem	4016	2.1	84	90	59	6081	1.8	110	93	86	19
Crimson	3774	1.9	71	88	76	5168	1.6	82	90	66	21
Persian	3684	2.4	90	91	80	4628	1.8	84	90	82	18
Red	2258	3.2	72	89	86	2090	2.5	51	84	68	13
White	2693	3.2	86	91	78	2663	3.0	80	90	71	12
Ave. for clovers	3248	2.5	80	90	76	3638	2.2	74	88	75	16
Std. dev.				3.3	16.2				3.6	13.0	

Notes: "DM" = dry matter. %Ndfa "by D" = difference method. %Ndfa "by ^{15}N" = natural abundance ^{15}N method. "Est. ave. C:N" = estimated C:N ratio, using the two year averages for %N and a %C value of 37%. C:N value of 16 represents C:N of 16:1.

Table 3-4: Soil NO_3-N (mg kg^{-1}) for 0 to 30 cm soil depth after plow down of clovers and fall rye, at Breton and Edmonton for 1997 and 1998.

	Soil NO_3-N (mg kg^{-1}), 0 -30 cm		
	Breton		Edmonton
	1997	1998	1997 & 1998
Initial	1	1.5	29
After plowdown			
Alsike	3.8 bc*	2.0 cd	12.75 cd
Balansa	2.5 cd	2.7 abc	12.88 cd
Berseem	5.0 ab	2.3 bcd	13.36 cd
Crimson	3.5 bc	3.7 a	11.42 de
Persian	5.0 ab	2.7 abc	13.73 bc
Red	3.2 bcd	1.6 cd	12.23 cde
White Dutch	6.0 a	3.5 ab	16.19 a
Rye	1.3 d	1.4 d	15.61 ab
Mustard	1.3 d	1.7 cd	10.51 e
Mean	3.5	2.4	13.19

Notes: *Means within columns followed by the same letter are not significantly different at the 0.05 level of probability using Fisher's LSD test. "Initial" - Results for general plot area, prior to seeding in 1996 and 1997. "After plowdown" - Samples were taken from 3 replicate, unmowed, species plots in April of the following year. "Mustard" = mustard-alone plots; mustard growth was not plowed down, but was removed from all plots before plowdown.

Table 3-5: Biomass (kg ha^{-1}), plant %N, total plant N (kg N ha^{-1}), %N derived from the atmosphere (Ndfa) and impact on soil NO_3-N (mg kg^{-1}) for berseem clover, compared with fall rye, for six sites in north-central Alberta in 1996 and 1997.

Location	Initial soil N	Sample at	Biomass		Plant %N		Total plant N		%Ndfa		Soil N after plowdown	
			Rye	Bers.	Rye	Bers.	Rye	Bers.	Berseem		Rye	Bers.
	NO_3-N mgkg^{-1}	weeks	kg ha^{-1}		%N		kg N ha^{-1}		% by diff.	% by ^{15}N	NO_3-N mg kg^{-1}	
Luvisolic sites 1996												
Breton	1	14	565	4016	1.5	2.1	8	84	90	59	1	5
Burger	2	9	831	1502	1.8	3.5	15	53	72	66	8	12
Bowick	6	12	2477	3644	1.9	2.3	48	84	44	50	5	6
Chernozemic sites 1996												
Melnychuk	6	12	264	1179	1.5	2.5	4	29	87	82	2	3
Radzick	45	9	5875	2932	3.8	3.8	222	111	0	32	10	8
Edmonton	39	16	3442	6753	2.8	2.7	97	179	46	42	14	9
Luvisolic sites 1997												
Breton	2	15	524	5592	1.6	1.8	8	101	93	86	1	2
Burger	3	12	467	1736	2.0	2.0	9	35	73	100	-	-
Bowick	6	4*	-	-	1.4**	2.8	-	-	75	100	-	-
Chernozemic sites 1997												
Melnychuk	4	6*	200	820	2.3	2.8	5	23	80	83	-	-
Radzick	16	4*	1890	1200	3.6	3.3	68	40	0	58	-	-
Edmonton	21	14	2780	10333	3.3	1.9	92	193	52	53	18	18

Notes: * Weeks of regrowth, instead of weeks after planting. **% N is for oats instead of rye. Plant N and Ndfa results are means (of 3 rep's) for Breton but for a single sample for other sites. Soil N results on plowdown are means (of 3 rep's) for Breton and Edmonton, but for a single sample for other sites. Soil N for 0-30 cm is the average of results from 0-15 cm and 15-30 cm. "Soil N after plow down" - samples were taken in April 1997 for 1996 plots and April 1998 for 1997 plots.

Table 3-6: Breton two year (1997 and 1998) means for barley plant number (no. m^{-2}), tiller number (no. m^{-2}), tillers $plant^{-1}$, dry matter and grain yield (kg ha^{-1}, g $plant^{-1}$ and g $tiller^{-1}$), grain yield as % of grain yield on mustard treatments and harvest index, and 1997 means for grain N (%).

Previous crop	Mean values for barley at Breton in 1997 and 1998											1997 only
	Plant no.	Tiller number	Tillers $plant^{-1}$	Dry matter (DM) yield	Grain yield	G. Yd. as %	DM $plant^{-1}$	Grain $plant^{-1}$	DM $tiller^{-1}$	Grain $tiller^{-1}$	H.I.	Grain N
	no. m^{-2}	number m^{-2}	number $plant^{-1}$	kg ha^{-1}	kg ha^{-1}	of M. G. Yd.	g $plant^{-1}$	g $plant^{-1}$	g $tiller^{-1}$	g $tiller^{-1}$	%	%N
Alsike	147	272 a*	1.86 a	3960 ab	2380 a	164	2.69 a	1.63 a	1.44 a	0.88 a	61	1.43
Balansa	163	224 bc	1.39 b	2700 c	1710 b	118	1.68 b	1.06 b	1.22 b	0.77 b	63	1.48
Berseem	154	249 ab	1.66 a	3620 b	2240 a	154	2.43 a	1.50 a	1.45 a	0.90 a	62	1.49
Crimson	152	252 ab	1.66 a	3610 b	2220 a	153	2.38 a	1.47 a	1.42 a	0.88 a	62	1.48
Persian	159	265 a	1.69 a	4030 a	2420 a	167	2.58 a	1.54 a	1.51 a	0.91 a	60	1.43
Red	152	258 a	1.72 a	3640 b	2280 a	157	2.43 a	1.52 a	1.42 a	0.88 a	63	1.45
White	153	271 a	1.83 a	3960 ab	2470 a	170	2.66 a	1.67 a	1.45 a	0.91 a	63	1.47
Rye	165	226 bc	1.38 b	2460 cd	1570 b	108	1.53 b	0.98 b	1.09 b	0.70 b	65	1.53
Mustard	157	213 c	1.38 b	2280 d	1450 b	100	1.48 b	0.94 b	1.09 b	0.69 b	64	1.55
Mean	156	248	1.62	3360	2080		2.21	1.37	1.35	0.84	62	1.48
LSD		31	0.21	370	260		0.38	0.26	0.14	0.09		
p value	ns	.0055	.0004	.0001	.0001		.0001	.0001	.0001	.0001	ns	ns

"% of Must. Gr. Yd." = grain yield (kg ha^{-1}) as a percentage of grain yield on mustard treatment plots. Mustard was removed prior to plowdown. "H.I." = harvest index, grain yield (kg ha^{-1}) as a percentage of total dry matter yield (kg ha^{-1}). * Means within columns followed by the same letter are not significantly different at the 0.05 level of probability using Fisher's LSD test.

Table 3-7: Edmonton 1997 means for barley dry matter and grain yield (kg ha^{-1} and g $tiller^{-1}$), grain yield (kg ha^{-1}) as % of the grain yield on mustard treatments, tillers $plant^{-1}$, harvest index (%) and grain N (%).

Edmon.	Grain Yield	Grain yield as	DM Yield	Grain $tiller^{-1}$	Tillers $plant^{-1}$	Harvest index	Grain N
Previous crop	kg ha^{-1}	% of M. yield	kg ha^{-1}	g $tiller^{-1}$	number $plant^{-1}$	%	%N
Alsike	6640 a	115	12850	1.50	3.92	52	2.26
Balansa	5280 b	91	10690	1.36	3.67	49	2.25
Berseem	5840 ab	101	11310	1.46	3.26	52	2.26
Crimson	5090 b	88	10150	1.33	3.28	50	2.25
Persian	5780 b	100	11120	1.33	3.16	52	2.05
Red	5330 b	92	11150	1.25	3.09	48	2.03
White	5700 b	98	11480	1.26	2.79	50	2.13
Rye	6520 a	113	12730	1.51	3.45	51	2.33
Mustard	5800 ab	100	11790	1.39	3.66	49	2.18
Mean	5770		11480	1.38	3.36	50	2.19
LSD	950						
p value	.0390		n s	n s	n s	n s	n s

* Means within columns followed by the same letter are not significantly different at the 0.05 level of probability using Fisher's LSD test. "ns" = not significant. "Grain yield as % of M. yield" - grain yield (kg ha^{-1}) as % of that on plots seeded to mustard in 1996. DM = dry matter. Harvest index = grain yield (kg ha^{-1}) as a percentage of total dry matter yield (kg ha^{-1}).

Table 3-8: Edmonton 1998 means for barley dry matter and grain yield (kg ha^{-1} and g $tiller^{-1}$), grain yield (kg ha^{-1}) as % of the grain yield on mustard treatments, tillers $plant^{-1}$, and harvest index (%).

Edmon.	Grain Yield	Grain yield as	DM Yield	Grain $tiller^{-1}$	Tillers $plant^{-1}$	Harvest index
	kg ha^{-1}	% of M. yield	kg ha^{-1}	g $tiller^{-1}$	number $plant^{-1}$	%
Alsike	4380	106	9270	0.70	5.69	47
Balansa	4220	103	9150	0.64	4.22	46
Berseem	4890	119	10870	0.61	6.52	45
Crimson	4170	101	9290	0.65	4.46	45
Persian	4160	101	8860	0.70	4.56	47
Red	4050	98	8380	0.76	4.51	48
White	4760	116	10710	0.63	5.66	45
Rye	4650	113	10110	0.69	4.67	46
Mustard	4120	100	8790	0.66	4.40	47
Mean	4380		9490	0.67	4.97	46
p value	n s		n s	n s	n s	n s

"Grain yield as % of M. yield" - grain yield (kg ha^{-1}) as % of that on plots seeded to mustard in 1996. DM = dry matter. Harvest index = grain yield (kg ha^{-1}) as a percentage of total dry matter yield (kg ha^{-1}). "ns" = not significant.

Table 3-9: Yield of oat grain (kg ha^{-1} and g $tiller^{-1}$), grain yield compared to yield on rye plowdown (%), oat plant dry matter (kg ha^{-1}), tillers $plant^{-1}$, harvest index, grain N (%) for four treatments at Burger farm (Luvisolic soil) in 1997.

Burger	Grain yield	Grain yield as %	DM yield	Grain $tiller^{-1}$	Tillers $plant^{-1}$	Harv. index	Grain N
Previous crop	kg ha^{-1}	of rye yield	kg ha^{-1}	g $tiller^{-1}$	til. no. $plant^{-1}$	%	%N
Berseem	5000 a*	134	9080 ab	2.88	1.32	55	1.59 a
Crimson	4560 a	122	8480 b	2.71	1.34	54	1.52 a
Persian	5180 a	139	9920 a	2.88	1.41	52	1.58 a
Rye	3740 b	100	6660 c	2.49	1.29	56	1.40 b
Mean	4620		8540	2.74	1.34	54	1.52
LSD	710		1320				0.09
p value	.0102		.0048	n s	n s	n s	.0105

* Means within columns followed by the same letter are not significantly different at the 0.05 level of probability using Fisher's LSD test. "ns" = not significant. "Grain yield as % of rye yield" - grain yield as % of grain yield on plots that were seeded to fall rye in 1996. DM = dry matter. Harvest index = grain yield (kg ha^{-1}) as a percentage of total dry matter yield (kg ha^{-1}).

Table 3-10: Yield of oat grain (kg ha^{-1} and g $tiller^{-1}$), grain yield compared to yield on rye plowdown (%), oat plant dry matter (kg ha^{-1}), tillers $plant^{-1}$, harvest index, and grain N (%) for four treatments at Bowick farm (Luvisolic soil) in 1997.

Bowick	Grain yield	Grain yield as %	DM yield	Grain $tiller^{-1}$	Tillers $plant^{-1}$	Harvest index	Grain N
Previous crop	kg ha^{-1}	of rye yield	kg ha^{-1}	g $tiller^{-1}$	til. no. $plant^{-1}$	%	%N
Berseem	4060	105	8420	1.50	1.42	48 b	1.73 ab
Crimson	4110	106	8050	1.59	1.40	51 ab	1.70 b
Persian	3710	96	7260	1.17	1.50	51 ab	1.83 a
Rye	3880	100	7430	1.51	1.38	53 a	1.65 b
Mean	3940		7790	1.44	1.42	51	1.73
LSD						2.7	.12
p value	n s		n s	n s	n s	.0395**	.0550*

** Means within columns followed by the same letter are not significantly different at the 0.05 level of probability using Fisher's LSD test. *Means within columns followed by the same letter are not significantly different at the 0.10 level of probability using Fisher's LSD test. "ns" = not significant. "Grain yield as % of rye yield" = grain yield as % of grain yield on plots that were seeded to fall rye in 1996. DM = dry matter. Harvest index = grain yield (kg ha^{-1}) as a percentage of total dry matter yield (kg ha^{-1}).

Table 3-11: Yield of barley grain (kg ha^{-1} and g $tiller^{-1}$), grain yield compared to yield on rye plowdown (%), barley plant dry matter (kg ha^{-1} and g $tiller^{-1}$), tillers $plant^{-1}$, harvest index, and grain N (%) for three treatments at Melnychuk farm (Chernozemic soil) in 1997.

Melny.	Grain yield	Grain yield as %	DM yield	Grain $tiller^{-1}$	DM $tiller^{-1}$	Tillers $plant^{-1}$	Harv. index	Grain N
Previous crop	kg ha^{-1}	of rye yield*	kg ha^{-1}	g $tiller^{-1}$	g $tiller^{-1}$	til. no. $plant^{-1}$	%	%N
Berseem	1340	125	2860	0.40	0.89	1.34	47	1.57
Crimson	1100	102	2270	0.42	0.90	1.26	49	1.58
Rye	1080	100	2270	0.39	0.83	1.22	48	1.55
Mean	1170		2460	0.41	0.87	1.27	48	1.56
p value	n s		n s	n s	n s	n s	n s	n s

"Grain yield as % of rye yield" = grain yield as % of grain yield on plots that were seeded to fall rye in 1996. "DM" = dry matter. Harvest index = grain yield (kg ha^{-1}) as a percentage of total dry matter yield (kg ha^{-1}). "ns" = not significant.

Table 3-12: Summary of significant increases in soil NO_3-N and grain yield (kg ha^{-1}) on clover/fall rye treatments, compared to check treatments, at five sites in north-central Alberta in 1997 and 1998.

Previous crop	Soil NO_3-N (ppm) signif. higher than on check			Grain yield (kg ha^{-1}) significantly higher than on check				
				Barley		Oats		Barley
	Breton		Edmon.	Breton	Edmon.	Burger	Bowick	Melny.
	1997	1998	2 years	2 years	2 years	1997	1997	1997
Alsike	√		√	√		na	na	na
Balansa			√			na	na	na
Berseem	√		√	√		√		
Crimson	√	√		√		√		
Persian	√		√	√		√		na
Red				√		na	na	na
White	√	√	√	√		na	na	na
Rye			√					
Check	mustard			mustard		rye		

Table 3-13: Summary of grain yields on clover/fall rye plowdown, as percent of grain yields on check plots, at five sites in north-central Alberta in 1997 and 1998.

Prev. crop	Grain yield (kg ha-1) on treatment plots as percent of yield on check plots										
	University sites				Farms			Averages			
	Breton		Edmonton		Burg.	Bow.	Mel.	University sites			F's
	1997	1998	1997	1998	1997			Bret	Edm.	B & E	
	percent (%)										
Alsike	178	152	115	106	na	na	na	165	110	138	
Balansa	126	111	91	103	na	na	na	118	97	108	
Berseem	173	139	101	119	134	105	125	156	110	133	121
Crimson	147	158	88	101	122	106	102	152	95	123	110
Persian	184	152	100	101	139	96	na	168	100	134	118
Red	166	150	92	98	na	na	na	158	95	127	
White	163	176	98	116	na	na	na	170	107	138	
Ave. clov.	163	148	98	106	132	102	114	155	102	129	116
Rye	116	102	113	113				109	113	111	
Check	mustard				fall rye						

"B & E" = average for Breton and Edmonton. "F's" = average for 3 farms.

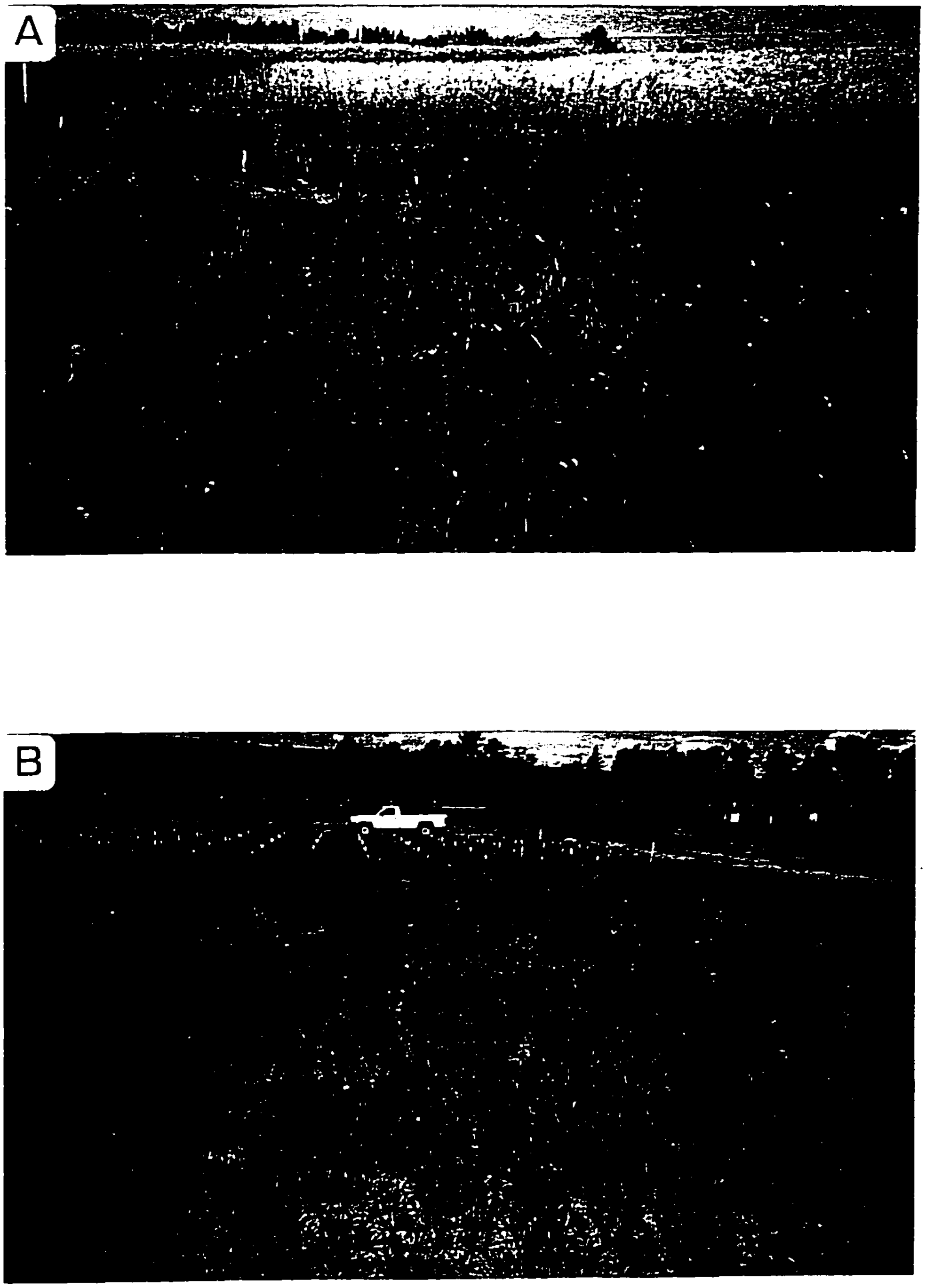

Plate 3-1: Breton. A) Clover plots (foreground) and barley on plowdown treatments (background) in September 1997. B) Early growth of barley on plowdown treatments.

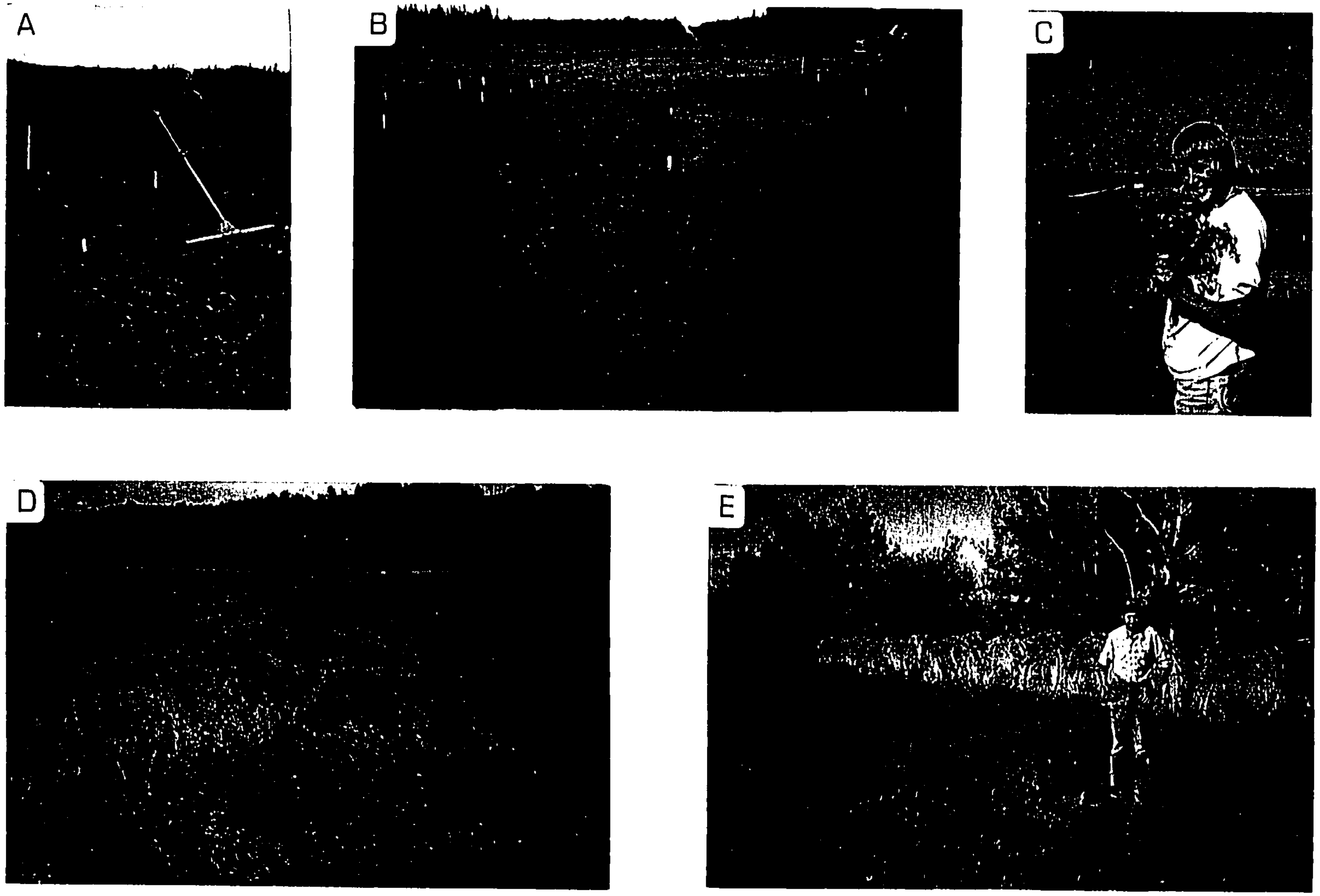

Plate 3-2: A) Larry Bogart raking plots, prior to seeding in 1996. B) Early growth of Burger/Bogart 1996 plots. C) Lois Burger with persian clover. D) Late growth of clover plots at Bowicks in 1996. E) Ron Bowick in 1997 with berseem clover regrowth (foreground) and hay bales from oat-berseem mixture.

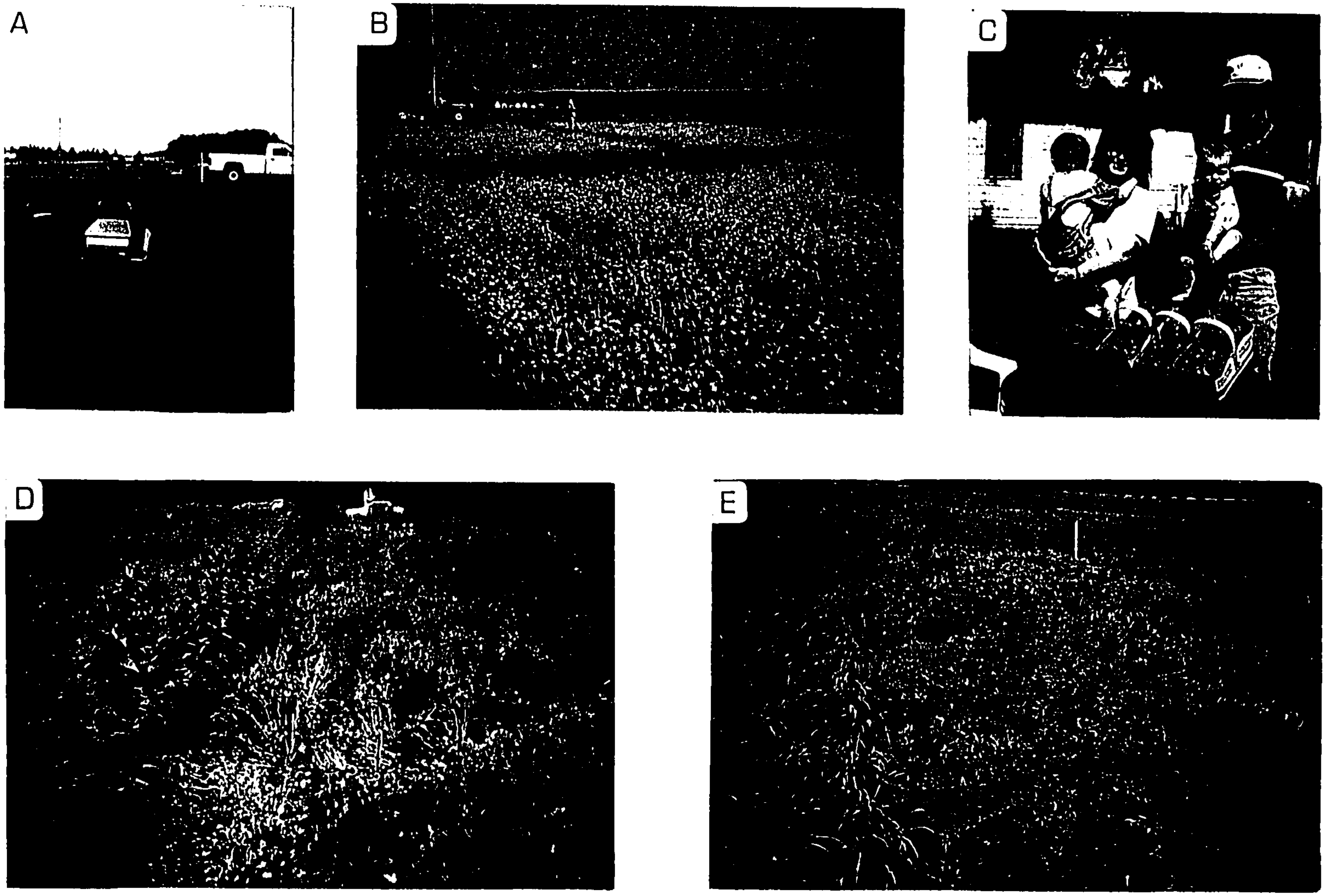

Plate 3-3: A) Joe Melnychuk harrowing test plots. B) Melnychuk clover plots with wild mustard in bloom. C) Radzick family. D) 1996 Radzick clover plots between rows of raspberries. E) 1997 Radzick plots of fall rye, berseem, persian and crimson clover.

Chapter 4

Synthesis

THE PROBLEM

New annual legume crops offer the potential to diversify crops and improve cropping systems in Alberta. In addition to their product value, legumes bring benefits to cropping systems such as improved soil quality, fertilizer replacement and rotational benefits. The use of legumes in north-central Alberta is largely confined to small-seeded perennial legumes (alfalfa, red, alsike and white clovers) and large-seeded annual legumes (field peas). There is a need for alternate annual legumes to fit with the rotations of cereals and oilseeds. The potential of small-seeded annual legumes (clovers, medics) has largely been untested in north-central Alberta. The soils and climate of the parkland and low boreal regions of Alberta offer some unique agricultural opportunities and challenges; higher rainfall than on the Brown and Dark Brown soils and the high fertility of the Thick Black soils give a boost to both crop and weed growth. Farming on Gray Luvisols requires a long-term strategy to build up organic matter in the soil. In any cropping system, the potential benefits of legumes may be lost due to heavy weed competition. New legume species for north-central Alberta should therefore be tested for their impact on key soil properties and their ability to compete with problematic weeds.

THE PROJECT

Hypothesis: With proper management, annual clovers may be used in cropping systems in north-central Alberta to improve soil, increase yields and aid weed control.

a) Four annual clovers (balansa, berseem, crimson and persian) were compared with three perennial clovers (alsike, red and white Dutch), and a non-legume "check" species (fall rye) on six sites in 1996 and 1997.
The objectives were to:

- investigate clover/weed interaction, using either brown mustard (as a model weed) or natural weed populations;
- determine the effect of mowing on clover/weed interaction;

- assess N fixation and N yield of clovers;
- measure the impact of clover/fall rye plowdown on soil NO_3-N and subsequent crop yield;
- compare results on Chernozemic and Luvisolic soils;
- test the use of annual clovers in organic farming systems.

b) A new soil quality test kit, designed for on-farm use, was compiled and given trial use.

c) The project tested a model of collaboration between farmers and university researchers.

FINDINGS AND IMPLICATIONS

CLOVER EXPERIMENTS

- All clover species demonstrated some ability to suppress weed phytomass, increase soil nitrate and increase subsequent grain yields, but results were affected by site characteristics and management practices (e.g. mowing).
- Persian clover had poorer emergence and establishment than the other clovers.
- In eight tests (mowed and unmowed treatments, Breton and Edmonton, 1996 and 1997), mustard phytomass was significantly suppressed by: fall rye in eight tests; alsike, berseem and crimson in seven; balansa in six; white Dutch in five; red in four; and persian in three.
- Weed suppression by berseem was equal or better than fall rye at five of six sites, in 71% of 14 tests. Weed suppression by persian and crimson was equal or better than fall rye in 43-50% of tests.
- Brown mustard was a very competitive model annual weed, with attributes of rapid early growth, large leaves, good height, high plasticity, and early seed set. Species similar to brown mustard, wild mustard (*Sinapsis arvensis* L.) and volunteer *Brassica* crop species, were problem weeds on two of the farm sites.

- Mowing had a beneficial impact on the clover/mustard balance at the site with high soil fertility, but timing of mowing was important to the outcome.
- Mowing did not have a beneficial impact on the clover/mustard balance at the site with low soil fertility, but mustard seed set was reduced.
- Biological characteristics of clover species, such as growth rate, growth habit and flowering date, affected competitive ability.
- Annual clovers had higher numbers of leaves, taller stems, higher total above-ground phytomass and lower N concentration in tissues than the perennial clovers.
- The average N yield of clover above-ground phytomass was 77 kg N ha^{-1} at Breton, with about 80% of N derived from the atmosphere.
- For the six test sites, the N yield of berseem clover above-ground phytomass ranged from 23 to 193 kg N ha^{-1}, with about 20 to 100 kg N ha^{-1} derived from the atmosphere.
- In the spring, following fall plowdown of clovers at Breton and Edmonton, increases in soil NO_3-N were most evident with white clover and least evident with red clover, compared to check plots.
- Clover plowdown affects on subsequent grain yield were greatest on two Luvisolic sites, with average grain yield increases of 55% and 32% on clover treatments, compared to check treatments.
- At Breton, subsequent grain yields were significantly increased by all clover treatments except balansa.
- On a high fertility Chernozemic soil, plowdown of fall rye resulted in soil NO_3-N levels and barley grain yields that were equal to or greater than those with clover plowdown.

Table 4-1 summarizes some of the characteristics and findings for the seven clover species that were tested.

Table 4-1: Summary of characteristics and findings for seven clover species.

	Characteristics and test results								
	A	B	C	D	E	F	G	H	
	Phytomass		Max. stem length		Flowering	Weed supp. ability	Phyto-mass N yield	Subseq. grain yield increase	Comments
	Bret.	Edm.	Bret.	Edm.	Breton				
	Mg ha^{-1}	Mg ha^{-1}	cm	cm	at 14 weeks	of 8	kg N ha^{-1}		
Alsike	2.6	6.1	57	115	early bloom	7	74	yes	better weed suppression than red or white clover
Balansa	2.9	7.2	60	134	seed set	6	58	no	tolerates flooding, best early ground cover, very early flowering
Berseem	5.0	9.2	91	163	no flowers	7	97	yes	highest yield, good regrowth, late flowering
Crimson	4.4	5.7	72	109	seed set	7	77	yes	largest seed size, early flowering, poor regrowth
Persian	4.2	7.0	101	149	early bloom	3	87	yes	poor emergence, good regrowth
Red	2.2	5.2	34	49	no flowers	4	62	yes	lowest number of leaves at early stages of growth
White	2.7	4.0	33	40	mid bloom	5	83	yes	higher soil NO_3-N after plowdown than with others

Notes: Clovers were grown as annuals. A.) Above-ground dry matter yield, average of 2 years, unmowed growth at Breton (low fertility soil) at 14-15 weeks. B.) Above-ground dry matter yield of mowed plots at Edmonton (high fertility soil) in 1997; total of 2 cuts, at 6-7 weeks and 14 weeks. C.) and D.) Stem length measured at 14 to 16 weeks, in unmowed plots at Breton and Edmonton in 1996. E.) Status of flowering at Breton at 14 weeks after planting, on September 9, 1996. F.) Significant suppression of mustard/weed dry matter (kg ha^{-1}), of 8 tests at Breton and Edmonton (2 sites, 2 years, mowed and unmowed treatments). G.) Average for 2 years, total N yield of above-ground phytomass at Breton. H.) Fall plowdown of clover resulted in significant increase in subsequent yield of barley at Breton.

Some caution must be exercised in using the results from the experiments to draw conclusions about hierarchies of competitive ability among clover species. The biological factors that shaped the results (e.g. plant height, growth rate, flowering date) are useful in predicting the behaviour of various clover species, but the influence of variable factors (e.g. poor emergence of persian clover, use of mustard as a model weed, timing of mowing and plowdown, rainfall, soil characteristics) preclude making generalizations from these results. Interaction of clover species with a low-growing perennial weed may be very different from interaction with mustard. Variables related to climate, site and management practices will influence clover/weed interactions.

The effects of clover plowdown on soil NO_3-N and subsequent crop may have been different if we had grown the clovers in monoculture on the University sites. By adding mustard to the University test plots, we tested the green manure benefits of clovers grown in mixtures, rather than clovers alone. At Edmonton, competition from the mustard phytomass likely reduced the clover N yields, compared to what they would have been in monoculture. In the unmowed plots at Edmonton, where impact on soil NO_3-N and grain yield were measured, clover phytomass represented about 30% of the total yield. At Breton, the effect of mustard on clovers was likely not as great. In the unmowed plots at Breton, clover phytomass represented about 75% of the total yield. In an Alaska study, the N yield of annual legumes was affected by the addition of N fertilizer, and effects of fertilizer on weed growth (Panciera and Sparrow, 1995). Some legume species had lower N yields on plots with added N fertilizer than on plots without added fertilizer, while the converse was true for other species (including berseem and crimson clovers). In our tests at Edmonton, the positive impact of fall rye on soil N and subsequent grain yield, may have been partly due to the ability of fall rye to suppress mustard growth. The phytomass and N yield results for the clovers were likely affected by their abilities to compete with weeds.

In semiarid Prairie regions, water use is an important factor in using legumes as green manures. In a study on Brown Chernozemic soils, Biederbeck and Bouman (1994) found that feed pea and chickling vetch used water more efficiently than black lentil, Tangier flatpea and spring wheat. Biederbeck et al. (1993) have proposed that annual legumes must meet several criteria if they are to be used for green manure or forage production in the semiarid Prairie environment. These criteria are:

- fast emergence to provide an early ground cover,
- high rate of N fixation and phytomass production,
- high water use efficiency (equal to or better than wheat),
- resistance to insects and diseases, and
- high potential for an emergency source of high protein forage in dry years.

The list of criteria could be adapted to suit the climate and soils of north-central Alberta. Criteria would be different for the parkland Chernozemic soils than for the low boreal Luvisolic soils. In either case, moisture deficits are less of a problem in north-central Alberta. High water use efficiency could be moved to the bottom of the list of criteria or removed. When annual legumes are used as green manures in areas with moisture deficits, they are plowed down after six to eight weeks in order to conserve soil water. Weed control and forage quality are of less importance in such a situation. The higher precipitation in north-central Alberta makes it possible to grow annual legumes for a longer period of time and possibly combine a forage cut with plowdown of regrowth for green manure.

Proposed criteria for annual legumes on Gray Luvisolic soils of the low boreal region are:

- high rate of N fixation and phytomass production,
- rapid establishment and growth under cool temperatures,
- late flowering and rapid regrowth after mowing,
- frost tolerance during early establishment and late in the season,
- high forage quality,
- resistance to insects and diseases.

In areas of the low boreal ecoregion such as Breton, the main limitations to agriculture are low heat units, a short growing season and low soil fertility.

Under these conditions, legumes need to grow well in cool temperatures and need to produce large amounts of N and phytomass in a short time. Given the need to improve the fertility of Luvisolic soils, production of N and phytomass is of primary importance. In trials at Breton, the annual clovers grew more rapidly and produced higher phytomass than the perennial clovers but the perennials had higher concentrations of tissue N, so there was little difference in N yield.

Late flowering is desirable, since after initiation of flowering, phytomass production and N fixation may decline. Balansa began flowering by six weeks. It was the only clover that failed to significantly increase subsequent grain yields at Breton.

With the low fertility of Luvisolic soils, weed competition may be less of an issue than on high fertility soils. At Breton, weed growth was probably limited by low nutrients. The N fixation of clovers gave them a competitive advantage over weeds. Annual and perennial clovers exhibited equal suppression of mustard at Breton. There were no apparent advantages linked to differences in growth habit. The importance of allelopathy was apparent with suppression of mustard by fall rye at Breton. Allelopathic properties in an annual legume would be beneficial to weed suppression. Soil nutrients were somewhat higher at Bowicks and there was substantial growth of weeds (mainly wild mustard and rapeseed) in the 1996 clover plots. Plots were cut for hay in September. It likely would have been beneficial to cut the plots at an earlier stage to reduce weed seed set and the competitive effects of weeds on the clovers. At Burgers, the growth of weeds did not warrant mowing of the plots.

The more rapid growth of annual clovers, may make it possible to combine forage and green manure use on Luvisolic soils. At Burgers, nine weeks of growth of berseem, crimson and persian clovers produced enough green manure phytomass to produce grain yield increases of 32% in a subsequent oat crop. Some areas with Luvisolic soils have longer growing seasons than at Breton (e.g. Bowick farm near Barrhead). In 1997, Ron Bowick grew a mixture of oats and berseem clover. The cut of hay in August was predominantly oats, but Ron was very happy with amount of berseem regrowth for green manure plowdown.

Proposed criteria for annual legumes on Black Chernozemic soils of the parkland region are:

- high forage quality,
- high rate of phytomass production,
- rapid growth under cool temperatures,
- rapid development of ground cover and upright growth to compete with weeds,
- late flowering and rapid regrowth,
- frost tolerance during early establishment and late in the season,
- high rate of N fixation,
- resistance to insects and diseases.

On Black Chernozemic soils that have high levels of soil N and organic matter, the green manure value of legumes is of less importance than on Luvisolic soils. As was demonstrated at Edmonton and Radzicks, on soils with high initial levels of NO_3-N, plowdown of a non-legume green manure (fall rye) may have equal or greater impact on soil NO_3-N and subsequent crop than a legume green manure. Levels of soil N and organic matter may become depleted in Black Chernozemic soils due to continuous cropping and/or soil erosion. Even in highly fertile soils, legumes may be used in cropping systems to replace and maintain levels of soil N. Melnychuks was an example of a depleted Chernozemic soil which would greatly benefit from green manuring. The problem with using legume green manuring at Melnychuks was that clover growth was limited by low levels of soil P and K, and by heavy weed pressures. Legumes cannot work miracles, but they can be used effectively as a component of a broader strategy to rebuild soil quality and control weeds.

For the majority of farms on Black Chernozemic soils in north-central Alberta, the predominant criteria for use of clovers would be their forage potential. Limitations of heat units and growing season are less significant than in the low boreal regions. A range of possibilities exist for using annual clovers as forages in the parkland zone: growing them as monocultures or in mixtures; taking a cut of silage, hay or grazing the growth; using regrowth for plowdown or fall grazing. High forage quality and yield, late flowering, rapid regrowth, and on-going weed competition ability would be important. Late flowering is desirable for high quality forage production. After initiation of flowering, plants may not regrow after mowing. At Edmonton, balansa and crimson were the earliest flowering of the clovers and they had the poorest regrowth after mowing. It has been suggested that crimson clover is poorly suited for use as a forage in northern climates because long daylengths stimulate flowering (Panciera and Sparrow, 1995).

As was demonstrated at Edmonton, weeds may produce prolific growth on high fertility soils. To compete with weeds, annual legumes need to establish early ground cover, but also need to continue to grow in the presence of taller weed species. Legumes with upright stems have an advantage over low-growing legumes in competing for light, avoiding shading and accessing light to fuel phytomass production and N fixation. Mowing may give clovers a competitive advantage over weeds on high fertility soils. At Radzicks, annual clovers were tested as cover crops, and suppression of weeds was the most important consideration. As cover crops, annual clovers had no advantage over fall rye on the high soil fertility areas where the plots were located. However, the soil is quite variable on Radzick's land and there are some very sandy areas with low organic matter and low soil N. On these areas, annual clovers might serve a useful role as green manure.

Clover species are viewed as having many attributes that make them non-competitive: small seed size, lack of seedling vigor, slow establishment, small leaves, low height, and high sensitivity to shading. Our experiments found that these attributes do not universally apply to all clover species and that there is considerable variation among species. The larger seed size of crimson clover gave it an initial advantage in seedling establishment, but the higher growth rate of the smaller-seeded balansa gave it an advantage in rapidly establishing ground cover. The annual clovers grew more rapidly than the perennial clovers. Clovers with upright growth habit were less susceptible to shading than low-growing species. The finding that weed suppression by berseem was equal or better than fall rye at five of six sites, counters the view of annual legumes as poor competitors. Clovers are adapted to grazing and some of the characteristics that are viewed as disadvantages in annual crops (low height, small leaves) are advantageous under grazing. Mowing may give clovers an advantage over weeds in cases where the weeds are more vulnerable to mowing than clovers. An understanding of biological characteristics can be used to favorably shift clover/weed balances.

MEASURING SOIL QUALITY

Related to the question of the impact of clovers on soil quality, is the question of how to measure soil quality. What are the key indicators of soil quality? What tests can we use to measure the impact of clovers on soil?

Soil scientists have proposed "minimum data sets" to represent the key indicators of soil quality. Kennedy and Papendick (1995) propose a minimum data set that includes chemical, physical, and biological properties of soil: aggregation, bulk density, depth to hardpan, electrical conductivity, fertility, infiltration, mineralizable N potential, organic matter, pH, respiration, and water-holding capacity. The initial soil testing that we did (NO_3-N, total N%, PO_4-P, total P%, K, SO_4-S, O.M., pH, E.C. and micro-nutrients Zn, Cu, Mn and Fe) covered about half of the properties in the minimum data set.

In assessing the impact of clover plowdown on soil, we used NO_3-N and subsequent grain yield as indicators of changes in soil quality. These dynamic properties are very inadequate indicators of soil quality, but they were useful as indicators of short-term changes. Soil properties vary in their sensitivity to change. For example, aggregate size and total N are considered more sensitive to change (e.g. could change significantly in less than 10 years) than soil moisture retention and cation exchange capacity (e.g. may change over decades) (Acton and Gregorich, eds., 1995). Measuring changes in soil total N and NO_3-N over a period of time would have given a better picture of the effect of clovers on soil nitrogen.

In an attempt to measure a wider range of key indicators of soil quality, we tested a new soil quality kit, developed by John Doran of the US Dept. of Agriculture in Nebraska. The kit was developed for on-farm use, with the intention that it be simple to use, require little in the way of expensive equipment, and give rapid results that are meaningful to producers' understanding of soil and soil processes (Doran et al. 1996). The tests include: bulk density, soil water content, water-filled pore space, electrical conductivity, pH, NO_3-N, water infiltration, water holding capacity and soil respiration. The "kit" was in preliminary stages and consisted of a list of supplies, a list of US suppliers and a guide to conducting the tests. Compiling the kit, through Canadian suppliers, took several months and was more expensive than in the US. The cost of supplies was about Cdn $560 in 1997, compared with Doran's 1994 cost estimate of US $250.

Some of the tests were fairly easy to perform and the test results were similar to the lab results (e.g. pH, E.C.). Others lacked the precision of the lab results (e.g. NO_3-N). The water infiltration rate test was easy to perform, and it might have provided a useful indicator of changes in soil quality, but we lacked information on how to use and interpret the test. The soil respiration test turned out to be the most complicated and expensive test to conduct. It was also one of the tests that we hoped to use to monitor the effect of clover plowdown on soil. Either the carbon dioxide detection tubes were not sensitive enough to detect soil respiration levels of CO_2, or we weren't doing the test properly, because we could only get the tubes to register at the minimum reading, despite testing under conditions that would be expected to give higher readings.

Ideally, the tests for dynamic soil characteristics, such as soil respiration, soil water content and NO_3-N might be used to monitor small changes due to cropping systems, seasonal changes, tillage practices, etc. Unfortunately, the kit tests for these parameters were lacking in ease, precision and interpretative information. It was interesting to assemble and try-out the kit, but it did not serve our needs to assess small changes in soil quality and differentiate between the impact of several species. Based on field testing of the kit in various countries, Doran et al. (1996) concluded that the overall procedures are too complicated and time consuming for practical use by farmers. With further development, the kit may provide farmers with some useful tools to diagnose soil problems and to monitor longer-term changes in soil quality.

In order to assess the impact of annual clovers on soil quality, a longer term study would be preferred, like that of the Hendrigan plots at Breton. The Hendrigan plots compare three cropping systems: continuous barley, continuous fescue-white clover forage, and an eight year agro-ecological rotation of barley-fababeans-barley-fababeans-barley-forage-forage-forage (where the forage is a brome-red clover mixture) (Ellert, K. M. 1995). With a similar design, the longer term impact of annual clovers could be assessed within cropping systems, and minimum data set tests could be applied to monitor changes in soil quality.

PARTICIPATORY RESEARCH

To some extent, a participatory research approach was used in conducting and evaluating the project. Participatory research originated in the Third World as a model for communities to shape their socio-economic development. It combines cooperative research and adult education to effect social change, and has a critical assumption that the people affected by a problem should be instrumental in solving it. (Friere 1970, cited by Rusmore, 1995). In adapting the model to agriculture, farmers devise the questions, direct the research process, and perform the work to fit their needs.

Participatory research approaches in Third World development usually involve working within an established community. With this project, I was working within a community of interest, the Sustainable Agriculture Association (SAA). The SAA is a small organization of farmers (mainly organic farmers) and urban consumers concerned about food and environmental issues. One of the main functions of the SAA is certification of organic farmers.

The idea to focus on annual legumes in this project was largely shaped by: discussions with an organic vegetable grower who was looking for annual legumes that could be used as green manures; information in a SAA survey of research needs; and, a tour of Joanna Fraser's research work with annual legumes in Lethbridge. The use of legumes in cropping systems is of particular interest to organic farmers because they rely on organic sources for replenishment of soil N, rather than synthetic fertilizers. The tour in Lethbridge was organized by the Alternative Energy Resources Organization (AERO). AERO is a participatory research and education group, based in Montana, that formed because "their sustainability concerns received scant attention from university-based agricultural research and extension" (Matheson, 1989 cited by Rusmore, 1995). AERO facilitates farm improvement clubs, groups of farmers that conduct collective research related to sustainability. The groups are required to link up with at least one agriculture researcher and the groups share their findings with other AERO members. The AERO farm improvement clubs are a successful model of participatory research by farmers and some SAA members (including myself) would like to see a similar model in Alberta. The project was designed with the AERO model in mind.

A weakness of this project is that the farmers that participated in the field tests were not involved in the formation of the project. They were recruited through the SAA to participate in the project. They didn't know each other and except for being organic farmers, they didn't necessarily have much in common. Ideally, in participatory research, the group of farmers would come together out of common interest and identify a research goal.

Most farmers are informal researchers: trying new crops and inputs; testing and adapting machinery; changing or adjusting management practices to improve crops or conserve resources. Organic farmers rely on their own research more than conventional farmers, because much of the research conducted by government agencies and agri-business is not relevant to organic systems. Stories abound among organic farmers of receiving responses ranging from no help to hostility, when they approach government extension workers for advice. Organic farmers tend to feel rather isolated and they mainly rely on advice from other organic farmers and information in alternative agriculture publications. For most conventional farmers, the primary information source, for making decisions about farming practices, is other farmers. In the case of organic farmers, they may be the only organic farm in their area, and they have a smaller pool of local information to draw upon.

The involvement of the four farms in the first growing season of the project was mainly as providers of space for on-farm trials. This is not to suggest that the farmers weren't involved with the plots. The plot locations and layout were determined through a consultative process, which took into account: the machinery that they would use to mow the plots; our need for replicate plots; the soil characteristics of the site; and the fit with their cropping system. Plots on farms were larger than the ones on University sites to account for machinery that they would use or the space to be covered (e.g. between raspberry rows at Radzicks). Some of the farmers participated in taking soil tests, staking plots, seeding, and hand raking of plots. They monitored growth in the plots and discussed developments with us when we visited. In both years of field trials, the demands of the University sites took up a great deal of time. It wasn't possible to spend as much time on the farms as we would have liked.

The farmers, project staff, project supervisors and I met during the winter of the first year to discuss results, assess the findings, and plan for the research trials in 1997. Although it would have been useful, from the standpoint of scientific research methods and possible publication, to replicate the farm trials in 1997, the farmers were given the option of changing the trials in 1997. Ron Bowick took up the offer and wanted to test a field size (10 acre) mixture of berseem clover and oats for forage and green manure. The other farmers opted for a continuation of test plots in 1997. Michael Radzick conducted an experiment of his own, seeding a mixture of annual clovers and buckwheat as a cover crop. He thought that the clovers would provide secondary growth after the buckwheat was cut. The clovers were overshadowed by the buckwheat and grew poorly. When the buckwheat was cut it continued to mature. In the end, the field area was plowed up to prevent seed set in the buckwheat. Joe Melnychuk also conducted an experiment in addition to the regular plots. He seeded berseem on three acres adjoining the plots and also seeded barley on part of the area seeded to berseem. There appeared to be less weed growth on the area with the barley-berseem mixture, than the area with just berseem.

In cooperative research between farmers and university researchers, it would be useful to have a project that lasts more than two years. In the second year, it took less time to establish the plots, because we all had a better idea of what we were doing. The farmers offered suggestions or equipment to reduce some of the work that we were doing by hand (e.g. hand raking replaced by harrowing). We organized tours of the Edmonton plots and two of the farms for the farmers. By the second year, we were developing the kind of rapport that would have helped the farmers to participate more fully in shaping the project. On the other hand, two years was probably enough time for some of the farmers to determine if the annual clovers would be useful to them. The major benefit of the research for Radzicks may have been the discovery of fall rye as an effective cover crop. The next step in the annual clover research pointed to testing forage potential. This would only be of interest to two of the farms. When we met during the winter of the second year of the project it was an opportunity to review the results, evaluate the project and bring some closure.

The farmers experienced some of the problems and risks of having research trials on their land. They had to work around our wooden stakes in their fields. Unfortunately, a few of our stakes were left in plot areas by mistake, so the farmers had to watch out for stray stakes. In an ironic turn of events, our experiments to assess weed competition resulted in the introduction of a serious weed to two of the farms. In early September in 1997, some patches of dodder (*Cuscuta* spp.) appeared in some of the persian clover plots. Dodder is rarely seen in Alberta and is a restricted weed. We had obtained the seed through a company in Quebec which had imported the seed from Italy. The inspection sheet with the seed mentioned that some checking had been done for the presence of *Cuscuta* spp. We grew the seed in 1996, but didn't see any evidence of dodder in the plots. A number of factors probably contributed to the germination of the dodder in 1997. The seed was kept in a refrigerator over the winter of 1996/97 and the "cooler treatment" apparently helps to break dormancy in dodder. Dodder also requires relatively high temperatures to germinate and a spell of hot weather in August met the requirements. The outbreak of dodder in a demonstration persian clover plot at the Edmonton Research Station generated more interest than the clovers attracted! We did our best to contain and destroy the infestations of dodder on the farms. We also provided the farmers with as much information as I could find about dodder.

The project attempted to bridge the gap between informal on-farm research (which is not reported in the scientific community) and formal university research (which may be conducted in isolation from the farming community). The farm trials provided a very useful learning process for me, about the challenges of managing weeds and soil fertility in organic systems. The farms provided a reality check regarding the practical uses of annual clovers. It was very beneficial to have access to functioning cropping systems and to conduct trials within whole farm systems.

It would have been a "stretch" to combine the research format that is most meaningful to farmers (field scale trials, measurement of results by yield and/or qualitative factors) with the research format that is meaningful to the scientific community (statistically valid experimental design, replication of treatments, check treatments, replication over years, adding of weeds to the plot area, labour-intensive gathering of quantitative data).

Rusmore (1995) identifies four key features of farmer involvement in participatory research that are of benefit in achieving a sustainable agriculture:

- Participatory research can be statistically sound and applicable to the whole farm.
- Participatory research is useful in addressing a wide range of concerns that face farmers daily. Farmers bring to the research the real economic, social, cultural and management factors which are integral to successful farming.
- Participatory research encourages innovation and adoption of new ideas.
- Participatory research creates community and leadership development opportunities.

Despite the difficulties of conducting participatory research, the benefits are substantial. Indeed, the involvement of farmers in research may be crucial to achieving sustainability in agriculture.

SYNOPSIS

With proper management, annual clovers could be used in cropping systems in north-central Alberta to improve soil, increase yields and aid weed control. The study provides additional understanding of biological, site-specific and management factors which influence clover/weed interaction and the impact of clovers on soil. Cropping systems are more sustainable when farmers customize their systems to fit with their particular climate and soil conditions. Knowledge of biological processes in plants and soils, combined with knowledge and experience of farmers, can be used to develop management practices that improve the sustainability of agriculture. In the broader picture, creation of sustainability in agriculture goes beyond agronomic techniques. It requires a commitment from society and institutions to be involved in finding ways to minimize the use of non-renewable inputs and maximize the use of information and knowledge in designing strategies for sustainability.

APPLICATION

• Annual clovers could be successfully used in north-central Alberta as beneficial components of cropping systems.

• Grown for green manure or forage, annual clovers compete reasonably well with weeds.

• Mowing of clovers may be a beneficial method of controlling annual weeds when weed infestations are high.

• Annual clovers may contribute to resource conservation by improving soil fertility and by offering an alternative to commercial fertilizers.

• The benefits of legume green manuring were more evident on Luvisolic soils than on high fertility Chernozemic soils, but the contribution to long-term replenishment of organic N reserves is important to both soils.

• Annual clover may contribute to profitability by improving crop yield and quality.

• Of the annual clovers, berseem clover appears to have the best potential for use as a forage or green manure crop in north-central Alberta.

FUTURE RESEARCH NEEDS

Additional research on clover/weed interaction could use different types of weeds to assess how interaction is affected by different growth habits. The research might assess competition for light by measuring light intensities within the canopy. The influence of mowing on clover/weed balance could be assessed, using several different mowing dates.

Longer term cropping system research, comparing systems containing annual clovers with systems containing other annual legumes or perennial clovers, would be beneficial to assess the impact of annual clovers on soil.

If the soil improvement benefits of berseem are to be utilized, more research is needed on the forage potential of berseem. Trials with berseem in north-central Alberta could assess forage use (hay, silage, mixtures with cereals for silage, green chop, grazing), yield, quality, and management. Research is needed on combining forage production with green manure/soil cover benefits. A Montana study concluded that managing berseem with a two cut harvest and plowdown of regrowth produced a good combination of forage yield (5.5 to 6 Mg ha^{-1}) and plowdown nitrogen (45 to 78 kg N ha^{-1}), on two irrigated sites (Westcott, 1995). Additional information is also needed on the bloat potential of berseem and the effects of Alberta (cold) temperatures on germination and establishment of berseem.

Participatory research is needed, involving farmers and scientists, to draw upon collective wisdom and develop agricultural practices and systems that are sustainable.

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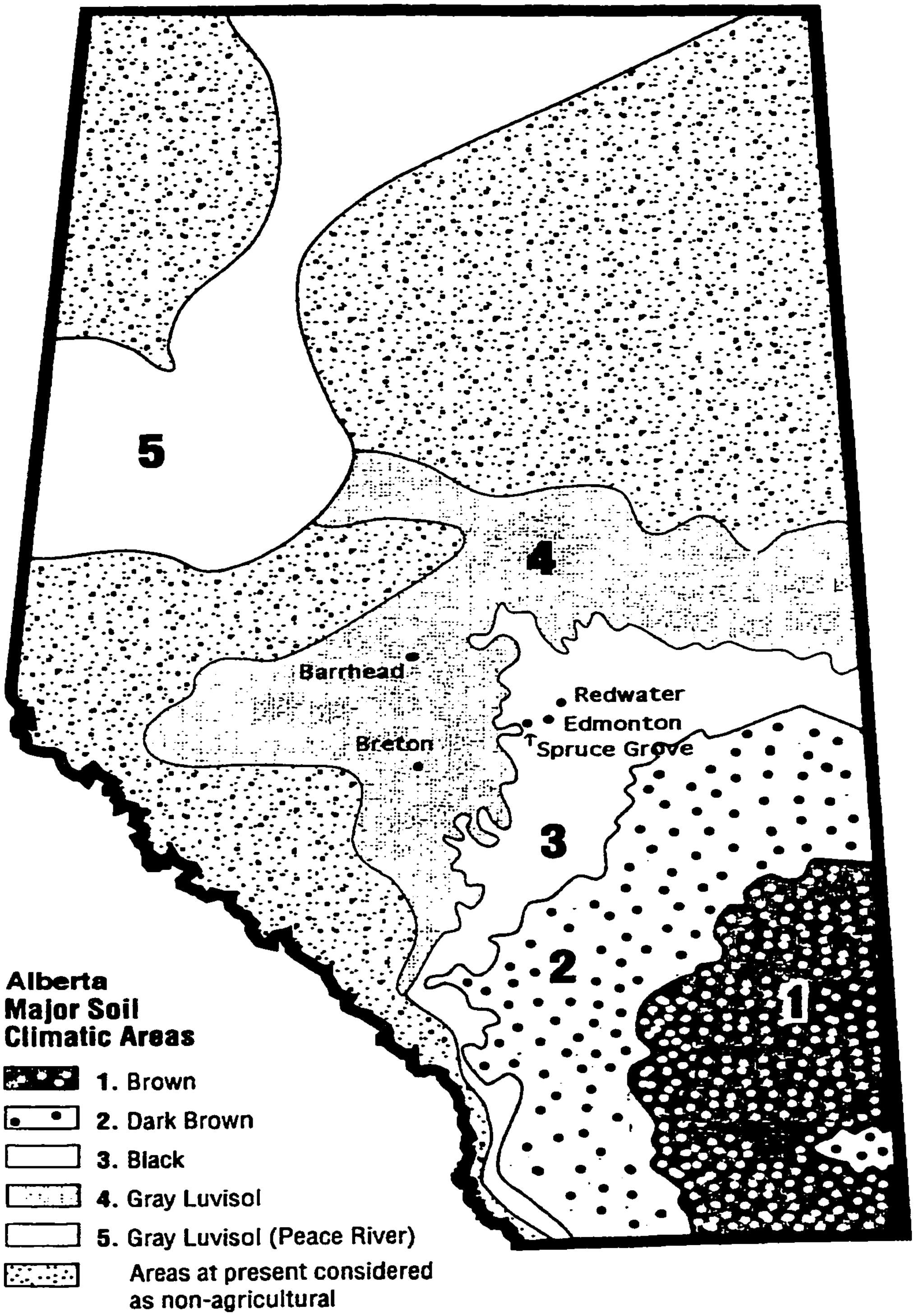
Appendix 1: Map of research sites.



Adapted from a map from Alberta Agriculture, Food and Rural Development

Appendix 2a: 1996 and 1997 soil test results for six research sites in north-central Alberta.

Location	Soil depth cm	NO_3-N ppm	Total N %	PO_4-P ppm	Total P %	K ppm	SO_4-S ppm	O.M. %	pH
Luvisolic sites 1996									
Breton U of A	0 - 15	1	0.13	7	0.04	103	3	3.3	6.1
	15- 30	1	0.07	2	0.03	85	2	2.3	6.1
Burger	0 - 15	8	0.19	8	0.05	318	3	5.2	5.7
	15- 30	1	0.06	2	0.03	141	2	2.4	5.4
Bowick	0 - 15	8	0.21	62	0.08	167	3	5.4	6.4
	15- 30	1	0.08	30	0.05	139	2	3.0	6.3
Chernozemic sites 1996									
Melnychuk	0 - 15	6	0.23	BDL*	0.05	31	78	5.8	7.9
	15- 30	5	0.13	BDL	0.04	27	198	3.1	7.8
Radzick	0 - 15	45	0.35	21	0.07	189	4	7.5	5.5
	15- 30	37	0.19	8	0.06	85	4	4.2	5.7
Edmonton U of A	0 - 15	38	0.57	21	0.09	296	17	12.1	6.5
	15- 30	40	0.38	13	0.07	216	9	8.5	5.7
Luvisolic sites 1997									
Breton U of A	0 - 15	3	0.16	6	0.05	102	2	3.8	6.0
	15- 30	BDL	0.08	2	0.04	119	3	2.5	6.1
Burger	0 - 15	6	0.25	4	0.06	129	3	7.0	6.2
	15- 30	BDL	0.06	3	0.04	83	1	2.1	5.7
Bowick	0 - 15	8	0.25	16	0.07	220	2	6.7	6.0
	15- 30	2	0.11	5	0.06	228	2	4.3	5.3
Chernozemic sites 1997									
Melnychuk	0 - 15	5	0.24	3	0.05	30	71	5.8	8.0
	15- 30	3	0.14	1	0.05	31	95	3.3	8.2
Radzick	0 - 15	17	0.24	6	0.04	50	4	5.4	7.5
	15- 30	14	0.08	4	0.03	34	3	2.0	7.6
Edmonton U of A	0 - 15	16	0.59	28	0.10	340	11	13.6	5.3
	15- 30	22	0.46	9	0.08	240	9	11.1	5.5
Gen. rec'd	0 - 15	15+		40+		150+	8+		

*BDL = below detection limit

Appendix 2b: 1997 micro-nutrient soil test results for six research sites in north-central Alberta.

Location	Soil depth cm	MN ppm	FE ppm	CU ppm	ZN ppm
Luvisolic sites					
Breton U of A	0 - 15	10.6	56	0.6	2.3
	15- 30	3.9	70	0.7	1.0
Burger	0 - 15	24.4	138	0.8	4.4
	15- 30	2.9	135	0.8	0.9
Bowick	0 - 15	6.4	148	1.1	10.7
	15- 30	2.1	343	3.9	3.2
Chernozemic sites					
Melnychuk	0 - 15	5.2	33	0.4	1.0
	15- 30	3.0	26	0.6	0.6
Radzick	0 - 15	4.7	29	0.7	2.8
	15- 30	2.4	28	0.5	1.0
Edmonton U of A	0 - 15	17.9	218	1.4	8.7
	15- 30	14.0	182	1.6	4.8
Gen. rec'd	0 - 15 cm	1.0+	4.0+	1.5+	1.0+

Appendix 3: Weather for (a) Edmonton and (b) Breton for 1996 and 1997.

(3a) Weather - Edmonton Research Station						
Month	Monthly Mean Temperature (C°)		*30 yr. Mean Temp. (C°)	Monthly Total Precipitation (mm)		30 yr Avg. Precip. (mm)
	1996	1997		1996	1997	
May	8.2	11.4	11.6	56.6	45.2	43.5
June	14.2	15.5	15.6	117.9	133.1	79.9
July	17.1	17.6	17.5	75.4	66.8	94.3
August	17.4	17.1	16.6	63.0	64.0	67.0
Sept.	9.8	12.9	11.1	62.7	79.5	41.6
Precip. total, 3 months, June-August				256.3	263.9	241.2
Precip. total, 4 months, May-August				312.9	309.1	284.7
Precip. total, 5 months, May-September				375.6	388.6	326.3

* 30 year averages are for 1961 to 1990 at Edmonton Municipal Airport - source Dept. of Earth and Atmospheric Science, U of Alberta.

(3b) Weather - Breton						
Month	Monthly Mean Temperature (C°)		*30 yr. Mean Temp. (C°)	Monthly Total Precipitation (mm)		30 yr Avg. Precip. (mm)
	1996	1997		1996	1997	
May	7.0		10.7	54.4	n a	50.3
June	12.8		14.7	126.6	108.0	81.2
July	16.2		16.3	78.0	63.4	100.0
August	16.1		15.4	107.0	76.8	67.7
Sept.	n a		10.5	n a	67.8	44.4
Precip. total, 3 months, June-August				311.6	248.2	248.9
Precip. total, 4 months, May-August				366.0	n a	299.2
Precip. total, 5 months, May-September				n a	n a	343.6

* 30 year averages for 1961 to 1990 for Breton were not available, so used data for Calmar provided by Dept. of Earth and Atmospheric Science, U of Alberta.

Appendix 4: Split-plot ANOVA statistics (p values) for effects of mowing, species and their interactions on mustard/weed phytomass (kg ha^{-1}) and mustard phytomass (g $plant^{-1}$) at Breton and Edmonton for 1996 and 1997.

	Breton		Edmonton	
	Weed/mustard	Mustard	Mustard	
	Phytomass		Phytomass	
	kg ha^{-1}	g $plant^{-1}$	kg ha^{-1}	g $plant^{-1}$
Year 1 (1996)				
Mowing	ns*	ns	0.0263	0.0679
Species	0.0001	0.0001	0.0002	0.0690
Mow x Species	0.0264	ns	0.0099	ns
Year 2 (1997)				
Mowing	ns	ns	0.0026	0.0035
Species	0.0001	0.0001	0.0001	0.0001
Mow x Species	ns	ns	0.0040	0.0017

* ns = not significant.