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Intercropping Berseem Clover with Oats, Barley or Triticale

by

Shirley Marilyn Ross ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Plant Science

Department of Agricultural, Food and Nutritional Science

Edmonton, 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 **Intercropping berseem clover with oats, barley or triticale** submitted by **Shirley Marilyn Ross** in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Plant Science**.

Dr. Martin H. Entz (External Examiner)

Date Sept 26, 2003

Plot view of berseem clover intercropped with barley, oat or triticale cultivars, prior to silage-stage harvest, at Edmonton, Alberta, 2001.

Plot view of regrowth of berseem clover, a few weeks after removal of barley, oats and triticale at silage-stage of cereals. Berseem-cereal intercrops at Edmonton, Alberta, 1998.

Dedication

In remembrance of my parents

Marian Ross

1917 – 1999

and

Herb Ross

1919 – 1997

Abstract

Intercropping berseem clover (*Trifolium alexandrinum* L.) with silage cereals may increase seasonal yield and improve forage quality. Berseem clover, an annual clover, was intercropped with oats (*Avena sativa* L.), barley (*Hordeum vulgare* L.) or triticale (*X Triticosecale* Wittmack) on a Black soil in Edmonton, Alberta. Several experiments were conducted to test the effects of seeding rate, cereal genotype and cutting date on intercrop performance.

The full-rate of cereals (240 plants m^{-2}) was very competitive, and severely reduced berseem growth. As cereal density decreased in intercrops, silage-stage (Cut 1) yield decreased, berseem percentage in Cut 1 (BP1) increased, and regrowth of berseem (Cut 2) increased. The relationship between oat plant density and berseem dry matter (DM) fit a rectangular hyperbolic model. Increasing berseem seeding rates from 6 to 24 kg ha^{-1} decreased tillering in oats, but did not necessarily reduce oat DM yield.

Berseem-cereal intercrops produced total seasonal yields of 12-13 t ha^{-1} DM, with 2-3 t ha^{-1} DM as berseem regrowth after silage-stage harvest. Reducing cereal seeding rates to 25-35% of the full-rate improved forage quality without reducing seasonal yield. A 20% berseem component in Cut 1 improved the forage quality by decreasing neutral detergent fibre. Intercropping berseem with cereals extended the harvest window for silage production without sacrificing seasonal yield.

The ranking of barley (B), oat (O) and triticale (T) intercrops was generally: T highest for Cut 1 DM yield, T>O>B for BP1, B highest for Cut 2 DM yield, T=B=O for total DM yield, and B>T ≥O for total protein yield. Differences between early-maturing oat intercrops (EO) and late-maturing oat intercrops (LO) were: LO≥EO for Cut 1 DM yield, EO=LO for total DM yield, and EO>LO for Cut 2 DM yield, total protein yield and BP1. Differences between semi-dwarf barley intercrops (S) and conventional-stature barley intercrops (C) were: C≥S for Cut 1

DM and protein yield, S≥C for BP1, S>C for Cut 2 DM yield, and S=C for total DM and protein yield. To maximize forage quality and increase growth for fall grazing, early-maturing and shorter-stature cultivars of cereals are recommended for berseem-cereal intercrops.

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List of Abbreviations

ADF, acid detergent fibre

B, barley-berseem intercrop

BE, berseem clover

BP1, berseem percentage of Cut 1

BSR, berseem seeding rate

C, conventional-stature barley intercrops with berseem.

CP, crude protein

DAP, days after planting

DM, dry matter

EO, early-maturing oat intercrops with berseem

LO, late-maturing oat intercrops with berseem

NDF, neutral detergent fibre

O, oat-berseem intercrop

O_{30}, O_{60}, O_{90}, and O_{240}, treatments with 30, 60, 90 and 240 oat plants m^{-2} respectively

OD, oat density

S, semi-dwarf barley intercrops with berseem

T, triticale-berseem intercrop

WAP, weeks after planting

Chapter 1

Introduction

The research presented in this thesis was conducted to assess the potential of intercropping berseem clover with cereal crops grown for silage in north-central Alberta. The research objectives for Chapters 2 to 6 are outlined at the end of this chapter, and a summary of conclusions is presented in Chapter 7. The remainder of this chapter provides background information on the purpose of the study and a review of relevant literature. The topics reviewed in this introduction are:

- The context
- Berseem clover
- Intercropping
  - Overview
  - Cereal intercropping in western Canada
- Legume-cereal intercrops
  - Competitive ability of legumes
  - Yield advantages
  - Berseem-cereal intercrops
- Plant characteristics and intercrops
  - Species effects
  - Cultivar effects
- Management of intercrops
  - Seeding rates
  - Emergence
  - Harvest management
  - Effects of environment
- Intercrop research

THE CONTEXT

The characteristics of the Parkland of north-central Alberta include a cool climate, higher rainfall than in prairie regions, a short growing season with long day-lengths, black soils with high fertility, and gray soils with low fertility. The growing season of the Alberta Parkland has a frost-free period of approximately 100 days with over 1300 growing degree days > 5° C from April 1 to September 30 (Campbell et al., 1990). Spring cereals, oilseeds and forages are the predominant crops in north-central Alberta. A substantial amount of barley (*Hordeum vulgare*) and oat (*Avena sativa*) production is used for silage production. In Alberta, the recent 5-year average for forage production from annual crops was 1.5 million acres (0.6 million hectares), with about 40% for greenfeed and 60% for silage (AAFRD, 2003). Barley makes up over 85% of the annual cereal silage production in Alberta.

The legumes used in the region are mainly small-seeded perennials [alfalfa (*Medicago sativa*), red clover (*Trifolium pratense*), alsike clover (*Trifolium hybridum*), and white clover (*Trifolium repens*)] and large-seeded annuals, mainly field peas (*Pisum sativum*). Pulse crops are sometimes intercropped with forage cereals, when higher nutritional quality is required (e.g. for dairy cattle). Additional annual legumes could be used to improve crop and soil quality, and to add diversity to cereal-oilseed, forage and horticulture cropping systems. The potential of small-seeded annual legumes has been largely unexplored in western Canada.

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. An agri-environmental indicators study by McRae et al. (2000) concluded that improvement of farm practices is needed in areas such as efficiency of nutrient use, protection of water quality and maintenance of soil quality. With proper management, legumes can be used to improve many aspects of soil quality: nitrogen levels, organic matter, erosion resistance, water-holding capacity, aeration, tilth, and biological activity (Biederbeck et al., 1998; Chalk, 1998). Annual forage legumes that will reliably winterkill can be important components of organic production systems and also for conventional systems if prices increase for synthetic nitrogen fertilizer (Sheaffer et al, 2001). Legume crops may become increasingly important to reduce greenhouse gas emissions from agricultural systems, reduce fossil fuel dependency, and increase soil carbon sequestration (Drinkwater et al., 1998; AAFC, 2000; Gill et al., 2001). Drinkwater et al. (1998) concluded that a legume-based cropping system resulted in greater carbon sequestration, improved soil physical properties, and cut the losses of nitrogen by half, compared to a conventional system. New approaches to farm practices require the use of 'eco-efficiency', which involves producing more-valuable products, using fewer material and energy inputs, while minimizing losses to the environment and reducing pollution (McRae et al., 2000).

As John Doran, a prominent soil scientist, has stated:

> "I see this new era that we're coming upon now as an opportunity where agriculture can be seen as a system which can help remediate environmental problems. In the past, I think it's been black-balled as a source of environmental problems, but I think it can also be a solution to some of our environmental problems" (Top Crop Manager, 2001).

BERSEEM CLOVER

The genus *Trifolium* is one of the most important genera of the Fabaceae, because of its large number of species (about 240) and its agricultural value (Zohary and Heller, 1984). Two-thirds of the *Trifolium* (clover) species are annuals, and one-third are perennials (Zohary, 1972). Clovers generally inhabit temperate regions, and prefer cool, moist climates or seasons.

Berseem clover (*Trifolium alexandrinum*) is a high yielding, cool-season annual clover, thought to have originated in the Middle East (Knight, 1985a). The name berseem comes from its Arab name "bersym" or "berzum" (Kretschmer, 1961). Berseem is one of the most important cultivated forages in the Middle East, Mediterranean, India and the Near East (Singh et al., 1989; Dunn, 1991). Berseem is also known as Egyptian clover (Knight, 1985a). Egypt is the world's largest producer of berseem, where it is grown as a winter forage crop, preceding cotton or vegetables in rotations (Dunn, 1991). Berseem cultivars are classified according to their branching habit (Duke, 1981; Knight, 1985a). The 'Miscawi' type has profuse basal branching and will regenerate after multiple harvests. The 'Saidi' type has both basal and apical branching and can be cut twice. The 'Fahl' type has only apical branching and can be cut only once. Berseem has an upright growth, with oblong leaflets, hollow stems, and self-sterile yellowish-white flowers. It has been grown in the United States since the early 1900's. The berseem cultivars grown in the USA are of the multicut type, and were derived from Egyptian common varieties (Dunn, 1991). 'Bigbee' berseem, a cultivar with improved cold tolerance for Mississippi, was selected from an Italian cultivar and registered in 1985 (Knight, 1985b).

The quality of berseem equals that of alfalfa, and it is probably best suited to green-chopped forage or pasture (Knight, 1985a). The bloat hazard of berseem is less than alfalfa, and there are no reported cases of bloat in ruminants feeding on berseem (Dunn, 1991; Sims et al., 1991). Berseem has also been used in the USA for hay, silage or as a cover crop (Dunn, 1991). It can be used as a green manure crop, or it can effectively provide a combination of forage and plowdown (Westcott et al., 1995; Shrestha et al., 1998 and 1999). Studies of berseem in Mediterranean regions include effects of cutting date and temperature on chemical composition (Guessous, 1981), effects of developmental stage on dry matter and nutrient partitioning (Iannucci et al., 1996), and effects of irrigation and harvest management on dry matter and seed yield (Martiniello, 1999). In southeastern USA, Brink and Fairbrother (1992) conducted a growth analysis study to assess forage quality and morphological components of berseem grown as a winter annual.

Although berseem is mainly grown as a winter annual, some research has investigated growing berseem as a summer crop. Spring-seeded berseem has been tested in northern USA (Dunn, 1991; Westcott et al., 1995; Shrestha et al., 1998). Westcott et al. (1995) reported dry matter yields of up to 10.7 t ha^{-1} in Montana. In Canada, berseem has been tested in forage mixtures (Stout et al., 1997), as a cover crop with corn (Abdin et al., 1998), and in rotation with potatoes to increase soil residue and organic matter (Holmstrom et al., 2001). Trials in southern Alberta assessed the forage potential of 18 annual legumes, including berseem and several other annual clovers (Fraser, 1995).

INTERCROPPING

Overview

Intercropping is a widespread practice for traditional production of food grains in tropical regions of the world (Anil et al., 1998). In temperate regions, intercropping is mainly associated with forage production. Since the 1970's, increased interest in intercropping and multiple cropping among researchers has generated several comprehensive books and reviews (Papendick et al., 1976; Willey, 1979ab; Francis, 1986; Ofori and Stern, 1987; Fukai, 1993). Review articles in more recent times indicate that there is continuing interest in intercropping among researchers (Anil et al., 1998; Connolly et al., 2001). Anil et al. (1998) suggested that despite numerous examples of research, intercropping had not found a niche in many countries, with the exception of grass-legume pastures. However, the growing attention to issues of sustainable agriculture has increased the interest in more complex farming systems and alternatives to high input monoculture cropping.

Potential benefits of intercropping include: increased yields and/or monetary returns; increased protein and forage quality; improved nitrogen relations and increased yields in subsequent crops; greater yield stability; reduced incidence of pests, weeds, and diseases; greater water use efficiency; reduced water run-off because of greater ground cover; and higher land use efficiency per unit land area (Anil et al., 1998). Potential limitations of intercropping include: increased cost of production; greater complexity in managing seeding, fertility, weed control and harvest; and inadequate information about the impact of intercropping on crop quality, such as the nutritional quality of intercrop silages.

Cereal Intercropping in Western Canada

Forage researchers in western Canada have tested silage cereals in intercrops with other annual seed crops (Walton, 1975; Berkenkamp and Meeres, 1987), with pulse crops (Jedel and Helm, 1993), with annual ryegrass (*Lolium multiflorum*) and annual legumes (Thompson et al., 1992 and 1997; Stout et al., 1997), and with other cereal genotypes (Baron et al., 1992 and 1995; Jedel and Salmon, 1995; Juskiw et al., 2000abc). Intercropping of cereals can reduce lodging, decrease disease, extend the window of harvest for silage, and improve forage quality and yield. For example, intercrops of oat and barley produced higher yields and quality than oat sole crops, when harvested at soft-dough of barley (Juskiw et al., 2000a). The potential to extend forage production has been demonstrated with intercrops of spring and winter cereals (Baron et al., 1992 and 1995; Jedel and Salmon, 1995). Although the growing season is short in central Alberta, the period of several weeks after silage harvest can be used to produce additional forage. Jedel and Salmon (1995) concluded that there was no apparent advantage to spring-winter cereal intercrops if silage production is the only requirement, but the mixtures provided an advantage of extended growth for fall pasture. The decline in protein content of cereals, after a peak in early summer, was more pronounced for spring cereal sole crops than for spring-winter cereal intercrops. Baron et al. (1992) reported that the forage quality of intercrops of spring oat with winter cereals was higher than oat sole crops. They concluded that the improved forage quality of spring-winter cereal intercrops should partially offset the slight reduction in DM yield that occurred, compared to spring cereal sole crops.

Cereal-legume intercrops have been investigated in Alberta from the perspective of cropping system sustainability (Izaurralde et al., 1990, 1992 and 1993). Increasing the use of annual legumes in cereal cropping systems, either as sole crops or as intercrops with cereals, can improve sustainability through biological nitrogen fixation, reduction of weed competition and increased input to soil organic matter (Izaurralde et al., 1993).

LEGUME-CEREAL INTERCROPPING

Competitive Ability of Legumes

Clover species are considered to be poor competitors because of their small seed size, lack of seedling vigor, and slow establishment (Lee, 1985). Competitive abilities vary among legume species and among clover species. Under dryland prairie conditions, large-seeded legumes and sweetclover (*Melilotus* spp) grown as green manure, provided better weed suppression than *Trifolium* species (Schlegel and Havlin, 1997; Jensen, 1992). Grown as winter cover in Iowa, alfalfa and sweetclover usually produced better ground cover than red or alsike clover (Exner and Cruse, 1993). Studies of spring-seeded smother plants in Iowa, found that berseem grown with corn reduced weed biomass by 65%, but when grown with soybeans (*Glycine max*), berseem was less effective than three medic (*Medicago*) species and yellow mustard (*Brassica hirta*) in reducing weed biomass (Buhler et al., 1998). In a Quebec study of corn interseeded with 12 cover crops (including seven *Trifolium* species), some clovers had little effect on weed or corn growth, but crimson clover (*Trifolium incarnatum*) produced greater competitive stress on corn than the other 11 species (Abdin et al., 1998). In another cover crop study, crimson clover provided better cover than red or white clover (Nelson et al., 1991). In north-central Alberta, berseem out-performed crimson clover and five other clovers in yield and ability to compete with weeds (Ross et al., 2001).

Many studies have demonstrated that alfalfa can be greatly suppressed by competition from cereal companion crops. A barley companion crop reduced alfalfa yields in the establishment year by 70% (Moyer, 1985). Alfalfa yields were reduced by 85-89% when grown with oat or barley companion crops that were harvested at soft dough stage (Simmons et al., 1995). In addition series experiments of alfalfa with oats or barley, Nickel et al. (1990) concluded that there was a large competitive influence of the cereal on itself and on the alfalfa, but competition from alfalfa on the cereal was negligible. Initial competition from a cereal companion crop may also affect subsequent alfalfa yields. Cereal companion crops had no effect on subsequent alfalfa yields in Minnesota (Simmons et al., 1995), reduced subsequent yields during the establishment year in California (Lanini et al., 1991), and reduced yields in the first two years of alfalfa growth in southern Alberta (Moyer, 1985).

Studies have also demonstrated the competitive effects of cereals on pulse crops. Lutman et al. (1996) studied yield losses for five crops, using additions of oats ranging from 10 to 349 plants m^{-2}. Mean oat densities causing 5% yield losses in barley, canola (*Brassica napus*), fababeans (*Vicia faba*), peas (*Pisum sativum*) and flax (*Linum usitatissimum*) were 27.2, 38.2, 6.2, 8.5 and 3.7 oat plants m^{-2}, respectively. In a study of oat-fababean intercrops, oat was the relatively stronger competitor (Helenius and Jokinen, 1994). Competition from oats reduced yields of peas by 71-72% (Brundage et al., 1979; Hornford and Drew, 1986), reduced lentil (*Lens culinaris*) yields by 81% (Hornford and Drew, 1986), and greatly reduced yields of common vetch (*Vicia sativa*) (Caballero et al., 1995).

Berseem yields have been greatly reduced by the presence of cereal or grass species in forage mixtures. When grown in a 50:50 seed ratio intercrop with Italian ryegrass (*Lolium multiflorum*), berseem constituted only 14% of a winter forage crop from four-harvests (Caballero et al., 1994). Berseem yields, from two or three harvests, were reduced about 50% when grown with oats (Welty et al., 1991; Holland and Brummer, 1999).

Ofori and Stern (1987) have provided a useful review of factors in competition between cereals and legumes in intercrops. Based on 40 papers on cereal-legume intercrop research, they concluded that legumes in intercrops declined on average by about 52% of sole crop yield, whereas the cereal yield was reduced by only 11%. Where cereals and legumes are arranged in defined rows, the degree of competition is determined by relative growth rates, growth durations, and proximity of roots of the component crops. Cereals, with relatively higher growth rates, height advantage, and more extensive rooting systems, are favoured in competition with legumes. Light and nitrogen are the main factors influencing the production efficiency of cereal-legume intercrops. Various studies show that the taller cereal component suppresses the companion legume through shading, and this is accentuated by application of nitrogen (N) fertilizer. Effects of cereal competition on N-fixation by legumes in intercrops differ among studies: e.g. shading of soybean by sorghum (*Sorghum bicolor*) decreased N-fixation, while shading of groundnut (*Arachis hypogaea*) by maize did not affect N-fixation. The quantity of N fixed by legumes in intercrops depends on species, morphology, density of legume in the intercrop, type of management and competitive abilities of component crops. In the absence of effective N-fixation by legumes, both cereals and legumes compete for available soil N. Cereal competition can also reduce uptake of phosphorus and potassium by legumes. Cereals generally have a competitive advantage over associated legumes in utilizing soil nutrients due to more extensive or faster-growing root systems (Trenbath, 1976).

Yield Advantages

The addition of a cereal or grass species to a forage legume may provide a yield advantage, compared to growing legume sole crops. Forage yields in the establishment year were higher with an oat companion crop than when alfalfa, red clover or birdsfoot trefoil (*Lotus corniculatus*) were grown alone (Lanini et al., 1991; Wiersma et al., 1999). Adding timothy (*Phleum pratense*) to red clover produced greater yield than clover alone (Kunelius et al., 2000). Adding oats to berseem increased total seasonal yield in Montana (Welty et al., 1991), but produced no forage yield advantage compared to berseem sole crops in Pakistan (Zada et al., 1998).

The addition of a pulse crop to a cereal may increase yields (Izaurralde et al., 1993; Willey et al., 1997) or may produce yields similar to sole crops (Jedel and Helm, 1993). Izaurralde et al. (1993) reported that dry matter yields of barley-pea intercrops were 22% greater than those of barley on a black soil near Edmonton. Pulse-cereal intercrops may increase protein production without increasing dry matter yield (Walton, 1975; Berkenkamp and Meeres, 1987), or may improve forage quality without increasing total N yield (Carr et al., 1998). Yield advantages of cereal-legume intercrops may occur under N-deficient conditions, but not under high soil N conditions (Moreira, 1989).

Although cereals usually contribute a greater proportion of the cereal-legume intercrop yield, the magnitude of intercropping advantage seems to be determined by the legume component (Ofori and Stern, 1987). One of the major sources of yield advantage with intercrops is better use of growth resources (light, water, nutrients) as a result of complementary effects between component crops (Willey, 1979b). Fukai and Trenbath (1993) stated that intercrops are most productive when component crops differ greatly in growth duration, and their maximum requirements for growth resources occur at different times. Willey (1979b) suggested that temporal complementarity in intercrops is likely to produce greater yield advantage than spatial complementarity, due to greater utilization of light over time. Temporal advantages are commonly used to increase forage production through manipulation of crop mixtures to optimize the use of the growing season (Anil et al., 1998).

Berseem-Cereal Intercrops

Intercropping berseem with cereals has: increased forage yield and quality compared to cereals-alone in sub-tropical climates (Singh et al., 1989; Zada et al., 1998); increased total dry matter yields, without reducing cereal grain yields (Reynolds et al., 1994; Ghaffarzadeh, 1997; Holland and Brummer, 1999); and improved forage quality, reduced fertilizer needs and increased subsequent crop yields (Stout et al., 1997; Ghaffarzadeh, 1997). Oat-berseem intercrops in Iowa were more suppressive of weeds than either oat or berseem sole crops (Holland and Brummer, 1999). Berseem intercropped with barley and annual ryegrass in British Columbia did not increase silage-stage yield, but did increase the yield of two subsequent harvests (Stout et al., 1997). In Mexico, berseem was successfully intercropped with cereals at suboptimal levels of N without apparent detriment to cereal grain yields or quality (Reynolds et al., 1994). In Iowa, regrowth of berseem that was intercropped with oats produced an average of 2.7 t ha^{-1} of herbage and had a fertilizer replacement value of 44 kg N ha^{-1} for a subsequent corn crop (Ghaffarzadeh, 1997). Intercropped with Italian ryegrass in Spain, berseem provided an annual N equivalence of 80 kg N ha^{-1} (Caballero et al., 1994). Mean berseem regrowth after cereal grain harvest was 2.1 t ha^{-1} for barley-berseem intercrops in Prince Edward Island (Holmstrom et al., 2001).

Berseem had greater potential to improve the forage quality and yields of barley-ryegrass-legume intercrops than did snail medic (*Medicago scutellata*), barrel medic (*Medicago truncatula*) or striate annual lespedeza (*Lespedeza striata*) (Stout et al., 1997). Berseem was better adapted than crimson clover or white clover for intercropping with wheat or barley to improve the ground cover, N-use efficiency and productivity of low input systems in Mexico (Reynolds et al., 1994). 'Bigbee' berseem had higher forage yields than a nondormant alfalfa variety in sole crops or in oat-legume intercrops in Iowa (Holland and Brummer, 1999). Berseem is better suited than many legumes to provide substantial regrowth after initial harvest of legume-cereal intercrops. In a study of oats intercropped with 18 annual legume species (medics, clovers and peas) in Oregon, only berseem produced significant fall regrowth after harvest of oats at the soft dough stage (Dovel and Bohle, 1997). In three of four environments in Michigan, regrowth of berseem in oat-berseem intercrops produced greater fall dry matter and N yield than did annual medic (*Medicago truncatula*) (Sheaffer et al., 2001).

PLANT CHARACTERISTICS AND INTERCROPPING

Pester et al. (1999) suggest that the traits that need to be considered in choosing cultivars for mixtures include: crop maturity, photoperiod sensitivity, temperature sensitivity, morphology, root system, seedling growth rate, and density response. The key biological factors in crop-weed interaction include: emergence time, seed size, seedling size, canopy architecture, reproductive strategy, genetic variation, physiological efficiency, phenology, growth rate, allelochemicals, life history, and growth form (Radosevich, 1988). Characteristics which enhance the competitive ability of crops include: rapid germination and root development, vigorous growth, large leaf area development and duration, greater plant height, profuse branching, and rapid canopy closure (Pester et al., 1999).

Species Effects

Choice of cereal species affects intercrop performance. Forage yield and quality of pulse-cereal intercrops differed with oats, barley or triticale (*X Triticosecale*) (Jedel and Helm, 1993). Oat-pulse intercrops produced greater silage yield than barley or triticale intercrops with peas or fababeans. Relative yield totals of pea-wheat intercrops were greater than for pea-barley intercrops (Tofinga et al., 1993). Oats and barley were more competitive than triticale or wheat in intercrops with peas, fababeans or sunflowers (*Helianthus annuus*) (Berkenkamp and Meeres, 1987). It was also concluded that oat was more competitive than barley in intercrops. Conversely, barley was more competitive than oats in cereal-cereal intercrops (Juskiw et al., 2000c) or as a companion crop for alfalfa (Nickel et al., 1990). Tesar and Marble (1988) recommended that oats is one of the best companion crops because it is not as leafy and competitive as other companion crops. In studying oat and barley companion crops for alfalfa, Brink and Marten (1986) reported that barley cultivars frequently had greater leaf area after the five-leaf stage than did oat cultivars, and thus had greater potential for competition for light with undersown alfalfa. Alfalfa seedling yield was greater with oats than with barley, at cereal stages of five-leaf, flag-leaf, dough and grain. However, alfalfa persistence and subsequent spring yield was not affected by oat and barley genotype when companion crops were harvested at dough stage.

Cultivar Effects

Holland and Brummer (1999) evaluated seven cultivars of berseem clover intercropped with eight cultivars of oats in Iowa. They observed considerable variability in important agronomic traits (forage stand, plant health, maturity, yield, height, weeds) due to berseem cultivar effects. They concluded that the agronomic performance of berseem cultivars in intercrops may not be predicted from monoculture evaluations. 'Bigbee' berseem was the most consistently high-performing cultivar across three environments.

Choice of cereal cultivar affects intercrop performance. Tesar and Marble (1988) recommend using shorter-stature, early-maturing cultivars of cereals as companion crops for alfalfa, as they are assumed to be less competitive. Positive relationships between height and competitive ability have been found in many studies of crop varieties and weeds (Berkowitz, 1988). Semi-dwarf varieties of oats and barley were less competitive than conventional-stature varieties, as companion crops for alfalfa (Nickel et al. 1990). Simmons et al. (1995) found that the amount of light penetrating the canopies of semi-dwarf oat and barley varieties to the top of alfalfa was higher than for conventional-stature varieties. Initial alfalfa growth was usually somewhat greater with semi-dwarf varieties, but there was no significant difference in subsequent harvests. Simmons et al. (1995) recommend semi-dwarf varieties as companion crops because they are less prone to lodging. Biomass yields of medic-barley intercrops were similar with semi-dwarf or conventional-stature barley, but yields with semi-dwarf barley were more variable (Moynihan et al., 1996). Thompson et al. (1992) found that a semi-dwarf barley was less competitive than conventional-stature barley in barley-ryegrass intercrops, and thus favoured ryegrass establishment. Holland and Brummer (1999) found that an oat cultivar with shorter height and earlier heading than average provided less intercropping competition than other oat cultivars. Juskiw et al. (2000c) reported that Kasota (a semi-dwarf barley) was less competitive than conventional-stature cultivars (AC Lacombe and Seebe) in small grain mixtures, perhaps due to stature or earliness.

Early-maturing barleys may be less competitive in mixtures than late-maturing cultivars (Juskiw et al., 2000c). Holland and Brummer (1999) reported that oat heading date, rather than height, may be more strongly associated with competitive effects on a companion crop. Maturity date of cereals affects the forage yield of intercrops (Thompson et al., 1992; Juskiw et al., 2000b). The total biomass per plant for cereal-cereal intercrops was affected by genotype, production practices, and time of harvest, with the latter having the greatest effect (Juskiw et al., 2000b).

Chapko et al. (1991) concluded that cereal cultivar was less important than cereal species for barley or oats intercropped with peas, as companion crops for alfalfa establishment. Of fifteen oat genotypes and nine barley genotypes, no single genotype, whether intercropped with peas or not, was distinctly superior for forage yield, forage quality, and subsequent alfalfa yield. Juskiw et al. (2000c) caution that prediction of cultivar competitive ability in mixtures cannot be based on height, biomass production, or a formula of traits. Holland and Brummer (1999) concluded that monoculture evaluation of oat cultivars could be used to predict the traits of oats in berseem-oat intercrops, but could not be used reliably to predict the effects on berseem forage yields.

MANAGEMENT OF INTERCROPS

Seeding Rates

Hoveland and Evers (1995) recommend seeding berseem at rates of 11-18 kg ha^{-1}. Graves et al. (1996) recommend seeding berseem at 13-17 kg ha^{-1} if seed is drilled, but rates of 22-28 kg ha^{-1} may be needed to establish a good stand if seed is broadcast. Wichman et al. (1991) assessed the forage yield, from one or two cuts, of berseem at 10, 20, 30, 40 or 50 plants ft^{-2}, with herbicides used to control weeds. They recommended the berseem rate of 40 plants ft^{-2} (430 plants m^{-2}), which they achieved by drill seeding at about 9 kg ha^{-1}. Higher rates of berseeem were recommended in the absence of herbicides. Intercrop studies using berseem have used rates of 10 kg ha^{-1} (Stout et al., 1997; Holland and Brummer, 1999) and 15 kg ha^{-1} (Ghaffarzadeh, 1997; Holmstrom et al., 2001).

Increasing the seeding rate of legumes in legume-cereal intercrops may or may not be advantageous. When two crops differ greatly in competitiveness, manipulation of the suppressed species may have little effect on the performance of the dominant species (Fukai and Trenbath 1993). Lanini et al. (1991) reported that alfalfa seeding rates of 18, 27 or 36 kg ha^{-1} did not affect yields or forage composition when intercropped with oats at 9, 18 or 36 kg ha^{-1}. However, increasing seeding rates of peas decreased weed growth in peas (Townley-Smith and Wright, 1994) and decreased barley yields in pea-barley intercrops (Izaurralde et al., 1990). Ofori and Stern (1987) concluded that the density of the cereal component in legume-cereal intercrops usually determined the level of intercrop yield, but the efficiency of the intercrop, as measured by land equivalent ratio (LER), followed the trend of the legume yield. Reduced cereal seeding rates may be required to increase the legume component of a cereal-legume intercrop (Caballero et al., 1995). Caballero et al. (1995) recommended that oat seed should not exceed 20% of an oat-vetch mixture, if a substantial vetch component is desired for forage quality. Tesar and Marble (1988) recommend using lower seeding rates and early removal of cereal companion crops for alfalfa.

Emergence

Relative time of emergence has been identified as an important factor in crop-weed competition (O'Donovan et al., 1985). Rate of emergence and subsequent seedling growth rate influence the species composition among establishing forage plants (Blaser et al., 1956). Tofinga et al. (1993) reported that emergence of peas after cereals in intercrops reduced the competitive ability of peas. In assessing competition between wild oats (*Avena fatua*) and winter cereals, Cousens et al. (1991) concluded that the relative timing of morphological development (with key phases being emergence, onset of tillering, and onset and cessation of stem extension) is critical to the outcome of competition. Some studies of cereal-legume intercrops have concluded that staggered sowing of components had no yield advantage over simultaneous sowing (Ofori and Stern, 1987). In those cases, the earlier-sown component has an initial advantage, but crop components were unable to fully compensate for the yield loss in the later-sown component. In other studies, the land equivalent ratio was increased when legumes were seeded prior to cereals (Ofori and Stern, 1987).

Harvest Management

Researchers in the USA recommend that the initial cut or grazing of berseem should begin after berseem reaches a height of 25-38 cm (Knight, 1985a) or when basal bud regrowth reaches 5 cm and plant height is 40-50 cm (Graves et al., 1996). In Italy, Iannucci et al. (1996) recommended that to obtain good quality forage without stressing the plant, berseem should be cut between the eighth internode elongation and early flowering stages. Kendall and Stringer (1985) stated there are three types of regrowth strategies among clover species. Red clover depends on reserve assimilates for recovery growth. White clover uses reserve carbohydrates in stolons under infrequent defoliation, and shifts to photosynthesis from remaining leaves under frequent defoliation. Annual clovers do not have stored reserves to support regrowth as in perennial clovers, but depend instead on residual leaf area and rapid leaf generation from active sites on shoot branches to support regrowth.

In some Mediterranean countries, spring cereals may be cut more than once to provide forage and grain (Royo, 1999). The forage component is obtained by cutting or grazing during cereal tillering, and then cereal regrowth is allowed to mature for grain harvest. In Alberta, forage cereals are usually cut at soft dough stage, with no expectation of regrowth. Oat biomass yields were greater with one cut at silage-stage than with two or three cuts to simulate a hay system or with repeated cuts to simulate grazing in Alberta (Berkenkamp and Meeres, 1987). Forage yields of barley, oats and wheat increased with each successive growth stage of jointing, boot, heading, milk and dough in a study in Quebec (McElroy and Gervais, 1983). As forage cereals mature, yield increases and quality decline, but some aspects of quality may plateau or improve after heading (Khorasani et al., 1997).

A few studies have looked at harvest management of berseem-cereal intercrops. In Montana, Welty et al. (1991) studied the effects of 2, 3 or 4-cut harvests on berseem grown with an oat companion crop. Oat yields were negligible in the third and fourth harvests. Yields were highest with 2 cuts over the growing season. In Pakistan, yields of berseem intercropped with oats, barley or wheat were measured for initial cut at 30, 60 or 90 days after planting, and for subsequent regrowth (Zada et al., 1998). Total seasonal yield increased as the initial harvest date was delayed.

Effects of Environment

The relative performances of crops in intercrops can be greatly affected by small changes in the growth environment (Fukai and Trenbath, 1993). Interactions between intercrop component crops depend on morphology, physiology, density and spatial arrangement, as affected by climate, edaphic and biotic environment, and management (Anil et al., 1998). Cultivar × environment interactions were significant for forage yield and quality of pea-cereal intercrops (Carr et al., 1998). Lutman et al. (1996) found that the competitive effects of oats on five other crops were less in dry years than in a wetter year. Stout et al. (1997) reported that berseem failed to establish at a high-altitude site in British Columbia, perhaps due to lower temperatures which favoured the grasses. Advantages of intercropping legumes with cereals were more prominent under conditions that were less than optimal for cereal growth, e.g. lower levels of soil nitrogen (Berkenkamp and Meeres, 1987; Moreira 1989; Anil et al., 1998). Moreira (1989) concluded that soil N availability had a greater effect on the legume proportion of oat-vetch mixtures than did seeding rate. Soil N conditions can strongly influence competition between plant species for light (Stern and Donald, 1962; Liebman and Robichaux, 1990) Competition for light will be strongest under high-productivity conditions (Goldberg, 1990).

INTERCROP RESEARCH

In the 1980's, Francis (1986) reflected on the future of multiple cropping systems and research needs. Francis sought to provide a wide perspective on the topic, as writers of individual chapters in the book had commented on future research within their particular discipline. It was felt that the study of natural ecosystems and the growing field of agroecology could provide useful clues about how to design cropping system alternatives. Identification and characterization of successful traditional and sustainable cropping systems still used by small farmers could provide an information base of successful and proven practices. Combining traditional knowledge with scientific approaches was seen as a new and promising avenue to pursue. Growing research on agroforestry could also be useful to agronomists and intercrop researchers. It was felt that agronomists and plant physiologists agreed on the need for more research on crop components and how they interacted in using resources in intercrops. With insight into the timing of competition for growth resources, new combinations or physical/spatial arrangements of crops could be used to reduce competition at crucial stages. Studies of detailed yield components and biomass of intercrops could give agronomists insight on system design and breeders direction in setting priorities in a selection and testing program. Francis noted that there was a serious need to investigate intercrops under conditions of low levels of production inputs and crop stress (e.g. in arid climates). Other areas of needed research included: effects of weed competition, root interactions, improvement of crop genotypes for intercrops, on-farm research, farming systems research, new and revised statistical techniques, and use of simulation models.

From the perspective of cereal-legume intercropping, Ofori and Stern (1987) suggested areas for future research. Research was needed on areas related to nitrogen (N) dynamics in intercrops: e.g. amounts and timing of N fertilizer additions, ways to promote N-fixation by legumes, more effective strains of rhizobia, N losses, effectiveness of slow-release N fertilizers. Other research needs were: a) component density combinations in legume-cereal intercrops that give maximum yield and efficiency, and b) finding ways to improve the production efficiency of cereal-legume intercropping systems by giving priority to maintaining the legume component.

Connolly et al. (2001) reviewed 50 papers published between 1990-1999, with a focus on the methods and indicators used in 72 intercropping experiments. The geographic range of studies indicated widespread interest and relevance of intercropping. Almost all of the studies addressed crop yield, and 53% of the studies were concerned with factors that affected the productivity and benefits of intercropping. Research interest was concentrated on the effects of different genotypes and companion crops on yield, and the effects of management such as fertilizer application and irrigation. The three most common intercrops in the studies were wheat-clover, millet-cowpea and corn-bean. The authors noted a number of areas that were lacking in the intercrop studies. There was little focus on understanding the processes and mechanisms of crop interactions. Only two studies measured effects at the level of the individual plant, and only two studies provided assessment of plant size or leaf area at initial pre-competition stages of growth. Many studies provided some information on sequential measurements over the course of the experiment, but this was generally not for all species, and rarely involved biological variables such as leaf area or biomass. Sequential information sometimes consisted of measurements such as the change in light at various heights in the crop. About half of the experiments lasted a single year, including 6 of 18 experiments involving perennial species. The short duration of many studies did not allow for evaluation of the effects of climatic variation or assessment of stability and sustainability. The overall conclusion was that intercrop researchers should ensure that the indicators and experimental methods they use are appropriate to the development and testing of sustainable systems.

OBJECTIVES

The objectives of the research presented in this thesis were:

1. To test the forage potential of oat-berseem, triticale-berseem and barley-berseem intercrops using a 2-cut (silage and regrowth) harvest system.

   Hypothesis: Forage yield and quality of cereal-berseem intercrops will differ using oat, barley or triticale in the intercrop.

2. To test the effects of seeding rate on the forage yield and quality of cereal-berseem intercrops.

   Hypothesis: Appropriate seeding rates, combined with appropriate choice of cereal genotype and cutting date, can be used to maximize the forage yield and quality of cereal-berseem intercrops.

3. To explore the effects of cutting date on interactions in intercrops between silage cereal crops and an annual clover.

   Hypothesis: Competitive effects of a silage cereal on an annual clover in an intercrop will differ with cereal growth stages of tillering through to soft dough.

4. To investigate how cereal stature and earliness influence legume-cereal interactions in intercrops.

   Hypothesis: Semi-dwarf and early-maturing cereal cultivars will cause less suppression of berseem in intercrops, compared to conventional stature and late-maturing cereal cultivars.

Chapter 2 examines the effects of oat plant density on berseem clover biomass, and the effects of berseem seeding rate on companion oat plants. Chapter 3 assesses the effects of cereal species (barley, oat and triticale) and cereal seeding rate on berseem-cereal intercrop performance. Chapter 4 assesses the effects of oat and barley cultivar on the performance of berseem-cereal intercrops, at one cereal seeding rate. The research presented in Chapters 5 and 6 involved sequential harvest of oat-berseem intercrops at 10-day intervals. Chapter 5 presents changes in initial yield, forage quality and competitive effects for intercrops at four oat seeding rates. Chapter 6 examines the effects of cutting date and oat plant density on the seasonal forage yields of berseem-oat intercrops. The concluding chapter, Chapter 7, provides a synthesis and a summary of findings.

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Chapter 2

Seeding rate effects in oat-berseem clover intercrops

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Chapter 2

Seeding rate effects in oat-berseem clover intercrops

INTRODUCTION

Berseem clover, an annual clover, is commonly grown in sub-tropical climates to provide forage and improve soil quality (Dunn 1991). Berseem may have promise as a new crop for Canada. In research conducted in north-central Alberta, berseem out-performed six other clovers in yield and ability to compete with weeds (Ross et al. 2001). Increasing the use of annual legumes in cereal cropping systems, as monocrops or intercrops, could improve sustainability through biological nitrogen fixation, reduction in weed competition and increased input to soil organic matter (Izaurralde et al. 1993).

Oats have frequently been used as a companion crop for forage legumes. Singh et al. (1989) described oats and berseem clover as the two most important cultivated forage crops of the sub-tropical world. Growing oats with alfalfa can substantially increase first cut forage yields (Lanini et al. 1991). Oats have also been used to provide legumes with physical support for climbing, improve light interception and facilitate mechanical harvesting (Caballero et al. 1995). However, oats have been shown to have substantial competitive effects on legumes such as alfalfa (Moyer 1985), faba bean (Helenius and Jokinen 1994) and vetch (Caballero et al.1995).

Some research has been conducted in Canada to investigate intercropping berseem for forage (Stout et al. 1997), as a cover crop (Abdin et al. 1998) or to increase soil residue and organic matter (Holmstrom et al. 2001). Berseem intercropped with barley and annual ryegrass did not increase yields of the first forage harvest, but did increase the yields of two subsequent harvests (Stout et al. 1997).

Research on cereal-legume intercropping has increased in temperate regions in recent years (Connolly et al. 2001; Anil et al. 1998). Potential benefits of intercropping include: greater yield stability; reduced incidence of pests, weeds, and diseases; increased yields and/or monetary returns; increased protein and forage quality; higher water use efficiency; reduced water run-off because of greater ground cover; and higher land use efficiency per unit land area. Intercropping cereals with legume may increase yields (Willey et al. 1997) or may produce yields similar to sole crops (Jedel and Helm 1993). Legume-cereal intercrops may improve forage quality, but may not increase total N yields (Carr et al. 1998).

Research on berseem-oat intercrops includes assessment of effects of seeding methods (Singh et al. 1989), potential rotation benefits (Ghaffarzadeh 1997; Sheaffer et al. 2001), and cultivar effects (Holland and Brummer 1999). In India, berseem-oat intercrop produced higher yields than oats alone (Singh et al. 1989). Adding berseem to oats increased total seasonal biomass and subsequent corn yields (Ghaffarzadeh 1997; Sheaffer et al. 2001). Holland and Brummer (1999) concluded that the agronomic performance of berseem cultivars in intercrops may not be predicted from monoculture evaluations. In a study of oats intercropped with 18 annual legume species (medics, clovers and peas), only berseem clover produced significant fall regrowth after harvest of oats at soft dough stage (Dovel and Bohle 1997). Other studies of mixtures involving berseem have looked at yield potential and harvest management (Welty et al. 1991; Caballero et al. 1994; Stout et al. 1997). Little information is available on the effect of seeding rate on oat-berseem interaction.

Clover species are considered to be poor competitors because of small seed size, lack of seedling vigor, and slow establishment (Lee 1985). Berseem yields may be greatly reduced by the presence of cereal or grass species in forage mixtures. When grown in a 50:50 seed ratio intercrop with Italian ryegrass, berseem constituted only 14% of a winter forage crop with a four-cut harvest (Caballero et al. 1994).

Interactions between component crops in a mixture will depend on their morphology, physiology, density and spatial arrangement, as affected by climate, edaphic and biotic environment, and management (Anil et al. 1998). Increasing seeding rates may make legumes more competitive. Increasing seeding rates of peas decreased weed growth (Townley-Smith and Wright 1994) and decreased barley yields in intercrops (Izaurralde et al. 1990). Caballero et al. (1995) recommended that oat seed should not exceed 20% of an oat-vetch mixture, if a substantial vetch component is desired for forage quality. With herbicide control of weeds, Wichman et al. (1991) recommended using berseem seeding rates of about 9 kg ha^{-1}. They suggested that when the use of herbicides is not economical, seeding at higher rates may improve berseem yields by inhibiting weed growth.

In a review article on intercropping, Connolly et al. (2001) noted that more research is needed to understand the mechanisms and processes of interspecific interaction in intercrops. Only two studies had measured interaction at the level of the individual plant. The objectives of this study were to assess the effects of oat plant density on berseem clover biomass, and the effects of berseem seeding rate on a low density of companion oat plants.

MATERIALS AND METHODS

Field experiments with mixtures of berseem clover and oats were conducted in 1996 and 1997 at Edmonton (53° 25' N, 113° 33' W), Alberta, on an Orthic Black Chernozemic Malmo silty clay loam. Experiments followed tilled fallow, and fields were disked and harrowed prior to seeding. The pH and total organic N from 0 to 15 cm depth, was 6.5 and 5.7 g kg^{-1}, respectively, at the 1996 site, which had been limed in 1995, and 5.4 and 5.9 g kg^{-1}, respectively, at the 1997 site (Appendix 1). No fertilizer was added.

Oat Density Experiment

An oat density (OD) experiment tested one seeding rate of berseem clover with several densities of oat plants. The experimental design was a randomized complete block with four replicates. Bigbee berseem clover was seeded at 15 kg ha^{-1} with oats at 0, 5, 25, 50 and 100 live seeds m^{-2} in 1996. In 1997, oats at 1 and 2 live seeds m^{-2} were added to rates of 0, 5, 25, 50 and 100 live seeds m^{-2} in order to increase assessment at low densities. Plots were 2 by 6 m in 1996 and 2 by 5 m in 1997. Oat cultivars were Calibre in 1996 and a common oat (Trace) in 1997. The rate of 100 live seeds m^{-2} was achieved by seeding oats at 35.5 kg ha^{-1} in 1996 and at 36.4 kg ha^{-1} in 1997. Berseem clover seed was inoculated with the appropriate strain of *Rhizobium trifolii*, prior to seeding. Berseem was broadcast onto the soil surface by hand and incorporated by hand raking. Oats were seeded at approximately 2.5 cm depth. Oat treatments of 1, 2 and 5 plants m^{-2} were seeded by hand. Oat treatments of 25, 50 and 100 plants m^{-2} were seeded in rows 23 to 25 cm apart with a single cone seeder in 1996, and with a 4-row Fabro drill in 1997. In 1996, plots were seeded on June 13 and were packed manually with a roller drum. In 1997, oats at 1, 2 and 5 seeds m^{-2} and berseem were seeded on May 29, and oats at 25, 50 and 100 seeds m^{-2} were seeded on May 30.

After emergence, a 1 m^2 quadrat with a 0.25 m^2 subquadrat was permanently marked in each plot. Quadrats were placed away from plot margins and in areas with uniform berseem and oat growth. Quadrat placement aimed for the desired oat plant densities of 1, 2, 5, 25, 50 or 100 plants m^{-2}. Some oat densities were achieved through a combination of quadrat placement and thinning. Seedling numbers of berseem plants in subquadrats were counted at 6 weeks after planting (WAP) in 1996 and at 4 WAP in 1997. Weeds were removed by hand.

In 1996, quadrats were harvested at 11 WAP (Cut 1), when oat plants were in the early stages of seed set (soft dough stage). A second 1 m^2 area was harvested from each plot at the end of the growing season (late September) at 15 WAP (Cut 2). Oat canopy height and maximum stem length of clover were measured in each plot prior to harvest. Vegetation was clipped at a stubble height of 5 to 7.5 cm, separated by species, and oat plants and oat tillers were counted. Harvested biomass was dried for 72 hours at 52 °C and weighed. Oat biomass from Cut 2 was threshed to measure grain yields.

In 1997, harvest procedures of 1996 were repeated with some changes. Oat canopy heights were not measured. After quadrats were harvested at 11 WAP, plots were mowed to a stubble height of 7 to 10 cm using a flail-type small plot harvester. Cut material was removed from plots. At 18 WAP harvest procedures were repeated. Plots were harvested before seed maturity so grain yield was not measured.

Data were analysed using regression and analysis of variance techniques to determine significant treatment effects ($P \leq 0.05$) using Statistical Analysis System (SAS Inst. 2000). Data for each year are presented separately, as the error variances were not homogeneous between years.

Relationships between berseem yield and oat variables were tested against linear and nonlinear models. Data were tested for fit with a simple linear regression model:

$$y = a + bd \qquad \text{(Equation 1)}$$

where y is the berseem yield, a (the intercept) is the oat-free berseem yield, b (the slope) is the estimated berseem yield loss per unit of oat density, and d is the oat density. Where the data indicated a curvilinear relationship, a nonlinear regression model proposed by Cousens (1985) was used to describe the relationship between berseem and oats.

$$y = Y_{of}[1 - (id/\,(100\,(1 + id\,/a))] \qquad \text{(Equation 2)}$$

where y is the estimated berseem yield, Y_{of} is the estimated oat-free berseem yield, i (initial slope) is the initial % yield loss of berseem per unit of oat density, d is the oat density, and a (asymptote) is the % yield loss of berseem at infinite oat density.

Berseem Seeding Rate Experiment

A berseem seeding rate (BSR) experiment tested one density of oat plants with four or five seeding rates of berseem clover. The experimental design was a randomized complete block with four replicates. Plots were 2 by 6 m in 1996 and 2 by 5 m in 1997. Oats were seeded at 20 seeds m^{-2} with berseem clover at 6, 12, 18 and 24 kg ha^{-1} in 1996, and at the same rates, including berseem at 0 kg ha^{-1} in 1997. Oat cultivars were Calibre in 1996 and a common oat (Trace) in 1997. Bigbee berseem clover seed was inoculated with *Rhizobium trifolii*, broadcast onto the soil surface by hand, and incorporated by hand raking. Oats were seeded at approximately 2.5 cm depth in rows 23 to 25 cm apart, with a single cone seeder in 1996 and a 4-row Fabro drill in 1997. In 1996, plots were seeded on June 14 and packed manually with a roller drum. In 1997, seeding of berseem was on May 29 and oats on May 30.

After emergence, a 1 m^2 quadrat with a 0.25 m^2 subquadrat was permanently marked in each plot. Quadrats were placed away from plot margins and in areas with uniform growth. In 1996, the number of oat plants per quadrat was not set. In 1997, quadrats were placed in a manner so that they would contain approximately 12 evenly spaced oat plants within the 1 m^2 area. Seedling numbers of berseem plants in subquadrats were counted at 6 WAP in 1996 and at 4 WAP in 1997. Weeds were removed by hand.

Environmental conditions were generally favorable for growth in 1996 and 1997. Rainfall for June to August was higher than the 30-year average (241 mm), with 256 mm in 1996 and 264 mm in 1997 (Appendix 2). Rainfall in June was much above the 30-year average of 80 mm: 118 mm in 1996 and 133 mm in 1997. With the exception of cooler temperatures in June 1996 (monthly mean of 14.2° C versus norm of 15.6° C), seasonal (June to August) temperatures were near normal, with three-month mean temperatures of 16.2 °C in 1996 and 16.7 °C in 1997.

With shallow broadcast seeding of the berseem, there is potential for the deeper seeded oats to germinate in advance of the berseem unless adequate rainfall follows seeding. In 1996, plots were seeded June 13-14, and there were small showers of 3.5 and 2 mm on June 13 and 17, respectively. A heavy rainfall of 66 mm followed on June 18-19. By June 24, the berseem and oats had both emerged, with some of the oats already about 5 cm high.

In 1997, rainfall was more conducive to early emergence of the berseem, relative to the oats. Plots were seeded on May 29-30 and rainfall of 6, 4, 6 and 9 mm fell on May 29, May 30, June 1 and June 4, respectively. Approximately 3 weeks after seeding, there was a very heavy rain (76 mm from June 18-22). The plots were located in a low-lying area with poor drainage, and growth in some plots appeared to be stressed by a subsequent period of waterlogging.

In both years, quadrats were harvested at 11 WAP (Cut 1) at the soft dough stage of oats. In 1996, a second 1 m^2 area was harvested from each plot at 15 WAP (Cut 2). Vegetation was clipped at a stubble height of 5 to 7.5 cm, separated by species, and oat plants and oat tillers were counted. Harvested biomass was dried for 72 hours at 52 °C and weighed. In 1996, oat biomass from Cut 2 was threshed to measure grain yields. In 1997, berseem regrowth in quadrats was harvested at 18 WAP.

Data were subjected to regression analysis and analysis of variance to determine significant treatment effects ($P \leq 0.05$) using Statistical Analysis System (SAS Inst. 2000). Data for each year are presented separately, as the error variances were not homogeneous between years.

RESULTS

Oat Density Experiment

Oat plant numbers were close to target densities in most treatments of the OD experiments (Table 2-1). The OD_{100} (target density of 100 oat plants m^{-2}) in 1996 produced 284 and 270 tillers from 79 and 73 plants, respectively, compared with 200 tillers from 111 plants in 1997. The oat plants in the OD_5 treatments averaged 13.2 tillers $plant^{-1}$ in 1996, compared with 5.2 tillers $plant^{-1}$ in 1997. Number of berseem clover plants (in 0.25 m^2 sub-quadrats) was greater in 1996 than in 1997, but the berseem plant densities were reasonably consistent among treatments within each year. Oat plants were taller than berseem plants, at all growth stages. At 11 WAP in 1996, oat canopy height averaged 135 cm and maximum stem length of berseem averaged 113 cm (Appendix 3).

In 1996, berseem dry matter (DM) yields were reduced ($P < 0.05$) by all OD treatments (Table 2-2). When grown with OD_5, berseem DM was reduced by 30% in Cut 1 and 51% in Cut 2, compared to OD_0. Berseem DM was reduced by 58-60%, 68-75 and 80-82% with OD_{25}, OD_{50}, and OD_{100}, respectively. Biomass exhibited quadratic responses to OD. The size of individual oat plants increased as oat density decreased. For Cut 1, the oats at OD_5 had 12.4 tillers $plant^{-1}$ and DM yields of 50.9 g $plant^{-1}$, while the oats at OD_{100} had 3.6 tillers $plant^{-1}$ and DM yields of 10.6 g $plant^{-1}$ (Tables 2-1 and 2-2). Although the oat rates in the OD_{50} and OD_{100} treatments were much less than the full oat rate for Alberta of 250 seeds m^{-2}, oat yields were comparable to those that occur with full rates. At 15 WAP, oats in OD_{50} and OD_{100} treatments yielded >12 Mg ha^{-1} of total DM (Table 2-2) and $\geq$ 4 Mg ha^{-1} of grain (Appendix 4).

In 1997, the effect of oat plants on berseem DM was not as great as in 1996. The OD_5 treatment had no detectable effect on berseem DM in 1997 (Table 2-3). The OD_{25} reduced berseem DM by 25%, and the OD_{100} reduced berseem DM by 44%. Berseem and oat biomass exhibited quadratic responses to OD, and the combined berseem-oat biomass exhibited linear responses to OD. Lower oat DM yields in 1997, compared to 1996, were balanced by greater berseem DM in the intercrops.

Mowing at 11 WAP in 1997 resulted in vigorous berseem regrowth, while oat regrowth was negligible. There was a trend towards decreasing berseem regrowth DM with increasing oat density ($P = 0.065$) (Table 3). With a two cut harvest, total berseem DM in OD_{100} was about 30% (3 Mg ha^{-1}) less than in treatments with little or no oat competition.

There was a nonlinear relationship between berseem DM yield and oat plant density (Figure 2-1). The relationship fit well with the rectangular hyperbolic model of Equation 2 (Table 2-4). Standard errors for parameters were within an acceptable range (less than one-half the value of parameter estimates) and asymptote values were biologically realistic (less than 100%). However, the relationship between oat plant density and berseem yield loss varied greatly between years and between harvests. Parameters estimates for initial slope (i) varied from 1.5% to 22% berseem yield loss per oat plant. Estimated asymptotic yield loss (a) ranged from 63.8% to 96.2%.

The relationship between berseem DM yield and oat DM yield fit well with a linear model at 11 WAP (Figure 2-2). Oat DM accounted for 94% of the variation in berseem DM in 1996 and 82% of the variation in 1997. Slope values were fairly consistent between years and harvests. For each g m^{-2} increase in oat DM, berseem yield losses were 0.58 ± 0.03 g m^{-2} in 1996 and 0.50 ± 0.05 g m^{-2} in 1997. At 15 WAP in 1996, the linear relationship between berseem DM and oat DM had an R^2 value of 0.80 and a slope value of -0.48 ± 0.06 g m^{-2} (Appendix 5).

The relationship between berseem DM yield and oat tiller density also fit well with a linear model at 11 WAP (Figure 2-3). Tiller density accounted for 93% and 84% of the variation in berseem DM, in 1996 and 1997 respectively. Berseem yield losses per oat tiller were 1.73 ± 0.11 and 1.64 ± 0.14 g m^{-2}, in 1996 and 1997 respectively. The greater DM of oat tillers at 11 WAP in 1996 (mean of 3.51 g tiller^{-1}) may have caused somewhat greater berseem suppression than the oat tillers from comparable treatments in 1997 (3.23 g tiller^{-1}) (Tables 2-1, 2-2 and 2-3). At 15 WAP in 1996, the relationship between berseem DM and oat tiller density had a partial fit with a linear model (R^2 value of 0.75), but the estimated intercept of 748 ± 52 g m^{-2} underestimated the observed berseem yield of 895 g m^{-2} at OD_0, and the estimated slope value of 2.21 ± 0.30 g m^{-2} did not represent the steepness of the initial slope (Appendix 6).

Berseem Seeding Rate Experiment

The focus of the BSR experiments was the growth of individual oat plants as affected by the density of companion berseem plants. The mean density of oat plants in quadrats was 17.5 ± 2.9

plants m^{-2} in 1996 and 11.9 ± 1.1 plants m^{-2} in 1997 (Table 2-5). Berseem plant density, indicated by establishment of plants in 0.25 m^{-2} sub-quadrats, was proportionate to seeding rate and was consistent between years. There were linear increases in berseem DM with increasing BSR, for initial harvests at 11 and 15 WAP.

In 1997, there were significant ($P < 0.001$) linear relationships between increases in BSR and decreases in oat tillering (tillers $plant^{-1}$), oat DM yield (Mg ha^{-1}) and oat plant DM (g $plant^{-1}$) (Table 2-5). Increasing BSR from 6 to 24 kg ha^{-1} decreased oat tillering by 51%, oat DM by 57%, and oat plant DM by 51%. There was a linear decrease ($P < 0.05$) in oat tiller DM (g $tiller^{-1}$) with increasing BSR, when BSR_0 (oats alone) was included in the analysis. There was no significant effect of BSR on oat tiller DM among the four intercrop treatments of BSR_6, BSR_{12}, BSR_{18}, and BSR_{24}.

In 1996, there were fewer significant effects of BSR on oats than in 1997 (Table 2-5). With increases in BSR in 1996, there were linear decreases in oat tillering for both cuts, and decreases in oat plant DM for Cut 2. BSR had no significant effects on oat DM (Mg ha^{-1}) in 1996. . Increasing BSR from 6 to 24 kg ha^{-1} decreased oat tillering by 22-25% and oat plant DM by 8-13%. Interestingly, there was a linear increase in oat tiller DM with increasing BSR, with increases of 17-18% in BSR_{24} compared to BSR_6. For the oats from Cut 2, the cereal grain yield per tiller was 31% higher in BSR_{24} (1.88 g grain $tiller^{-1}$) than in BSR_6 (1.44 g grain $tiller^{-1}$) (Appendix 7).

In 1997, regrowth of berseem after the silage-stage harvest averaged 2.8 Mg ha^{-1} at 18 WAP (Table 2-5). There was a trend of increasing berseem regrowth DM with increasing BSR ($P = 0.067$). Compared to BSR_6, the berseem DM yield for BSR_{24} was 45% higher at initial harvest, 28% higher for regrowth, and 40% higher for the total of two harvests.

DISCUSSION

Competitive Effects of Oat Plants on Berseem Clover

Results indicate that competition from oat plants can severely reduce berseem biomass yield, but effects may vary greatly between years. Berseem yield reductions with OD_{100} ranged from 44% to 82% for a one-cut harvest. The yield reduction in this study is comparable to suppression of other legume species by oats in earlier studies. Oats at about 150 plants m^{-2} reduced alfalfa biomass by 85-89% (Simmons et al. 1995) and pea biomass by 72% (Brundage et al. 1979). Oats at 50 plants m^{-2} reduced grain yields of peas by 71% and lentils by 81% (Hornford and Drew 1986).

The plasticity of oats through tillering was a significant factor in oat competition. In the OD_5 treatments of 1996, a mere 6 oat plants m^{-2} produced up to 81 tillers m^{-2} and 5.3 Mg ha^{-1} DM, and reduced berseem DM by up to 51%. Monocots have been reported to be significantly more plastic than dicots (Wilson 1991). Helenius and Jokinen (1994) found that oat monocrop DM and grain yields were rather insensitive to seeding rate, using rates ranging from 150 to 700 oat seeds m^{-2}. Our results suggest that it may be possible for oat DM to plateau at rates as low as 50 plants m^{-2}.

There was a linear relationship between increases in oat DM and decreases in berseem DM. The decrease in berseem DM was about 0.50 ± 0.1 g m^{-2} for each g m^{-2} increase in oat DM. Linear effects on legume yields have been reported in other studies. Malik et al. (1993) reported a linear decline in seed yield of white bean averaging 0.38 kg ha^{-1} for each kg ha^{-1} of weed biomass. Caballero et al. (1995) found that vetch dry matter decreased linearly as the percentage of oat seed increased in vetch-oat mixtures. The relationship between oat tiller density and berseem DM fit well with a linear model at 11 WAP, but fit less well at 15 WAP in 1996.

The relationship between berseem DM and oat plant density was nonlinear and fit well with a hyperbolic model (Equation 2). Model parameters varied greatly between years and harvests. Although oat plant density could be used to explain berseem yield losses in individual harvests, it would likely be a poor predictor of berseem suppression. Effects of year and location will influence the relationship between berseem and oat plants. A hyperbolic response curve, based on six years of testing the effects of oat plant density on field bean yield, was a poor predictor of bean yield losses in three subsequent years (Lutman 1999). In studies by O'Donovan and Blackshaw (1997), the initial slope for the effect of barley plants on pea seed yields varied between Alberta locations and ranged from 1.4% to 11.9%. The amount of variation observed in monocot-dicot intercrops may be greater than with monocot mixtures. Fairly consistent barley or wheat grain yield losses of 0.5% to 1% per wild oat plant have been reported in weed competition studies (Wilson et al. 1990; O'Donovan et al. 1999).

Oat-berseem relationships were affected by environmental conditions. Cool, wet weather in June 1996 provided favorable conditions for oat establishment and tillering. Heavy rainfall caused waterlogging at 3 WAP in 1997, which likely stressed the oat plants and reduced tiller production. The relative performance of crops in intercrops can be greatly affected by small changes in the growth environment (Fukai and Trenbath 1993). When rainfall was more conducive to early relative emergence of berseem, berseem produced a higher proportion of total yield, and suppression by oats was not as great. Earlier relative emergence of berseem in 1997 may have also increased the competitive effect of berseem on oats, resulting in decreased oat tillering. Relative time of emergence has been identified as an important factor in crop-weed competition (O'Donovan et al., 1985) and in legume-cereal intercrops (Tofinga et al.1993). Cousens et al. (1991) concluded that the relative timing of morphological development is critical to the outcome of competition.

High levels of soil N at the Edmonton site may have provided the oats with a greater competitive advantage than would have occurred at a site with less soil N. In research comparing the growth of annual clovers at Edmonton with a site with lower productivity, suppression of weeds by clovers was greater at the low soil-N site (Ross et al. 2001). Moreira (1989) reported that forage oats showed a very high yield response to N and rainfall, and the proportion of vetch in oat-vetch mixtures increased under N-deficient conditions. It was concluded that soil N availability had a greater effect on the legume proportion of oat-vetch mixtures than did seeding rate.

The effects of a two cut harvest on oat-berseem mixtures warrant further research. In 1997, one harvest was made at silage-stage of oats and a second harvest at the end of the growing season. The total berseem DM in OD_{100} was about 30% less than in treatments with little or no oat competition. Other studies of berseem-oat mixtures have reported greater yield reductions. With two or three harvests, berseem yields were reduced by about 50% with oats at 323 seeds m^{-2} (Holland and Brummer 1999) or with oats at approximately 40 kg ha^{-1} (Welty et al. 1991).

Effects of Berseem Seeding Rates

Increasing berseem seeding rates (BSR) had consistent effects of reducing oat tillering. Increasing BSR from 6 to 24 kg ha^{-1} decreased oat tiller production (tillers $plant^{-1}$) by 22-51%. The results are similar to the finding of Tofinga et al. (1993) that pea shoot competition reduced ears $plant^{-1}$ of wheat and barley by 30%.

The effects of BSR on oat DM varied between years. In 1997, increasing BSR significantly ($P < 0.001$) reduced oat DM yield (Mg ha^{-1}) and oat plant DM (g $plant^{-1}$), with reductions of up to 57%. In 1996, BSR had few significant effects on oat yields. The greater competitive effect of berseem in 1997 may have been due to earlier relative emergence of berseem in that year. In addition, greater uniformity of the density and proximity of oat plants within quadrats in 1997 likely improved precision in measuring competitive effects of berseem, compared to 1996.

The significant effects of BSR on oat yields in 1997 would be consistent with studies showing that increasing seeding rates of peas increased competitive ability (Izaurralde et al. 1990; Townley-Smith and Wright 1994). The limited effect of BSR on oat yields in 1996 would be consistent with some studies of alfalfa-cereal mixtures. Lanini et al. (1991) reported that alfalfa seeding rates of 18, 27 or 36 kg ha^{-1} did not affect yields or forage composition when intercropped with oats at 9, 18 or 36 kg ha^{-1}. In experiments with mixtures of alfalfa with oats or barley, Nickel et al. (1990) concluded that there was a large competitive influence of the cereal on itself and on the alfalfa, but competition from alfalfa on the cereal was negligible. The OD experiment showed that relatively small changes in oat plant density can have substantial effects on berseem yield. The BSR experiment showed that large changes in berseem plant density may have relatively little effect on oat yield. When two crops differ greatly in competitiveness, manipulation of the suppressed species often has little effect on the performance of the dominant species (Fukai and Trenbath 1993).

Effects of BSR on oat tiller DM (g $tiller^{-1}$) varied between years. Increasing BSR from BSR_6 to BSR_{24} resulted in an increase in oat tiller DM of 17-18% in 1996, and had no effect on oat tiller DM in 1997. The results suggest a mechanism of yield compensation, where oat tiller DM is maintained or increased when tiller production has been reduced. The results also suggest that although berseem had competitive effects on early stages of oat growth (e.g. tillering), the effects were less at later stages of oat growth.

With increasing BSR, there was a linear increase in berseem DM yield for initial harvest, and a trend of increased regrowth yield. Similarly, Wichman et al. (1991) found that increasing the seeding rate of berseem monocrops had a greater effect on initial forage yield than on regrowth yield. They recommended rates of 40 berseem plants ft^{-2} (430 plants m^{-2}) to optimize forage yield from one or two cuts. In our study, a BSR of 18 kg ha^{-1} was required to produce 400+ berseem plants m^{-2}.

In considering what BSR to recommend for intercrops, increasing BSR can increase berseem yield and competitive ability, but gains may not be economic. Recommended rates for berseem in monoculture are 11-18 kg ha^{-1} (Hoveland and Evers 1995). Our results suggest that using the upper range of recommended seeding rates may improve the ability of berseem to compete in intercrops. However, given that berseem is not a strong competitor, additional management practices such as mowing (Ross et al. 2001) or early harvest may help to improve the contribution of berseem to intercrops.

Feasibility of Intercropping

Intercropping oats with berseem increased DM yields compared to berseem alone. Total intercrop DM yields for OD_{100} were 3 to 4 Mg ha^{-1} greater than for OD_0. Similarly, Wiersma et al. (1999) found that forage yields of alfalfa, red clover or birdsfoot trefoil in the establishment year were higher with an oat companion crop than for legumes alone.

The Edmonton site had good levels of soil nutrients and rainfall. Under these highly productive conditions for cereals, the addition of berseem may have little impact on the yield and quality of a cereal silage crop. Advantages of intercropping legumes with cereals are more prominent under conditions that are less than optimal for cereal growth, e.g. lower levels of soil nitrogen (Anil et al. 1998; Moreira 1989).

After harvest at silage-stage of oats, berseem-oat intercrops showed potential for additional forage production from berseem regrowth. Mean berseem regrowth after harvest at silage-stage of oats was 3.3 Mg ha^{-1} in the OD experiment and 2.8 Mg ha^{-1} in the BSR experiment. Similar or somewhat less berseem regrowth (2.1-2.7 Mg ha^{-1}) has been reported in intercrop studies where initial harvest was taken at cereal grain maturity (Ghaffarzadeh 1997; Holmstrom et al. 2001). Fukai and Trenbath (1993) state that intercrops are most productive when component crops differ greatly in growth duration, and their maximum requirements for growth resources occur at different times. With mid-season removal of cereal competition, berseem may provide a yield advantage by increasing total seasonal yield.

CONCLUSION

Under highly productive conditions at Edmonton, berseem clover biomass was greatly reduced by competition from oats. Berseem DM decreased linearly with increasing oat DM. Oats were the dominant species in the oat-berseem intercrops, but competitive effects varied between years. The high plasticity of oats and the influence of environmental factors reduce the potential of using oat plant density to predict berseem suppression. Increasing the seeding rate of berseem resulted in decreased tillering of oats, but effects on oat DM varied between years. Using the upper range of recommended berseem seeding rates of 11-18 kg ha^{-1} may increase the yield and competitive ability of berseem. There was a biomass yield advantage in adding oats to berseem, compared to growing berseem alone. The addition of berseem to silage cereals may provide a yield advantage by increasing total seasonal yields.

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Table 2-1. Counts of berseem clover plants (BP) at early growth stage, and oat plants (OP) and oat tillers (OT) at silage harvest stage, for oat-berseem mixtures in 1996 and 1997 at Edmonton

Target	1996 Cut 1[z]			1996 Cut 2[y]		1997[x]		
oat	BP	OP	OT	OP	OT	BP	OP	OT
density	(no. 0.25 m^{-2})	—(no. 1.0 m^{-2})—		—(no. 1.0 m^{-2})—		(no. 0.25 m^{-2})	—(no. 1.0 m^{-2})—	
0	158	-	-	-	-	88		
1	-	-	-	-	-	82	1	7
2	-	-	-	-	-	79	2	14
5	107	6	74	6	81	72	5	26
25	109	25	158	18	135	68	26	127
50	127	54	247	48	231	79	57	146
100	101	79	284	73	270	86	111	200
F test	NS	***	***	***	***	NS	***	***

[z]Berseem plants counted 6 WAP and oat plants and tillers counted at 11WAP.

[y]Berseem plants not counted, oat plants and tillers counted at 15 WAP.

[x]Berseem plants counted at 4 WAP, oat plants and tillers counted at 11 WAP.

*** significant at the 0.001 probability level, NS, not significant.

Table 2-2. Dry matter yields of berseem clover (BE), oats and totals for oat-berseem clover mixtures for five oat density treatments (OD) in 1996 at Edmonton

	Dry matter biomass					
Target	Cut 1 at 11 WAP			Cut 2 at 15 WAP		
oat	BE	Oat	Total	BE	Oat	Total
density	(Mg ha^{-1})					
0	6.2	0	6.2	9.0	0	9.0
5	4.3	3.1	7.4	4.4	5.3	9.7
25	2.6	5.8	8.4	3.6	8.5	12.1
50	1.5	8.2	9.7	2.9	12.5	15.3
100	1.1	8.3	9.5	1.7	12.4	14.1
F test	***	***	***	***	***	***
Contrasts						
OD linear	***	***	***	***	***	***
OD quadratic	***	***	***	***	***	**
OD deviation	**	*	NS	**	NS	NS

*,**,*** significant at the 0.05, 0.01, and 0.001 probability levels, respectively; NS, not significant.

Table 2-3. Dry matter yields of berseem clover (BE), oats and totals for oat-berseem mixtures for seven oat density treatments (OD) in 1997 at Edmonton

Target oat density	11 WAP Cut 1 BE	11 WAP Cut 1 Oat	11 WAP Cut 1 Total	Regrowth[z] BE	Total for 2 cuts BE	Total for 2 cuts Oat	Total for 2 cuts Total
	Dry matter biomass ($Mg\ ha^{-1}$)						
0	6.6	0	6.6	3.3	9.9	0	9.9
1	7.4	0.3	7.7	3.8	11.3	0.3	11.5
2	7.1	0.6	7.7	3.1	10.2	0.6	10.8
5	7.0	0.9	8.0	3.4	10.4	0.9	11.3
25	5.3	4.0	9.3	3.4	8.6	4.0	12.6
50	4.6	4.4	9.0	3.0	7.6	4.4	12.0
100	4.0	6.6	10.6	3.0	7.0	6.6	13.6
F test	***	***	***	NS	***	***	***
Contrasts							
OD linear	***	***	***	t	***	***	***
OD quadratic	**	***	NS	NS	**	***	NS
OD deviation	NS	**	**	NS	NS	**	*

[z]Oat regrowth was negligible.
t,*,**,*** significant at the 0.10, 0.05, 0.01, and 0.001 probability levels, respectively; NS, not significant.

Table 2-4. Parameter estimates (with standard error in parentheses) for a rectangular hyperbolic model describing the effect of oat plant density (plants m^{-2}) on berseem clover biomass dry matter (DM) in 1996 and 1997 at Edmonton

Year	Harvest	Oat-free berseem DM Y_{of} ($g\ m^{-2}$)	Initial slope i (%)	Asymptotic yield loss a (%)	(R^2)
1996	11 WAP	615 (19)	6.4 (1.1)	96.2 (5.4)	0.96
	15 WAP	893 (46)	22.6 (7.8)	77.4 (4.8)	0.89
1997	11 WAP	719 (19)	1.5 (0.6)	63.8 (13.9)	0.81

Data were fitted to the equation $y = Y_{of}[1 - (id/(100(1 + id/a)))]$ where y is the estimated berseem yield, Y_{of} is the estimated berseem yield without oats, i (initial slope) is the initial % yield loss of berseem per oat plant, d is the number of oat plants m^{-2}, and a (asymptote) is the % yield loss of berseem at infinite oat density.

Table 2-5. Plant density, oat tiller numbers, and dry matter (DM) biomass yields for initial harvest (Hv 1) and regrowth (RG) for oat-berseem clover mixtures at four berseem seeding rates (BSR) in 1996 and 1997 at Edmonton

Berseem seeding rate	Berseem[z] Plant density	Berseem[z] DM Hv 1	Berseem[z] DM RG	Oat – initial harvest Plant density	Tillers plant^{-1}	Area DM	Plant DM	Tiller DM
	(no. 0.25 m^{-2})	—(Mg ha^{-1})—		(no. m^{-2})	(no. plant^{-1})	(Mg ha^{-1})	(g plant^{-1})	(g tiller^{-1})
	1996 - Cut 1 harvest at 11 WAP							
6	49	2.6	-	16.0	9.1	5.2	33.2	3.7
12	68	3.3	-	18.8	7.8	5.8	31.7	4.1
18	103	3.4	-	16.3	7.9	5.1	31.5	4.0
24	136	3.6	-	18.0	7.1	5.5	30.5	4.3
F test	***	t	-	NS	*	NS	NS	NS
BSR linear[y]	***	*	-	NS	*	NS	NS	*
	1996 - Cut 2 harvest at 15 WAP							
6	-	3.1	-	18.3	8.5	8.3	45.8	5.4
12	-	3.5	-	16.0	8.0	7.1	44.9	5.6
18	-	3.6	-	18.0	7.4	8.1	44.8	6.1
24	-	4.8	-	18.5	6.3	7.3	39.7	6.3
F test	-	*	-	NS	**	NS	NS	*
BSR linear	-	**	-	NS	***	NS	*	**
	1997 - Initial harvest at 11 WAP, regrowth harvest at 18 WAP							
0	-	-	-	12.0	9.4	4.5	37.4	4.0
6	43	5.2	2.5	12.3	6.1	2.6	20.9	3.4
12	80	6.0	2.7	12.0	4.5	2.1	18.0	3.9
18	117	7.2	2.9	12.5	3.3	1.4	11.3	3.4
24	126	7.5	3.2	10.8	3.0	1.1	10.3	3.3
F test	***	**	NS	NS	***	***	***	*
BSR linear	***	***	t	NS	***	***	***	*
BSR quadratic	NS	NS	NS	NS	*	NS	NS	NS

[z]Berseem plants were counted at 6 WAP for Cut 1 in 1996, and at 4 WAP in 1997.

[y]Quadratic contrasts all non-significant ($P \geq 0.05$) in 1996.

t,*,**,*** Significant at the 0.10, 0.05, 0.01, and 0.001 probability levels, respectively; NS, not significant.

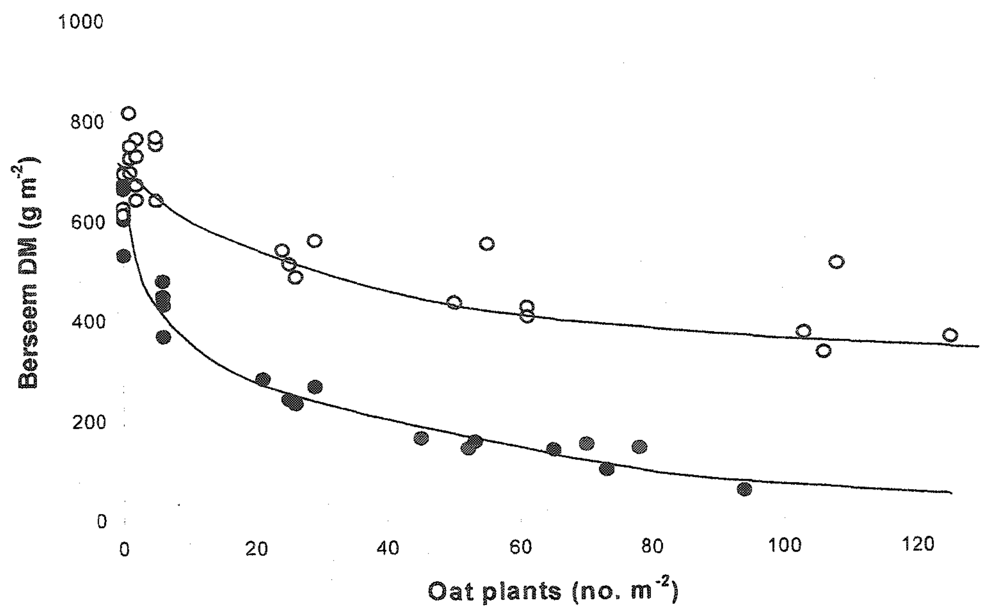

Figure 2-1: Effect of oat plant density on berseem dry matter (DM) at 11 weeks after planting in 1996 (●) and 1997 (○) at Edmonton.

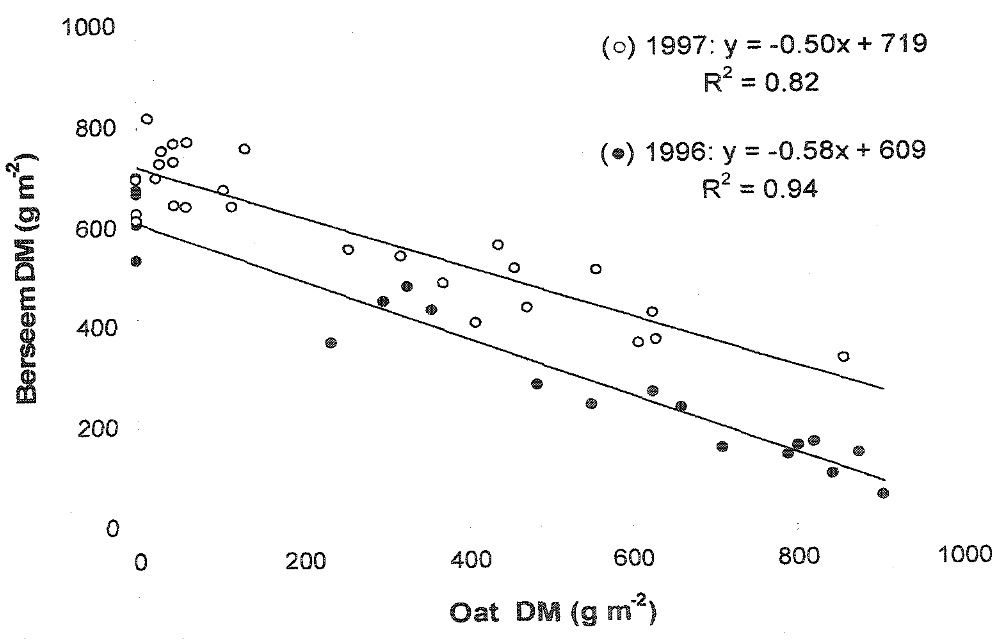

Figure 2-2: Effect of oat dry matter (DM) on berseem DM at 11 weeks after planting in 1996 (●) and 1997 (○) at Edmonton.

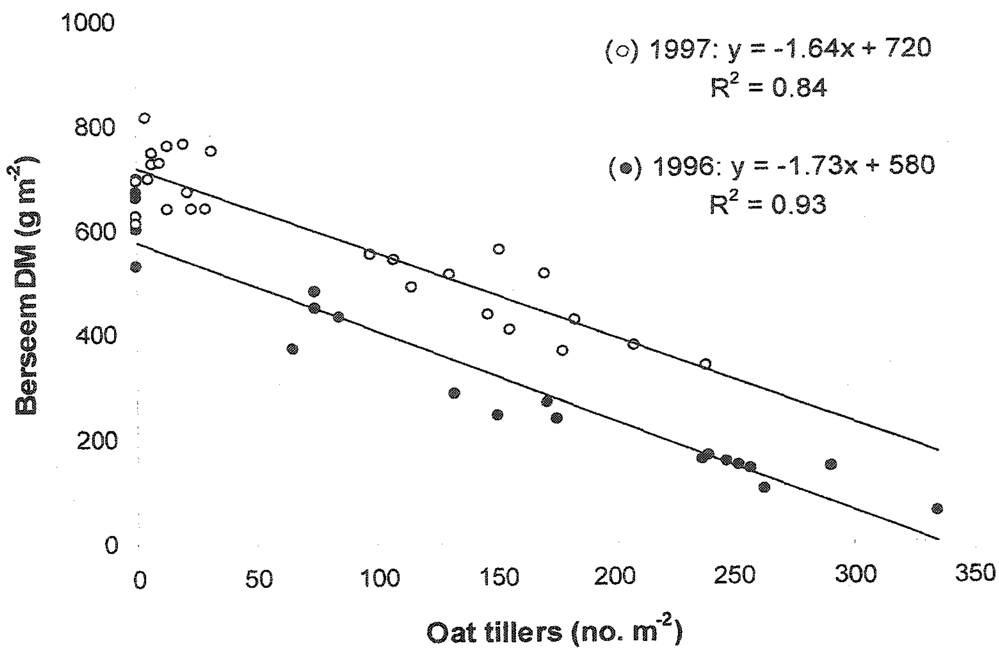

Figure 2-3: Effect of oat tiller density on berseem dry matter (DM) at 11 weeks after planting in 1996 (●) and 1997 (○) at Edmonton.

Chapter 3 Forage potential of intercropping berseem clover with barley, oat or triticale

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Chapter 3

Forage potential of intercropping berseem clover with barley, oat or triticale

INTRODUCTION

Intercropping of berseem clover with spring cereals, grown for forage silage, may improve forage quality and yield. Potential benefits of intercropping include increased yields, increased protein and forage quality, nitrogen contributions from legumes, greater yield stability, and reduced incidence of pests, weeds, and diseases (Anil et al., 1998). However, farmers are unlikely to take on the increased cost and complexity of managing intercrops without demonstrated evidence of potential advantages over monocropping.

A substantial amount of barley and oat grown in western Canada is used for forage, and it is expected that cereal silage production will increase (Helm and Salmon, 2002). Research in western Canada has tested silage cereals in mixtures with other annual seed crops (Walton, 1975; Berkenkamp and Meeres, 1987), with pulse crops (Jedel and Helm 1993), with annual ryegrass and annual legumes (Thompson et al., 1992; Thompson and Stout, 1997; Stout et al., 1997), and with other cereal genotypes (Juskiw et al., 2000abc). Cereal intercrops in western Canada can help to improve forage quality and yield, control lodging, decrease disease, and extend the window of harvest for silage. Although the growing season is short in central Alberta, the period of several weeks after silage harvest can be employed for additional forage production. This potential to extend forage production and provide fall grazing has been demonstrated with mixtures of spring and winter cereals (Baron et al., 1992 and 1995; Jedel and Salmon, 1995). Cereal-legume intercrops have also been investigated in Alberta from the perspective of cropping system sustainability (Izaurralde et al., 1990, 1992 and 1993). Increasing the use of annual legumes in cereal cropping systems, either as sole crops or as intercrops with cereals, can improve sustainability through biological nitrogen fixation, reduction of weed competition and increased soil organic matter (Izaurralde et al., 1993).

Intercropping pulse crops with cereals may increase dry matter yields (Izaurralde et al., 1993), provide no dry matter advantage but increase protein production (Walton, 1975;

Berkenkamp and Meeres, 1987), or improve forage quality but not increase total N yield (Carr et al., 1998). Yield advantages of cereal-legume intercrops may occur under N-deficient conditions, but not under high soil N conditions (Moreira, 1989). The addition of Persian clover (*Trifolium resupinatum* L.) to barley-ryegrass mixtures in British Columbia reduced fertilizer needs, improved mid-season forage yield and improved forage nutritive value (Thompson and Stout, 1997). Temporal complementarity in intercrops is likely to produce greater yield advantage than spatial complementarity (Willey, 1979). Temporal advantages are commonly used to increase forage production through manipulation of crop mixtures (Anil et al., 1998).

Berseem clover is a high yielding nutritious cool-season forage crop thought to have originated in the Middle East (Knight, 1985). In research conducted in north-central Alberta, berseem out-performed six other clovers in yield and ability to compete with weeds (Ross et al., 2001). Research has demonstrated that intercropping berseem with cereals can increase forage yield and quality compared to cereals-alone in sub-tropical climates (Singh et al., 1989; Zada et al., 1998), increase total dry matter yields without reducing cereal grain yields (Reynolds et al., 1994; Ghaffarzadeh, 1997; Holland and Brummer, 1999) and improve forage quality, reduce fertilizer needs and increase subsequent crop yields (Stout et al., 1997; Ghaffarzadeh, 1997). Intercropped with Italian ryegrass, berseem reduced fertilizer needs by providing an N equivalence of 80 kg N ha^{-1} per year (Caballero et al., 1994). Berseem had greater potential to improve the forage quality and yields of barley-ryegrass-legume intercrops than did annual *Medicago* and *Lespedeza* species (Stout et al., 1997). Berseem was better adapted than crimson clover (*Trifolium incarnatum* L.) or white clover (*T. repens* L.) for intercropping with wheat or barley to improve the ground cover, N-use efficiency and productivity of low input systems in Mexico (Reynolds et al., 1994). Holland and Brummer (1999) concluded that Bigbee berseem was the most consistently high-performing cultivar in oat-berseem intercrops tested in Iowa.

Legumes have often been found to be less competitive than cereal or grass species. Clover species are considered to be poor competitors because of small seed size, lack of seedling vigor, and slow establishment (Lee, 1985). Berseem constituted only 14% of the forage yield from a 50:50 seed intercrop of berseem with Italian ryegrass (Caballero et al., 1994). Berseem yields, from two or three harvests, were reduced about 50% when grown with oats (Welty et al., 1991; Holland and Brummer, 1999). Reduced cereal seeding rates may be required to increase the legume component of cereal-legume intercrops. Caballero et al. (1995) recommended that oat seed should not exceed 20% of an oat-vetch mixture if a substantial vetch component is desired for forage quality. Little information is available on the effect of cereal seeding rate on the performance of berseem-cereal intercrops.

Intercropping results can differ among small grain cereal species. Forage yield and quality of pulse-cereal intercrops differed with oats, barley or triticale (Jedel and Helm 1993). Relative yield totals of pea-wheat intercrops were greater than for pea-barley intercrops (Tofinga et al., 1993). Triticale and wheat were less competitive in mixtures than were oats and barley (Berkenkamp and Meeres, 1987). Barley was more competitive than oats in cereal-cereal intercrops (Juskiw et al., 2000c).

The choice of cereal species and seeding rate of the cereal may affect the performance of cereal-berseem intercrops. The objectives of this study were i) to test the effects of cereal species on cereal-berseem intercrops; ii) to test the effects of cereal seeding rate on cereal-berseem intercrops; and iii) to test the feasibility of intercropping berseem with cereals for forage in a short-season growing environment.

MATERIALS AND METHODS

Intercrops of berseem clover with oats, barley or triticale were grown at Edmonton (53° 25' N, 113° 33' W), Alberta, Canada on a Malmo silty clay loam [orthic Black Chernozem (Typic Cryoboroll)] from 1998 to 2001. Experiments followed tilled fallow, and fields were disked and harrowed prior to seeding. Soil pH at test sites ranged from 5.7 to 7.0 and soil nitrate levels ranged from 34 to 56 mg kg^{-1} at 0-30 cm depth. No fertilizer was added except for the application of triple superphosphate 0-45-0 at approximately 28 kg ha^{-1} of P_2O_5 in 2000.

Experiments tested intercrops with spring cereal cultivars that are used for forage in Alberta: 'AC Lacombe', a mid-maturing, six-rowed spring barley; 'Waldern' oats, a late-maturing, high yielding silage/feed oat; and 'Pronghorn', an early-maturing, spring triticale. In 1998, the experimental design was a split-plot randomized complete block (RCB) with cereal type as the main plot and cereal density as the sub-plot. There were three replicates and sub-plot size was 2 m x 6 m. Cereal treatments were 240 (full rate), 120 and 60 plants m^{-2}. In 1999, 2000 and 2001 the cereal treatments were 240, 90, 60 and 30 plants m^{-2}, and berseem-alone treatments were added. All 13-14 treatments were randomized in RCB designs, with four blocks and plot size of 1.8 m x 6 m.

Seeding and harvest dates are listed in Table 2-1. Cereals were seeded at 2.5-4 cm depth with Fabro double disc press drills. 'Bigbee' berseem clover was inoculated with the appropriate *Rhizobium trifolii* and seeded at 15 kg ha^{-1}. In 1998, cereals were seeded with a 6-row disc drill at 18 cm row spacing, and berseem was cross-seeded with the same seeder. In 1999, 2000 and 2001, cereals were seeded with a 4-row disc seeder with 23 cm row spacing. In 1999, berseem was hand-seeded by broadcasting on the surface and incorporation by raking. The cereals emerged in advance of the berseem in 1999, and the plots were irrigated 3 weeks after seeding to promote berseem growth. To reduce the potential for late relative emergence of berseem in 2000 and 2001, berseem was cross-seeded at approximately 1.5-2 cm depth at 18 cm row spacing using a 6-row disc drill. Spring conditions were very dry in 2001, and plot areas were irrigated before and after seeding. Plots were hand weeded.

Cut 1 was taken at silage stage (milk to soft dough) of cereals. Sub-samples were cut by hand at 5-7.5 cm above soil level, with separation of the berseem and cereal biomass. In 1998 and 2001, sub-sampling was from two quadrats sized 0.5 m^2 or 0.6 m^2 in each plot. Quadrats had been marked after emergence, with target cereal plant densities achieved through placement or thinning. For each plot in 1999 and 2000, species composition was measured by one randomly chosen sub-sample sized 0.23 m^2 or 0.27 m^2, and yield was measured by sickle mower harvest of a 2.25 m^2 area. After sampling, the remainder of plot growth was cut with a sickle mower and raked to remove the cut biomass. Cut 2 measured the regrowth at the end of the growing season in late September or early October. Sub-sampling for Cut 2 was from the marked quadrats in 1998 and 2001, and one randomly chosen 0.5 m^2 area from each plot in 2000. In 1999, regrowth was not measured because it was negligible. Sub-samples were dried for 72 hours at 52 °C, and weighed. Species composition and dry matter yields were determined for all treatments. Samples from a subset of treatments were analyzed for crude protein (CP), acid detergent fibre (ADF) and neutral detergent fibre (NDF) by Norwest Labs. Protein was determined using the Association of Official Analytical Chemists (AOAC, 1990) Method 988.05 ($CuSO_4$/ TiO_2 Mixed Catalyst Kjeldahl). ADF was determined using the AOAC (1990) Method 973.18 (by Refluxing), and NDF was determined using Amylase Procedure (Undersander et al., 1993).

Data were analyzed using analysis of variance techniques to determine significant treatment effects ($P \leq 0.05$) using Statistical Analysis System (SAS Inst., 2000). Results for percentage of berseem in Cut 1 (BP1) were transformed to square root of x + 0.5 for analysis. Cereal density effects were originally separated with orthogonal contrasts, using coefficients derived in the IML procedure of SAS. Cereal density contrasts beyond quadratic were pooled as deviations. Where significant year x treatment interactions occurred data are presented by year.

RESULTS

In north-central Alberta, silage is usually harvested in August. In 1998, cereal maturity and dates of Cut 1 silage-stage harvests were earlier than in other years (Table 3-1). Seasonal mean temperatures for May to September were above-average in 1998 (16.5 °C), and were near the 30-year average (14.5 °C) in other years (Appendix 2). In all years, barley reached silage-stage 8-9 days earlier than the oats. Oats and triticale were harvested at the same time, except in 1998 (Table 3-1).

Cut 1 dry matter (DM) yields were lowest for 30-rate treatments and exhibited linear or quadratic increases in response to increasing cereal density (Table 3-2). The species effects for Cut 1 DM yields were: greater yields for triticale intercrops (T) than for barley intercrops (B) and oat intercrops (O) in 2 of 4 years, and greater yields for O than for B in 3 years. Cut 1 DM yields averaged 9.9 Mg ha^{-1} for T, 9.7 Mg ha^{-1} for O, and 8.8 Mg ha^{-1} for B.

The percentage of berseem in Cut 1 (BP1) was affected by cereal density and species in all years (Table 3-2). The full rate of cereals (240) was very suppressive of berseem, with BP1 of less than 6% in 3 of 4 years. The BP1 decreased as cereal rate increased, exhibiting quadratic responses. The ranking of BP1 by species was generally T > O > B, with T > B in all 4 years, T > O in 3 years, and O > B in 3 years. The BP1 averaged 17% for T, 10% for O, and 8% for B. Compared to berseem alone, berseem Cut 1 yields in 240-rate treatments were reduced by 89% in B, 93% in O, 60% in T in 2000, and by 96% in B, 95% in O, 93% in T in 2001. Compared to berseem alone, berseem Cut 1 yields in 60-rate treatments were reduced by 72% in B, 73% in O, 56% in T in 2000, and by 87% in B, 83% in O, 78% in T in 2001.

The percentage of berseem in Cut 1 was affected by relative emergence and moisture availability. In 1999, BP1 was nearly negligible because the berseem emerged after cereal establishment. The cereals began emerging by June 1. Due to the shallow broadcast seeding of berseem in that year, the berseem had only partial emergence by June 11, and a second wave of emergence followed irrigation on June 15-16. The BP1 component in intercrops was much higher in 2000 than in other years, with an average BP1 of 29% (Table 3-2). In 2000, the berseem emerged before the cereals, and the cereals emerged unevenly in two flushes. Rainfall for May to September was near the 30-year average (326 mm) in 2000 (330 mm), but was less than normal in 1998 (280 mm), 1999 (259 mm) and 2001 (267mm).

In 3 of 4 years, protein yields of Cut 1 decreased with decreasing cereal density (Table 3-3). Cut 1 protein yields varied among cereal species but there were no consistent differences between years. Berseem regrowth (Cut 2 DM) was lowest for 240-rate treatments, and exhibited linear increases with decreasing cereal density. Regrowth of cereals was negligible in all years except 2001. In 2001, heavy rainfall (146 mm) in mid to late July caused some flooding and lodging. Tillering in barley can resume after flowering, under conditions of abundant moisture and lodging (Smith et al., 1999). Regrowth of cereals in 2001 averaged 1.1 Mg ha^{-1} for barley, 0.1 Mg ha^{-1} for oats, and 1.8 Mg ha^{-1} for triticale (Appendix 8). Cereal regrowth is included in Total DM, but Cut 2 here refers only to berseem regrowth. For Cut 2, DM yields of B were greater than T in 3 years and were greater than O in 2 years. The length of time of berseem regrowth was 9+ days greater for B than for O and T (Table 3-1). Cut 2 DM yields of T were greater than O in 2 years, when days of regrowth were equal, and was less than O in 1998, when O had more days of regrowth. Cut 2 DM yields averaged 3.4 Mg ha^{-1} for B, 2.3 Mg ha^{-1} for O, and 2.1 Mg ha^{-1} for T. The effects of cereal competition on subsequent berseem yield varied between years. In 2001, the Cut 2 DM of intercrops was much less than that of berseem grown alone. In 2000, the Cut 2 DM of intercrops was not significantly different from that of berseem grown alone.

Total DM yields (total of Cut 1 and Cut 2) for intercrops averaged 12.5 Mg ha^{-1} for 1998, 2000 and 2001 (Table 3-4). Cereal density effects on Total DM varied between years. In 1998, there was a linear decrease ($P < .001$) in Total DM yield with increasing cereal density. Total DM yields for 60-rate treatments of B and T of 1998 were 2.0+ Mg ha^{-1} greater than for the respective 240-rate treatments. In 2000 and 2001, there were linear or quadratic ($P < .05$) increases in Total DM yield with increasing cereal density. Compared to 240-rate, Total DM yield was not significantly different with B or O at 60-rate, but was lower with T at 60-rate, in 2000 and 2001. The effects of cereal density were most evident in T and least evident in O. There were no significant differences in Total DM yield among cereals in 1998 and 2000. In 2001, Total DM yields of T > B > O, partly reflected differences in cereal and berseem regrowth. Average Total DM yield, for the 3 years with 2 cuts, was 12.7 Mg ha^{-1} for T, 12.6 Mg ha^{-1} for B, and 12.3 Mg ha^{-1} for O.

The percentage of berseem in total yield was lowest for 240-rate treatments and exhibited quadratic increases in response to decreasing cereal density (Table 3-4). The percentage of berseem in total yield averaged 34% for B and T, and 28% for O, and effects of cereal species varied between years. Total protein yield of B was greater than T and O in all 3 years, and T was greater than O in 2001. Total protein yield from 2 cuts averaged 1.91 Mg ha^{-1} for B, 1.66 Mg ha^{-1} for T and 1.59 Mg ha^{-1} for O. The effects of cereal density on total protein yield were not significant in 2 of 3 years. In 2000 and 2001, somewhat lower Total DM yields at lower cereal density were balanced by greater protein contribution from larger berseem components. In 1998, the linear increase in total protein with decreasing cereal density reflected increases in both yield and berseem component at lower cereal rate.

The Total DM yield of berseem-alone treatments (BE 1 and BE 2) was less than that of intercrops in 2001 but did not differ from intercrops in 2000 (Table 3-4). Cut 1 DM yield of berseem-alone was less than for intercrops (Table 3-2), and Cut 2 DM yield of berseem-alone was less than or equal to intercrops (Table 3-3). In 1999, when berseem regrowth was negligible, the seasonal yield for berseem-alone was much less than that of intercrops.

Berseem had better forage quality than cereals at Cut 1, with 40+ g kg^{-1} higher crude protein (CP) and 140 g kg^{-1} lower neutral detergent fibre (NDF) (Table 3-5). The CP of the cereals alone was quite high (106 to 139 g kg^{-1}), and the CP of barley was 20-30 g kg^{-1} higher than that of oat and triticale. The CP of B intercrops was 30 g kg^{-1} higher than that of O or T. Relatively small berseem components in 60-rate intercrops (average of 20%) did cause some improvement in forage quality. The NDF of 60-rate mixtures was 30 g kg^{-1} lower than that of cereals alone.

The quality of berseem regrowth from Cut 2 was high with mean CP of 210 g kg^{-1} %, ADF of 215 g kg^{-1}, and NDF of 310 g kg^{-1} (Table 3-5). There was little difference in berseem from different treatments. The ADF of the younger berseem regrowth in O and T was lower than that of the older regrowth in B.

DISCUSSION

Potential of Cereal-Berseem Intercrops

Cereal-berseem intercrops produced high forage yields, with cereals as the dominant component. Silage-stage intercrop yields averaged 9.6 Mg ha^{-1} DM, with 12% berseem for 1998 to 2001. Total 2-cut intercrop yields averaged 12.5 Mg ha^{-1} DM, with 32% berseem for 1998, 2000 and 2001. Biomass DM yields were greater than or equal to those reported for pulse-cereal intercrops in central Alberta of 6.6 to 12.3 Mg ha^{-1} (Berkenkamp and Meeres 1987) and 8 to 11 Mg ha^{-1} (Jedel and Helm 1993) for oat, barley or triticale intercropped with pea or fababeans, and 8.9 Mg ha^{-1} for barley-pea intercrops (Izaurralde et al., 1993).

Berseem had relatively little impact on the forage quality of intercrops at silage-stage. The NDF of 60-rate intercrops was 30 g kg^{-1} lower than that of cereals alone, indicating improved potential for forage intake. There was a trend of higher CP in berseem-cereal mixtures than with cereals alone. Other intercrop studies have reported greater impact of legumes on quality. Adding peas to oats or barley increased CP by 44 g kg^{-1} % and 30 g kg^{-1} %, decreased ADF by 5-10 g kg^{-1} %, and decreased NDF by 71 g kg^{-1} % and 62 g kg^{-1} %, respectively in Chapko et al. (1991). The addition of berseem to a barley-ryegrass mixture substantially increased the CP of the Cut 1 harvest (Stout et al., 1997). High initial soil N levels at Edmonton may have reduced the impact of berseem on intercrop CP. The CP of the cereals (106 to 139 g kg^{-1}) was quite high. Lower protein levels have been reported in other studies of silage cereals in central Alberta: 60-100 g kg^{-1} CP for oats, barley and triticale (Juskiw et al., 2000a) and 90-125 g kg^{-1} CP for barley and triticale (Jedel and Salmon 1995). Carr et al. (1998) found that adding peas to oats or barley did not increase forage CP in high-soil-N environments but did increase CP in low-soil-N environments.

On highly productive soils such as at Edmonton, the greatest potential for yield advantage from berseem-cereal intercrops may be in the berseem regrowth after silage harvest. Berseem regrowth (Cut 2) provided an average of 2.6 Mg ha^{-1} DM of high quality forage. Cut 2 yields were highest under conditions of above-average seasonal temperatures, early silage-stage harvest and adequate moisture following Cut 1. Cut 2 yields were similar to berseem regrowth reported in other studies: 2.1 Mg ha^{-1} after barley grain harvest (Holmstrom et al., 2001); 2.7 Mg ha^{-1} after oat grain harvest (Ghaffarzadeh, 1997); approx. 4 Mg ha^{-1} after silage harvest of a barley-ryegrass-berseem intercrop (Stout et al., 1997). Berseem regrowth compares well with fall yields of 0.05 to 2.39 Mg ha^{-1} in central Alberta from spring and winter cereal intercrops after silage harvest (Jedel and Salmon, 1995).

Early or concurrent emergence of berseem, relative to cereals, increased the berseem component in intercrops. Late relative emergence of berseem resulted in negligible berseem growth in intercrops. Relative time of emergence is an important factor in crop-weed competition (O'Donovan et al., 1985). For pea-cereal intercrops, the competitive ability of peas was reduced when peas emerged after cereals, and relative yield totals were greatest when peas and cereals emerged concurrently (Tofinga et al., 1993). In our study, timely and adequate moisture also enhanced the berseem component in intercrops.

Cereal Species Effects on Intercrops

Barley intercrops (B) had advantages of greater Cut 2 yield and greater total protein yield than triticale intercrops (T) and oat intercrops (O). The T and O intercrops had greater silage-stage yields containing higher percentages of berseem (BP1). The general ranking of cereal species effects on intercrops were T highest for Cut 1 DM yield, T > O > B for BP1, B > T ≥ O for Cut 2 DM yield, and B > T ≥ O for total protein yield. Total DM yield was T = B = O in 2 of 3 years.

Greater Cut 1 yield with oat intercrops (average of 9.7 Mg ha^{-1}) than with barley intercrops (average of 8.8 Mg ha^{-1}) agrees with other studies of cereal intercrops in central Alberta (Berkenkamp and Meeres, 1987; Jedel and Helm, 1993; Jedel and Salmon, 1994). Averaged over 4 years, forage yields for cereals intercrops with peas or fababeans were 11.1 Mg ha^{-1} with oats, 9.4 Mg ha^{-1} with triticale and 9.0 Mg ha^{-1} with barley, with cereals seeded at approx. 80 seeds m^{-2} and pulses at approx. 90 seeds m^{-2} (Jedel and Helm, 1993). We had similar Cut 1 yields for triticale intercrops (average of 9.9 Mg ha^{-1}), but our ranking of T ≥ O differed from their relative ranking of O > T.

Differences in BP1 among cereals indicated that barley caused greater suppression of berseem than did oats or triticale. Similarly, Juskiw et al. (2000c) found that barley was more competitive than oats or triticale in cereal mixtures. Brink and Marten (1986) reported that alfalfa seedling growth was less with barley cultivars than with oat cultivars. Higher average BP1 values for T intercrops (17%) than for O and B intercrops (8-10%) indicated less berseem suppression by triticale. It appeared that the triticale canopy allowed for greater penetration of light through the canopy than occurred with the barley or oats. Based on visual determination, Jedel and Helm (1993) observed higher pulse content in intercrops with triticale than with oats or barley.

Total DM yield did not differ among cereals in 2 of 3 years, as greater Cut 1 yields of O and T were balanced by greater Cut 2 yields for B. Barley reached silage-stage earlier than triticale and oats. Earlier Cut 1 for barley provided for longer periods of berseem regrowth. There were indications that less initial suppression of berseem in T resulted in increased berseem regrowth. When T and O had equal days of regrowth, Cut 2 yields were greater with T.

Higher total protein yields for B (average of 1.91 Mg ha^{-1}) than for T and O (1.59 to 1.66 Mg ha^{-1}) reflected a combination of high CP for barley (139 g kg^{-1}) and a substantial yield component of high quality berseem regrowth (CP 200 g kg^{-1}). Higher cereal quality for barley than oats and triticale is consistent with silage research at Lacombe, Alberta (Helm and Salmon, 2002). At the soft-dough stage, they rank the cereal quality of barley as highest, followed by triticale, then wheat, and oat as the lowest quality. The CP of B intercrops at silage-stage (149 g kg^{-1}) was greater than that of O or T intercrops (118-119 g kg^{-1}). Jedel and Helm (1993) also found that CP of barley intercropped with pulses (138-149 g kg^{-1}) was higher than for oat intercrops (111-127 g kg^{-1}), but triticale intercrops had CP values (137-147 g kg^{-1}) similar to barley intercrops.

We tested one cultivar each of barley, oat and triticale. Studies have shown that cultivars of barley and oat differ in their competitiveness in intercrops (Holland and Brummer, 1999; Juskiw et al., 2000c). A wider survey of cultivars would aid in the understanding of the general effects of barley, oats and triticale in intercrops with berseem.

Cereal Density Effects on Intercrops

In response to increasing cereal density, Cut 1 DM yield increased, percentage of berseem in Cut 1 decreased, and Cut 2 DM yield decreased. The full rate of cereals (240 plants m^{-2}) was very competitive with the berseem, resulting in low BP1 (average of 5%). Compared to Cut 1 yields of berseem alone in 2001, berseem yields in intercrops were reduced by an average of 83% with 60-rate cereals and by 94% in 240-rate cereals. In related experiments with berseem-oat intercrops, the relationship between berseem DM and oat plant density at silage-stage fit the rectangular hyperbolic model proposed by Cousens in 1985, and had a steep initial slope and predicted asymptotic yield losses up to 96% (Ross et al., 2003).

The effects of cereal competition on berseem regrowth (Cut 2) varied between years. Similar to our results in 2000 of no difference between Cut 2 yields for berseem alone or intercrops, Thompson and Stout (1997) reported that Cut 2 of barley-Persian clover intercrops equalled that of clover alone, indicating that the barley had no negative effect on clover establishment. In a 1997 experiment with oat densities of 0, 1, 2, 5, 25, 50 and 100 plants m^{-2}, there was no significant difference among Cut 2 berseem yields after a silage-stage cut, but a linear relationship between decreasing oat density and increasing berseem regrowth was significant at $P = 0.065$ (Ross et al., 2003). In this study, linear relationships between increasing cereal density and decreasing Cut 2 were significant at $P < 0.001$, and Cut 2 yields in intercrops were less than those of berseem alone in 2001, indicating substantial effects of cereal competition on berseem regrowth. As with companion crops for alfalfa, the recovery of berseem from cereal competition may vary with moisture, temperature, and management of companion crops. Cereal companion crops had no effect on subsequent alfalfa yields in Minnesota (Simmons et al., 1995), reduced subsequent yields during the establishment year in California (Lanini et al., 1991), and reduced yields in the first two years of alfalfa growth in southern Alberta (Moyer 1985).

The effects of cereal density on total yield varied between years. Carr et al., (1998) found that forage yields of cereal-pea intercrops were significantly reduced with a half-rate of barley or oats. In our study, seeding cereals at 60 or 90 plants m^{-2} in intercrops resulted in equal or higher total DM and protein yields, compared to full cereal rates, in the majority of cases. Yield compensation in reduced-rate cereal treatments was due to a combination of cereal tillering and berseem content. The effects of cereal density were most evident with triticale and least evident with oats. For triticale, rates higher than 60 plants m^{-2} would be recommended for cereal-berseem intercrops in order to maintain silage-stage yields. Jedel and Salmon (1994) noted that triticale forage yields respond positively to higher seeding rates and optimal forage yield of monocrop triticale may require rates greater than 250 seeds m^{-2}.

Berseem Sole Crops versus Intercrops

Higher forage yields for intercrops than for berseem sole crops have been reported in studies of berseem-cereal intercrops (Welty et al., 1991; Holland and Brummer, 1999). In our study, intercrops provided greater mid-season forage and greater yield stability than berseem alone. However, the high yield potential of berseem was demonstrated by total seasonal yields equal to those of intercrops in 2000. Growing berseem as a sole crop might be preferable where the emphasis is on providing high quality late season grazing. Forage conservation would likely be easier with berseem-cereal intercrops than with berseem alone. The cereal component would counter problems that may occur with sole crop berseem including lodging, high moisture content and capacity to buffer the acid production required for silage preservation.

CONCLUSION

Performance of cereal-berseem intercrops was influenced by cereal species, cereal density, relative emergence, and environmental conditions. Intercrops with AC Lacombe barley had advantages of earliness and greater total protein yield. Intercrops with Waldern oat and Pronghorn triticale had greater silage-stage yield, with a greater berseem component. Reducing cereal seeding rates to 25-40% of full rate usually improved forage quality without reducing total yield. Seeding of the intercrop must ensure that berseem emerges before or with the cereals. Early silage harvest would be recommended to increase the yield of berseem regrowth. On highly productive soils, the main benefit of cereal-berseem intercrops may be through the addition of high-quality late-season forage.

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Table 3-1: Harvest dates for Cut 1 and Cut 2, with number of days after planting† or days of regrowth in parentheses, for cereal-berseem clover intercrops at Edmonton, AB for 1998 to 2001.

Treatment	1998	1999	2000	2001
	date	date	date	date
		Cut 1 – Silage stage harvest		
Barley intercrops	21-Jul (68)	4-Aug (71)	1-Aug (75)	1-Aug (70)
Oats intercrops	30-Jul (77)	12-Aug (79)	10-Aug (84)	10-Aug (79)
Triticale intercrops	4-Aug (82)	12-Aug (79)	10-Aug (84)	10-Aug (79)
Berseem - BE 1‡	-	-	4-Aug (78)	1-Aug (70)
Berseem - BE 2	-	12-Aug (79)	10-Aug (84)	10-Aug (79)
		Cut 2		
Barley intercrops	28-Sep (69)	-§	5-Oct (65)	7-Oct (67)
Oats intercrops	28-Sep (60)	-	5-Oct (56)	7-Oct (58)
Triticale intercrops	28-Sep (55)	-	5-Oct (56)	7-Oct (58)
Berseem - BE 1	-	-	5-Oct (62)	7-Oct (67)
Berseem - BE 2	-	-	5-Oct (56)	7-Oct (58)

† Plots were seeded on May 14, 25, 18 and 23 in 1998, 1999, 2000 and 2001 respectively.

‡ BE 1 and BE 2 were berseem alone treatments, with BE 1 harvested about the same time as barley intercrops and BE 2 harvested at the same time as oat and triticale intercrops.

§ Cut 2 was not harvested in 1999 because it was negligible.

Table 3-2: Mean Cut 1 dry matter (DM) biomass and % berseem for Cut 1 (BP1) for cereal-berseem clover intercrops and berseem alone (BE) at Edmonton, AB from 1998 to 2001.

		Cut 1							
	Cereal	Biomass DM				BP1†			
Treatment	Density	1998	1999	2000	2001	1998	1999	2000	2001
		Mg ha^{-1}				%			
Barley (B)	30	-	7.8	8.6	6.7	-	0	32	10
intercrops	60	7.8	10.0	9.2	7.6	10	0	22	5
	90	-	10.3	10.5	8.1	-	0	27	3
	120	8.9	-	-	-	3	-	-	-
	240	8.9	11.4	11.8	8.4	1	0	7	1
Oat (O)	30	-	7.9	10.1	9.2	-	2	37	18
intercrops	60	8.5	9.2	11.5	9.3	15	1	23	9
	90	-	10.1	11.1	9.5	-	1	16	6
	120	8.8	-	-	-	8	-	-	-
	240	9.8	10.1	12.6	9.8	5	0	6	3
Triticale (T)	30	-	8.7	8.8	8.6	-	3	67	22
intercrops	60	10.1	9.9	9.5	8.9	23	1	46	13
	90	-	10.6	11.5	9.8	-	0	31	13
	120	9.9	-	-	-	8		-	-
	240	10.2	11.0	12.0	10.2	3	0	35	4
BE 1	0	-	-	7.3	3.0	-	-	-	-
BE 2	0	-	4.6	9.7	5.0	-	-	-	-
Intercrop mean		9.3	9.8	10.6	8.8	8	1	29	9
s.e.		0.2	0.7	0.9	0.4	0.6	>0.1	14.9	0.4
Density (D) F-test		***	***	***	***	***	***	***	***
Species (SP) F-test		**	ns	*	***	**	**	***	***
D X SP F-test		*	ns	ns	ns	***	**	ns	***
CONTRASTS									
D linear		***	***	***	***	***	***	***	***
D quadratic		ns	***	*	**	***	***	***	***
D deviation		-	ns	ns	ns	-	ns	ns	***
B vs T		***	ns	ns	***	***	***	***	***
B vs O		**	ns	**	***	***	*	ns	***
O vs T		***	*	ns	ns	*	ns	***	***
BE vs intercrop		-	***	***	***	-	-	-	-
60 VS 240		***	**	***	***	***	ns	***	***
90 VS 240		-	ns	ns	ns	-	ns	*	***
120 vs 240		*	-	-	-	***	-	-	-

*,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively; ns is not significant.
† BP1 (Cut 1 percentage of berseem) data was transformed to square root of x + 0.5 for analysis and original lsmeans are presented here.

Table 3-3: Mean Cut 1 protein yield and Cut 2 dry matter (DM) berseem yield for cereal-berseem clover intercrops and berseem-alone (BE) at Edmonton, AB from 1998 to 2001.

		Cut 1				Cut 2		
	Cereal	Protein				Berseem DM		
Treatment	Density	1998	1999	2000	2001	1998	2000	2001
		Mg ha^{-1}						
Barley (B)	30	-	0.86	1.29	0.93	-	4.0	3.1
intercrops	60	1.10	1.09	1.37	1.04	6.0	3.2	2.8
	90	-	1.13	1.57	1.11	-	3.5	2.5
	120	1.23	-	-	-	4.5	-	-
	240	1.18	1.25	1.73	1.14	2.7	1.3	2.5
Oat (O)	30	-	0.91	1.40	1.15	-	1.7	1.4
intercrops	60	0.90	1.05	1.55	1.11	4.8	2.0	0.9
	90	-	1.15	1.47	1.12	-	1.7	1.0
	120	0.88	-	-	-	4.3	-	-
	240	0.95	1.15	1.62	1.13	3.8	1.2	0.5
Triticale (T)	30	-	1.04	1.25	1.04	-	2.5	1.8
intercrops	60	1.20	1.15	1.23	1.02	4.3	1.9	1.1
	90	-	1.23	1.42	1.13	-	1.9	1.3
	120	1.10	-	-	-	3.1	-	-
	240	1.15	1.28	1.50	1.10	1.8	2.2	0.5
BE 1	0	-	-	1.15	0.53	-	-	6.7
BE 2	0	-	0.86	1.52	0.89	-	2.6	4.0
Intercrop mean		1.07	1.11	1.45	1.09	3.9	2.3	1.6
s.e.		0.02	0.08	0.12	0.05	0.2	0.4	0.3
Density (D) F-test		ns	***	***	*	***	***	***
Species (SP) F-test		*	*	*	*	*	***	***
D X SP F-test		*	ns	ns	ns	**	***	ns
CONTRASTS								
D linear		ns	***	***	*	***	***	***
D quadratic		ns	***	ns	ns	ns	ns	*
D deviation		-	ns	ns	ns	-	ns	ns
B vs T		ns	*	*	ns	***	***	***
B vs O		***	ns	ns	**	ns	***	***
O vs T		***	**	**	*	***	*	*
BE vs intercrop		-	***	ns	***	-	ns	***
60 VS 240		ns	**	**	*	***	***	**
90 VS 240		-	ns	ns	ns	-	***	**
120 vs 240		ns	-	-	-	***	-	-

*,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively; ns is not significant.

Table 3-4: Mean total dry matter (DM) yield, protein yield and % berseem clover for 2 cuts of cereal-berseem clover intercrops and berseem alone (BE) at Edmonton, AB in 1998, 2000 and 2001.

		Total for 2 cuts								
	Cereal	Biomass DM			% Berseem			Protein		
Treatment	Density	1998	2000	2001	1998	2000	2001	1998	2000	2001
		Mg ha^{-1}			%			Mg ha^{-1}		
Barley (B)	30	-	12.6	10.8	-	54	34	-	2.23	1.65
intercrops	60	14.2	12.5	11.5	48	43	27	2.01	2.13	1.73
	90	-	14.0	12.0	-	44	23	-	2.38	1.78
	120	13.6	-	-	34	-	-	1.90	-	-
	240	11.7	13.0	11.7	24	16	23	1.60	2.02	1.72
Oat (O)	30	-	11.8	10.8	-	45	28	-	1.79	1.45
intercrops	60	13.3	13.5	10.3	45	34	17	1.62	2.01	1.30
	90	-	12.9	10.6	-	27	15	-	1.87	1.32
	120	13.0	-	-	38	-	-	1.52	-	-
	240	13.5	13.8	10.4	31	14	7	1.51	1.90	1.24
Triticale (T)	30	-	11.4	11.5	-	74	32	-	1.84	1.55
intercrops	60	14.3	11.3	11.6	46	54	19	1.85	1.67	1.42
	90	-	13.5	13.0	-	41	20	-	1.87	1.60
	120	13.0	-	-	29	-	-	1.58	-	-
	240	12.3	14.2	13.1	17	47	7	1.41	2.01	1.45
BE 1	0	-	-	9.7	-	-	-	-	-	1.82
BE 2	0	-	12.3	9.0	-	-	-	-	2.14	1.59
Intercrop mean		13.2	12.9	11.4	34	41	21	1.64	1.98	1.52
s.e.		0.3	1.0	0.5	1.5	6.4	2.4	0.04	0.15	0.07
Density (D) F-test		**	**	*	***	***	***	***	ns	ns
Species (SP) F-test		ns	ns	***	*	***	***	*	***	***
D X SP F-test		*	ns	ns	*	ns	**	**	ns	ns
CONTRASTS										
D linear		***	**	*	***	***	***	***	ns	ns
D quadratic		ns	ns	*	**	**	***	ns	ns	ns
D deviation		-	ns	ns	-	ns	**	-	ns	*
B vs T		ns	ns	**	*	***	***	***	***	***
B vs O		ns	ns	***	*	*	***	***	***	***
O vs T		ns	ns	***	***	***	*	ns	ns	***
BE vs intercrop		-	ns	***	-	-	-	-	ns	***
60 VS 240		***	*	ns	***	***	***	***	ns	ns
90 VS 240		-	ns	ns	-	**	***	-	ns	*
120 vs 240		*	-	-	***	-	-	***	-	-

*,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively; ns is not significant.

Table 3-5: Mean† crude protein (CP), acid detergent fibre (ADF), and neutral detergent fibre (NDF) for cereals, berseem and cereal-berseem intercrops for Cut 1 and Cut 2 at Edmonton, AB for 1998, 2000 and 2001.

Treatment	Cereal Density	Sample	Cut 1 CP	Cut 1 ADF	Cut 1 NDF	Cut 2 CP	Cut 2 ADF	Cut 2 NDF
			g kg^{-1}					
Barley intercrops (B)	60	Barley	140	345	580	-	-	-
	60	Berseem	180	310	395	205	250	335
	60	Barley-BE	150	335	545	-	-	-
Oat intercrops (O)	60	Oat	115	370	585	-	-	-
	60	Berseem	170	355	440	210	190	290
	60	Oat-BE	120	365	560	-	-	-
Triticale intercrops (T)	60	Triticale	105	335	555	-	-	-
	60	Berseem	150	370	455	230	190	300
	60	Triticale-BE	120	360	510	-	-	-
BE 1‡	0	Berseem	175	310	410	175	265	335
BE 2	0	Berseem	165	340	430	205	195	280
Cereal mean			120	349	574	-	-	-
Berseem mean			167	339	427	209	215	309
Mixture mean			129	354	536	-	-	-
s.e			10	16	19	19	21	35
Treatment F-test			***	**	***	ns	**	ns
CONTRASTS								
Berseem vs cereals			***	ns	***	-	-	-
Mixtures vs cereals			ns	ns	**	-	-	-
B vs O			**	ns	ns	ns	**	ns
B vs T			**	ns	ns	ns	**	ns
O vs T			ns	ns	*	ns	ns	ns

*,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively; ns is not significant.

† Means are for 2 years (2000 and 2001), except for Cut 1 CP and ADF which are for 3 years (1998, 2000 and 2001).

‡ BE 1 and BE 2 were berseem alone treatments, with BE 1 harvested about the same time as barley intercrops and BE 2 harvested at the same time as oat and triticale intercrops.

Chapter 4 Intercropping berseem clover with barley and oat cultivars for forage

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Chapter 4

Intercropping berseem clover with barley and oat cultivars for forage

INTRODUCTION

Intercropping berseem clover with barley or oats, grown for forage, may increase cropping options for northern producers and also provide agronomic benefits. Potential benefits of legume-based intercropping include increased yields, increased protein and forage quality, nitrogen contributions from legumes, greater yield stability, and reduced incidence of pests, weeds, and diseases (Anil et al., 1998). More time and complexity in managing seeding, fertility, weed control and harvesting can make intercropping less attractive than monocrop production. However, increased interest in intercropping reflects the gains in economics and sustainability that may be achieved with more complex farming systems.

A substantial amount of barley and oat production in western Canada is used for forage, and it is expected that cereal silage production will increase (Helm and Salmon, 2002). Researchers in western Canada have tested silage cereals in mixtures with other annual seed crops (Walton, 1975; Berkenkamp and Meeres, 1987), with pulse crops (Jedel and Helm, 1993), with annual ryegrass and annual legumes (Thompson et al., 1992; Thompson and Stout, 1997; Stout et al., 1997), and with other cereal genotypes (Juskiw et al., 2000abc). Cereal intercrops in western Canada can improve forage quality and yield, control lodging, decrease disease, and extend the window of harvest for silage. The addition of Persian clover (*Trifolium resupinatum* L.) to barley-ryegrass mixtures reduced fertilizer needs and improved subsequent forage yields after silage harvest (Thompson and Stout, 1997). Although the growing season is short in central Alberta, the period of several weeks after silage harvest can be employed for additional forage production. This potential to extend forage production has been demonstrated with mixtures of spring and winter cereals (Baron et al., 1992 and 1995; Jedel and Salmon, 1995). Cereal-legume intercrops have also been investigated in Alberta from the perspective of cropping system sustainability (Izaurralde et al., 1990,1992 and 1993). Increasing the use of annual legumes in cereal cropping systems, either as sole crops or intercropped with cereals, can improve sustainability through biological nitrogen fixation, reduction of weed competition and increased soil organic matter (Izaurralde et al., 1993).

Berseem clover is a high yielding, nutritious, cool-season forage crop thought to have originated in the Middle East (Knight, 1985). In research conducted in north-central Alberta, berseem out-performed six other clovers in yield and ability to compete with weeds (Ross et al., 2001). Research has demonstrated that intercropping berseem with cereals can increase forage yield and quality compared to cereal sole crops in sub-tropical climates (Singh et al., 1989; Zada et al., 1998), increase total dry matter yields without reducing cereal grain yields (Reynolds et al., 1994; Ghaffarzadeh, 1997; Holland and Brummer, 1999) and improve forage quality, reduce fertilizer needs and increase subsequent crop yields (Stout et al., 1997; Ghaffarzadeh, 1997). Intercropped with Italian ryegrass, berseem reduced fertilizer needs by providing an N equivalence of 80 kg N ha^{-1} per year (Caballero et al., 1994). Berseem had greater potential to improve the forage quality and yields of barley-ryegrass-legume intercrops than did annual *Medicago* and *Lespedeza* species (Stout et al., 1997). Berseem was better adapted than crimson clover (*Trifolium incarnatum* L.) or white clover (*T. repens* L.) for intercropping with wheat or barley to improve the ground cover, N-use efficiency and productivity of low input systems in Mexico (Reynolds et al., 1994). Holland and Brummer (1999) concluded that Bigbee berseem was the most consistently high-performing cultivar in oat-berseem intercrops tested in Iowa.

Spring cereals have been used as companion crops to provide legumes with physical support, improve light interception and facilitate mechanical harvesting of legumes (Caballero et al., 1995). The addition of a cereal to a forage legume may provide a yield advantage compared to growing the legume alone. Forage yields from two to four harvests were greater for oat-berseem mixtures than for berseem alone (Welty et al., 1991). Legumes have often been found to be less competitive than cereal or grass species. Berseem constituted only 14% of the forage yield from a 50:50 seed intercrop of berseem with Italian ryegrass (Caballero et al., 1994). Berseem yields, from two or three harvests, were reduced about 50% when grown with oats (Welty et al., 1991; Holland and Brummer, 1999). Substantial reductions in oat and barley seeding rates were required to increase the berseem yield component of berseem-cereal intercrops on highly productive soils (Ross et al., 2003ab).

The choice of cereal species may greatly affect the performance of intercrops. Forage yield and quality of legume-cereal intercrops differed for oat, barley or triticale intercrops (Jedel and Helm, 1993; Ross et al., 2003b). Tesar and Marble (1988) recommend that oats is one of the best companion crops for alfalfa because it is not as leafy and competitive as other companion crops. Reports differ on the relative competitive abilities of oats and barley. Berkenkamp and Meeres (1987) concluded that oats were more competitive than barley in intercrops with peas, fababeans or sunflowers. Nickel et al. (1990) concluded that barley was more competitive than oats as a companion crop for alfalfa. Barley was more competitive than oats in small grain cereal mixtures (Juskiw et al., 2000c).

Cultivar differences can affect performance in intercrops. Traits to consider in choosing cultivars for mixtures include: crop maturity, photoperiod sensitivity, temperature sensitivity, morphology, root system, seedling growth rate, and density response (Pester et al., 1999). Tesar and Marble (1988) recommend using shorter-stature, early-maturing cultivars of cereals as companion crops for alfalfa, as they are assumed to be less competitive. Semi-dwarf cultivars of oats and barley were less competitive than conventional-stature cultivars as companion crops for alfalfa (Nickel et al., 1990). Thompson et al. (1992) found that a semi-dwarf barley was less competitive than conventional-stature barleys, and thus favored ryegrass establishment. Conversely, Holland and Brummer (1999) reported that oat height at grain maturity did not correlate with total berseem yield in oat-berseem intercrops. Simmons et al. (1995) recommend semi-dwarf cultivars as companion crops because they are less prone to lodging. They found that initial alfalfa growth was usually somewhat greater with semi-dwarf cultivars, but there was no significant difference in subsequent harvests. Moynihan et al. (1996) suggest that conventional-stature barley may be preferred for intercropping with medic because intercrop yields with semi-dwarf barley were more erratic. Chapko et al. (1991) concluded that cereal cultivar was less important than cereal species for barley or oats intercropped with peas, as companion crops for alfalfa establishment. Juskiw et al. (2000c) caution that prediction of cultivar competitive ability in mixtures cannot be based on height, biomass production, or a formula of traits. Holland and Brummer (1999) concluded that monoculture evaluation of oat cultivars can be used to predict the traits of oats in berseem-oat intercrops, but cannot be used reliably to predict the effects on berseem forage yields.

Little information is available on intercropping berseem clover with barley or oat cultivars for forage in short-season environments. The objectives of this study were i) to test the feasibility of intercropping berseem with oats and barley for forage in a short-season growing environment, and ii) to test the effects of oat and barley cultivar on the performance of cereal-berseem intercrops.

MATERIALS AND METHODS

Intercrops of berseem clover with oats and barley were grown at Edmonton (53° 25' N, 113° 33' W), Alberta, Canada on a Malmo silty clay loam [orthic Black Chernozem (Typic Cryoboroll)] in 2000 and 2001. Experiments followed tilled fallow, and fields were disked and harrowed prior to seeding. Soil pH was 6.6 to 7.0 and soil nitrate levels were 48 to 56 mg kg^{-1} at 0-30 cm depth (Appendix 1). No fertilizer was added except for the application of triple superphosphate 0-45-0 at approximately 28 kg ha^{-1} of P_2O_5 in 2000.

Five oat cultivars (AC Juniper, Jasper, AC Mustang, Waldern and Murphy), and four barley cultivars (Kasota, AC Lacombe, Niska and Seebe) were seeded at 60 viable seeds m^{-2} in 2000 and at 69 viable seeds m^{-2} in 2001. Cereal cultivars are described in Table 4-1. Cereals were seeded with a 4-row disc drill at 23 cm row spacing. Bigbee berseem clover was inoculated with the appropriate *Rhizobium trifolii* and seeded at 15 kg ha^{-1}. Berseem was cross-seeded at approximately 1.5-2 cm depth and 18 cm row spacing with a 6-row disc drill. Plot size was 1.8 m x 6 m, with 8 rows of cereal in each plot. Berseem sole crop plots were also grown. Plots were seeded on May 18 in 2000 and on May 23 in 2001. In 2001, the plot area was irrigated before and after seeding.

The experimental design was a randomized complete block with four blocks. In 2000, one 0.5 m x 1 m quadrat was permanently marked in each plot. In 2001, two such 0.5 m^{-2} quadrats were marked in each plot. Quadrats were placed away from margins, and the desired cereal density of 60 plants m^{-2} was achieved through placement of the quadrat and thinning of the cereal plants. Plots were hand weeded, with particular attention to quadrat areas. In 2001 at 44 DAP (days after planting), light transmittance was measured at top of the cereal canopy, top of the berseem canopy, and at soil level using a Li-Cor Inc. LI-188B Line Quantum Sensor. Cut 1 harvest was at the silage-stage of cereals (milk to soft dough stage) on dates listed in Table 4-1. Canopy height of each cereal was measured at harvest. Biomass in quadrats was cut by hand at 5-7.5 cm above soil level, with separation of the berseem and cereal biomass. Cereal tillers were counted. For berseem sole crop plots, 0.5 m^{-2} quadrats were harvested to coincide with the beginning and end of silage-stage harvests. Immediately after sampling, treatment plots were cut using a small sickle mower and then hand raked to remove growth. The harvest procedure was repeated at the end of the growing season on October 6 in both years. Days of regrowth after Cut 1 ranged from 53-65 days for treatments in 2000 and 57-71 days in 2001. Samples were dried for 72 hours at 52 °C, and weighed. Species composition and dry matter yields were determined for all treatments. Samples from a subset of treatments were analyzed for crude protein (CP), acid detergent fibre (ADF) and neutral detergent fibre (NDF) by Norwest Labs. Protein was determined using the Association of Official Analytical Chemists (AOAC, 1990) Method 988.05 ($CuSO_4$/ TiO_2 Mixed Catalyst Kjeldahl). ADF was determined using the AOAC (1990) Method 973.18 (by Refluxing), and NDF was determined using Amylase Procedure (Undersander et al., 1993).

Data were analyzed using analysis of variance to determine significant treatment effects ($P \leq 0.05$) using Statistical Analysis System (SAS Inst., 2000). Where significant year × treatment interactions occurred, data are presented by year.

RESULTS

The four barley cultivars reached silage-stage an average of 7-8 days earlier than the five oat cultivars (Table 4-1). Cut 1 of early-maturing oat cultivars (AC Juniper and Jasper) was 3-6 days earlier than late-maturing oat cultivars (Murphy and Waldern). Cut 1 of the early-maturing barley cultivar (Kasota) was 1-7 days earlier than the late-maturing barley cultivar (Seebe). Cut 1 of the semi-dwarf barley cultivars (Kasota, Niska) was 0-3 days earlier than for the conventional-stature barley cultivars (AC Lacombe, Seebe).

Mean canopy height of oat cultivars was 50-56 cm greater than that of barley cultivars (Table 4-2). Mean tiller production (tillers plant^{-1}) of barley was greater than oat. Mean tiller weight of oat was greater than barley. Late-maturing genotypes had greater canopy height than early-maturing genotypes. Late-maturing oat cultivars had fewer but heavier tillers than early-maturing oat cultivars. The late-maturing barley had more tillers than the early-maturing barley, but did not differ in tiller weight. Mean canopy height of conventional-stature barley cultivars was 21-23 cm greater than that of semi-dwarf cultivars, and differences in tiller production and tiller weight varied between years. The forage quality of barley cultivars was higher than that of oat cultivars at silage-stage, with greater CP and less than or equal ADF (Table 4-3). In 2000, late-maturing genotypes had lower NDF than early-maturing genotypes. In 2001, early-maturing genotypes exhibited lower ADF and NDF than late-maturing genotypes. There were few differences in quality between semi-dwarf and conventional barleys.

The total Cut 1 DM yield for intercrops was greater in 2000 than in 2001, with differences largely due to berseem yields (Table 4-4). Seasonal five-month mean temperatures for May to September were near the 30-year average of 14.5 °C in both years. Rainfall for May to

September was near the 30-year average (326 mm) in 2000 (330 mm), but was less than normal in 2001 (267mm). In 2001, plots were irrigated at seeding to counter dry soil conditions, and soil crusting appeared to cause some inhibition of berseem emergence. Cut 1 DM yield of oat-berseem intercrops (O) was greater than barley-berseem intercrops (B) in both years, with 21-25% greater yield for O. The greater DM for O was largely due to the cereal component. There was less difference between O and B for Cut 1 protein yield than for DM yield, with 8% greater protein yield for O than B in 2001 and no difference in 2000 (Table 4-5).

Compared to the yield of berseem sole crop treatments, Cut 1 berseem yields in intercrops were reduced by 60% in 2000 and by 85% in 2001 (Table 4-4). Mean berseem percentage of Cut 1 (BP1) was higher in 2000 than in 2001, due to better general berseem growth in 2000 and greater suppression by cereals in 2001 (Table 4-5). BP1 can be interpreted as a measure of the relative competitiveness of barley and oat cultivars. Percentage of legume in intercrops has been used to compare competitive abilities of cereals (Berkenkamp and Meeres, 1987). In 2000, the mean BP1 of O was less than that of B, suggesting that oats caused greater suppression of berseem than did barley. Cut 1 berseem yields for O equalled those for B, but the reduction of berseem yield was greater for O (65%) than for B (54%), when compared to yields of berseem sole crops with equivalent days of growth. In 2001, results were consistent with greater suppression of berseem by barley than by oats: mean BP1 for B was less than for O; Cut 1 berseem DM for B was less than for O; berseem yield reduction was greater with B (88%) than with O (83%). Light readings in 2001 indicated that barley cultivars caused more shading of berseem than did oat cultivars (Appendix 9). At 44 days after planting (DAP) in 2001, available light under barley canopies averaged 33% at the top of berseem and 9% at soil level, while available light under oat canopies averaged 47% at the top of berseem and 16% at soil level.

Cereal biomass was a factor in suppression of berseem by barley and oat cultivars. Within B intercrops, there were negative correlations between Cut 1 berseem DM and barley DM ($r = -.75$, $P < 0.01$ for 2000; $r = -.63$, $P < 0.01$ for 2001). Within O intercrops, there were somewhat weaker correlations between Cut 1 berseem DM and oat DM ($r = -.51$, $P = 0.02$ for 2000; $r = -.34$, $P = 0.04$ for 2001). Cereal tillering was a minor factor in berseem suppression by barley cultivars, with a moderate correlation between Cut 1 berseem DM and barley tiller production in 2001 ($r = -.44$, $P = 0.01$).

In 2001, Cut 1 yields of conventional-stature barley cultivar intercrops (C) were greater than those of semi-dwarf barley cultivar intercrops (S), with 22% greater cereal DM, 20% greater intercrop DM, and 20% greater protein yield (Table 4-4). In 2000, C and S had equal Cut

1 DM and protein yields, as the 28% greater cereal DM for C was balanced by the 40% greater berseem DM for S. In 2000, there was evidence that semi-dwarf cultivars caused less suppression of berseem than did conventional cultivars: mean BP1 for S was greater than for C, Cut 1 berseem DM for S was greater than for C, and Cut 1 berseem yield reduction for C (62%) was greater than for S (46%). Barley canopy height was correlated with Cut 1 berseem DM in 2000 ($r = -.54$, $P = 0.03$). In 2001, the BP1 and Cut 1 berseem DM of S and C were not significantly different. However, in 2001 the canopy height of oat cultivars was correlated with Cut 1 berseem DM ($r = -.60$, $P < 0.01$).

Intercrops with early-maturing oat cultivars (EO) had greater yields of Cut 1 berseem DM and lower yields of Cut 1 cereal DM than did intercrops with late-maturing oat cultivars (LO) (Table 4-4). In 2001, total Cut 1 DM yield was greater for LO than for EO. In 2000, total Cut 1 DM yield was EO=LO, as greater cereal yield for LO was balanced by greater berseem yield for EO. There were indications of less berseem suppression by early-maturing oat cultivars, as EO had greater BP1 and Cut 1 berseem DM yield than did LO (Tables 4-4 and 4-5). Mean yield reductions for Cut 1 berseem DM were 58% and 80% for EO and 75% and 86% for LO in 2000 and 2001 respectively. Cut 1 berseem DM was negatively correlated with cutting date of oat cultivars ($r = -.60$, $P < 0.01$ for 2000; $r = -.44$, $P < 0.01$ for 2001). Similar trends in differences between early-maturing barley cultivar intercrops (EB) and late-maturing barley cultivar intercrops (LB) were observed for Cut 1 as with oat cultivars. In 2001, LB had greater Cut 1 barley DM and total DM than EB, and EB had greater BP1 than LB.

Mean Cut 2 berseem yields for intercrops were similar in both years (Table 4-5). Cereal regrowth was negligible in 2000, but averaged 0.9 Mg ha^{-1} for barley cultivars and 0.2 Mg ha^{-1} for oat cultivars in 2001. Cereal regrowth in 2001 may have been related to heavy rainfall (146 mm) in mid to late July. Cut 2 berseem yields were greater for B than for O, greater for EO than for LO, greater for S than for C, and in 2001 were greater for EB than for LB. Days of regrowth was 8 days more for B than O, 4-6 days more for EO than LO, 1-7 days more for EB than LB, and 1-4 days more for S than C. Cut 2 berseem yield was negatively correlated with Cut 1 date among oat cultivars in both years ($r = -.73$, $P < 0.01$ for 2000; $r = -.54$, $P < 0.01$ for 2001) and Cut 1 date among barley cultivars in 2001 ($r = -.85$, $P < 0.01$). Cut 2 berseem yield was negatively correlated with Cut 1 cereal DM among barley cultivars in both years ($r = -.59$, $P < 0.05$ for 2000; $r = -.37$, $P < 0.05$ for 2001) and with Cut 1 cereal DM among oat cultivars in 2000 ($r = -.51$, $P < 0.05$).

The Total DM yields for intercrops were greater in 2000 than in 2001, mainly due to greater Cut 1 berseem DM in 2000 (Tables 4-6 and 4-4). Total DM yield of O was greater than B in 2000, largely due to greater Cut 1 oat DM. Total DM yield of EB was greater than LB in 2001, due to greater berseem yield. Total protein yields were greater for B than for O, greater for EO than for LO, and in 2001 were greater for EB than for LB. There were no differences in Total DM or protein yield between S and C.

Yields of berseem sole crops treatments differed from those of berseem-cereal intercrops. Mean Cut 1 yield of berseem sole crops was 30-41% less than intercrop yields (Table 4-4). Mean Cut 2 yield of berseem sole crops was 32-177% greater than intercrop yields (Table 4-5). Mean Total DM yield of berseem sole crops was 17% less in 2000 and 9% greater in 2001 than intercrops (Table 4-6). Mean total protein yield of berseem sole crops was 43% greater than intercrops in 2001.

The forage quality of berseem at Cut 1 was greater than mean quality of oat and barley cultivars, with equal or higher CP and lower NDF (Tables 4-3 and 4-7). Berseem quality declined over the period of Cut 1 harvest, with higher quality for early-harvested berseem (BE1) than for late-harvested berseem (BE3) (Table 4-7). Although berseem generally had higher quality than cereals, adding berseem to Niska barley or Waldern oat did not improve Cut 1 quality. Berseem was 40% of mixtures with Niska barley in 2000, but the quality of the barley was very high in that year. In 2001, berseem quality was greater than that of Niska, but berseem was only 5% of the mixture. Berseem had higher quality than Waldern oat, but the berseem component of mixtures was only 12-17%.

There was no difference in quality of Cut 2 berseem among treatments (Table 4-8). Berseem regrowth in Cut 2 had high nutritional quality with mean CP of 210 g kg^{-1}.

DISCUSSION AND SUMMARY

Barley and Oat Comparisons

Results for oat intercrops (O) and barley intercrops (B) can be summarized as follows: O>B for Cut 1 DM yield, O≥B for Cut 1 protein, B>O for BP1 in 2000 and O>B for BP1 in 2001, B>O for Cut 2 DM yield, O≥B for total DM yield, and B>O for total protein yield.

A greater forage yield advantage with oat intercrops than with barley intercrops has been reported in studies of cereals intercropped with pulse crops or other cereals (Berkenkamp and Meeres, 1987; Jedel and Helm, 1993; Jedel and Salmon, 1994). In our study, greater Cut 1 yields for O than for B can be partly explained by later maturity date and larger tillers for oat cultivars. Juskiw et al. (2000b) concluded that total biomass per plant for small grain cereals was affected by genotype, production practices, and time of harvest, with the latter having the greatest effect. They observed that biomass yields of barley, oat and triticale increased with increasing maturity date.

The higher CP values for barley cultivars and B intercrops, compared to oat cultivars and O intercrops, were consistent with research at Lacombe, Alberta (Jedel and Helm, 1993; Helm and Salmon, 2002). Similarly, Brink and Marten (1986a) concluded that barley-alfalfa mixtures had better forage quality than oat-alfalfa mixtures at dough stage. Conversely, Chapko et al. (1991) reported higher CP for oat-pea mixtures than for barley-pea mixtures, but they harvested at an earlier cereal stage (emergence of spikelets from the boot).

Results in 2001 indicated that barley cultivars caused greater suppression of berseem than did oat cultivars. Other studies have found that barley was more competitive than oats in mixtures (Nickel et al, 1990; Juskiw et al., 2000c). In experiments related to this study, BP1 values for AC Lacombe barley-berseem intercrops were less than those for Waldern oat-berseem intercrops in 3 of 4 years (Ross et al., 2003b). Brink and Marten (1986b) reported that barley cultivars frequently had greater LAI than did oat cultivars, and had greater potential for light competition with undersown alfalfa. We found that barley cultivars had greater tillers plant^{-1} than oats, and there were indications of greater shading of berseem in 2001. Kendall and Stringer (1985) stated that the relative growth rates of clover plants decrease rapidly in response to shading in full daylight. The greater tiller density of barley (and likely greater leaf area) may have caused greater shading of the berseem than did oats from early stages of growth onwards.

In 2000, there was less suppression of the berseem by the cereals than in 2001. Cereal emergence was uneven in 2000 and occurred in two flushes. Earlier relative emergence and establishment of berseem, and timely rainfall, may have decreased the early competitive effects of cereals on berseem. Relative time of emergence has been identified as an important factor in crop-weed competition (O'Donovan et al., 1985) and in pea-cereal competition (Tofinga et al., 1993). There were indications that oats caused greater suppression of berseem than did barley in 2000. With less effect of barley leaf area at early stages, greater shading by the taller oat canopy may have occurred at later stages of growth. Berkenkamp and Meeres (1987) concluded that oats were more competitive than barley in intercrops with peas, fababeans or sunflowers.

Although oat intercrops provided higher biomass yields, barley intercrops provided greater protein yield. Greater Cut 1 yields for O were often balanced by greater Cut 2 yields for B. The earlier maturity of barley provided for longer periods of regrowth, and greater yield of fall forage. Total protein yields were greater for B than O, due to a combination of greater CP for barley cultivars and substantial yield contributions from high-quality berseem regrowth.

Cereal Stature Effects

Results for semi-dwarf barley intercrops (S) and conventional-stature barley intercrops (C) can be summarized as follows: C≥S for Cut 1 DM and protein yield, S≥C for BP1, S>C for Cut 2 DM yield, and S=C for total DM and protein yield. Although Cut 1 cereal DM yields were greater for conventional barley cultivars, the C intercrops did not provide an advantage to total yield. Moynihan et al. (1996) reported that biomass yields for medic-barley intercrops were similar with semi-dwarf or conventional-stature cereals. There were some indications that semi-dwarf cultivars caused less suppression of berseem than did conventional cultivars in our study. The canopy of semi-dwarf cultivars may have caused less shading of berseem. Simmons et al. (1995) found that the amount of light penetrating cereal canopies to alfalfa was greater for semi-dwarf cultivars than for conventional-stature cultivars. Earlier Cut 1 harvest for Kasota, may partly account for greater Cut 2 yields for S than for C. The results for Kasota barley represent a combination of semi-dwarf stature and earliness. Juskiw et al. (2000c) found that Kasota was less competitive than Seebe or AC Lacombe in cereal mixtures, and suggested that differences may have been due to stature or earliness. Holland and Brummer (1999) found that a shorter and earlier oat cultivar was less suppressive of berseem than other oat cultivars, but they suggested that heading date may be more strongly associated with competitiveness than oat height.

Early versus Late-Maturing Cultivars

Results for early-maturing oat intercrops (EO) and late-maturing oat intercrops (LO) can be summarized as follows: LO≥EO for Cut 1 DM yield, EO>LO for BP1, EO>LO for Cut 2 DM yield, EO=LO for total DM yield, and EO>LO for total protein yield. In 2001, the differences between an early-maturing barley intercrop (EB) and a late-maturing barley intercrop (LB) were the same as the differences between early and late-maturing oat intercrops, except that EB was greater than LB for total DM yield. In 2000, when harvest date between EB and LB differed by only one day, there were no differences between EB and LB yields.

Given the relationship between maturity date and biomass yield of silage cereals reported by Juskiw et al. (2000b), higher Cut 1 yields would be expected with later maturing cultivars. Thompson et al. (1992) reported that late-maturing barley cultivars intercropped with ryegrass had greater first cut yields than a medium-maturing barley intercrop. Our late-maturing genotype intercrops usually had greater Cut 1 cereal yield than early-maturing genotypes, and in 2001 had greater Cut 1 total yield.

Late-maturing barley and oat cultivars caused greater suppression of berseem than did early-maturing cultivars. Similarly, Holland and Brummer (1999) concluded that the latest-heading oat cultivar had the greatest competitive effect on berseem forage yield. Juskiw et al. (2000c) found that barley cultivars with early maturity were less competitive than later maturing barley cultivars. The competitive effects of late-maturing cultivars may be partly explained by greater cereal biomass. Within cereal species, there was correlation between increasing cereal DM and decreasing berseem DM. Similar effects of biomass have been reported in other oat-berseem intercrop studies. Holland and Brummer (1999) found that oat straw yield was negatively correlated with berseem yield. With a single oat cultivar, Waldern, at a range of seeding rates, there were significant linear relationships between either increasing oat DM or oat tiller density and decreasing berseem yield (Ross et al., 2003a).

Holland and Brummer (1999) suggested that the greater competitiveness of late-maturing oat cultivars might be associated with greater tillering in the vegetative phase. Some of our results for barley cultivars would support this hypothesis. The late-maturing barley, Seebe, had greater tiller production and was more competitive than the early-maturing barley, Kasota. Barley tillering was negatively correlated with Cut 1 berseem yield in one year. However, oat tiller production did not correlate with Cut 1 berseem yield, and late-maturing oat cultivars had fewer tillers plant^{-1} than did early-maturing oat cultivars. Thus, tiller production was not consistently associated with late-maturity or with berseem suppression. Jedel et al. (1998) concluded that competitive ability of barley cultivars in intraspecific barley mixtures was not associated with tillering. Greater competitiveness of late-maturing cultivars may be associated with greater partitioning of biomass into leaves. Juskiw et al. (2000b) found that early-maturing barley cultivars had lower proportions of biomass as leaf and stem, and higher proportions as spike, compared to late-maturing cereal cultivars between heading and soft dough stages.

Cereals with both earliness and short stature may be the best choice for cereal-berseem intercrops. Total DM and protein yields of early-maturing genotype intercrops were equal or greater than those of late genotypes, due to greater berseem growth. The early-maturing semi-dwarf barley, Kasota, had the highest Cut 2 and total yield among barley intercrops. The tallest late oat, Murphy, had the lowest Cut 2 and total yields amongst the oat intercrops. Juskiw et al. (2000c) stated that inclusion of a highly competitive cultivar or species in a mixture may not lead to any overall yield advantage. It was true of our experiment that higher total yields often occurred with the less competitive oat and barley cultivars.

Potential of Cereal-Berseem Intercrops

Total DM yield averaged 13.2 Mg ha^{-1}, with 32% berseem, for oat-berseem intercrops and 12.8 Mg ha^{-1}, with 41% berseem, for barley-berseem intercrops. Yields compared favorably with biomass DM yields reported in central Alberta for oat-pulse and barley-pulse intercrops of 8.2 to 12.3 Mg ha^{-1} by Berkenkamp and Meeres (1987) and 9 to 11 Mg ha^{-1} by Jedel and Helm (1993), and 8.9 Mg ha^{-1} for barley-pea intercrops by Izaurralde et al. (1993). Although cereal seeding rates were ¼ of the full seeding rate in this study, total intercrop yields equalled those for full-rate oat-berseem and barley-berseem intercrops (12.1-12.3 Mg ha^{-1}) in related experiments (Ross et al., 2003b).

Mean CP levels of oat cultivars (110-120 g kg^{-1}) and barley cultivars (130-150 g kg^{-1}) were higher than in some studies of silage cereals in central Alberta: 70-100 g kg^{-1} CP for oats and barley (Juskiw et al., 2000a) and 90-125 g kg^{-1} CP for barley (Jedel and Salmon 1995). The high CP values for cereals were likely related to high initial soil N levels at Edmonton. Results for intercrops with Niska barley and Waldern oats indicated that adding berseem to cereals had relatively little effect on forage quality at silage-stage. The lack of impact of berseem on intercrop quality was likely due to a combination of small percentage of berseem in some mixtures and high CP levels for cereals. Carr et al. (1998) found that adding peas to oats or barley did not increase forage CP in high-soil-N environments but did increase CP in low-soil-N environments. The high quality of berseem, with mean CP of 150-190 g kg^{-1} and low NDF at Cut 1, may make a valuable contribution to forage quality even on productive soils. In related experiments at Edmonton, berseem-cereal intercrops with a 20% berseem component had lower NDF, compared to oats, barley and triticale alone at silage-stage (Ross et al., 2003b).

Cereal-berseem intercrops offer the potential to partition forage yield between silage harvest and fall grazing. Berseem regrowth (Cut 2) provided an average of 2.8 Mg ha^{-1} DM of high-quality late-season forage. Berseem regrowth compares well with fall yields of 0.05 to 2.39 Mg ha^{-1} in central Alberta from spring and winter cereal intercrops after silage harvest (Jedel and Salmon, 1995). Using an early-maturing barley or oat cultivar in cereal-berseem intercrops can increase the fall grazing proportion of forage yield. Early-maturing, semi-dwarf barley cultivars would be recommended to maximize Cut 2 yield.

CONCLUSION

Cereal genotype affected the performance of cereal-berseem intercrops. Intercrops with barley cultivars had advantages of greater total protein yield and greater fall forage yield. Intercrops with oat cultivars had greater silage-stage yield and may produce greater total forage yield. Early-maturing and semi-dwarf cultivars caused less suppression of berseem than late-maturing and conventional-stature cultivars. Total yields were sometimes greater with less competitive cultivars. Competitive effects of oat and barley cultivars varied between years. On highly productive soils, the greatest benefit of cereal-berseem intercrops may be the addition of a high-quality late-season forage. To maximize fall forage and increase the legume component of silage harvest, early-maturing and short-stature cultivars of oats and barley are recommended for cereal-berseem intercrops.

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Table 4-1: Description of oat and barley cultivars, and dates for Cut 1 silage-stage harvest (with number of days after planting† in parentheses) of cereal-berseem clover intercrops, and berseem sole crops in 2000 and 2001.

			Cut 1 harvest	
Crop	Cultivar	Description	2000	2001
			—— date (days after planting) —	
Barley	Kasota	early, semi-dwarf, 6 row	2-Aug (76)	27-Jul (65)
	AC Lacombe	mid-maturity, 6 row	3-Aug (77)	1-Aug (70)
	Niska	semi-dwarf, 6 row	3-Aug (77)	2-Aug (71)
	Seebe	late, 2 row	3-Aug (77)	3-Aug (72)
Oat	AC Juniper	early, short, general purpose	8-Aug (82)	6-Aug (75)
	Jasper	early, general purpose	8-Aug (82)	7-Aug (76)
	AC Mustang	good yield silage/feed	11-Aug (85)	8-Aug (77)
	Murphy	late, high yield silage/feed	14-Aug (88)	10-Aug (79)
	Waldern	late, high yield silage/feed	14-Aug (88)	10-Aug (79)
Berseem sole crop BE1 - early cut			-	27-Jul (65)
Berseem sole crop BE2 - mid cut			4-Aug (78)	3-Aug (72)
Berseem sole crop BE3 - late cut			14-Aug (88)	10-Aug (79)

† Plots were seeded on May 18 in 2000 and on May 23 in 2001.

Table 4-2: Canopy height, tillers per plant, and tiller weight at Cut 1 for barley and oat cultivars; and grouped means for barley, oat, early-maturing oat, late-maturing oat, semi-dwarf barley and conventional height barley cultivars in 2000 and 2001.

		Canopy height		Tillers per plant		Tiller weight	
Species	Genotype	2000	2001	2000	2001	2000	2001
		—— cm ——		— no. plant^{-1} —		—— g tiller^{-1} —	
Barley	Kasota	85	65	8	9	1.3	1.0
	AC Lacombe	100	85	7	9	1.9	1.6
	Niska	85	70	7	12	1.3	1.0
	Seebe	105	95	10	12	1.3	1.0
Oat	AC Juniper	130	115	6	8	2.5	1.6
	Jasper	140	130	6	7	2.7	1.7
	AC Mustang	145	140	3	4	4.6	3.4
	Murphy	160	150	5	5	3.6	2.6
	Waldern	145	130	4	5	4.7	2.8
Genotype F-test		***	***	***	***	***	***
s.e.†		3.4	1.5	0.4	0.6	0.32	0.12
Barley cultivars (B)		93	77	8.2	10.6	1.5	1.1
Oat cultivars (O)		143	133	4.7	5.8	3.6	2.4
s.e.		1.6	0.7	0.2	0.3	0.15	0.06
Early-maturing oat cultivars (EO)		135	124	5.8	7.4	2.6	1.7
Late-maturing oat cultivars (LO)		150	139	4.4	5.1	4.1	2.7
s.e.		4.9	2.1	0.6	0.8	0.45	0.16
Semi-dwarf barleys (S)		83	66	7.7	10.9	1.3	1.0
Conventional barleys (C)		104	89	8.6	10.2	1.6	1.3
s.e.		4.9	2.1	0.6	0.8	0.45	0.16
CONTRASTS							
B vs O		***	***	***	***	***	***
EO vs LO		***	***	***	***	***	***
E barley (EB) vs L barley (LB)		***	***	***	***	ns	ns
S vs C		***	***	**	ns	ns	***

,* Significant at 0.01 and 0.001 probability levels, respectively; ns is not significant.
EO = AC Juniper and Jasper oat; LO = Murphy and Waldern oat; EB = Kasota barley; LB = Seebe barley; S = Kasota and Niska barley; C = AC Lacombe and Seebe barley.
† s.e. = standard error of the difference of least square means immediately proceeding above in column.

Table 4-3: Crude protein (CP), acid detergent fibre (ADF), and neutral detergent fibre (NDF) at Cut 1 for barley and oat cultivars; and grouped means for barley, oat, early-maturing oat, late-maturing oat, semi-dwarf barley and conventional height barley cultivars in 2000 and 2001.

		Quality					
		CP		ADF		NDF	
Species	Genotype	2000	2001	2000	2001	2000	2001
		$g\ kg^{-1}$					
Barley	Kasota	130	135	325	275	575	495
	AC Lacombe	130	140	335	295	585	495
	Niska	170	145	285	305	515	540
	Seebe	150	145	310	365	525	590
Oat	AC Juniper	110	125	305	340	500	540
	Jasper	115	120	340	350	550	550
	AC Mustang	110	125	370	385	600	590
	Murphy	110	120	315	385	475	615
	Waldern	110	115	335	380	520	600
Genotype F-test		**	*	ns	**	***	*
s.e.†		8.8	7.5	23.3	20.7	11.8	38.1
Barley cultivars (B)		144	140	314	309	550	530
Oat cultivars (O)		112	120	334	367	529	579
s.e.		4.2	3.6	11.0	9.8	5.6	15.5
Early-maturing oat cultivars (EO)		114	123	324	343	524	545
Late-maturing oat cultivars (LO)		111	116	324	383	498	608
s.e.		12.4	10.7	32.9	29.3	16.7	43.1
Semi-dwarf barleys (S)		147	140	306	291	545	516
Conventional barleys (C)		141	141	322	328	555	544
s.e.		12.4	10.7	32.9	29.3	16.7	43.1
CONTRASTS							
B vs O		***	***	ns	***	**	*
EO vs LO		ns	ns	ns	*	*	*
E barley (EB) vs L barley (LB)		*	ns	ns	**	**	*
S vs C		ns	ns	ns	*	ns	ns

*,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively; ns is not significant.
EO = AC Juniper and Jasper oat; LO = Murphy and Waldern oat; EB = Kasota barley; LB = Seebe barley; S = Kasota and Niska barley; C = AC Lacombe and Seebe barley.
† s.e. = standard error of the difference of least square means immediately proceeding above in column.

Table 4-4: Cut 1 dry matter (DM) yields of cereal, berseem clover and total for cereal-berseem clover intercrops and berseem sole crops; and grouped means for barley, oat, early-maturing oat, late-maturing oat, semi-dwarf barley and conventional height barley cultivar intercrops in 2000 and 2001.

		Cut 1					
		Cereal DM		Berseem DM		Total DM	
Treatment	Genotype	2000	2001	2000	2001	2000	2001
		Mg ha^{-1}					
Barley intercrops	Kasota	6.6	5.6	3.3	0.6	9.9	6.2
	AC Lacombe	8.3	7.9	2.5	0.4	10.8	8.3
	Niska	5.8	6.9	4.0	0.3	9.7	7.3
	Seebe	7.5	7.3	2.7	0.5	10.2	7.8
Oat intercrops	AC Juniper	8.5	7.1	3.2	1.2	11.7	8.3
	Jasper	9.3	7.7	3.6	1.2	12.9	8.8
	AC Mustang	9.4	8.1	3.8	1.1	13.2	9.2
	Murphy	10.4	8.2	2.0	0.7	12.4	8.9
	Waldern	11.0	8.3	2.3	1.1	13.3	9.5
BE1- early cut - berseem sole crop		-	-	-	2.9	-	2.9
BE2 - mid cut - berseem sole crop		-	-	6.8	4.8	6.8	4.8
BE3 - late cut - berseem sole crop		-	-	9.5	7.1	9.5	7.1
Treatment F-test		***	***	***	***	***	***
s.e.†		0.82	0.31	0.56	0.25	0.78	0.40
Barley intercrops (B)		7.0	7.0	3.1	0.4	10.2	7.4
Oat intercrops (O)		9.7	7.9	3.0	1.1	12.7	9.0
s.e.		0.39	0.15	0.25	0.04	0.39	0.15
Early-maturing oat intercrops (EO)		8.9	7.4	3.4	1.2	12.3	8.6
Late-maturing oat intercrops (LO)		10.7	8.3	2.2	0.9	12.9	9.2
s.e.		1.16	0.43	0.76	0.13	1.15	0.45
Semi-dwarf barley intercrops (S)		6.2	6.3	3.6	0.5	9.8	6.7
Conventional barley intercrops (C)		7.9	7.6	2.6	0.4	10.5	8.1
s.e.		1.16	0.43	0.76	0.13	1.15	0.45
Berseem alone		-	-	8.2	4.9	8.2	4.9
Intercrops		8.5	7.5	3.1	0.8	11.6	8.3
s.e.		-	-	0.31	0.14	0.43	0.22
CONTRASTS							
B vs O		***	***	ns	***	***	***
EO vs LO		**	***	**	***	ns	*
Early barley (EB) vs late barley (LB)		ns	***	ns	ns	ns	***
S vs C		**	***	*	ns	ns	***
Berseem alone vs intercrops		-	-	***	***	***	***

*,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively; ns is not significant.
EO = AC Juniper and Jasper oat; LO = Murphy and Waldern oat; EB = Kasota barley; LB = Seebe barley; S = Kasota and Niska barley; C = AC Lacombe and Seebe barley.
† s.e. = standard error of the difference of least square means immediately proceeding above in column.

Table 4-5: Percentage of berseem clover and protein yield for Cut 1 and dry matter (DM) yields for Cut 2 for cereal-berseem intercrops and berseem alone; and grouped means for barley, oat, early-maturing oat, late-maturing oat, semi-dwarf barley and conventional height barley cultivar intercrops in 2000 and 2001.

		Cut 1				Cut 2 DM		
		% Berseem		Protein		Berseem		Cereal
Treatment	Genotype	2000	2001	2000	2001	2000	2001	2001
		%		Mg ha^{-1}				
Barley	Kasota	33	9	1.33	0.86	4.1	5.7	0.7
intercrops	AC Lacombe	23	5	1.47	1.18	3.1	3.0	0.8
	Niska	40	5	1.56	1.07	3.9	2.4	1.5
	Seebe	26	7	1.53	1.14	3.7	2.5	0.7
Oat	AC Juniper	27	15	1.42	1.14	2.7	3.0	0.5
intercrops	Jasper	28	13	1.63	1.14	2.6	2.5	0.2
	AC Mustang	29	12	1.62	1.21	2.3	2.2	0.3
	Murphy	16	8	1.45	1.11	1.4	1.5	0.1
	Waldern	17	12	1.58	1.16	1.8	2.2	0.1
BE1- early cut - berseem sole crop		-	-	-	0.65	-	10.4	-
BE2 - mid cut - berseem sole crop		-	-	1.08	1.03	4.5	7.1	-
BE3 - late cut - berseem sole crop		-	-	1.26	1.10	3.0	5.5	-
Treatment F-test		***	***	***	***	***	***	***
s.e.†		4.5	1.0	0.100	0.056	0.45	0.38	0.21
Barley intercrops (B)		31	6	1.47	1.06	3.7	3.4	0.9
Oat intercrops (O)		24	12	1.54	1.15	2.2	2.3	0.2
s.e.		2.1	0.5	0.048	0.020	0.14	0.16	0.10
Early-maturing oat intercrops (EO)		28	14	1.52	1.14	2.6	2.7	0.3
Late-maturing oat intercrops (LO)		17	10	1.51	1.13	1.6	1.8	0.1
s.e.		6.4	1.5	0.140	0.059	0.42	0.48	0.30
Semi-dwarf barley intercrops (S)		37	7	1.45	0.97	4.0	4.1	1.1
Conventional barley intercrops (C)		25	6	1.50	1.16	3.4	2.7	0.7
s.e.		6.4	1.5	0.140	0.059	0.42	0.48	0.30
Berseem alone		-	-	1.17	0.93	3.8	7.7	-
Intercrops		12	8	1.23	0.92	2.8	2.8	0.5
s.e.		-	-	0.055	0.031	0.25	0.22	-
CONTRASTS								
B vs O		**	***	ns	***	***	***	***
EO vs LO		**	***	ns	ns	***	***	ns
Early barley (EB) vs late barley (LB)		ns	*	ns	***	ns	***	ns
S vs C		***	ns	ns	***	**	***	*
Berseem alone vs intercrops		-	-	***	***	***	***	-

*,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively; ns is not significant.
EO = AC Juniper and Jasper oat; LO = Murphy and Waldern oat; EB = Kasota barley; LB = Seebe barley; S = Kasota and Niska barley; C = AC Lacombe and Seebe barley.
† s.e. = standard error of the difference of least square means immediately proceeding above in column.

Table 4-6: Total dry matter (DM) yield, % berseem clover and protein yield for cereal-berseem intercrops and berseem sole crops; and grouped means for barley, oat, early-maturing oat, late-maturing oats, semi-dwarf barley and conventional height barley cultivar intercrops in 2000 and 2001.

		Total of 2 cuts					
		Total DM		% Berseem		Total protein	
Treatment	Genotype	2000	2001	2000	2001	2000	2001
		Mg ha^{-1}		%		Mg ha^{-1}	
Barley	Kasota	14.0	12.6	53	50	2.25	1.96
intercrops	AC Lacombe	14.0	12.2	39	28	2.16	1.86
	Niska	13.6	11.2	57	25	2.43	1.75
	Seebe	13.8	11.0	46	27	2.34	1.70
Oat	AC Juniper	14.4	11.8	41	36	2.08	1.83
intercrops	Jasper	15.5	11.5	40	32	2.25	1.67
	AC Mustang	15.5	11.7	40	28	2.17	1.72
	Murphy	13.9	10.5	25	20	1.79	1.43
	Waldern	15.1	11.7	27	28	2.01	1.64
BE1- early cut - berseem sole crop		-	13.3	-	-	-	2.60
BE2 - mid cut - berseem sole crop		11.3	11.9	-	-	2.09	2.42
BE3 - late cut - berseem sole crop		12.5	12.6	-	-	1.98	2.26
Treatment F-test		**	*	***	***	*	***
s.e.†		1.00	0.86	4.4	2.2	0.164	0.113
Barley intercrops (B)		13.9	11.7	49	32	2.30	1.82
Oat intercrops (O)		14.9	11.5	35	29	2.06	1.66
s.e.		0.44	0.28	2.1	1.0	0.065	0.046
Early-maturing oat intercrops (EO)		14.9	11.7	41	34	2.16	1.75
Late-maturing oat intercrops (LO)		14.5	11.1	26	24	1.90	1.53
s.e.		1.31	0.83	6.2	3.1	0.190	0.136
Semi-dwarf barley intercrops (S)		13.8	11.9	55	37	2.34	1.85
Conventional barley intercrops (C)		13.9	11.6	43	27	2.25	1.78
s.e.		1.31	0.83	6.2	3.1	0.190	0.136
Berseem alone		11.9	12.6	-	-	2.03	2.43
Intercrops		14.4	11.6	41	30	1.80	1.80
s.e.		0.55	0.38	-	-	0.091	0.063
CONTRASTS							
B vs O		**	ns	***	***	**	***
EO vs LO		ns	ns	***	***	*	**
Early barley (EB) vs late barley (LB)		ns	**	ns	***	ns	*
S vs C		ns	ns	***	***	ns	ns
Berseem alone vs intercrops		***	**	-	-	ns	***

*,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively; ns is not significant.
EO = AC Juniper and Jasper oat; LO = Murphy and Waldern oat; EB = Kasota barley; LB = Seebe barley; S = Kasota and Niska barley; C = AC Lacombe and Seebe barley.
† s.e. = standard error of the difference of least square means immediately proceeding above in column.

Table 4-7: Crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), for berseem-cereal intercrops and berseem (BE) sole crops for Cut 1 in 2000 and 2001.

		Cut 1					
		CP		ADF		NDF	
Treatment	Sample	2000	2001	2000	2001	2000	2001
		g kg^{-1}					
Niska barley	Barley	170	145	285	305	515	540
intercrop	Berseem	140	190	390	280	470	390
	Barley-berseem mixture	165	145	340	285	490	485
Waldern oat	Oat	110	115	335	380	520	600
intercrop	Berseem	170	170	380	335	465	435
	Oat-berseem mixture	125	120	365	380	535	580
BE1 - early	Berseem	-	225	-	230	-	325
BE2 - mid	Berseem	160	220	365	275	460	350
BE3 - late	Berseem	130	155	385	315	470	405
Sample F-test		**	**	**	**	ns	***
s.e.†		9.2	15.2	18.2	21.5	21.7	21.6
Berseem mean		150	192	379	286	465	381
CONTRAST							
Mixtures vs cereals		ns	ns	*	ns	ns	ns

*,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively; ns is not significant.
† s.e. = standard error of the difference of two least square means.

Table 4-8: Crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF) and days of regrowth for Cut 2 berseem in intercrops and berseem sole crops in 2000 and 2001.

	Cut 2 Berseem				
	Days regrowth		2 year mean		
Treatment	2000	2001	CP	ADF	NDF
	days		g kg^{-1}		
Niska barley intercrop	64	66	200	240	335
Waldern oat intercrop	53	57	225	190	290
Berseem sole crop - BE1- early	-	71	190	230	350
Berseem sole crop - BE2 - mid	63	64	195	240	350
Berseem sole crop - BE3 - late	53	57	210	200	310
Treatment F-test	-	-	ns	ns	ns
s.e.†	-	-	20.6	24.9	33.1
Mean	-	-	210	220	320

ns = not significant at 0.05 probability level.
† s.e. = standard error of the difference of two least square means.

Chapter 5 Oat-berseem clover intercrops. I. Effects of sampling date and oat plant density on initial forage yield and quality

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Chapter 5

Oat-berseem clover intercrops. I. Effects of sampling date and oat plant density on initial forage yield and quality

INTRODUCTION

Interest in intercropping has increased in temperate regions in recent years (Connolly *et al.*, 2001; Anil *et al.*, 1998). Potential benefits of cereal-legume intercropping include increased yields, increased protein and forage quality, nitrogen contributions from legumes, greater yield stability, and reduced incidence of pests, weeds, and diseases (Anil *et al.*, 1998). The sustainability of cereal cropping systems could be improved by greater use of annual legumes as sole crops or as intercrops with cereals (Izaurralde *et al.*, 1993).

Berseem clover, an annual clover, is a high yielding nutritious forage extensively cultivated in subtropical regions (Duke, 1981). It is adapted for growth as a winter crop, but can also be grown as a summer annual in regions with moist, cool summers (Knight, 1985). Research in northern USA has investigated the yield potential of berseem grown as a summer annual (Westcott *et al.*, 1995; Shrestha *et al.*, 1998). Berseem may have a potential as a new forage for western Canada (Stout *et al.*, 1997; Ross *et al.*, 2001). Growth analysis studies of berseem have been conducted on berseem grown as a winter annual (Guessous, 1981; Brink and Fairbrother, 1992; Iannucci *et al.*, 1996). In Morocco, Guessous (1981) studied the effects of plant age, cutting date and temperature on the chemical composition of berseem. In southeastern USA, Brink and Fairbrother (1992) measured changes in forage quality and morphology of berseem over 70 days of spring growth. In Italy, Iannucci *et al.* (1996) assessed the effects of developmental stage on dry matter and nutrient partitioning. Little information is available on the growth rate and forage quality of spring-seeded berseem in northern climates.

Cereals or grasses may be added to legume crops for various reasons. Oat companion crops have been used to provide legumes with physical support for climbing, improve light interception, and facilitate mechanical harvesting (Caballero *et al.*, 1995). Forage yields of berseem were increased by the addition of oat (Welty *et al.*, 1991) or barley companion crops (Martiniello, 1999). Inclusion of a companion grass with legumes may provide a more balanced chemical composition for ensiling and livestock feeding (Laidlaw and McBratney, 1980). Legumes dry more slowly than grasses, and grass components have been used in red clover swards to hasten hay drying (Collins and Moore, 1995). Thompson and Stout (1997) suggested that sole-cropped annual clovers may be more difficult to hay or ensile than grasses. The high moisture content of berseem can make it best suited for green-chopped forage or non-bloat pasture (Knight, 1985; Graves *et al.*, 1996). Adding cereals to berseem might aid conservation of berseem as hay or silage. Growing oats with berseem can decrease weed growth, but oats also compete with berseem (Welty *et al.* 1991, Holland and Brummer, 1999). Blaser *et al.* (1956) concluded that if non-aggressive forage species are to develop in mixtures, aggressive species should be used at low seeding rates.

Intercropping berseem with small grain cereals can increase total dry matter yield, improve forage quality, reduce fertilizer needs and increase subsequent crop yield (Singh *et al.*, 1989; Reynolds *et al.*, 1994; Ghaffarzadeh, 1997; Stout *et al.*, 1997; Zada *et al.*, 1998; Holland and Brummer, 1999). Berseem had greater potential to improve forage yield of intercrops than other legume species tested by Reynolds *et al.* (1994), Stout *et al.* (1997), and Sheaffer *et al.* (2001). In a study of oats intercropped with 18 annual legume species, only berseem produced significant fall regrowth after harvest at the soft dough stage of oats (Dovel and Bohle, 1997). Research on berseem-oat intercrops has included assessment of seeding methods (Singh *et al.*, 1989), potential rotation benefits (Ghaffarzadeh, 1997; Sheaffer *et al.*, 2001), and cultivar effects (Holland and Brummer, 1999). Other studies of mixtures involving berseem have looked at yield potential and harvest management (Welty *et al.*, 1991; Caballero *et al.*, 1994; Stout *et al.*, 1997). Little information is available on growth analysis of berseem-cereal intercrops.

Connolly *et al.* (2001) noted that more research is needed to understand the mechanisms and processes of interspecific interaction in intercrops. Sampling oat-berseem intercrops at a series of dates after sowing, with a range of oat densities, would help to understand the mechanisms of competitive interactions in such intercrops. The objectives of this study were to assess the effects of oat plant density and harvest sampling date on berseem-oat intercrop forage yield and quality in a short-season northern climate.

MATERIALS AND METHODS

Intercrops of berseem clover and oats were grown at Edmonton (53° 25' N, 113° 33' W), Alberta, Canada, on an Orthic Black Chernozemic Malmo silty clay loam in 1999 and 2000. Experiments followed tilled fallow, and fields were disked and harrowed prior to seeding. Soil pH was 5.8 to 7.0 and soil nitrate levels were 34 to 50 mg kg^{-1} at 0-30 cm depth (Appendix 1). No fertilizer was added.

'Bigbee' berseem clover was seeded at 15 kg ha^{-1} with 'Waldern' oat, a late-maturing high-yielding silage/feed oat, at rates of 30, 60, 90 and 240 plants m^{-2}. The berseem-oat intercrops with oat densities of 30, 60, 90 and 240 plants m^{-2} are referred to as O_{30}, O_{60}, O_{90} and O_{240}, respectively. Berseem sole crops were also grown. The experimental design was a split-plot arrangement of a randomized complete block with four blocks. In 1999, oat density treatment was the main plot and five cutting dates were the sub-plots, with main plot size of 3 × 7 m. In 2000, six cutting dates were the main plots and oat density was the sub-plot, with sub-plot size of 1 × 6 m. Plots were seeded on May 25 in 1999 and May 19 in 2000. Cereals were seeded at a 23 cm row spacing, using a 4-row double disc press drill. In 1999, berseem was hand-seeded by broadcasting on the surface and incorporation by raking. In 2000, berseem was cross-seeded at approximately 1.5-2 cm depth at 18 cm row spacing using a 6-row disc drill. Berseem was inoculated with the appropriate *Rhizobium* species prior to seeding. Plots were hand weeded following establishment.

Plots were harvested at intervals of approximately 10 days, beginning at 35-36 days after planting and ending at the soft dough stage of oats, in mid-August (Table 5-1). Treatments were sampled by hand cutting a 0.5 m^2 area 5-7.5 cm above soil level, with separation of berseem and oat biomass at cutting. Quadrats sized 0.5 × 1 m had been marked after emergence in all plots in 1999 and in O_{30} and O_{60} plots in 2000, with target cereal plant densities achieved through placement or thinning. Prior to each harvest, light transmittance readings were taken in each oat density treatment in 1999 and in O_{60} and O_{240} treatments in 2000. Light readings were taken at mid-day, at the top of the oat canopy, top of the berseem canopy, and at soil level using a light meter (LI-188B Line Quantum Sensor, LI-COR, Inc. NE). The surface area of leaves and stems were measured using a leaf area meter (LI-3100, LI-COR, Inc. NE) for all oat and berseem sub-samples in 1999, and for oats from O_{60} and O_{240} sub-samples in 2000. After leaf area measurements, samples were dried for 72 hours at 52 °C and then weighed. Dry matter yields and species composition were determined for all treatments. Samples from a subset of treatments were analyzed for crude protein (CP), acid detergent fibre (ADF) and neutral detergent fibre (NDF), using methods described in Chapter 4.

Data were analyzed by year using analysis of variance techniques to determine significant treatment effects ($P \leq 0.05$) using Statistical Analysis System (SAS Inst., 2000). Oat density and sampling date effects were originally separated with orthogonal contrasts, using coefficients derived in the IML procedure of SAS.

RESULTS AND DISCUSSION

Rainfall for the growing season of May to September was near the 30-year average (326 mm) in 2000 (330 mm), but was less than normal in 1999 (259 mm) (Appendix 2). Seasonal five-month mean temperatures for May to September were near the 30-year average of 14.5 °C in 1999 and 2000. Sampling date and oat density main effects were significant for all measured traits, while interactions were significant within berseem DM, protein yield, berseem and oat leaf area index (LAI) in 1999, oat DM in 2000, and oat tiller weight in 2000 (Tables 5-2 and 5-3).

Berseem and Oat Growth Rates

Berseem was relatively slow to establish and berseem yields were negligible at initial sampling dates (Figure 5-1). Yields of berseem sole crops increased up to 6.7 t ha^{-1} DM at 76 DAP in 1999 and to 8.1 t ha^{-1} DM at 88 DAP in 2000. These yields compare favourably with spring growth of berseem in other studies. Brink and Fairbrother (1992) reported a maximum yield of 5.5 t ha^{-1} at 61 days of spring growth from fall-seeded berseem in Mississippi. Fall-seeded berseem in Italy yielded 3-5 t ha^{-1} DM in late May (Martiniello, 1999). Spring-seeded berseem in northern USA averaged yields of 5.8 t ha^{-1} DM (with 2 cuts) by 115 DAP (Westcott *et al.*, 1995) and 4 t ha^{-1} (with 2 cuts) by 90 DAP (Shrestha *et al.*, 1998). Brink and Fairbrother (1992) observed a linear increase in berseem biomass of 7 g DM m^{-2} day^{-1} ($Y = 53 + 7.04 \times$ days of growth beginning in mid-March). In our study, increases in berseem yields in sole crop treatments fit well with linear or quadratic regression equations (Table 5-4). In both years, increases in sole crop berseem yield averaged 15-16 g DM m^{-2} day^{-1} between 35-36 DAP and final sampling date, and averaged 9 g DM m^{-2} day^{-1} over the period from seeding to final sampling date.

Oat biomass yields increased up to 12.4 and 14.7 t ha^{-1} DM with the full-rate of 240 oat plants m^{-2} in O_{240} intercrops (Figure 5-1). Oat biomass yields increased linearly with sampling date. The regression equations for oats in O_{240} indicated average yield increases of about 26-28 g DM m^{-2} day^{-1}after 35-36 DAP (Table 5-4). In assessing seedling growth of forage grasses and legumes, Blaser *et al.* (1956) reported that many spring-seeded grasses had much higher growth rates than did legumes between 36 and 51 DAP in Virginia. We observed similar differences between oat and berseem growth rates. Between 35-36 and 55-56 DAP, oat biomass in O_{240} increased by 26-27 g DM m^{-2} day^{-1}, while berseem biomass in berseem sole crop treatments increased by only 5 g DM m^{-2} day^{-1} in 1999 and 10 g DM m^{-2} day^{-1} in 2000. After that period, berseem and oats had similar growth rates. Between 55-56 and 75-76 DAP, oat biomass in O_{240} continued to increase by 26-27 g DM m^{-2} day^{-1}, while berseem biomass in sole crops increased by 28 g DM m^{-2} day^{-1} in 1999 and 21 g DM m^{-2} day^{-1} in 2000.

Oat biomass yields exhibited quadratic responses to oat density (Tables 5-2 and 5-3). Oat yields for O_{90} did not differ from those of O_{240} in 1999, indicating a plateau in yield response to oat density. Compared to O_{240} treatments, the O_{60} treatment had 25% of the oat plant density, but had 84% and 71% of oat DM yield and 74% and 64% of the oat leaf area in 1999 and 2000, respectively (Figures 5-1 and 5-2). Adequate moisture and soil N supported extensive tillering of oats in O_{30} and O_{60} treatments. In 2000, oats in O_{30} and O_{60} averaged 8 and 5 tillers $plant^{-1}$ respectively, compared to 2 tillers $plant^{-1}$ in O_{240} (Appendix 10). The plasticity of oats was also illustrated by differences in tiller weight among oat treatments. At later sampling dates, there was a linear increase in tiller weight (g $tiller^{-1}$) with decreasing oat density (Table 5-3). There was a DM yield compensation of increased tiller weight at lower oat densities, that was evident at later growth stages. Peltonen-Sainio and Jarvinen (1995) observed that increasing the seeding rate of oats in Finland decreased several yield components of the main shoot. Studies with other cereal species have concluded that crop dry matter production can be maintained at low plant densities by increases in relative growth rate (Whaley *et al.*, 2000). Whaley *et al.* (2000) reported that with low plant densities of winter wheat in England, there were increases in green area per shoot, duration of tiller production and shoot survival.

Leaf Area Index and Light Interception

The responses to sampling date and oat density were the same for berseem leaf area index (LAI) as for berseem DM yield in 1999 (Table 5-2). Berseem LAI was highly correlated with berseem DM ($r = 0.99$, $P < 0.01$). In a study of seedling growth of four annual clovers, Evers (1999) also observed a high correlation of seedling weight with LAI. In our study, berseem remained vegetative over the sampling period, and flowering was negligible. Using berseem DM yield to predict LAI, the regression equation was berseem LAI = 0.14 (s.e. 0.037) + 1.32 (s.e. 0.024) × berseem DM t ha^{-1} ($r^2 = 0.97$, $P < 0.01$).

The correlation between oat LAI and oat DM was $r = 0.79$, $P < 0.01$ in 1999. While oat DM increased linearly with sampling date, oat LAI exhibited quadratic responses (Tables 5-2 and 5-3). The LAI of oats peaked at 65-66 DAP with oats in stages of heading and head development (Figure 5-2, Table 5-1). Oat LAI declined at later sampling dates, as plant nutrients were translocated to support grain development and leaf senescence increased. Oat LAI exhibited quadratic responses to oat density (Tables 5-2 and 5-3). Rates of increase in LAI were similar among oat treatments (Table 5-4). Oat LAI was greater for O_{240} than for O_{60} at all stages except at the final sampling in 1999 (Figure 5-2). Maximum LAI values were 7.3-7.6 for oats in O_{240} and 5.6-5.7 for oats in O_{60}. Under northern growing conditions, the peak LAI of oats varies from 2 to 12, and the optimum LAI to support grain production ranges from 3 to 5 (Peltonen-Sainio, 1999). With oats grown for forage, greater LAI would be desirable.

Oat plants were taller than berseem plants at all sampling dates and the oat plants caused considerable shading of berseem plants (Table 5-5, Figure 5-2). In 2000, the height of the oat canopy exceeded 140 cm at later stages, while the maximum height for the top of berseem in the intercrop canopy was about 65 cm. The light available at the top of berseem as percentage of incident light (light measured at the top of the oat canopy) decreased with increasing oat LAI. The height of berseem plants within intercrops was not uniform, and values for percentage of incident light represented the amount of light available to the taller berseem plants in the canopy. Levels of light available to berseem were lowest at the fourth sampling date, when oat LAI peaked. At fourth sampling in 2000, the oat canopy height was 130-137 cm, and berseem in O_{60} received 23% of incident light at 56 cm, while berseem in O_{240} received 6% of incident light at 44 cm.

Berseem Suppression

Berseem yield in intercrops was severely reduced compared to the yield in sole crops (Figure 5-1). Even at the lowest oat density of 30 oat plants m^{-2} (O_{30}), berseem yields averaged 22% of those in sole crops in 1999 and 56% in 2000. Berseem yields in O_{60} intercrops averaged 14% of those in sole crops in 1999 and 32% in 2000. Over the sampling period, berseem biomass in O_{60} intercrops increased by 2-5 g DM m^{-2} day^{-1}, while oat biomass in O_{60} increased by 20-29 g DM m^{-2} day^{-1} (Table 5-4). There were significant date × oat density interactions for berseem yield in intercrops (Tables 5-2 and 5-3). Berseem yields in intercrops generally increased linearly with sampling date, except for O_{240} where there was minimal or no increase (Figure 5-1, Table 5-4).

Between 56 and 76 DAP in 1999, there was no increase in berseem LAI in O_{240} treatments. At later sampling dates, berseem plants in the O_{240} intercrops were sparse and small. At the final sampling date, berseem yield in O_{240} intercrops was 1% and 6% of that in sole crops in 1999 and 2000, respectively. The effects of oat density on berseem yield were not significant until the second or third sampling date, and then berseem yield exhibited quadratic decreases with increasing oat density. There was a nonlinear response of berseem yield to oat plant density at later sampling dates that was consistent with a rectangular hyperbolic relationship identified in previous experiments (Ross *et al.*, 2003a).

Competition for light may largely account for the reduction of berseem yields in intercrops. Kendall and Stringer (1985) reported that the relative growth rates of clover plants decrease rapidly in response to shading. In response to increased shading, the rates of photosynthesis of individual leaves of forage plants decrease in a curvilinear manner, and growth rates and biomass yield decrease likewise (Buxton and Mertens, 1995). By the time that sole crop berseem exhibited a marked increase in growth rate (after 55-56 DAP), berseem plants in intercrops were heavily shaded by oat plants. At 55-56 DAP, the LAI of oats in O_{60} intercrops was 4-5 and incident light available to berseem was 38% in 1999 and 52% in 2000 (Figure 5-2). Shading of berseem in O_{60} intercrops reached a maximum point at 65-66 DAP with only 23-24% of incident light available at the top of the berseem canopy. Although berseem growth was reduced in intercrops, other forage legumes may not provide any advantage in shade tolerance. Lin *et al.* (1999) observed that yields of berseem and seven other cool-season legumes were significantly reduced when grown under 80% shade during spring-early summer in Missouri, but yields of berseem and alfalfa were not significantly reduced under 50% shade. In previous research, it was concluded that an upright growth habit and long stems gave berseem an advantage over shorter clover species in competing with weeds for light (Ross *et al.*, 2001).

Below-ground competition may have had a role in berseem suppression. The proximity of roots influences the degree of competition between cereals and legumes (Ofori and Stern, 1987). Competition from cereals can reduce the uptake of nitrogen, phosphorus and potassium by legumes. Cereals generally have a competitive advantage over associated legumes in utilizing soil nutrients due to more extensive or faster-growing root systems.

Berseem in intercrops was generally more suppressed by oats in 1999 than in 2000. The berseem component of intercrop yield averaged 4% in 1999 and 18% in 2000. Relative time of emergence of berseem and oats was likely a factor. Rate of emergence and subsequent seedling growth rate influence the species composition among establishing forage plants (Blaser *et al.*, 1956). In 1999, the oats were seeded into moisture and they emerged rapidly, but berseem emergence was slow and uneven due to shallow broadcast seeding and lack of surface moisture. In 2000, deeper seeding and adequate moisture supported rapid berseem emergence. Higher rainfall over the growing season in 2000 may have also contributed to higher berseem components in intercrops in that year.

Forage Quality

The forage quality of berseem was higher than that of oats, with higher crude protein (CP) and lower values for acid detergent fibre (ADF) and neutral detergent fibre (NDF) (Table 5-6).

Between 35 and 88 DAP in 2000, CP of berseem from sole crop treatments declined from 310 to 180 g kg^{-1} (Figure 5-3). Berseem CP values were consistent with ranges of 180-270 g kg^{-1} from Duke (1981) and 180-300 g kg^{-1} from Guessous (1981). Brink and Fairbrother (1992) reported a decline in CP to 140 g kg^{-1} after 70 days of spring growth in fall-established berseem. They observed a quadratic relationship between berseem CP and sampling date of $Y = 279 - 3.2d + 0.02d^2$ (d = days of growth beginning in mid-March). A similar daily decline in CP was observed in our study, with a linear decline in berseem sole crop CP of 2.9 g kg^{-1} day^{-1} between 35 and 88 DAP (Table 5-7). Over the same time period, the ADF of berseem had a linear increase of 5.1 g kg^{-1} day^{-1}, and NDF had a quadratic response to sampling date with regression equation $Y = 171 + 12.8d - 0.15d^2$. Brink and Fairbrother (1992) reported a linear decline in digestible dry matter concentration of berseem that was inversely related to total DM accumulation. Declines in berseem digestibility have been linked to factors such as stem properties (Brink and Fairbrother, 1992) and acceleration of maturation with elevated temperatures (Guessous, 1981). Brink and Fairbrother (1992) concluded that stem accumulation has the greatest potential negative impact on forage quality of berseem, with stem digestibility declining at a greater rate than that of leaves and petioles.

There was a quadratic response of oat CP to sampling date, declining from 350 to 110 g kg^{-1} between 35 and 88 DAP in 2000, with an average decline of 4.5 g kg^{-1} day^{-1} (Figure 5-3, Table 5-7). The decline in oat CP between boot and soft dough (approximately 3 g kg^{-1} day) was comparable to 3.2 g kg^{-1} day^{-1} reported by Khorasani *et al.* (1997). The CP of oats was approximately 280 g kg^{-1} at stem elongation, 145 g kg^{-1} at heading, and 110 g kg^{-1} at soft dough. McElroy and Gervais (1983) reported lower oat CP levels of 123-127 g kg^{-1} at jointing, 92-93 g kg^{-1} at heading, and 67-75 g kg^{-1} at dough, in a Quebec study. The quality of oats at soft dough was higher than that reported by Juskiw *et al.* (2000), but was similar to values in other studies (McCartney and Vaage, 1994; Baron *et al.*, 1992). Increases in oat ADF and NDF exhibited quadratic responses to sampling date (Figure 5-3, Table 5-7). Similar to the finding of Khorasani *et al.* (1997), the ADF and NDF concentrations in oats increased in early stages, leveled off during heading and then declined at soft dough. Khorasani *et al.* (1997) suggested that the increase in fibrous content of leaves and stems at later stages of maturity is offset by increases in starch content as heads fill.

In 2000, the CP concentrations for O_{60} mixtures were 280 g kg^{-1} at oat stem elongation, 160 g kg^{-1} at oat heading, and 120 g kg^{-1} at soft dough (Figure 5-3). These CP levels equalled or exceeded those reported by Brink and Marten (1986) for oat-alfalfa mixtures: 185-240 g kg^{-1} at five-leaf stage, 125-160 g kg^{-1} at flag leaf stage and 100-110 g kg^{-1} at dough stage of oats. Stout *et al.* (1997) found that the addition of berseem to a barley-ryegrass mixture substantially increased the CP of an initial forage harvest in British Columbia. In our study, the CP of O_{60} mixtures did not differ from that of O_{60} oats (Table 5-6). The relatively small impact of berseem on intercrop quality was likely due to a combination of small percentage of berseem in the mixture, and high CP levels for oats. Berseem had higher quality than oats, but the berseem component averaged only 19% of O_{60} intercrops. The high CP for oats was likely related to high initial soil N levels at Edmonton. Carr *et al.* (1998) found that adding peas to oats or barley did not increase forage CP in high-soil-N environments but it did increase CP in low-soil-N environments. The ADF of O_{60} mixtures in intercrops did not differ from O_{60} oats, but mixtures did have lower NDF levels. The addition of berseem to oats reduced NDF by an average of 30 g kg^{-1}, indicating improved potential for forage intake. Baron *et al.* (1992) cited Van Soest (1965) in stating that NDF levels $\geq$ 550 g kg^{-1} could severely reduce voluntary intake. Baron suggested that intercropping a winter cereal with oats may reduce the oat NDF to improve intake. In our study, the NDF of oat exceeded 550 g kg^{-1} at the last three sampling dates in 2000. The significant reduction of NDF by berseem components in intercrops may have a substantial effect on the quality of oat forage cut after oat heading.

The mean CP of O_{60} berseem was lower than that of berseem in sole crops ($P < 0.05$), with average differences in CP of 25 g kg^{-1} (Table 5-6, Figure 5-3). Reports vary on the effects of shading on the CP of forage plants. Lin *et al.* (2001) concluded that CP concentrations increased in most of 15 forage species grown in 50% or 80% shade. However, Buxton and Mertens (1995) stated that the CP response of legumes to shading is generally less than that of grasses, and shading typically has less effect on forage quality than on morphology. Shading of berseem may have reduced the leaf-to-stem ratio, compared to berseem in sole crops. Shading can induce elongation of stems, petioles and leaves (Buxton and Mertens, 1995). It was observed that the berseem plants in intercrops had greater proportion of stem, compared to berseem in sole crops. An increase in stem proportion could decrease berseem CP concentration. Iannucci *et al.* (1996) reported average CP concentrations for berseem plant fractions of 270 g kg^{-1} for leaves, 125 g kg^{-1} for stems and 135 g kg^{-1} for roots. Changes in the leaf-to-stem ratio of berseem would also likely affect ADF and NDF, as stems have higher concentrations of cell wall constituents and lower digestibility than leaves (Brink and Fairbrother, 1992; Buxton and Mertens, 1995). The ADF and NDF values for intercropped O_{60} berseem averaged 35 g kg^{-1} higher than for berseem in sole crops, but differences were not significant at $P < 0.05$. Competition for soil N may have been a factor in lowering CP levels for berseem in intercrops. Uptake of soil N by the oat plants may have reduced the availability of soil N to berseem in intercrops. Interaction between shoot and root factors was likely. Shading affects production of photosynthate, but can also affect root growth, uptake of N from the soil and N metabolism (Trenbath, 1976). Shading by cereals can reduce the N_2 fixation potential of legumes and result in competition between cereals and legumes for available soil N (Ofori and Stern, 1987).

Biomass and Protein Yields

Total DM yields of intercrops increased with sampling date (Table 5-8). At final sampling date, total yields did not differ among O_{60}, O_{90}, and O_{240} intercrops, with means of 13.1 t ha^{-1} DM in 1999 and 14.0 t ha^{-1} DM in 2000. Total yields did not differ between O_{60} and O_{240} from 56 to 76 DAP in 1999 and at 66 and 88 DAP in 2000. Berseem sole crop biomass yields were 53-59% of mean intercrop yields at 76-88 DAP. Similarly, Martiniello (1999) reported that berseem sole crops yielded 61% of berseem-barley mixtures under irrigation, and 45% of mixtures without irrigation in Italy.

The mean protein yield of intercrop treatments increased to 1.5 t ha^{-1} by 65 DAP in 1999, and to 1.6 t ha^{-1} by 88 DAP in 2000 (Table 5-9). At final sampling, protein yields did not differ among O_{60}, O_{90}, and O_{240} treatments in 1999 and did not differ for oat density in 2000. Protein yields did not differ between O_{60} and O_{240} at the last three sampling dates. Jedel and Salmon (1995) noted that protein content of cereals peaked in early summer in Alberta and then declined. This decline was more pronounced for spring cereal monocrops than for intercrops of spring cereals with winter cereals. Berkenkamp and Meeres (1987) found that intercropping pulse crops with oats in Alberta had greater impact on forage protein yield than on biomass yield. Although O_{30} had the lowest DM yields of all intercrops in our study, a greater berseem component and the high CP concentration of berseem enhanced protein yields in this treatment. The protein yields of berseem sole crops were generally lower than those of intercrops.

The impact of harvesting berseem-oat intercrops prior to the soft dough stage of oats was greater for biomass yield than for protein yield. When oats were at heading stage, approximately 20 days before soft dough, intercrop biomass was 54-66% of yield at soft dough, but protein yield was 82-86% of yield at soft dough (Tables 5-7 and 5-8). At approximately 10 days before soft dough, intercrop biomass was 74-80% of soft dough yield, but protein yield was 81-97% of that at soft dough.

CONCLUSION

Under the growing conditions of central Alberta, oat was the dominant species in spring-seeded berseem-oat intercrops. The berseem component of intercrop yield averaged 4% in 1999 and 18% in 2000. A higher initial growth rate, rapid canopy development and greater height gave oats advantages over berseem in competing for light. Between 35 and 56 DAP, oat DM in O_{240} intercrops increased by 26-27 g m^{-2} day^{-1}, while berseem DM in sole crops increased by only 5-10 g m^{-2} day^{-1}. At the time when berseem in sole crops exhibited a marked increase in growth rate (after 55-56 DAP), berseem plants in intercrops were heavily shaded by oats. Shading of berseem peaked when oats were heading or at subsequent stages of head development. With oats at the full seeding rate of 240 plants m^{-2}, the growth rate of berseem was practically negligible. With oats at 25% of full-rate in O_{60}, there was still substantial suppression of berseem within intercrops. Berseem in O_{60} received only 24% of incident light when shading peaked, and yielded only 14-32% of berseem sole crop yield. The mean CP of berseem grown in O_{60} intercrops was lower than that of berseem in sole crops, indicating effects of oat competition on berseem quality. If oats are to be used as a companion crop for berseem, the oat seeding rate should be reduced to less than 20% of full-rate. Less competitive cereals, such as triticale or semi-dwarf barley, may be more suitable as companion crops for berseem (Ross *et al.*, 2003b; Chapter 4).

The addition of berseem to oats may not increase silage yield, but a berseem component may improve forage quality. Crude protein declined more rapidly in oats than in berseem. Between 66 and 88 DAP, the NDF of oats was at levels that could greatly reduce the voluntary intake of oat forage. The addition of berseem to oats in O_{60} reduced NDF by an average of 30 g kg^{-1}. Significant improvement of oat forage quality due to berseem components may provide for increased intake and digestibility of forage, supporting higher animal productivity.

Over the series of sampling dates, changes in yield and quality followed expected patterns of declining forage quality as biomass increased. It was interesting to note that harvest of intercrops at 10-20 days before oat soft dough resulted in substantial reduction of biomass yield but the reduction in protein yield was not always significant. The next chapter continues assessment of the oat-berseem intercrop treatments presented in this chapter. The effects of cutting date are followed further into the growing season to assess regrowth and total seasonal yield. The effects of cutting oat-berseem intercrops prior to the soft dough stage of oats are explored further.

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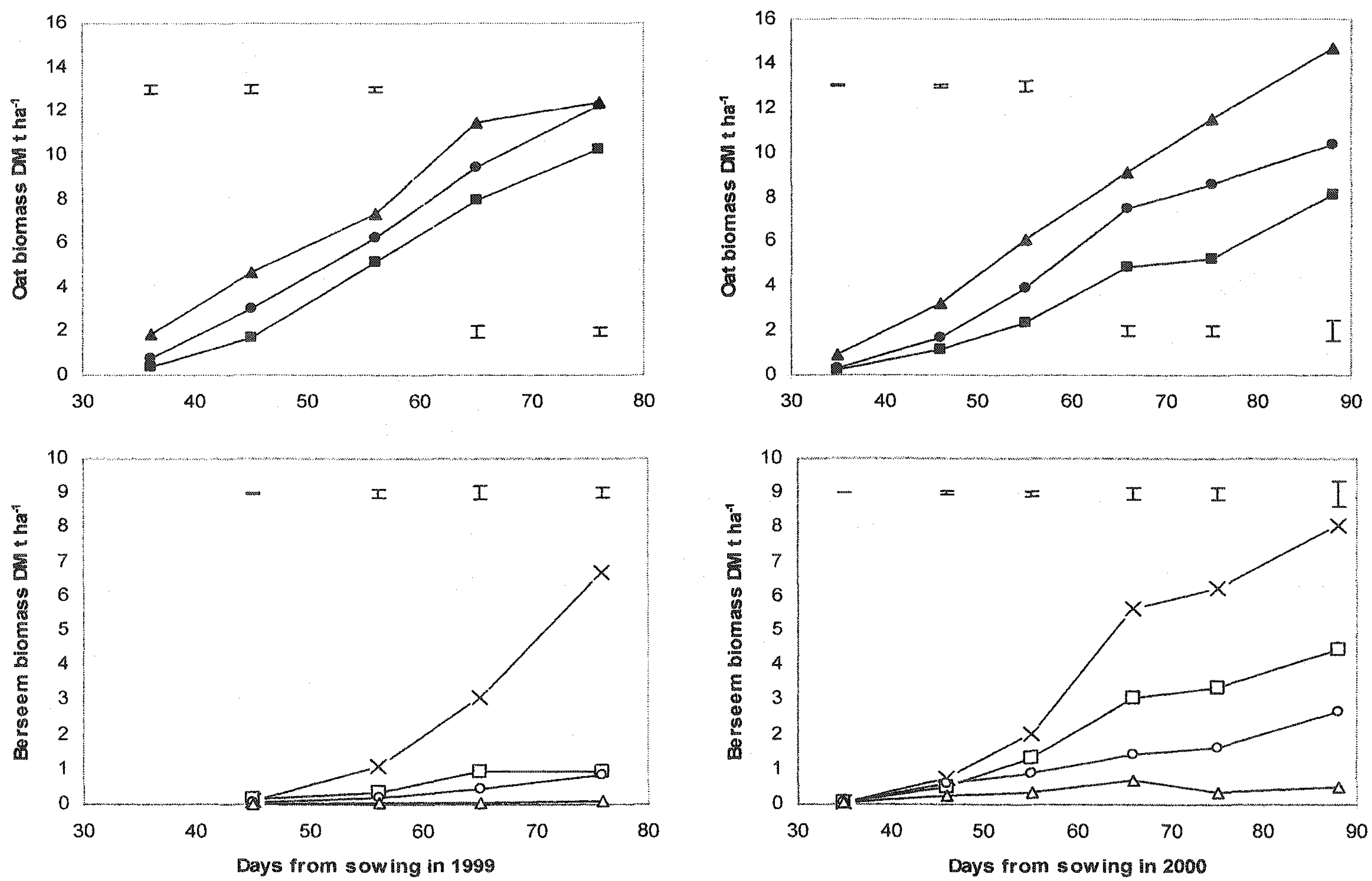

Figure 5-1: Dry matter (DM) yields of oats at 240 (▲), 60 (●) and 30 (■) plants m^{-2} and berseem clover grown with oats at 240 (△), 60 (○), 30 (□) or 0 (×) plants m^{-2} in oat-berseem intercrops in 1999 and 2000. Bars indicate standard error of difference of 2 least-square means.

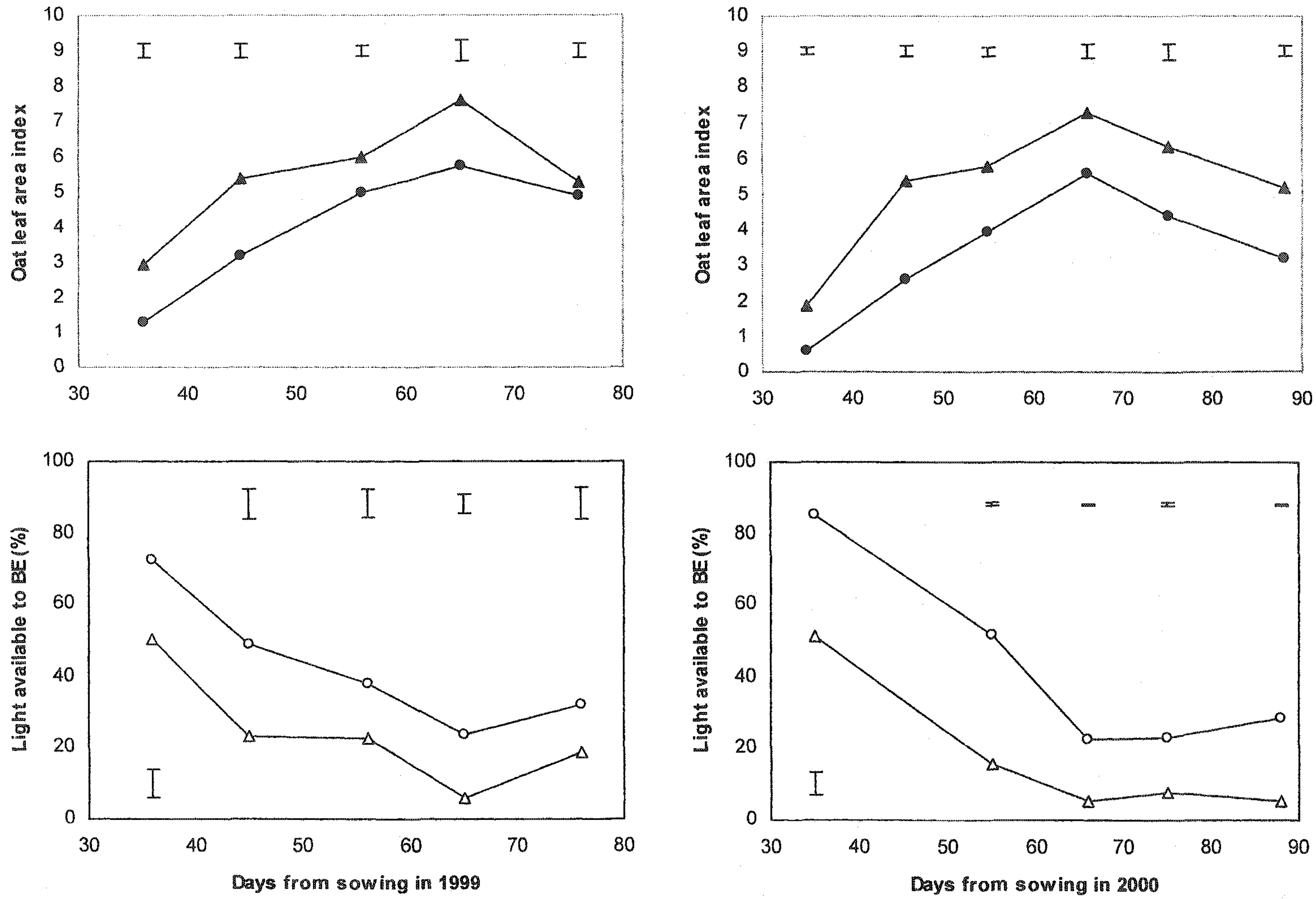

Figure 5-2: Leaf area index of oats at 240 (▲) and 60 (●) plants m^{-2} and light available to berseem (BE) with oats at 240 (△) and 60 (○) plants m^{-2} in oat-berseem intercrops in 1999 and 2000. Bars indicate standard error of difference of 2 least-square means.

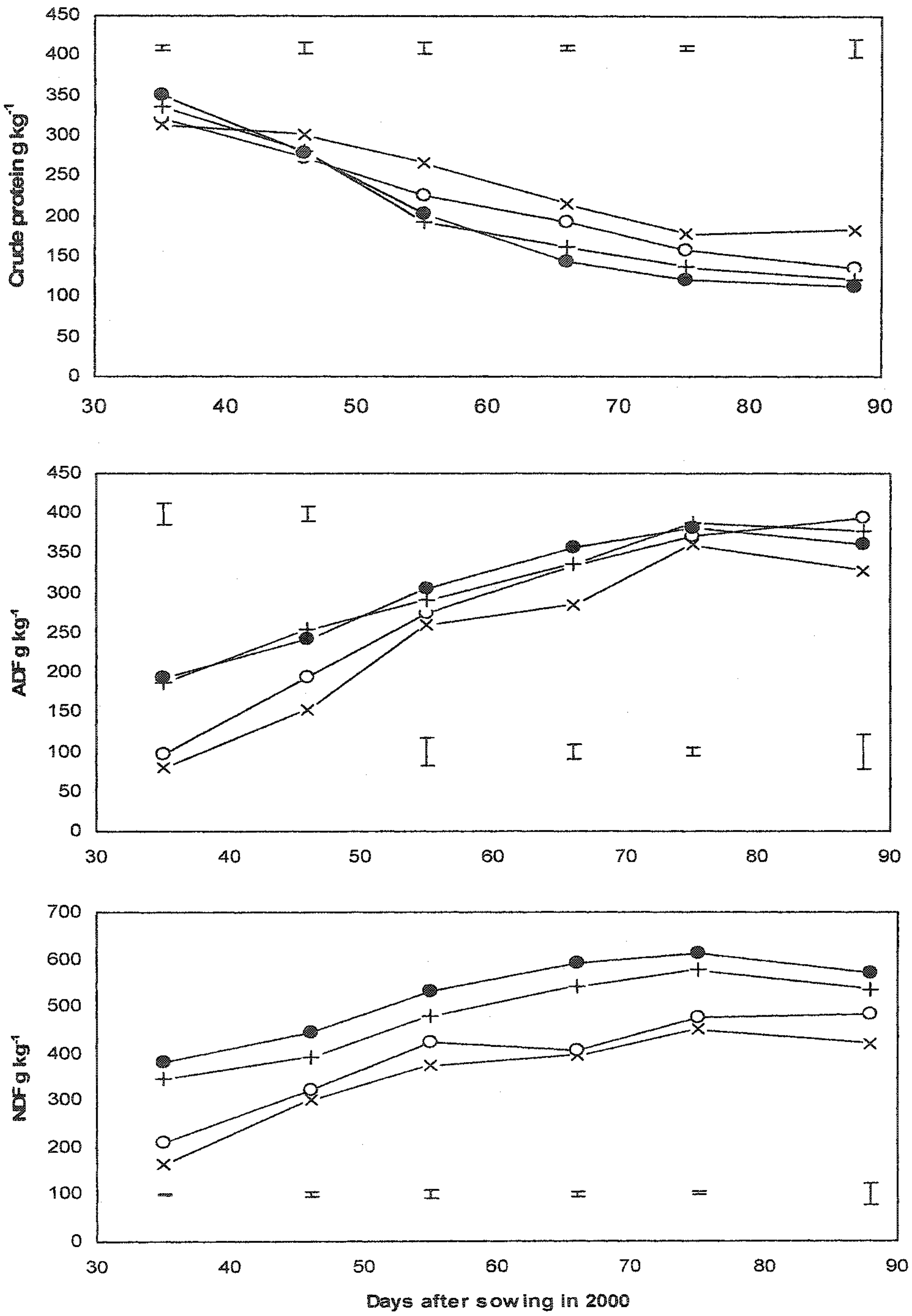

Figure 5-3: Crude protein, acid-detergent fibre (ADF) and neutral-detergent fibre (NDF) for berseem (○), oat (●) and oat-berseem mixtures (+) from oat-berseem intercrops with oats at 60 plants m^{-2}, and for sole crop berseem (x) in 2000. Bars indicate standard error of difference of 2 least-square means.

Table 5-1: Sampling dates, number of days from sowing, and oat stage of development for oat-berseem clover intercrops in 1999 and 2000.

	1999			2000		
Sampling	date	days†	Oat stage	date	days†	Oat stage
1	30-Jun	36	tillering	23-Jun	35	tillering
2	9-Jul	45	elongation to boot	4-Jul	46	elongation
3	20-Jul	56	heading	13-Jul	55	mostly boot
4	29-Jul	65	heads developing	24-Jul	66	heading
5	9-Aug	76	milk to soft dough	2-Aug	75	heads developing
6	-	-	-	15-Aug	88	milk to soft dough

†Days from sowing, with sowing dates of May 25, 1999 and May 19, 2000.

Table 5-2: Sources of variation for oat and berseem biomass dry matter (DM) yield (t ha^{-1}), leaf area index (LAI), light interception at the top of berseem (BER), and protein yield (t ha^{-1}) for berseem-oat intercrops† in 1999.

	Oat		Light available	Berseem		Protein
Source	DM yield	LAI	top BER	DM yield	LAI	yield
Sampling date (Date)	**	**	**	**	**	**
Oat density (OD)	**	**	**	**	**	**
Date x OD	ns	*	ns	**	**	*
CONTRASTS						
Date linear	**	**	**	**	**	**
Date quadratic	ns	**	**	ns	*	**
Date deviation	*	**	ns	ns	ns	ns
OD linear	**	**	**	**	**	**
OD quadratic	**	**	ns	**	**	**
OD deviation	ns	ns	ns	ns	ns	ns

* $P < 0.05$; ** $P < 0.01$; ns, not significant.

†Analysis does not include berseem sole crop treatments.

Table 5-3: Sources of variation for oat biomass dry matter (DM) yield (t ha^{-1}), leaf area index (LAI), and tillers; and light interception at the top of berseem (BER), berseem DM yield and protein yield (t ha^{-1}) for berseem-oat intercrops† in 2000.

	Oat				Light	Berseem	
	Biomass	LAI	Tiller No.	Tiller DM	available	biomass	Protein
Source	DM		no. m^2	g tiller^{-1}	top BER	DM	yield
Sampling date (Date)	**	**	**	**	**	**	**
Oat density (OD)	**	**	**	*	**	**	**
Date x OD	**	ns	ns	**	ns	**	**
CONTRASTS							
Date linear	**	**	ns	**	**	**	**
Date quadratic	ns	**	**	**	**	ns	**
Date deviation	ns	ns	ns	*	ns	ns	**
OD linear	**	-‡	**	**	-‡	**	**
OD quadratic	**	-	**	ns	-	**	ns
OD deviation	*	-	ns	ns	-	**	ns

* $P < 0.05$; ** $P < 0.01$; ns, not significant.

†Analysis does not include berseem sole crop treatments.

‡ Oat LAI and light available to BER were measured for only two oat density treatments in 2000.

Table 5-4: Regression equations, with standard error of parameters in parentheses, relating dry matter yield, leaf area index and light available at top of berseem to days after planting (d), beginning at 35 days, for berseem and oats in intercrops at five oat densities (OD) in 1999 and 2000.

Year	OD	Berseem - regression equations	R^2		Oat - regression equations	R^2	
Dry matter (g m^{-2})							
1999	0	$Y = -103(45) + 16.4(1.9)\ d$	0.81	**	-		
	0	$Y = 4(32) - 5.4(3.8)\ d + 0.55(0.09)\ d^2$	0.94	**	-		
	30	$Y = -4(12) + 2.7(0.5)\ d$	0.64	**	$Y = -1(43) + 26.0(1.8)\ d$	0.92	**
	60	$Y = -9(5) + 2.1(0.2)\ d$	0.83	**	$Y = 63(34) + 29.2(1.4)\ d$	0.96	**
	90	$Y = -1(5) + 1.1(0.2)\ d$	0.57	**	$Y = 171(56) + 28.3(2.3)\ d$	0.89	**
	240	$Y = 0(2) + 0.2(0.1)\ d$	0.38	**	$Y = 211(45) + 27.8(1.9)\ d$	0.92	**
2000	0	$Y = -48(44) + 16.5(1.4)\ d$	0.86	**	-		
	0	$Y = -41(57) + 15.6(4.9)\ d + 0.02(0.09)\ d^2$	0.86	**	-		
	30	$Y = -17(19) + 8.9(0.6)\ d$	0.90	**	$Y = -21(29) + 15.0(0.9)\ d$	0.92	**
	60	$Y = 1(20) + 4.7(0.7)\ d$	0.70	**	$Y = 13(29) + 20.4(0.9)\ d$	0.96	**
	90	$Y = 7(15) + 3.3(0.5)\ d$	0.68	**	$Y = 23(36) + 22.4(1.2)\ d$	0.95	**
	240	$Y = 15(9) + 0.8(0.3)\ d$	0.24	*	$Y = 74(26) + 26.6(0.8)\ d$	0.98	**
Leaf area index							
1999	0	$Y = -2.5(0.7) + 0.26(0.03)\ d$	0.87	**	-		
	30	$Y = 0.1(0.3) + 0.03(0.01)\ d$	0.42	**	$Y = 0.5(0.3) + 0.25(0.04)\ d - 0.004(0.001)\ d^2$	0.84	**
	60	$Y = -0.2(0.1) + 0.03(0.004)\ d$	0.79	**	$Y = 1.2(0.3) + 0.29(0.03)\ d - 0.005(0.001)\ d^2$	0.91	**
	90	$Y = 0.03(0.18) + 0.02(0.006)\ d$	0.32	*	$Y = 2.5(0.4) + 0.25(0.05)\ d - 0.004(0.001)\ d^2$	0.69	**
	240	$Y = 0.03(0.05) + 0.003(0.002)\ d$	0.22	ns	$Y = 2.9(0.5) + 0.32(0.06)\ d - 0.006(0.001)\ d^2$	0.68	**
2000	60	-			$Y = 0.4(0.3) + 0.27(0.02)\ d + 0.004(0.0004)\ d^2$	0.89	**
	240	-			$Y = 2.1(0.4) + 0.30(0.03)\ d - 0.004(0.0005)\ d^2$	0.83	**
Light available at top of berseem (% of incident light)							
1999	30	$Y = 77(6) - 3.3(0.7)\ d + 0.06(0.02)\ d^2$	0.69	**			
	60	$Y = 72(5) - 2.8(0.6)\ d + 0.04(0.01)\ d^2$	0.76	**			
	90	$Y = 62(6) - 2.5(0.7)\ d + 0.04(0.02)\ d^2$	0.68	**			
	240	$Y = 49(6) - 2.6(0.7)\ d + 0.05(0.02)\ d^2$	0.58	**			
2000	60	$Y = 87(7) - 2.9(0.6)\ d + 0.03(0.01)\ d^2$	0.76	**			
	240	$Y = 51(3) - 2.2(0.3)\ d + 0.03(0.01)\ d^2$	0.88	**			

** $P < 0.01$; ns, not significant

Table 5-5: Height of oats and berseem in oat-berseem intercrops at oat densities of 60 plants m^{-2} (O60) and 240 plants m^{-2} (O240) for sampling dates in 2000.

Sampling	Oat		Berseem	
date†	O60	O240	O60	O240
		cm		
1	27	33	12	14
2	-	-	-	-
3	93	109	67	48
4	130	137	56	44
5	143	142	51	37
6	141	137	60	29
s.e.d‡	3.1	2.5	4.0	5.8

† Sampling dates were 35, 46, 55, 66, 75 and 88 days after planting.
‡ Standard error of the difference of 2 least-square means.

Table 5-6: Sources of variation and means (g kg^{-1}) across sampling dates for crude protein (CP), acid detergent fibre (ADF), and neutral detergent fibre (NDF) presented in Figure 5-3 for berseem sole crops and oat-berseem intercrops at 60 oat plants m^{-2} (O60) in 2000.

	CP	ADF	NDF
SOURCE			
Sampling date (Date)	**	**	**
Component (C)	**	**	**
Date x C	ns	ns	ns
CONTRASTS			
Date linear	**	**	**
Date quadratic	**	**	**
Date deviation	ns	ns	ns
Component		g kg^{-1}	
Sole crop berseem	245^a	245^b	350^c
O60 berseem (BE)	220^b	280^b	385^c
O60 oat	200^c	305^a	520^a
O60 mixture (BE+oat)	195^c	315^a	490^b
s.e.d.†	7	12	10

** $P < 0.01$; ns, not significant.

Means within columns with similar superscripts are not significantly different based on LSD ($P < 0.05$).

† Standard error of the difference of 2 least-square means.

Table 5-7: Regression equations, with standard error of parameters in parentheses, relating crude protein (CP), acid-detergent fibre (ADF), and neutral-detergent fibre (NDF) to days after planting (d), beginning at 35 days, for berseem sole crops and oat-berseem intercrops at 60 oat plants m^{-2} (O60) in 2000 as presented in Figure 5-3.

Sample	Regression equation	R^2	
CP (g kg^{-1})			
Berseem sole crop	Y = 319(11) - 2.9(0.3) d	0.88	**
O60 berseem (BE)	Y = 310(8) - 3.6(0.3) d	0.95	**
O60 oat	Y = 359(9) - 9.5(0.8) d + 0.90(0.01) d^2	0.98	**
O60 mixture (BE+oat)	Y = 348(15) - 8.6(1.2) d + 0.08(0.02) d^2	0.96	**
ADF (g kg^{-1})			
Berseem sole crop	Y = 113(26) + 5.1(0.8) d	0.80	**
O60 berseem (BE)	Y = 130(19) + 5.7(0.6) d	0.90	**
O60 oat	Y = 183(11) + 8.1(1.0) d - 0.09(0.02) d^2	0.95	**
O60 mixture (BE+oat)	Y = 182(11) + 7.2(0.9) d - 0.06(0.02) d^2	0.97	**
NDF (g kg^{-1})			
Berseem sole crop	Y = 171(19) + 12.8(1.7) d - 0.15(0.03) d^2	0.93	**
O60 berseem (BE)	Y = 216(21) + 10.8(1.8) d - 0.11(0.03) d^2	0.92	**
O60 oat	Y = 365(14) + 11.1(1.2) d - 0.13(0.02) d^2	0.95	**
O60 mixture (BE+oat)	Y = 313(24) + 11.0(1.9) d - 0.13(0.03) d^2	0.90	**

** $P < 0.01$

Table 5-8: Total dry matter yields (t ha^{-1}) for oat-berseem intercrops for progressive sampling dates in 1999 and 2000.

Sampling date†	Oat density (oat plants m^{-2}) of intercrops 0	30	60	90	240	s.e.d.
			1999			
1	-	0.4	0.8	1.9	1.9	0.46
2	0.1	1.8	3.1	4.0	4.7	0.56
3	1.1	5.5	6.4	8.0	7.4	0.93
4	3.1	8.9	9.9	9.8	11.5	0.90
5	6.7	11.2	13.1	13.6	12.5	0.66
s.e.d.‡	0.38	0.67	0.69	0.76	0.70	-
			2000			
1	0.1	0.3	0.4	0.5	1.0	0.05
2	0.7	1.6	2.3	2.6	3.5	0.19
3	2.0	3.7	4.8	5.3	6.4	0.36
4	5.6	8.0	9.0	9.2	9.8	0.49
5	6.2	8.7	10.2	9.9	11.9	0.60
6	8.1	12.6	13.0	13.8	15.2	1.06
s.e.d.	0.81	0.61	0.50	0.53	0.59	-

† Sampling dates were 36, 45, 56, 65 and 76 days after planting in 1999, and 35, 46, 55, 66, 75 and 88 days after planting in 2000.
‡ Standard error of the difference of 2 least-square means.

Table 5-9: Total protein yields (t ha^{-1}) for oat-berseem intercrops for progressive sampling dates in 1999 and 2000.

Sampling date†	Oat density (oat plants m^{-2}) of intercrops 0	30	60	90	240	s.e.d.
			1999			
1	-	0.12	0.26	0.59	0.61	0.17
2	0.03	0.52	0.88	1.13	1.31	0.16
3	0.35	1.04	1.18	1.45	1.33	0.19
4	0.74	1.38	1.46	1.44	1.66	0.16
5	1.26	1.39	1.61	1.64	1.49	0.09
s.e.d.‡	0.10	0.12	0.12	0.14	0.14	-
			2000			
1	0.02	0.11	0.13	0.19	0.35	0.02
2	0.22	0.45	0.63	0.72	0.98	0.06
3	0.54	0.82	1.00	1.08	1.31	0.07
4	1.22	1.33	1.36	1.40	1.45	0.09
5	1.11	1.21	1.30	1.27	1.45	0.08
6	1.48	1.62	1.52	1.59	1.72	0.16
s.e.d.	0.15	0.08	0.08	0.08	0.09	-

† Sampling dates were 36, 45, 56, 65 and 76 days after planting in 1999, and 35, 46, 55, 66, 75 and 88 days after planting in 2000.
‡ Standard error of the difference of 2 least-square means.

Chapter 6 Oat-berseem clover intercrops. II. Effects of cutting date and oat plant density on seasonal forage yield

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Chapter 6

Oat-berseem clover intercrops. II. Effects of cutting date and oat plant density on seasonal forage yield

INTRODUCTION

The sustainability of cereal cropping systems in western Canada may be improved by greater use of annual legumes as intercrops with cereals (Izaurralde *et al.,* 1993). Interest in cereal-legume intercropping has increased in temperate regions in recent years, but benefits attributed to intercropping vary among studies (Connolly *et al.,* 2001; Anil *et al.*, 1998). Legume-cereal intercropping may increase yields (Izaurralde *et al.,* 1993), may increase protein yield but not increase biomass (Berkenkamp and Meeres, 1987a) or may improve forage quality but not increase total N yield (Carr *et al.,* 1998). Yield advantages of cereal-legume intercrops may occur under N-deficient conditions, but not under high soil N conditions (Moreira, 1989). Interactions between component crops will depend on their morphology, physiology, density and spatial arrangement, as affected by climate, edaphic and biotic environment, and management (Anil *et al.,* 1998).

Berseem clover, an annual clover, is a high yielding nutritious forage extensively cultivated in subtropical regions (Duke, 1981). It is adapted for growth as a winter crop, but can also be grown as a summer annual in regions with moist, cool summers (Knight, 1985). Intercropping berseem with cereals can increase forage yield and quality compared to cereal monocrops (Singh *et al.,* 1989; Zada *et al.,* 1998), increase total dry matter yields without reducing cereal grain yields (Reynolds et al., 1994; Ghaffarzadeh, 1997; Holland and Brummer, 1999) and improve forage quality, reduce fertilizer needs and increase subsequent crop yields (Stout *et al.,* 1997; Ghaffarzadeh, 1997). Berseem had greater potential to improve the forage yields of intercrops than did other legume species tested by Reynolds *et al.* (1994), Stout *et al.* (1997), and Sheaffer *et al.* (2001). In a study of oats intercropped with 18 annual legume species, only berseem produced significant fall regrowth after harvest at the soft dough stage of oats (Dovel and Bohle, 1997). Berseem may have potential as a new forage for western Canada (Stout *et al.,* 1997; Ross *et al.,* 2001).

Oats are commonly used as companion crops for forage legumes, and the addition of oats can increase dry matter yield (Lanini *et al.,* 1991; Wiersma *et al.,* 1999). Oats can provide legumes with physical support for climbing, improve light interception and facilitate mechanical harvesting (Caballero *et al.,* 1995). However, oats may also compete with legumes. Berseem yields were reduced about 50% when grown with oats (Welty *et al.,* 1991; Holland and Brummer, 1999).

In Alberta, the harvest of forage oats usually involves 1-cut at soft dough stage, with no expectation of regrowth. Berkenkamp and Meeres (1987b) found that the forage yield of oats was greater with 1-cut at silage-stage than with 2 or 3-cuts to simulate a hay system or with repeated cuts to simulate grazing in Alberta. A late single-cut of spring cereals produced greater forage yield than double-cut harvest (McElroy and Gervais, 1983; Royo, 1999). Harvest management of berseem-oat intercrops usually involves 2 or more cuts (Singh *et al.,* 1989; Welty *et al.,* 1991; Zada *et al.,* 1998). Welty *et al.* (1991) recommended that a 2-cut harvest was preferable to 3 or 4-cuts for spring-seeded berseem-oat intercrops in northern USA. Little information is available about the optimal timing of the initial harvest of berseem-cereal intercrops. The forage yield of the oat component would be expected to increase with successive growth stages of jointing, boot, heading, milk and dough stages (McElroy and Gervais, 1983). Similarly, the forage yield of oat-pea intercrops increased up to oat milk stage in Alaska (Brundage *et al.,* 1979). Harvest management of berseem-oat intercrops needs to take into account the impact on initial yield and quality, but also the impact on berseem regrowth and total seasonal yield. In Pakistan, seasonal yield of oat-berseem intercrops increased with successive initial harvest at 30, 60 or 90 days after planting (Zada *et al.,* 1998). In the short-season environment of central Alberta, earlier timing of initial harvest of berseem-oat intercrops may be advantageous.

Harvest management of oat-berseem intercrops warrants further research. Timing of the initial harvest may affect seasonal yield, and the effects may vary with different seeding rates of oats. The objectives of this study were to assess the effects of cutting date and oat plant density on performance of berseem-oat intercrops in a short-season northern climate.

MATERIALS AND METHODS

Intercrops of berseem clover and oats were grown at Edmonton (53° 25' N, 113° 33' W), Alberta, Canada, on an Orthic Black Chernozemic Malmo silty clay loam in 1999 and 2000. Experiments followed tilled fallow, and fields were disked and harrowed prior to seeding. Soil pH was 5.8 to 7.0 and soil nitrate levels were 34 to 50 mg kg^{-1} at 0-30 cm depth (Appendix 1). No fertilizer was added.

'Bigbee' berseem clover was seeded at 15 kg ha^{-1} with 'Waldern' oat, a late-maturing high-yielding silage/feed oat, at rates of 30, 60, 90 and 240 plants m^{-2}. The berseem-oat intercrops with oat densities of 30, 60, 90 and 240 plants m^{-2} are referred to as O_{30}, O_{60}, O_{90} and O_{240}, respectively. Berseem sole crops were also grown. Five or six cutting date treatments were applied, and dates of harvests are listed in Table 6-1. The experimental design was a split-plot arrangement of a randomized complete block, with four blocks. In 1999, oat density was the main plot and five cutting treatments (A, B, C, D, E) were the sub-plots, with main plot size of 3 × 7 m. In 2000, six cutting treatments (A, B, C, D, E, F) were the main plots and oat density was the sub-plot, with sub-plot size of 1 × 6 m. Plots were seeded on May 25 in 1999 and May 19 in 2000. Cereals were seeded at a 23 cm row spacing, using a 4-row double disc press drill. In 1999, berseem was hand-seeded by broadcasting on the surface and incorporation by raking. In 2000, berseem was cross-seeded at approximately 1.5-2 cm depth in 18 cm row spacings using a 6-row disc drill. Berseem was inoculated with the appropriate *Rhizobium* species prior to seeding. Plots were hand weeded following establishment.

Cut 1 harvests were made at intervals of approximately 10 days, beginning at 35-36 days after planting and ending at the soft dough stage of oats in mid-August. Treatments were sub-sampled by hand cutting a 0.5 m^2 area at 5-7.5 cm above soil level, with separation of berseem and oat biomass. Quadrats sized 0.5 × 1 m had been marked after emergence in all plots in 1999 and in O_{30} and O_{60} plots in 2000, with target cereal plant densities achieved through placement or thinning. All quadrats were marked after sub-sampling, and surrounding areas were cut and hand raked to remove growth. Harvest procedures were repeated with one or two harvests of regrowth. In 2000, oat tillers were counted in each sub-sample at Cut 1 and 2. Samples were dried for 72 hours at 52 °C and then weighed. A subset of oat and berseem samples were analyzed for crude protein, and results were used to calculate protein yields.

Data were analyzed by year using analysis of variance techniques to determine significant treatment effects ($P \leq 0.05$) using Statistical Analysis System (SAS Inst., 2000). Oat density and cutting treatment effects were originally separated with orthogonal contrasts, using coefficients derived in the IML procedure of SAS. Oat density contrasts beyond quadratic were pooled as deviations.

RESULTS AND DISCUSSION

The timing of oat stages of maturity was fairly similar between years, when compared by calendar date (Table 6-1). Duration of phenophases in oats is influenced by genotype and environment, with temperature and day length being the major environmental influences (Peltonen-Sainio, 1999). Seasonal five-month mean temperatures for May to September were near the 30-year average of 14.5 °C in 1999 and 2000. Oats in treatments with 240 oat plants m^{-2} (O_{240}) tended to mature slightly faster than the oats in treatments with 30 oat plants m^{-2} (O_{30}) and 60 oat plants m^{-2} (O_{60}). Plant population affects the rate of apical development in cereal crops (Smith *et al.,* 1999).

Cut 1 Yields

Cut 1 biomass dry matter (DM) yields averaged 6.8 t ha^{-1} in both years and exhibited linear increases with successive cutting date (Table 6-2). Between oat heading and soft dough stages, Cut 1 yields increased by 85% in 1999 and 52% in 2000. Cut 1 yields did not reach a plateau, but further yield increases may have been minimal if cutting treatments had been extended to later stages of oat maturity. Brundage *et al.* (1979) reported that DM yields of oats and oat-pea mixtures increased by 64-75% between oat heading and milk stage, but yields did not increase with further maturity of oats. Initial yields of mixtures of barley and winter cereals increased up to heading plus 4 weeks, but had no further increase at heading plus 6 weeks (Baron *et al.*, 1995). In our study, oats were at approximately heading plus 3 weeks at the latest cutting treatments. Silage-stage Cut 1 DM yields of 12.6-13.6 t ha^{-1} at soft dough stage of oats equalled or exceeded those reported in central Alberta of 6.6 to 12.3 t ha^{-1} for pulse-cereal intercrops (Berkenkamp and Meeres 1987a; Jedel and Helm, 1993; Izaurralde *et al.*, 1993) and 6.7-8.0 t ha^{-1} for oats intercropped with winter cereals (Baron *et al.*, 1992).

Cut 1 yields showed a quadratic response to oat density, and suggested a plateau in yield response to oat density (Table 6-2). Cut 1 yields with oat plants at 90 plants m^{-2} equalled yields with oat plants at 240 plants m^{-2} in 1999. In related research with berseem intercropped with oats at 5, 25, 50 and 100 plants m^{-2}, Cut 1 oat biomass yields reached a plateau at rates as low as 50 plants m^{-2} given favourable soil nutrients and moisture (Ross *et al.*, 2003a). Thus substantial decreases in oat seeding rate will not necessarily decrease the initial forage yield of oat-berseem intercrops, given favourable growing conditions.

Oat was the dominant component of Cut 1 yield (Figure 6-1). Berseem percentage of Cut 1 yield in O_{240} intercrops averaged < 1% in 1999 and 5% in 2000, and in O_{60} intercrops averaged 4% in 1999 and 19% in 2000.

Regrowth Yields

In 1999, total regrowth yields averaged 6.5 t ha^{-1} DM (Table 6-2). Regrowth yields showed a quadratic response to cutting treatment and a linear response to oat density, with highest yields for A cutting treatment and lowest for O_{240}.

In 2000, total regrowth yields averaged 6.1 t ha^{-1} DM, and cutting treatment × oat density interactions were significant (Table 6-2). The effects of oat density on regrowth were not significant for A, had quadratic effects for B and C, and linear effects for D, E and F. The effects of cutting treatment varied between low and high oat densities. For lower oat density treatments of O_{30} and O_{60}, there was a linear decline in regrowth between A and F. For higher oat density treatments of O_{90} and O_{240}, there was a non-linear decline in regrowth between A and F, with a steep drop in regrowth between A and B.

Regrowth differences between years may be partly explained by differences in oat regrowth. In 1999, oat regrowth was a substantial component of yield for all cutting treatments (Figure 6-1). In 2000, oat regrowth was less than in 1999 for cuts A, B and C, and was negligible (≤ 1% of total) for cuts D, E and F. McElroy and Gervais (1983) observed that the amount of regrowth of oats, barley and wheat varied with cultivars, year and stage of growth at harvest.

The number of oat tillers capable of regrowth declined as initial harvest was delayed in 2000 (Table 6-3). At Cut 1 of A at 35 DAP, oats were tillering, first node had not yet appeared, and tillers were capable of regrowth. Stem elongation of oats was occurring by Cut 1 of B at 46 DAP, and only 38% of tillers regrew. By Cut 1 of C at 55 DAP, the majority of tillers were in the boot stage and only 8% of tillers regrew. Tiller growth ceases when the floral apex is removed by cutting or grazing. The percentage of regrowth of oat tillers was greater for O_{60} than for O_{240} at cuts B and C, suggesting that the tillers in O_{60} were more asynchronous than those in O_{240}.

The majority of total berseem yield was from regrowth, with an average of 2.5 t ha^{-1} in 1999 and 4.3 t ha^{-1} in 2000 (Appendix 11). Berseem percentage of Cut 2 yield in O_{240} intercrops averaged 15% in 1999 and 76% in 2000, and in O_{60} intercrops averaged 51% in 1999 and 80% in 2000 (Figure 6-1).

If the goal of a producer is to use an oat-berseem intercrop to provide late season grazing or to use berseem regrowth as a green manure, earlier Cut 1 harvest would be recommended. Greater regrowth yield could be achieved by cutting the intercrop soon after oat heading. When initial cut was at oat heading rather than at soft dough stage, total intercrop regrowth yield increased by 125% in 1999 and by 275% in 2000 (Table 6-2). Similar regrowth advantages can be achieved by using early maturing cereal cultivars in berseem-cereal intercrops (Chapter 4). Early removal of oat competition from berseem may have a greater effect on berseem yield than reducing the oat plant density in intercrops. Willey (1979) suggested that temporal complementarity in intercrops is likely to produce greater yield advantage than spatial complementarity.

Total Yields

In 1999, total intercrop DM yield averaged 13.3 t ha^{-1} (Table 6-4). Total yields exhibited a quadratic response to cutting treatment, with lowest yields for C cutting treatment (cut at oat heading) and highest for D and E.

In 2000, total intercrop DM yield averaged 12.9 t ha^{-1}, and cutting treatment × oat density interactions were significant (Table 6-4). Total yields tended to be lowest for B and C, with initial cut at oat elongation to boot stages. Similarly, Klebesadel and Smith (1960) reported that oat-alfalfa mixtures in Wisconsin had lower total forage yield with initial harvest at boot stage than at late milk to early dough stage of oat. McElroy and Gervais (1983) reported that total seasonal forage yields of oats cut at jointing were 38-45% less than oats cut at dough. Royo (1999) observed yield reductions of 26-28% at anthesis for barley and triticale that had been cut at pseudostem elongation. In our study, total yields of intercrops that had been cut at oat stem elongation were 12% less in 1999 and 19-41% less in 2000 than those cut at oat soft dough stage.

Differences in total yield among cutting treatments decreased with decreasing oat density in 2000 (Table 6-4). With O_{30} and O_{60}, total yields of A, D and E equalled those of F. With O_{90}, total yields of A and D equalled those of F. With O_{240}, total yields were greatest for F. When oats were cut before stem elongation (A) or after heading (D, E), oat yield potential was somewhat reduced compared to soft dough stage (E, F). In lower oat density treatments, berseem growth compensated for the reduction in oat yield. With the O_{240} treatment, the berseem component was small and there was little capacity for berseem to compensate for reduction in oat yield.

Oat density did not affect total yields in 1999 and did not affect yields of A, E and F in 2000 (Table 6-4). In 2000, there were linear or quadratic responses to oat density within B, C and D, with higher yields for low oat density intercrops. Densities of O_{30} and O_{60} in B and C had greater yields than O_{90} and O_{240}, and O_{30} had greater yields than O_{240} in D in 2000. If part of the goal of using a berseem-oat intercrop is to increase the flexibility of harvest timing, reduced oat seeding rates would be recommended. A lower oat density can produce higher intercrop yields when the timing of harvest is detrimental to the yield potential of the oat component.

The timing of the initial cut of oat-berseem intercrops could be used to divide the seasonal yield to meet forage needs. To increase the forage yield for late-season grazing, a producer should cut the intercrop before soft dough stage of oats. With a cut of O_{60} at D, regrowth yield was 4.4–4.9 t ha^{-1} and comprised 30-35% of the total yield (Table 6-2, Figure 6-1). Regrowth was 2.6–3.5 t ha^{-1} or 16-26% of the total yield with cut of O_{60} at E, and was 1.3 t ha^{-1} or 9% of total yield with cut of O_{60} at F in 2000.

Protein yields averaged 2.02 t ha^{-1} in 1999 and 2.10 t ha^{-1} in 2000 (Table 6-5). In 1999, protein yields were greatest for B and D cutting treatments. Protein yields did not differ among oat density treatments, but exhibited a quadratic response to oat density in 1999. In 2000, protein yields exhibited quadratic responses to cutting treatment and oat density. Protein yields were highest for D cutting treatment and for O_{30} in 2000. Although some increases in DM yield may be achieved by delaying Cut 1 until soft dough of oats, protein yields were higher when Cut 1 occurred after heading of oats.

Species Composition

Total oat biomass DM yields averaged 10.6 t ha^{-1} in 1999 and 7.4 t ha^{-1} in 2000 (Table 6-6). Total berseem biomass DM yields in intercrops averaged 2.8 t ha^{-1} in 1999 and 5.4 t ha^{-1} in 2000. Oat yields generally exhibited quadratic responses to cutting treatment and oat density, with highest yields for E and F cutting treatments and for O_{90} and O_{240} densities. Total berseem yields exhibited linear and quadratic responses to cutting treatment, with lowest yields for E in 1999 and F in 2000. The highest berseem yields were with A and B in 1999 and with A, C and D in 2000. Similarly, Klebesadel and Smith (1960) found that total alfalfa yield in establishment year was somewhat greater when companion oats were harvested at boot stage than at silage stage. However, they also found that weed growth was greater with harvest of oats at boot stage. Berseem yields had a quadratic relationship with oat density, with highest yields for O_{30}.

Nonlinear relationships between berseem yield and oat density were consistent with findings in other experiments with berseem-cereal intercrops (Ross *et al.*, 2003ab).

The highest percentage of berseem in total yield was in cutting treatment B in 1999 and in C in 2000, coinciding with the lowest oat yields (Table 6-6). Berseem percentage of total yield averaged 21% in 1999 and 43% in 2000. The higher berseem percentage in 2000 may have been due to earlier relative emergence of berseem and higher moisture availability in 2000. Rate of emergence influences the species composition among establishing forage plants (Blaser *et al.*, 1956). Berseem establishment was slower in 1999 due to shallow broadcast seeding and lack of early moisture. Rainfall for May to September was near the 30-year average (326 mm) in 2000 (330 mm), but was less than normal in 1999 (259 mm). Greater regrowth of oats in 1999 than in 2000 was likely also a factor in greater competitive effects on berseem in 1999.

Effect of Early Defoliation

In some Mediterranean countries, spring cereals are cut or grazed during tillering stages and then cereal regrowth is allowed to mature for grain harvest (Royo, 1999). In our study, the cutting treatment A illustrated the effect of an early cut during oat tillering. Oat tiller density at Cut 1 of A was lower than with the later cutting treatments in 2000 (Table 6-3). Oats were in the process of tillering at Cut 1 of A, and first node had not yet appeared. Tillering in spring cereals normally declines or ceases at the time of stem elongation (Langer, 1963). Greater tiller density for O_{30} and O_{60} at Cut 2 than at Cut 1 in A indicates that the oats continued to tiller after Cut 1 or were stimulated to increase tillering. Royo (1999) reported that cuts at either pseudostem elongation or first node of barley and spring triticale resulted in increased numbers of tillers per plant at anthesis. Defoliation may stimulate tillering due to reduction of shading (Lambert, 1963). Tiller density in Cut 2 of A did not reach the levels observed in Cut 1 of B, C, D and E. It is possible that tiller density increased after Cut 1 of A but then had greater mortality than with uncut oats. Royo (1999) observed that although tiller density increased with early cutting, fewer tillers survived into maturity. Lambert (1963) suggests that the effects of cutting on tiller numbers can be highly variable and will be influenced by factors such as temperature, light intensity, and soil nitrogen.

Total DM yield for A was greater than for C in 1999 and was greater than B or C for some oat densities in 2000 (Table 6-4). In 1999, total DM yield for A was less than for E, suggesting that an early cut was detrimental to yield potential. In 2000, total DM yields of A equalled those of E. Comparison between A and other cutting treatments in 2000 had an advantage of greater equivalence of final harvest (Table 6-1). In 2000, cutting treatments A and F were comparable, except for the early cut of A at 35 DAP.

Results for A and F cutting treatments in 2000 suggest that early cutting or grazing of oat-berseem intercrops will shift the species composition in favour of berseem, and may increase protein yield without substantial effect on total DM yield. Compared to cutting treatment F, yields for cutting treatment A were 11% higher for protein, 62% higher for berseem DM, 32% lower for oat DM, and 72% higher for berseem component of total in 2000 (Tables 6-5 and 6-6). Total DM yields of A equalled those of F in O_{30}, O_{60} and O_{90} intercrops, but were 15% less for A than for F in O_{240} (Table 6-4).

Berseem Sole Crop Yields

Total biomass yields of berseem sole crop treatments averaged 12.5 t ha^{-1} DM in 1999 and 11.5 t ha^{-1} DM in 2000 (Table 6-7). Total DM yields and protein yields did not differ among cutting treatments for berseem sole crops. Responses to cutting treatment were linear or quadratic for Cut 1 yields and linear for regrowth yields. Total DM yields of berseem sole crops were less than O_{90} intercrops in 1999 and less than all intercrops in 2000. Berseem has high yield potential, but it may not consistently match yields of cereal-berseem intercrops. In related experiments, total seasonal yields of berseem sole crops were less than those of cereal-berseem intercrops in 3 of 5 cases (Chapter 2, 3 and 4). Forage yields of oat-berseem intercrops were 50-100% higher than yields of berseem sole crops with a 2-cut harvest in Montana (Welty *et al.,* 1991). Protein yields of berseem sole crops were greater than all intercrops in 1999 and were greater than O_{90} in 2000. Berseem regrowth yields were greater for berseem sole crops than for intercrops. Kendall and Stringer (1985) stated that annual clovers do not have stored reserves to support regrowth as in perennial clovers, but depend instead on residual leaf area and rapid leaf generation to support regrowth. Berseem sole crops likely had greater residual leaf area after harvest to support regrowth. Growing berseem as a sole crop might be preferable where the emphasis is on providing high quality late season grazing. Berseem-cereal intercrops would provide greater mid-season forage and may provide greater yield stability than berseem sole crops.

CONCLUSION

Berseem-oat intercrops showed potential to increase the flexibility of forage harvest without reducing dry matter or protein yield. Intercrops with 60 oat plants m^{-2} (O_{60}) were preferable to intercrops with the full oat rate of 240 plants m^{-2} (O_{240}). Compared to O_{240} intercrops, the O_{60} intercrops had a greater berseem component and had equal or higher dry matter and protein yield. In response to increasing oat density in intercrops, Cut 1 yield increased, regrowth yield decreased, oat yield increased, berseem yield decreased, and percentage of berseem in total yield decreased. The flexibility of harvest timing was increased by using reduced seeding rates of oats in intercrops. Cutting treatment had less effect on total yield for intercrops with greater berseem components. With lower oat densities, cutting effects that reduced oat yield potential were countered by increased berseem growth.

The optimal timing of initial harvest for O_{60} intercrops was at 65-66 days after planting, when oat heads were developing. With a cut at this stage, protein yields were higher and total dry matter yields were equal to those of the cutting treatment with initial cut at oat soft dough stage (76-88 days after planting). Producers could vary the timing of the initial harvest of berseem-oat intercrops to match their particular forage needs. Results for the earliest initial cut demonstrated that oat-berseem intercrops could be cut or grazed during tillering of oats without reduction of total seasonal yield. An early cut also increased the berseem component of yield. Early cutting or grazing during oat tillering might be used to provide early forage or to control weeds, but the net effect on weed growth would likely vary with weed species and timing of cut (Ross et al., 2001). Cutting the intercrop at soft dough stage of oats would favour greater silage yield. Cutting the intercrop after oat heading would provide a combination of good silage yield and substantial regrowth. Intercrop regrowth provides the producer with high quality late season forage that could be cut or grazed to extend the pasture season. When cut after oat heading, regrowth yield for O_{60} intercrops was over 4 t ha^{-1} DM and comprised 30-35% of the total yield. Producers would be advised to avoid cutting berseem-oat intercrops between stem elongation and heading of oats. Cutting at these stages resulted in substantial loss of oat yield potential and reduced total seasonal yield. When intercrops were cut before oat stem elongation or after oat heading, oat yield potential was somewhat reduced, but this reduction was countered by greater berseem yield.

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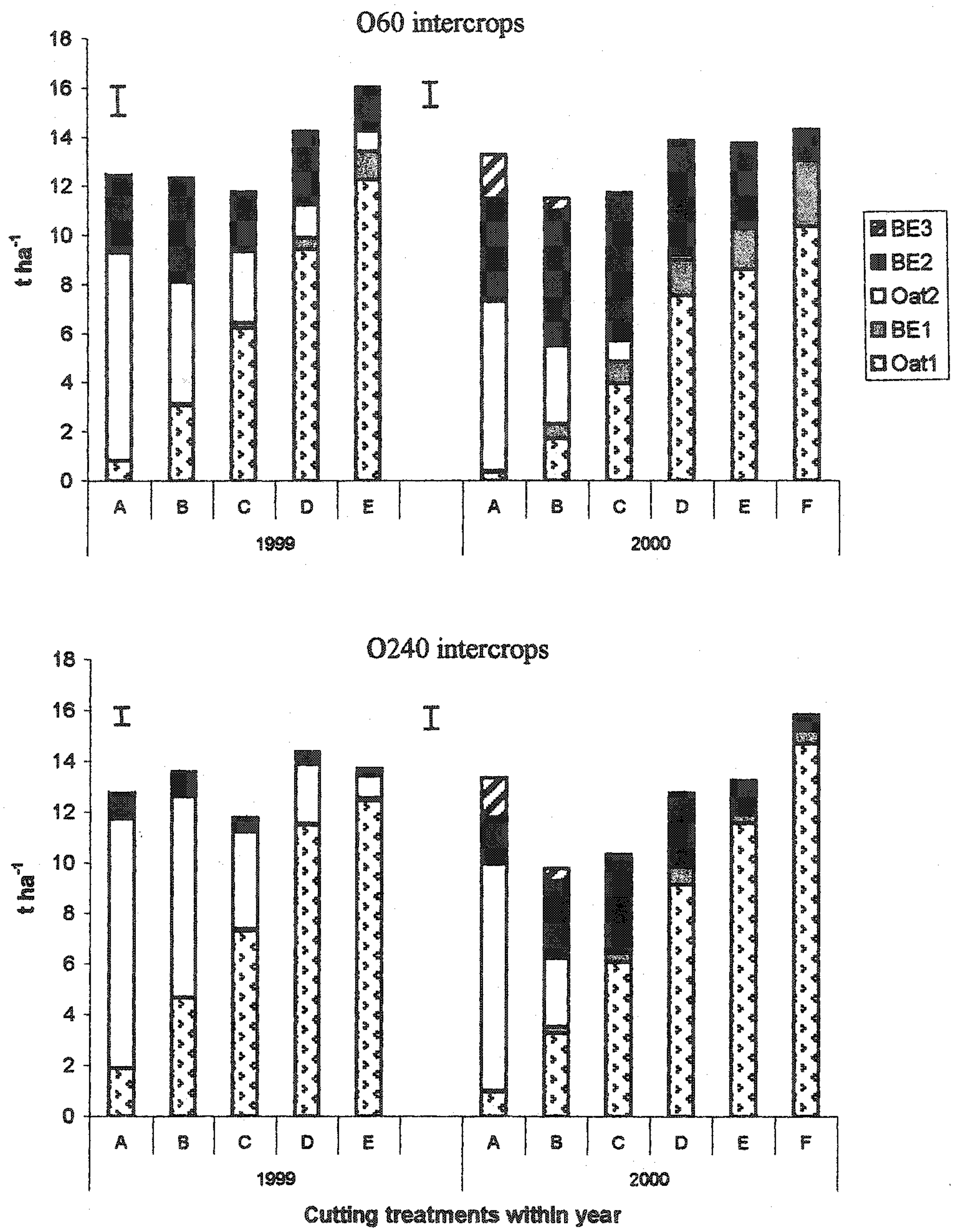

Figure 6-1: Berseem and oat biomass dry matter yields for berseem-oat intercrops for cutting treatments of A to F (described in Table 1) at oat densities of 60 (O60 intercrops) and 240 plants m-2 (O240 intercrops) in 1999 and 2000. Yield components are Cut 1 oats (Oat1), Cut 1 berseem (BE1), Cut 2 oats (Oat2), Cut 2 berseem (BE2) and Cut 3 berseem (BE3). Error bars indicate standard error of difference of 2 least-square means for total yield within year.

Table 6-1: Harvest dates, number of days after planting (DAP) for Cut 1, oat stage at Cut 1, and number of days of regrowth (DRG) for cutting treatments of oat-berseem clover intercrops.

Cutting	Cut 1			Cut 2		Cut 3	
treatment	date	DAP†	Oat stage	date	DRG	date	DRG
				1999			
A	30-Jun	36	tillering	26-Aug	57	-	-
B	9-Jul	45	elongation to boot	10-Sep	63	-	-
C	20-Jul	56	heading	17-Sep	59	-	-
D	29-Jul	65	heads developing	30-Sep	63	-	-
E	9-Aug	76	milk to soft dough	4-Oct	56	-	-
				2000			
A	23-Jun	35	tillering	15-Aug	53	8-Oct	54
B	4-Jul	46	elongation	25-Aug	52	8-Oct	44
C	13-Jul	55	mostly boot	7-Sep	56	-	-
D	24-Jul	66	heading	6-Oct	74	-	-
E	2-Aug	75	heads developing	6-Oct	65	-	-
F	15-Aug	88	milk to soft dough	8-Oct	54	-	-

†Days after planting, from dates of May 25, 1999 and May 19, 2000.

Table 6-2: Effects of cutting treatment (CUT) and oat plant density (OD) on Cut 1 and regrowth biomass dry matter (DM) yields for berseem-oat intercrops.

	Cut 1 biomass DM		Regrowth biomass DM						
	1999	2000	1999	2000					
Source									
CUT	**	**	**	**					
OD	**	**	*	**					
Cut × OD	ns	ns	ns	**					
				O30	O60	O90	O240		
CUT				t ha^{-1}					
A	1.2	0.6	11.8	13.8	12.9	13.3	12.4		
B	3.4	2.5	9.6	10.1	9.2	6.5	6.3		
C	6.8	5.1	5.1	8.3	6.9	4.9	3.9		
D	10.0	9.0	3.9	7.0	4.9	4.9	2.9		
E	12.6	10.2	2.2	4.2	3.5	3.2	1.4		
F	-	13.6	-	1.8	1.3	1.6	0.6		
s.e.d.†	0.36	0.25	0.41	0.91	0.84	0.67	0.44		
CONTRASTS									
CUT linear	**	**	**	**	**	**	**		
CUT quadratic	ns	ns	**	ns	ns	**	**		
CUT deviation	*	ns	*	ns	ns	**	**		
				A	B	C	D	E	F
OD				t ha^{-1}					
30	5.6	5.8	7.0	13.8	10.1	8.3	7.0	4.2	1.8
60	6.7	6.6	6.7	12.9	9.2	6.9	4.9	3.5	1.3
90	7.5	6.9	6.8	13.3	6.5	4.9	4.9	3.2	1.6
240	7.6	8.0	5.6	12.4	6.3	3.9	2.9	1.4	0.6
s.e.d.	0.32	0.20	0.36	1.00	0.74	0.58	0.67	0.59	0.29
CONTRASTS									
OD linear	**	**	**	ns	**	**	**	**	**
OD quadratic	**	**	ns	ns	**	**	ns	ns	ns
OD deviation	ns	ns	ns	ns	ns	ns	ns	ns	ns

* $P < 0.05$; ** $P < 0.01$; ns, not significant.

† Standard error of the difference of 2 least-square means.

Table 6-3: Effects of cutting treatment (CUT) and oat plant density (OD) on oat tiller density for Cut 1 and Cut 2 for oat-berseem intercrops in 2000.

Oat tiller density (oat tillers m^{-2})

Cut 1

Source	
CUT	**
OD	**
Cut × OD	ns

OD	CUT A	B	C	D	E	F	s.e.d.
30	168	244	241	265	239	196	29
60	241	325	366	369	359	293	20
90	316	419	420	407	399	335	40
240	528	597	567	553	506	460	35
s.e.d.†	22	31	20	36	34	29	

Cut 2

Source	
CUT	**
OD	**
Cut × OD	**

OD	CUT A	B	C	D	E	F	s.e.d.
30	201	86	23	16	22	0	13
60	285	154	55	27	36	0	18
90	319	156	31	23	19	0	20
240	415	205	16	37	44	0	27
s.e.d.	23	31	11	15	18	0	

** $P < 0.01$; ns, not significant.

† Standard error of the difference of 2 least-square means.

Table 6-4: Effects of cutting treatment (CUT) and oat plant density (OD) on total biomass dry matter (DM) yield for berseem-oat intercrops.

	Total intercrop biomass DM						
	1999	2000					
Source							
CUT	**	**					
OD	ns	0.07					
Cut × OD	ns	*					
		O30	O60	O90	O240		
CUT		t ha^{-1}					
A	13.0^{b}	14.1^{ab}	13.3^{abc}	13.9^{ab}	13.3^{b}		
B	13.0^{b}	11.7^{c}	11.5^{c}	9.1^{c}	9.8^{c}		
C	11.9^{c}	12.0^{bc}	11.7^{bc}	10.1^{c}	10.3^{c}		
D	13.9^{ab}	14.9^{a}	13.8^{ab}	14.2^{ab}	12.7^{b}		
E	14.8^{a}	12.8^{abc}	13.7^{ab}	13.1^{b}	13.2^{b}		
F		14.3^{a}	14.3^{a}	15.4^{a}	15.8^{a}		
s.e.d.†	0.56	1.08	1.00	0.74	0.69		
CONTRASTS							
CUT linear	**	ns	*	**	**		
CUT quad	**	ns	ns	**	**		
CUT deviation	ns	ns	ns	**	**		
		A	B	C	D	E	F
OD		t ha^{-1}					
30	12.5^{a}	14.1^{a}	11.7^{a}	12.0^{a}	14.9^{a}	12.8^{a}	14.3^{a}
60	13.4^{a}	13.3^{a}	11.5^{a}	11.7^{a}	13.8^{ab}	13.7^{a}	14.3^{a}
90	14.2^{a}	13.9^{a}	9.1^{b}	10.1^{b}	14.2^{ab}	13.1^{a}	15.4^{a}
240	13.2^{a}	13.3^{a}	9.8^{b}	10.3^{b}	12.7^{b}	13.2^{a}	15.8^{a}
s.e.d.	0.50	0.94	0.75	0.49	0.64	0.59	1.05
CONTRASTS							
OD linear	ns	ns	*	**	*	ns	ns
OD quad	**	ns	*	*	ns	ns	ns
OD dev	ns	ns	ns	ns	ns	ns	ns

* $P < 0.05$; ** $P < 0.01$; ns, not significant.

Means within columns with similar superscripts are not significantly different ($P > 0.05$).

† Standard error of the difference of 2 least-square means.

Table 6-5: Effects of cutting treatment (CUT) and oat plant density (OD) on total protein yield for berseem-oat intercrops.

	Protein yield	
	1999	2000
Source		
CUT	*	*
OD	ns	**
Cut × OD	ns	ns
CUT	$t\ ha^{-1}$	
A	1.94^{b}	2.19^{b}
B	2.15^{a}	1.93^{d}
C	1.91^{b}	2.11^{bc}
D	2.15^{a}	2.39^{a}
E	1.94^{b}	2.00^{cd}
F	-	1.97^{d}
s.e.d. †	0.09	0.07
CONTRASTS		
CUT linear	ns	ns
CUT quad	ns	*
CUT deviation	ns	ns
OD	$t\ ha^{-1}$	
30	1.95^{a}	2.28^{a}
60	2.03^{a}	2.11^{b}
90	2.16^{a}	2.04^{bc}
240	1.94^{a}	1.96^{c}
s.e.d.	0.08	0.06
CONTRASTS		
OD linear	ns	**
OD quad	**	**
OD deviation	ns	ns

* $P < 0.05$; ** $P < 0.01$; ns, not significant.
Means within columns with similar superscripts are not significantly different ($P > 0.05$).
† Standard error of the difference of 2 least-square means.

Table 6-6: Effects of cutting treatment (CUT) and oat plant density (OD) on total dry matter (DM) biomass yields of oats and berseem, and percentage of berseem for berseem-oat intercrops.

	Oat biomass DM		Berseem biomass DM		% Berseem of total yield	
	1999	2000	1999	2000	1999	2000
Source						
CUT	**	**	**	**	**	**
OD	**	**	**	**	**	**
Cut × OD	ns	*	ns	ns	ns	ns
CUT	t ha^{-1}				%	
A	9.9^{c}	7.7^{c}	3.1^{ab}	5.9^{ab}	24^{b}	43^{c}
B	9.2^{c}	4.9^{d}	3.8^{a}	5.6^{b}	30^{a}	52^{b}
C	9.5^{c}	4.7^{d}	2.3^{cd}	6.4^{a}	20^{b}	57^{a}
D	11.2^{b}	7.5^{c}	2.8^{bc}	6.4^{a}	20^{b}	45^{c}
E	13.0^{a}	8.6^{b}	1.8^{d}	4.5^{c}	12^{c}	34^{d}
F		11.3^{a}		3.6^{d}		25^{e}
s.e.d.†	0.51	0.35	0.38	0.37	2.3	2.2
CONTRASTS						
CUT linear	**	**	**	**	**	**
CUT quad	**	**	ns	**	**	**
CUT deviation	ns	**	ns	ns	ns	**
OD	t ha^{-1}				%	
30	8.0^{c}	5.0^{d}	4.6^{a}	8.3^{a}	36^{a}	63^{a}
60	10.1^{b}	7.3^{c}	3.2^{b}	5.8^{b}	25^{b}	45^{b}
90	11.7^{a}	7.9^{b}	2.5^{c}	4.7^{c}	18^{c}	39^{c}
240	12.5^{a}	9.6^{a}	0.7^{d}	2.9^{d}	6^{d}	25^{d}
s.e.d.	0.45	0.28	0.34	0.31	2.1	1.8
CONTRASTS						
OD linear	**	**	**	**	**	**
OD quad	**	**	**	**	**	**
OD deviation	ns	**	ns	*	ns	**

* $P < 0.05$; ** $P < 0.01$; ns, not significant.
Means within columns with similar superscripts are not significantly different ($P > 0.05$).
† Standard error of the difference of 2 least-square means.

Table 6-7: Effects of cutting treatment (CUT) on total berseem biomass dry matter (DM), protein, Cut 1and regrowth yields for berseem sole crops.

	Berseem sole crop							
	Cut 1 biomass DM		Regrowth biomass DM		Total biomass DM		Protein yield	
Treatment	1999	2000	1999	2000	1999	2000	1999	2000
				t/ha				
CUT								
A	-	0.1	-	11.7	-	11.8	-	2.16
B	0.1	0.7	13.3	11.2	13.4	12.0	2.48	2.11
C	1.1	2.0	11.9	9.8	13.0	11.9	2.36	2.24
D	3.1	5.6	8.1	6.8	11.2	12.4	2.47	2.55
E	6.7	6.2	5.7	4.6	12.3	10.8	2.49	2.14
F	-	8.1	-	2.3	-	10.4	-	1.87
s.e.d.	0.36	0.80	1.37	1.12	1.15	1.52	0.20	0.29
F-test Cut	**	**	**	**	ns	ns	ns	ns
Contrast								
CUT linear	**	**	**	**	ns	ns	ns	ns
CUT quad	**	ns	ns	ns	ns	ns	ns	ns
CUT deviation	ns	ns	ns	ns	ns	ns	ns	ns
MEANS								
Berseem sole (BE)	2.7	3.8	9.8	7.6	12.5	11.5	2.45	2.18
All intercrops	6.8	6.8	6.5	6.1	13.3	12.9	2.02	2.10
O60 intercrop	6.7	6.6	6.7	6.4	13.4	13.0	2.03	2.11
O90 intercrop	7.5	6.9	6.8	5.7	14.2	12.6	2.16	2.04
F-test OD all	**	**	**	**	ns	**	**	**
CONTRAST								
BE vs all intercrops	**	**	**	**	0.055	**	**	ns
BE vs O60 intercrops	**	**	**	**	ns	**	**	ns
BE vs O90 intercrops	**	**	**	**	*	**	**	*

* $P < 0.05$; ** $P < 0.01$; ns, not significant.

Chapter 7
Synthesis

BACKGROUND

The topic of intercropping berseem clover with silage cereals was an outgrowth of my M.Sc. research with annual clovers. That research investigated the ability of seven clover species to suppress weed growth, increase soil N and increase subsequent barley yield (Ross, 1999). Berseem was the most promising of the clovers tested. The high biomass yield, upright growth habit, and rapid post-harvest regrowth of berseem gave it advantages as a potential cover crop or annual forage. The study presented in Chapter 2, investigating competition between berseem and oats, began as a crop-weed study with oats representing a grassy weed. Considering the berseem-oat mixtures from the perspective of forage potential, rather than as weedy legume crops, led to the idea of investigating berseem in intercrops with silage cereals.

Silage cereals form the backbone of the feedlot, backgrounding and dairy industries in the Prairie provinces. The addition of a legume, intercropped with a forage cereal, can be an economic way to increase the nutrient value of the crop, and reduce fertilizer inputs, while improving soil quality. Growing berseem with silage cereals could also extend the harvest window for silage production and increase seasonal yield. The regrowth of berseem, following silage harvest, may provide high quality pasture to extend the growing season, increase soil cover, or provide green manure as ploughdown.

OBJECTIVES

The objectives of the research conducted in this thesis were:

1. To test the forage potential of oat-berseem, triticale-berseem and barley-berseem intercrops using a 2-cut (silage and regrowth) harvest system.
2. To test the effects of seeding rate on the forage yield and quality of cereal-berseem intercrops.
3. To explore the effects of cutting date on interactions in intercrops between silage cereal crops and an annual clover.
4. To investigate how cereal stature and earliness influence legume-cereal interactions in intercrops.

SUMMARY OF FINDINGS

Cereal density

- The full rate of cereals (240 plants m^{-2}) was very competitive, and severely depressed berseem growth.
- Berseem with 60 oat plants m^{-2} received only 24% of incident light when shading peaked at 65 days after planting (DAP), and berseem yielded 14-32% of sole crop berseem.
- As cereal density decreased in intercrops, Cut 1 yields decreased, berseem percentage in Cut 1 increased, and Cut 2 yields increased.
- Reducing cereal seeding rates to 60 plants m^{-2} usually improved forage quality, and produced equal or greater total seasonal yields than with full rate cereals.
- Somewhat higher densities than 60 plants m^{-2} would be recommended for triticale to maintain silage-stage yields.
- There was a linear decline in Cut 1 berseem DM as oat DM or oat tiller density increased.
- The relationship between oat plant density and Cut 1 berseem DM was nonlinear and varied between years and harvests. The high plasticity of cereals, where tillering is inversely related to plant density, reduced the potential of using plant density to predict berseem suppression.

Berseem seeding rates

- Increasing the seeding rate of berseem from 6 to 24 kg ha^{-1} decreased oat tillering by 22% in one year and 51% in a second year, with oats at 10-20 plants m^{-2}.
- Increasing berseem seeding rate had no effect on oat DM in one year and decreased oat plant DM by 57% in a second year.

Cereal genotype

- Barley-berseem intercrops had advantages of earliness, greater berseem regrowth yield, and greater protein yield.
- Oat-berseem intercrops had greater silage-stage yield and ≥ total forage yield compared to barley-berseem intercrops.

- Triticale caused less suppression of berseem than did barley and oats, and had ≥ silage-stage yield than oat intercrops.
- Early-maturing and semi-dwarf cereal cultivars caused less suppression of berseem than late-maturing and conventional-stature cultivars.
- Early-maturing oat intercrops had greater berseem regrowth yield and total protein yield than late-maturing oat intercrops.
- Semi-dwarf barley intercrops had greater yields of berseem regrowth than conventional-stature barley intercrops.

Cutting date

- Berseem-oat intercrops exhibited potential to increase the flexibility of forage harvest, and to divide the seasonal yield without reducing total dry matter or protein yield.
- Reduced seeding rates of oats in intercrops reduced the effect of cutting date. With lower oat densities, cutting effects that reduced oat yield potential were countered by increased berseem yield.
- Optimal timing of harvest for berseem-oat intercrops with 60 oat plants m^{-2} (O_{60}) was at 65-66 DAP, when oat heads were developing. With an initial cut at this stage, total protein yield was higher and total DM yield equalled intercrops with an initial cut at the oat soft dough stage (76-88 DAP). Regrowth yield was over 4 t ha^{-1} DM and comprised 30-35% of total yield.
- Cutting the intercrop at soft dough stage of oats produced the greatest Cut 1 yield.
- Harvest of oat-berseem intercrops prior to oat dough stage reduced Cut 1 DM yield, but did not necessarily reduce Cut 1 protein yield.
- An early initial cut during oat tillering increased the berseem component of yield, without reducing total seasonal yield.
- Seasonal yields were lowest when an initial cut occurred during the stem elongation to heading stages of oats, due to a substantial loss of oat yield potential.

Forage quality

- At cereal silage-stage cut, berseem had higher CP and lower NDF than cereals.
- Crude protein declined more rapidly in oat than in berseem. Between 35 and 88 DAP, CP declined linearly in berseem sole crops from 310 to 180 g kg^{-1}. Crude protein exhibited a quadratic response in oats, declining from 350 to 110 g kg^{-1}.

- The neutral detergent fibre (NDF) of Cut 1 of O_{60} intercrops averaged 30 g kg^{-1} less than cereals alone, indicating improved potential for forage intake.
- The mean CP of berseem grown in O_{60} intercrops was lower than that of berseem in sole crops, suggesting that the oat intercrop contributed to a decline in CP in beseem.

General conclusions

- Cereals were the dominant component in cereal-berseem intercrops. With cereals at the full seeding rate of 240 plants m^{-2}, berseem Cut 1 yields were minimal.
- At the point when berseem in sole crops exhibited a marked increase in growth rate (after 55 DAP), berseem plants in intercrops were greatly shaded by oats.
- When cereals emerged much ahead of the berseem, berseem yield was practically negligible.
- Using less competitive cereal genotypes at 25% of the full seeding rate was usually not detrimental to intercrop yield and sometimes produced higher total yields than with the full-rate of more competitive cereal genotypes.
- Compared to berseem sole crops, cereal-berseem intercrops increased Cut 1 DM yield and more consistently produced seasonal DM yields of 12-13 t ha^{-1}.
- A 20% berseem component in Cut 1 of 60-rate intercrops improved forage quality.
- To maximize forage quality and increase growth for fall grazing, shorter-stature and early-maturing varieties of cereals would be recommended for intercropping with berseem.
- On highly productive soils, the greatest benefit of cereal-berseem intercrops may be the addition of high-quality late-season forage after silage-stage harvest.
- Berseem regrowth after silage-stage harvest of intercrops averaged 2.6-2.8 t ha^{-1} DM, with mean crude protein of 200-210 g kg^{-1}.
- Berseem regrowth could be cut or grazed to extend fall pasture, aid winter cover, or be ploughed down to increase soil nitrogen and organic matter. Early silage-stage harvest would be recommended to maximize berseem regrowth.
- Producers could choose the cereal genotype and timing of the initial harvest of berseem-cereal intercrops to maximize forage quantity or quality, biomass or protein yield, silage or fall growth, and biomass for forage or for soil benefit.

CONTRIBUTION TO KNOWLEDGE

The research that I conducted makes a substantial contribution to the practical and theoretical knowledge of intercrops. The detailed study of plant parameters, as affected by a range of variables, provides knowledge to better understand the processes and mechanisms of intercrop dynamics. Reviewers of intercrop research have commented on the scarcity of intercrop research measuring factors such as leaf area, individual plant size and other biological variables over time (Connolly et al., 2001). Our sequential measurement of leaf area and biomass, and assessment of other plant factors such as cereal tillering, provides a valuable data sets in the study of legume-cereal intercrops and crop-weed competition. Such information provides insight into the timing of competition for resources in intercrops, and is useful to the design and management of intercrops. The detailed information of plant parameters is also useful to crop breeders in setting priorities for selection criteria. For example, our findings suggest that cereal tillering would be an unreliable predictor of competitive ability.

One of the interesting findings in this study was that cereal competition affected the forage quality of berseem. The crude protein of berseem grown in an intercrop with oats was lower than that of a berseem sole crop. It is hypothesized that the difference in quality may be attributed to shading of the berseem, increased stem elongation, and a lower leaf-to-stem ratio for the berseem grown in an intercrop.

The advantages in total intercrop yield that were sometimes observed with less competitive cereal cultivars, and with reduced seeding rates of cereals, are contrary to conventional crop production theory. In monocrop cereal production, yield advantage is associated with higher seeding rates and more competitive cultivars. The findings in this study illustrate that the theory and approaches in intercrop production will differ from those used in monocrop production.

A model of key factors in a legume-cereal forage intercrop system

The research conducted with berseem-cereal intercrops provides a detailed case study of a legume-cereal forage intercrop system. Experiments assessed the interaction of many of the factors illustrated in Figure 7-1.

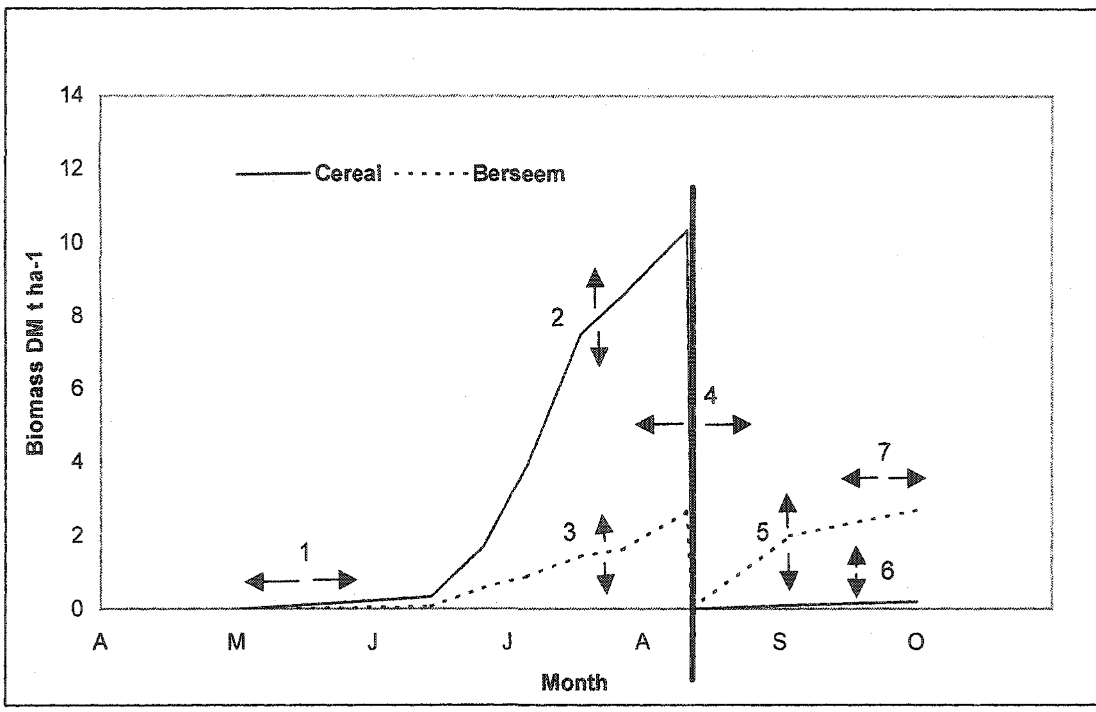

Figure 7-1: A model of factors affecting the biomass yield and composition of a berseem-cereal intercrop over the months of April (A) to October (O), where (1) is the emergence of the crops, (2) is the initial cereal growth, (3) is the initial berseem growth, (4) is the timing of the initial harvest, (5) is the berseem regrowth, (6) is the cereal regrowth, and (7) is the termination of the growing season.

The amount of initial cereal biomass yield (Factor 2) can be varied by the choice of cereal seeding rate, species and variety. The amount of initial berseem biomass yield (Factor 3) will vary with changes in Factor 2, and with berseem seeding rate and establishment. Factors 2 and 3 will be influenced by the relative timing of emergence (Factor 1). Factors 2 and 3 will also be influenced by environmental conditions, soil moisture and availability of soil nutrients. A reduction in the level of Factor 2 would be expected to occur on a soil with low levels of available nitrogen. The timing of the initial harvest (Factor 4) may be at the soft dough stage of the cereal, or earlier timing may be chosen. If Factor 4 is tied to the maturity of the cereal, the earliness of the cereal species/variety will affect Factor 4. The timing of Factor 4 will greatly affect the subsequent regrowth of berseem (Factor 5) and the potential for cereal regrowth (Factor 6). Factors 5 and 6 will be influenced by each other, by the availability of soil moisture and the length of the growing season (Factor 7). Selection of a berseem cultivar with greater tolerance of cool/cold temperature would extend the Factor 7 period. In general, enhancement of the berseem component of intercrop yield could be promoted by early relative timing of Factor 1, reduction of Factor 2, early timing of Factor 4, and a lengthy period for Factor 7.

In order to maximize the forage yield and quality of a berseem-cereal intercrop, it is necessary to ensure that some spatial complementarity occurs between Factors 2 and 3 (Figure 7-1). Without the spatial complementarity of Factors 2 and 3, the temporal complementarity provided by Factor 5 may be minimal. Thus, the choice is not whether temporal complementarity is more advantageous than spatial complementarity, but that the advantage of temporal complementarity is dependent on initial provision of spatial complementarity in this intercrop system. In this system, management of the intercrop requires a combination of both spatial and temporal complementarity to maximize crop yield and quality.

PRODUCTION POTENTIAL IN ALBERTA

Berseem clover has potential as a new crop for Alberta, for use as a sole crop or intercropped with silage cereals. New forage legumes expand the cropping choices of producers. Berseem-cereal intercrops provide another option for high quality silage. By reducing NDF and increasing CP of silage, the addition of berseem could increase intake and digestibility of conserved forage and contribute to higher animal productivity. Intercropping berseem with barley, oats or triticale can increase the harvest window for silage production without sacrificing silage quality.

Berseem regrowth after silage has potential to increase the total productivity of land and reduce the cost of production. The high N content of berseem regrowth could provide forage and soil benefits. Late-season berseem regrowth would supply high-quality forage at a time when forage quality and quantity is often limited. From the perspective of soil benefits and sustainability, plough-down of berseem regrowth could increase soil N, reduce N fertilizer requirements and improve soil quality. With a regrowth yield of 2 to 3 t ha^{-1} DM and nitrogen content of about 3%, the berseem regrowth would provide 60 to 90 kg N ha^{-1}.

There are a number of factors that could limit the adoption of berseem as a new crop in Alberta. The higher moisture requirements of berseem and intercrop production may restrict them to the Black and Gray soil zones and irrigated areas. Availability of berseem seed and the appropriate inoculant could be a limitation. The growing season of north-central Alberta is likely too short to support seed production of berseem. Farmers looking for annual legumes for forage or ploughdown may prefer grain legumes (e.g. peas) that afford an easy seed supply. From the perspective of extending the grazing season and increasing the productivity of land, producers may prefer to use intercrops of spring and winter cereals. Unlike berseem-cereal intercrops, spring-winter cereal intercrops could extend forage growth into a second year.

More time and complexity in managing seeding, fertility, weed control and harvesting can make intercropping less attractive than monocrop production. Establishment of a significant berseem component in intercrops would require careful management. Seeding an intercrop could increase labour and fuel requirements – e.g. two seeding passes instead of one. Just as agricultural technology has been developed to support direct seeding and reduced tillage, improved technology for seeding and harvesting of intercrops would aid the adoption of intercropping.

The use of berseem for soil benefit may be of most interest to organic farmers and those on soils with low N status, e.g. Gray soils. Many silage growers using legumes to improve quality forage, such as feedlot operators and dairy farmers, have limited interest in the N fertilizer benefits of legumes because they have large supplies of livestock manure. For other farmers, interest in using annual legumes for soil benefit will be shaped by the cost of N fertilizer and public policy. Sheaffer et al. (2001) stated that the availability of relatively inexpensive synthetic N fertilizers and government subsidization of grain crop production in the USA presents a challenge to the promotion of widespread use of annual legumes in modern cropping systems. It has been more economical for producers to use N fertilizers than annual legumes. Sheaffer et al. (2001) concluded than an increase in price of synthetic N fertilizers and the development of farm programs that reward crop diversification would support greater use of annual legumes in cropping systems. Similarly in Canada, economics and public support of environmental and sustainability issues may provide future incentives for farmers to increase their use of legume crops.

FURTHER RESEARCH NEEDS

1. Different locations/environment

It would be valuable to test the performance of berseem-cereal intercrops at other locations in western Canada. The levels of soil nutrients and rainfall at the Edmonton site made it highly productive. The addition of berseem to silage cereals may have greater impact on yield and quality at other locations. Advantages of intercropping legumes with cereals are more prominent under conditions that are less than optimal for cereal growth, e.g. lower levels of soil nitrogen (Anil et al. 1998; Moreira 1989). Suppression of weeds by clover species differed between a Black soil site at Edmonton and a Gray soil site at Breton (Ross et al., 2001). Carr et al. (1998)

observed cultivar × environment interactions for forage yield and quality of pea-cereal intercrops. Brink and Marten (1986) concluded that annual yields of protein and in-vitro digestible dry matter for oat-alfalfa and barley-alfalfa mixtures were influenced more by location and year than by small grain species or cultivar. Testing of berseem-cereal intercrops at other locations, including sites with low levels of soil N, would provide a greater understanding of berseem-cereal intercrops and their potential.

2. Relative emergence

The substantial differences between years for berseem yields and berseem suppression by cereals warrant further investigation. It is suspected that differences in relative emergence of berseem and cereals played a significant role. Relative time of emergence has been identified as an important factor in crop-weed competition (O'Donovan et al., 1985) and in pea-cereal intercrops (Tofinga et al.1993). Research on relative emergence in berseem-cereal intercrops is needed to determine how the timing of emergence affects yield and species composition. Such research is generally needed for the use of small-seeded forage legumes in mixtures.

3. Comparison with other legumes

It would be valuable to do a comparative study of a cereal intercrops with a range of legumes. Berseem could be compared with pulses (e.g. field peas, faba bean) and small-seeded legumes (e.g. other clovers, non-dormant alfalfa) in intercrops with cereals with assessment of impact on forage quality and yield.

4. Berseem as sole crop forage

In our study, intercrops provided greater mid-season forage and greater yield stability than berseem sole crops. However, berseem sole crops produced higher regrowth yield, and had total DM yields equal to intercrops in 3 of 6 cases. Growing berseem as a monocrop might be preferable where the emphasis is on providing high-quality late-season grazing. Forage conservation as hay or silage may be easier with berseem-cereal intercrops than with berseem sole crops. Little information is available on the potential to conserve berseem as hay or silage. Further research in these areas would be useful to producers considering berseem as an option for annual forage production.

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Appendices

APPENDIX 1: SOIL DATA

Soil analysis for plot areas for berseem-cereal intercrop experiments at the University of Alberta Edmonton Research Station for 1996 to 2001.

	Soil depth	N Nitrate	P Phosphate	K Potassium	S Sulfate	pH
	cm	ppm				
1996	0 - 15	38	21	296	17	6.5
	15 - 30	40	13	216	9	5.7
1997	0 - 15	16	28	340	11	5.3
	15 - 30	22	9	240	9	5.5
1998	0 - 15	39	30	403	8	5.7
1999	0 - 15	34	34	420	14	5.9
	15 - 30	38	15	329	15	5.8
2000	0 - 15	50	37	272	4	7.0
	15 - 30	48	22	225	17	6.6
2001	0 - 15	50	26	228	14	6.6
	15 - 30	56	14	199	15	7.0

APPENDIX 2: CLIMATE DATA

Monthly precipitation and mean temperatures for May to September at the University of Alberta Edmonton Research Station for 1996 to 2001.

	Weather - Edmonton Research Station						
	1996	1997	1998	1999	2000	2001	Norm†
	Precipitation						
	mm						
May	56.6	45.2	39.6	85.4	73.9	17.7	43.5
June	117.9	133.1	110.2	32.3	69.9	54.5	79.9
July	75.4	66.8	23.6	64.8	98.8	149.5	94.3
August	63.0	64.0	63.0	67.1	36.3	25.0	67.0
September	62.7	79.5	43.2	9.7	51.3	20.0	41.6
Total	375.6	388.6	279.6	259.3	330.2	266.7	326.3
	Mean temperature						
	°C						
May	8.2	11.4	15.3	10.1	10.2	norm‡	11.6
June	14.2	15.5	15.6	14.8	14.4	norm -1	15.6
July	17.1	17.6	19.2	15.8	18.3	norm	17.5
August	17.4	17.1	19.3	17.7	15.9	norm +1	16.6
September	9.8	12.9	13.0	11.4	10.9	norm	11.1
Mean	13.3	14.9	16.5	14.0	13.9		14.5

† Norm is the 30 year (1961-1990) normal at the Edmonton Municipal Airport.
‡ Temperature data was not collected at the Edmonton Research Station in 2001, and temperature trends in 2001 are based on information from the website: www.agric.gov.ab.ca/climate/mwthfall.html.

APPENDIX 3: PLANT HEIGHT

Height of oat canopy and maximum length of berseem stems at harvest at 11 and 15 weeks after planting (WAP) in 1996.

Harvest	Oat Density	Canopy Height Oats	Maximum stem length Berseem
		cm	cm
11 WAP	0		107
	5	133	116
	25	132	121
	50	138	116
	100	138	105
	Mean	135	113
15 WAP	0		151
	5	137	140
	25	139	130
	50	136	135
	100	137	113
	Mean	137	134

APPENDIX 4: OAT GRAIN YIELD – OAT DENSITY

Oat grain yield at 15 weeks after planting in oat-berseem intercrop treatments with 4 oat densities in 1996.

Oat Density	Oat grain yield	
	$g\ m^{-2}$	$Mg\ ha^{-1}$
5	145	1.4
25	270	2.7
50	417	4.2
100	402	4.0
Mean	309	3.1

APPENDIX 5: REGRESSION PARAMETERS – OAT DRY MATTER

Estimated linear regression parameters (with standard errors in parentheses) for berseem clover biomass dry matter (DM) as a function of oat biomass DM in 1996 and 1997 at Edmonton

Year	Harvest	Oat-free berseem DM y_{of} g m^{-2}	Slope i g m^{-2}	R^2
		Using a fixed value for 'y_{of}'		
1996	11 WAP	620	-0.59 (.02)	0.94
	15 WAP	895	-0.57 (.03)	0.77
1997	11 WAP	704	-0.47 (.03)	0.81
		Using an estimated value for 'y_{of}'		
1996	11 WAP	609 (20)	-0.58 (.03)	0.94
	15 WAP	804 (52)	-0.48 (.06)	0.80
1997	11 WAP	719 (16)	-0.50 (.05)	0.82

Data were fitted to the equation $y = y_{of} + id$ where y is the predicted berseem yield, y_{of} is the yield of berseem without oats, i is the % yield loss per g m^{-2} of oat DM, and d is oat DM g m^{-2}.

APPENDIX 6: REGRESSION PARAMETERS – OAT TILLERS

Estimated linear regression parameters (with standard errors in parentheses) for berseem clover biomass dry matter (DM) as a function of the number of oat tillers in 1996 and 1997 at Edmonton.

Year	Harvest	Oat-free berseem DM y_{of} g m^{-2}	Slope i g m^{-2}	R^2
		Using a fixed value for 'y_{of}'		
1996	11 WAP	620	-1.91 (.07)	0.92
	15 WAP	895	-2.89 (.20)	0.65
1997	11 WAP	704	-1.53 (.10)	0.83
		Using an estimated value for 'y_{of}'		
1996	11 WAP	580 (20)	-1.73 (.11)	0.93
	15 WAP	748 (52)	-2.21 (.30)	0.75
1997	11 WAP	720 (15)	-1.64 (.14)	0.84

Data were fitted to the equation $y = y_{of} + id$ where y is the predicted berseem yield, y_{of} is the yield of berseem without oats, i is the % yield loss per oat tiller, and d is number of oat tillers m^{-2}.

APPENDIX 7: OAT GRAIN YIELD – BERSEEM RATE

Oat grain yield in berseem seeding rate treatments in 1996.

Berseem seeding rate	Oat grain yield		
	$g\ m^{-2}$	$g\ plant^{-1}$	$g\ tiller^{-1}$
6	221	12.2	1.44
12	178	11.3	1.41
18	245	13.6	1.86
24	214	11.9	1.88
Mean	214	12.3	1.65

APPENDIX 8: CEREAL REGROWTH

Dry matter (DM) biomass of cereal regrowth in berseem-cereal intercrops with 4 densities of cereals in 2001.

Cereal density	Cereal - Cut 2 biomass DM		
	Barley	Oat	Triticale
		$Mg\ ha^{-1}$	
30	1.0	0.2	1.1
60	1.2	0.1	1.6
90	1.4	0.1	1.9
240	0.7	0.1	2.4
Mean	1.1	0.1	1.8

APPENDIX 9: LIGHT READINGS

Light readings in berseem-cereal intercrops taken July 6, 2001.

		Percentage of incident light available	
Crop	Cultivar	Top of berseem	Soil level
Barley	Kasota	44%	14%
	AC Lacombe	31%	6%
	Niska	32%	8%
	Seebe	27%	7%
	Mean - barley	33%	9%
Oat	AC Juniper	54%	19%
	Jasper	48%	16%
	Murphy	49%	19%
	AC Mustang	39%	16%
	Waldern	46%	12%
	Mean - oats	47%	16%
	Mean - all	41%	13%

APPENDIX 10: OAT TILLERS

Number of oat tillers per plant for oat-berseem intercrops in 4 oat density treatments at 5 sampling dates in 2000.

Sampling	Number of oat tillers per plant within intercrop treatments with oat densities (oat plants m^{-2})				
date	30	60	90	240	Mean
1	5.6	4.0	3.5	2.2	3.8
2	8.1	5.4	4.7	2.5	5.2
3	8.0	6.1	4.7	2.4	5.3
4	8.8	6.2	4.5	2.3	5.4
5	8.0	6.0	4.4	2.1	5.2
6	6.5	4.9	3.7	1.9	4.3
Mean	7.5	5.4	4.2	2.2	4.9

APPENDIX 11: REGROWTH OF BERSEEM

Dry matter (DM) biomass regrowth of berseem in 5 or 6 cutting treatments of oat-berseem intercrops in 1999 and 2000.

Year	Oat density	Berseem Regrowth t ha^{-1} DM						
		CUT						
		A	B	C	D	E	F	Mean
1999	30	4.8	6.5	3.5	3.7	1.9	-	4.1
	60	3.2	4.2	2.4	3.0	1.8	-	2.9
	90	3.4	3.0	2.0	2.0	1.2	-	2.3
	240	1.1	1.0	0.6	0.5	0.3	-	0.7
	Mean	3.1	3.7	2.1	2.3	1.3	-	2.5
2000	30	8.5	7.8	8.0	6.8	4.1	1.8	6.1
	60	6.0	6.0	6.0	4.6	3.4	1.3	4.5
	90	5.5	3.4	4.6	4.8	3.2	1.6	3.8
	240	3.4	3.5	3.8	2.8	1.3	0.6	2.6
	Mean	5.8	5.2	5.6	4.7	3.0	1.3	4.3