The Effect of Intercropping Systems and Cultivar Mixtures on Weed and Disease Suppression in Organically Managed Spring Wheat.

BY

JACQUELINE CLAIRE PRIDHAM

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Plant Science
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ABSTRACT

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Without the chemical supports of high-input agriculture, weeds and diseases can become serious hindrances to successful organic wheat production. Diversifying the cropping system through strategies such as intercropping and cultivar mixtures may provide effective suppression of weeds and diseases and thereby improve grain yield and quality. An intercropping system trial and a cultivar mixture trial were evaluated at Carman, Manitoba and Clearwater, Manitoba in 2004 and at Carman, Manitoba in 2005 to determine their impact on weed and disease levels as well as biomass and grain yield. The study consisted of two trials, the first of which examined intercrop mixtures comprised of three representative systems. The first system was wheat and other cereal mixtures, which included wheat and oats, wheat and barley and wheat and spring rye. The second system was wheat and other seed intercrop mixtures and included wheat and flax, wheat and field peas and wheat and oriental mustard. The third system was wheat and cover crops, which included wheat and red clover, wheat and hairy vetch, and wheat and annual ryegrass. In the cereal intercrop system, wheat-barley was the highest yielding and most profitable of the cereal treatments, with additional benefits in weed suppression. Within the wheat and other seed intercrop system, wheat-flax could be profitable but flax reduced the wheat crop in all site-years, and underwent crop failure due to frost damage in one site-year. Wheat-field peas reduced disease levels in the wheat crop in all three site-years but yields and net returns were only as profitable as the full-rate monoculture in one site-year. Wheat-oriental mustard was profitable in all site-years even with the oriental mustard being largely decimated by flea beetles in two of three site-years. In the cover crop system, wheat-red clover had little variation in yield or profit from the half-rate wheat treatment in all site-years, but tended to lower disease levels. Wheat-hairy vetch could boost wheat yields and profitability to levels comparable to full-rate wheat, but it also could overwhelm the wheat crop and cause a net loss in a site-year with excess precipitation. Wheat-annual ryegrass could also overwhelm the crop in a wet site-year, but it also could significantly reduce weed levels. The second trial of the study examined the heritage and modern varieties of Red Fife, Marquis, AC Barrie and 5602HR within monocultures and cultivar mixtures under organic management. This trial included treatments of all possible combinations of the varieties, as well as sole variety treatments. There was little variation among the treatments, which demonstrates the ability of cultivar mixtures to stabilize yields. However, amongst the sole variety treatments, 5602HR and Red Fife had higher yields than AC Barrie or Marquis, with 5602HR having significantly higher yields than many other treatments in conditions of flooding stress. Red Fife and mixtures containing Red Fife also had lower levels of disease than the other treatments. Both intercropping systems and cultivar mixtures present examples of crop mixtures which, while increasing diversity, can also provide benefits of weed/disease suppression as well as stabilizing or increasing grain yield and profitability.

1.0 INTRODUCTION

Organic production has emerged in the agricultural sector as a viable and profitable alternative to conventional agriculture (Dimitri and Greene, 2002). The philosophies of the early organic movement focused on methods of production that would reduce environmental impact, enhance soil quality and biological productivity and promote the health of producers, consumers and rural communities (Canadian Organic Growers [COG], 2001). This set of philosophies and practices is now being subjected to standards internationally and consumer demand has increased its profile to be that of a major presence within the retail sector.

As organic standards prohibit the use of synthetic pesticides and herbicides, organic agriculture must employ other strategies when striving for successful crop production amongst weed and disease pressures; weeds being considered the greatest obstacle to production (Penfold et al., 1995; Stonehouse et al., 1996; Clark et al., 1998). The most important tool producers can utilize within their cropping system is that of diversity, with any increase in biodiversity bringing more stability to the agroecosystem (Andow, 1991; Altieri, 1995). The ultimate model of stability through diversity is that of nature, which, through having a variety of flora and fauna, can remain resilient despite the presence of pests and disease (Trenbath, 1999). Traditional farms were often havens of genetic diversity with some farms in the world supporting up to hundreds of different crop varieties (Orr, 1991). Organic cropping systems typically raise the level of diversity within an agroecosystem by integrating such methods into their cropping systems as effective crop rotations, green manures, intercropping, beneficial habitats and cultivar mixtures (Bengtsson et al., 2005; Kuepper and Gegner, 2004; Hole et al., 2005) which subsequently increase the number of weed species (Hyvönen and Salonen, 2002), carabid beetles (Dritschilo and Wanner, 1980; Kromp 1989; Pfinner & Niggli, 1996) and birds (Freemark and Kirk, 2001) in the landscape. Implementing such cropping methods also allows for the breaking of pest and disease cycles, the smothering of weeds and reduction of seed banks, as well as contributing to the nutrient and organic matter levels of the soil. Intercropping can be one method of increasing diversity that producers employ to potentially reduce weed and disease levels within the crops, better utilize resources, provide for a stable and comparable to monoculture yield, and reduce environmental and financial risk (Anil et al., 1998; Willey et al., 1983). Although intercropping is widely used in tropical agriculture due to space and dietary factors, attempting to achieve a complete diet on the smallest amount of land as possible, the role this practice plays in the sustaining of agricultural activities on marginal land bases cannot be disregarded (Trenbath, 1999). Temperate conventional agriculture, conversely, is an increasingly specialized cropping system that is based upon the use of monocultures and uniform production practices. Little research has been conducted on the feasibility of temperate grain intercropping, especially that of organic/low-input systems, although instances of intercropping can be found in settings such as pastures, where harvesting and uniform production is not an issue (Anil et al., 1998). Intercropping for grain is still not considered practical within the conventional agricultural context, yet it has been increasingly studied for use in forage production (Anil et al., 1998). Wheat intercropping has been surprisingly neglected in temperate studies (Anil et al., 1998) although cereal and intercrop studies such as cereals with pulses (Papastylianou, 1990; Hall and Kephart, 1991; Carr et al., 2004; Berkenkamp and Meeres, 1987), cereals with cover crops

(Balsdon et al., 1997; Lanini et al., 1991; Hartl, 1989; Thiessen Martens et al., 2001) and cereal mixtures (Baron et al., 1992; Jedel and Salmon, 1995) have been conducted which provide a basis to suggest that intercropping can be successful within the temperate climate.

Cultivar mixtures are primarily used to slow the spread of foliar disease within the crop using a mixture of varieties that exhibit resistances to the primary disease threats (Jeger et al., 1981; Stuke and Fehrmann, 1988; Finckh and Wolfe, 1997). Varietal mixtures have been widely used in production within developing countries to stabilize income and to reduce pest pressures but are rarely utilized within developed countries, despite their researched benefits (Smithson and Lennè, 1996; Gallandt et al., 2001). Genetic diversity inhibits the spread of pathogens to susceptible plants, thereby working to stabilize yield, but benefits to stability and yield can also be realized through enhanced resource utilization and optimization of variant niches, as have been researched within intercropping systems (Gallandt et al., 2001). Although the level of diversity does not match that of intercropping, it is better suited to modern agricultural production methods.

The objective of this project was to evaluate wheat intercropping systems and wheat cultivar mixtures to determine their effectiveness in (i) reducing weed and disease populations in the crop, (ii) stabilizing/increasing yield, (iii) increasing profitability. The hypotheses that resulted from these objectives and were tested by this study included:

(a) Wheat with intercrops will suppress weed populations more effectively than wheat monocultures due to increased competition and resource utilization

(b) Wheat with intercrops will have a lessened severity of disease compared to standard disease levels in wheat monocultures due to the presence of non-host plants that prevent disease spread and establishment

(c) Cultivar mixtures of wheat will suppress weeds more effectively than a monoculture of one wheat variety due to varying heights and root masses

(d) Cultivar mixtures of wheat will have decreased disease severity compared to monocultures of one wheat variety due to varying disease resistances of the wheat cultivars which decreases the disease inoculum and prevents disease establishment

2.0 LITERATURE REVIEW

2.1 Diversity in Nature and Agroecosystems

Nature is used as the model of sustainability for agroecosystems as it has efficiently incorporated a diverse range of flora and fauna into many resilient landscapes while maintaining productivity for thousands of years (Sullivan, 2001; Trenbath, 1999). History has illustrated that the agricultural systems that were sustainable contained many different species (Trenbath, 1999). However, the conflict within modern agriculture seems to be that "the highly localized adaptations needed for ecologically healthy agriculture and healthy, stable rural communities are often in conflict with the apparent requirements of rapidly industrializing nations and an expanding international economy" (Wright, 1990). This rapid agricultural industrialization has resulted in two-thirds of cropland worldwide being grown as annual crop monocultures (Food and Agriculture Organization, 2003) and a dominant agroecosystem that requires "constant human intervention" to maintain its functioning (Altieri, 1999 cited in Hole et al., 2005). When monocultures are instituted in an agricultural setting, diversity is forcibly removed, and there is a resultant struggle to keep elements of diversification, "weeds" and "pests", out of the cropping system (Sullivan, 2001). Generally, the more complexity and diversity that exists within a system, the more stable that system is, with a gradual balance being obtained of species diversity, composition and flow of materials (Sullivan, 2001; Trenbath, 1999). This concept is easily observed in the beginning stages of wild community establishment or human-impacted landscapes as they are prone to extreme fluctuations in species, diseases and pests (Sullivan, 2001). To incorporate diversity in the production system, effective crop rotations, farmscaping, intercropping, and integrating livestock into the operation are all effective measures to employ (Sullivan, 2001).

2.2 Organic Production

2.2.1 Diversity in Organic Production

Diversity is the most powerful tool available to organic producers for their cropping system. In managing components of their cropping systems, producers subsequently determine what the outputs of the farm will be, the amounts of nutrients that will be required in the system, and how the crops utilized will affect soil quality (Olesen et al., 1999). The selection of crops used in rotations and for cover crops is a major factor determining successful production in the presence of weed, pest, disease and nutrient limitation pressures that can be experienced in organic production (Olesen, 1999). Organic producers typically incorporate green manures, winter/spring cereals, pulses/other legumes, row crops, and cover/catch crops into their rotation, with the sequence of the crops planned to prevent pest/disease/weed/nutrient problems (Olesen, 1999; Askegaard et al., 1999). The farms which utilize diverse cropping systems are more likely to support beneficial predators and pollinators and promote the complexity of the soil faunal community, which contributes to nutrient cycling, disease suppression and soil structure and fertility (Keupper and Gegner, 2004). A comprehensive review of the literature regarding the impacts of organic and conventional production systems on biodiversity conducted by Hole et al. (2005) found that organic systems supported a higher abundance and variety of weed species, greater earthworm, carabid beetle and bird abundance, and displayed a trend towards increased bacterial and fungal abundance and activity.

In organic agriculture's present state, it has been restricted to environmentally benign practices within the framework of modern agriculture (Hill and MacRae, 1992). As knowledge of the potential of agroecosystems increases however, so too can the ecological diversity and stability of organic cropping systems (Hill and MacRae, 1992).

The twenty-one year "DOK" system comparison trial, which analyzed biodynamic, organic, conventional with mineral supplements and conventional using farmyard manure systems reported a mean organic crop yield 20% lower than the conventional systems (Mäder et al., 2002).Within the organic system, there were significant differences in stability in the crops under production. Potato yields were 58 to 66% lower than conventional yields due to nutrient and disease pressures, while winter wheat was 90% of conventional yields, and grass-clover yield differences were only reported as "small" between the systems (Mäder et al., 2002). These variant yields, dependant on crop type, denote the importance of risk management in a cropping system, as well as how diversity can stabilize production. Monocropped potatoes were ill-suited to the organic system, whereas wheat had more stability in the system, and the grass-clover system remained stable in yield throughout the systems, suggesting resilience to variant pest and nutrient issues.

2.2.2 Weed and Disease Pressures in Organic Production

Without herbicides and fungicides to bolster the system, organic production can be faced with severe weed and disease pressures if the cropping system is not functioning to provide resilience to these constraints. Weed levels are considered to be the major factor in limiting crop yields in organic systems, and often require more labour and monetary inputs than for any other facet of production (COG, 2001). Various "soil-building" strategies employed on organic farms such as green manures and pastures work to break weed and disease cycles while encouraging a complex soil organic network that further assists in these goals. Organic producers display a range of participation in these activities however, and a study of farms in the northern Great Plains showed that alfalfa (*Medicago sativa* L.) could constitute 1- 40% of the farm area and sweet clover (*Melilotus officinalis* Lam.) 1-16% (Entz et al., 2001). This variance in the implementation of green manures suggests little effort by some producers to control weed and nutrient issues in their cropping system. An evaluation of weed species in the prairies led to the conclusion that organic systems contained a higher level of weeds than conventional systems and an increased diversity of weed species with the top weed species identified as wild mustard [*Brassica kaber* (DC.) L.C. Wheeler], Canada thistle [*Cirsium arvense* (L.) Scop.], redroot pigweed (*Amaranthus retroflexus* L.), green foxtail [*Setaria viridis* (L.) Beav.], wild oat (*Avena fatua* L.) and lamb's quarters (*Chenopodium album* L.) (Frick, 1993; Entz et al., 2001). Perennial forages in the rotation have also been found to greatly influence the weed dynamics in the cropping system, with perennial forages selecting for the prevalence of perennial and biennial weeds, whereas annual crops promote the establishment of annual weeds within their system (Leeson et al., 2000).

Diseases are thought by some to be a minor issue within organic systems since the increased diversity of the organic cropping system should work to break disease cycles and halt the spread of disease, and the method of slow-release fertilization through green manuring should make the plants less suitable for attack by pathogens (COG, 2001). It is then thought that if a disease issue persists within the system, the efforts to improve the quality of the soil have been insufficient and/or the crop rotation is not suitable (COG, 2001). However, few empirical studies have tested these theories, and this disregards diseases spread by wind dispersal (e.g. stem rust).

Pathogens can persist and spread within a crop as fungi survive on residues from the previous crop (Krupinsky et al., 2004). Hence, crop rotations are vital to breaking the disease cycle as non-host crops allow natural methods of disease control to occur such as host material decomposition and the increase of natural predators which reduce the pathogen presence in the system (Cook and Veseth, 1991; Krupinsky et al., 2002). Although crop rotations are an essential tool in the reduction of leaf spot diseases, effective disease management requires the use of various long-term disease suppression strategies simultaneously (Krupinsky, 2004).

2.2.3 Organic Wheat Production in Canada

Worldwide, Canada is ranked amongst the top five producers of organic grains and oilseeds, the value of which approaches $1 billion worldwide when including both processed and non-processed goods (Agriculture and Agri-Food Canada [AAFC], 2003). Wheat is considered the most important Canadian organic crop, since it has the largest export market of any organic crop, ($14 million in 2003) and it is grown on the highest proportion of certified organic land, (72560 ha in 2004) (Macey, 2004; 2006). In 2003, approximately 941 producers in Canada were involved in wheat production, with the majority of production being centralized in Western Canada (Macey, 2004). Saskatchewan led wheat production in 2003 with 53674 ha wheat and an additional 5023 ha of durum wheat, followed by Alberta with 7238 ha and Manitoba with 2828 ha

(Macey, 2004). The estimated farm gate value of this prairie wheat crop is $44,180,012 and $3,481,566 for durum wheat (Macey, 2004).

From a study of farms within Manitoba, Saskatchewan and North Dakota, it was found that organic wheat yields from these locations were approximately 25% less than conventional wheat production, with wheat occupying 15.1% of the landbase of the farms (Entz et al. 2001). In rotations involving spring wheat, alfalfa or sweet clover were typically grown before wheat for their contributions to soil nitrogen and weed suppression, while oats (*Avena sativa* L.) or fall rye (*Secale cereale* L.) were grown after the wheat crop (Entz et al., 2001).

2.3 Intercropping

Intercropping as a production method has been relegated to a practice used within tropical agriculture, and as a footnote about historical farming practices in industrialized countries. Intercropping can be defined as a system where two or more crop species are grown in the same field at the same time during a growing season (Ofori and Stern, 1987). Intercrop types include row intercropping: crops in alternating rows, strip intercropping: crops in alternating strips, mixed intercropping: crops mixed together, or relay intercropping: second crop overseeded into current crop (COG), 2001). Within tropical agriculture, intercropping is essential to food security, with estimates such as 98% of cowpeas in Africa, 90% of beans in Colombia and 80% of potatoes, 90% of corn and 80% of beans in Kenya being intercropped (Gutierrez et al., 1975 cited in Vandermeer, 1989) (Arnon, 1972 cited in Vandermeer, 1989) (Maina et al., 1996 cited in Hartwig and Ammon, 2002). For centuries farmers have used this technique, in a process of trial and error to create a combination of cropping systems that are uniquely suitable to their specific environments (Theunissen, 1997). Such subsistence farmers generally do not have access to large areas of land, hence the need for intensive production, nor do they have the resources to afford the chemical and mechanical supports that are the mainstay of conventional agriculture (Francis, 1986; Liebman, 1995). Thus, in the typically low-input areas used for production throughout developing countries, intercropping benefits such as yield stability, pest and disease suppression, and differential responses to nutrient and moisture stress are essential for survival (Anil et al., 1998). Temperate agriculture employed intercropping to a lesser extent historically, implementing techniques such as undersowing clover into wheat to control weeds and provide a fertilization benefit (Theunissen, 1997). These benefits were disregarded with the advent of the green revolution, with natural weed/pest controls and fertilizers replaced by synthetic fertilizers and pesticides, and the demand for ever-increasing production and efficiency leading to the machination and specialization of the production system itself (Theunissen, 1997). Despite the reliance on monocultures and uniform principles of management, examples of intercropping can still be found, such as the mixtures of grasses and legumes in pastures, and the growing reoccurrence of the underseeding of legumes into cereals (Francis, 1986; Liebman, 1995).

Intercropping is being increasingly re-examined in industrialized countries as a viable production strategy in response to the problems of conventional agriculture. Although conventional agriculture has allowed for increased production with less on-farm human labour, synthetic chemicals are the primary tool used to control weeds, insects and diseases, and this has led to environmental pollution, resistance of target populations (LeBaron and McFarland, 1990; Beckie et al., 1999), and negative effects to non-target populations (Grue et al., 1986; Floate et al., 1989; Elliott et al., 1997).

Effective intercropping attempts to benefit from varying patterns of resource utilization of the intercrops to provide for overyielding, yield stability, reduction of economic risk and pest pressures, increased quality of the crops, optimal water utilization and erosion control (Putnam and Allan, 1992; Theunissen, 1997). It is believed that the benefits of intercropping are realized through two theoretical principles: the "Competitive Production Principle" and the "Facilitative Production Principle" (Vandermeer, 1989). The Competitive Production Principle explains that optimal intercrops are those which have divergent resource requirements (Putnam and Allan, 1992). In having varied niches, intercrops may have less competition for light, water or nutrients than that of a monoculture in which the crops would have all of the same requirements (Putnam and Allan, 1992). This principle can be expressed in intercrops through varying rooting depths, soil N demands, maturities and canopy positions/cover (Putnam and Allan, 1992). The "Facilitative Production Principle" focuses on the benefits that one crop receives from the environmental modification produced by its intercrop (Putnam and Allan, 1992). The clearest example of this principle is found within the transfer of N from a legume to a non-legume intercrop, although shading in hot environments, tall plants as support for climbing plants, support crops for crops prone to lodging, and the reduction of pest/weed/disease pressures are further examples (Putnam and Allan, 1992).

2.3.1 Weed Suppression in Intercrops

The suppression of weeds is commonly stated as an advantage of an intercropping system (Moody, 1980; Shetty & Rao, 1979; Unamma et al., 1986; Robinson & Dunham, 1954; Ibgozurike, 1971; Liebman, 1986). Red clover (*Trifolium pratense* L.) in winter wheat was shown to significantly reduce common ragweed (*Ambrosia artemisiifolia* L.) biomass production in a study conducted in Michigan (Mutch et al., 2003) while British research showed that the addition of Italian ryegrass (*Lolium multiflorum* Lam.) or red clover to barley (*Hordeum vulgare* L.) or faba bean (*Vicia faba* L.) was effective at suppressing the growth of the perennial grass weed *Agropyron repens* (L.) Beauv. (Dyke and Barnad, 1976; Williams, 1972). Another study by Baumann et al. (2000) showed that a leek (*Allium porrum* L.)-celery (*Apium graveolens* L. var. *dulce* (Mill.) Pers.) intercrop reduced the density of *Senecio vulgaris* L. by 58% and biomass by 98%. The competitive pressure exerted by multiple crops in the agroecosystem reduces the available space for weed species. This enhanced competition can be exhibited through soil shading and resource competition that subsequently impedes weed germination and additional growth (Anil et al., 1998). Intercrops that include both dicotyledonous and monocotyledonous plants are particularly effective as they can compete with a wide range of weed species (Anil et al., 1998). This weed suppression capability has been readily observed within an array of cover crops planted in monoculture studies, with Liebman (1986) finding in a review of 23 cases of crop-cover crop systems that only three of the cases did not significantly suppress weeds. However, research on two crop combinations (e.g. grain-seed) is sparse in comparison, and the weed suppression abilities of combinations is quite variable (Vandermeer, 1989). Liebman and Dyck's 1993 review of the literature revealed that in 50% of the studies, weed biomass was lower than the intercrop biomass, intermediate in 42%, and higher in only 8% of the studies. Although there has been a very limited amount of studies done on intercropping in the prairies (Izaurralde et al., 1990; Waterer et al., 1994), and none of the studies were conducted under organic management, the proven competitiveness of intercrops suggests that they would be ideal for use in organic environments, where chemical weed control options are not available (Szumigalski and Van Acker, 2005).

2.3.2 Disease Suppression in Intercrops

Fungicides and breeding for resistance are the main controls for disease suppression in conventional agriculture, and yet these methods are becoming increasingly fallible. The need for alternatives to slow the spread of disease is imperative, and intercropping has been noted as a potential method for such goals (Theunissen, 1997). Mixed cropping and undersowing have provided variable results in disease reduction which are not easily explained due to the complex interactions that occur within a mixed cropping system (Theunissen, 1997). The presence of an intercrop changes the entire growing environment, with its presence influencing factors such as competition for resources, changes in soil conditions and organisms, and alteration of crop canopies (Theunissen, 1997). Three mechanisms have been suggested to explain the functioning of intercrops to reduce pest/disease pressure when impeding the growth and spread of the pest/disease in question (Trenbath, 1993). The first mechanism is that the intercrop causes the susceptible plant to be a "poorer" host (Anil et al., 1998). A poor host is one that has been altered by an intercrop in such a manner to make it less suitable to the pest/disease. For example, it may be reduced in vigour and stature within an intercropped environment (Anil et al., 1998). The second mechanism involves the intercrop providing direct interference against the pest/disease (Anil et al., 1998). The third mechanism is that the intercrop modifies the environment in such a manner as to attract natural enemies of the pest/disease in the host crop (Anil et al., 1998). By increasing the diversity of the agroecosystem, host crops are dispersed within the system, thereby slowing the spread of the disease as there is greater distance between host plants (Anil et al., 1998). This genetic diversity is particularly effective against airborne fungal pathogens (Vilich-Meller, 1992). A study by Vilich-Meler (1992) found that in a mixture of barley and oats, barley's main pathogen *Erysiphe graminis* f.sp *hordei* was significantly reduced, in some cases the reduction was equivalent to fungicide applications. In the wheat and rye mixtures of the study, *Puccinia recondita* f.sp. *tritici* on wheat and *Rhynchosporium secalis* on rye were significantly lower than in pure stands of the crops (Vilich-Meler, 1992). A recent study conducted in Denmark by Jensen et al. (2005) found that when barley is intercropped with pea, faba bean, or narrow-leaved lupin (*Lupinus angustifolius* L.), disease severity was reduced by at least 20% in all of the intercrop systems compared to the pure stands.

2.3.3 Intercropping as a Risk Management Strategy

Employing intercropping as a strategy to minimize risk in the cropping system is based on the simple fact that more than one crop is being grown in the field at the same time (Woolley and Davis, 1991). Yields are stabilized, as are net incomes, and it attempts to avoid total crop failure, such as can be the case in water-limited regions (Anil et al, 1998). By diversifying crops and incomes, a producer can better withstand widely variant weather and economic environments (Anil et al., 1998). Intercropping generally reduces yields of component crops from what they would be in monocultures, but intercrops have the potential to more effectively use the land area and hence be more productive than if the components were grown separately in monoculture (Liebman and Dyck, 1993).

Bulson (1997) found that wheat and beans planted at 75% of the recommended density under organic management used the land area more efficiently than monocultures of the crops and was more profitable. Szumigalski and Van Acker (2005) in a Manitoba study found that a wheat-pea intercrop treatment generally produced high total yields comparable to sole crop treatments of wheat and pea although the canola-pea intercrop treatment was the most productive compared to its monocultures and the most stable over the site-years. A farm-scale experiment carried out in Saskatchewan intercropping peas (*Pisum sativum* L.) and mustard resulted in overyielding of both pea-mustard and pea-canola crops over monocultures of the crops, along with higher net returns (Rosengren, 2005).

Intercropping can reduce the dependence of a cropping system on one crop, and on fertilizers (Ecological Agriculture Projects [EAP], 1997). This practice also provides for more flexibility in labour distribution, and allows for a farmer with limited capital to produce a wide range of products with the possibility to recoup investments in a shorter timeframe (EAP, 1997). Profitability of organic production relies on crop yield and price premiums over conventional products, but as price premiums can vary widely over time and markets, diversifying crops through intercropping can allow for stabilization in income that is not possible when reliant on one main crop (Smith et al., 2004).

2.3.4 Wheat and Cereal Intercropping

Growing oat/barley or oat/wheat intercrops used to be common practice to produce livestock feed on the prairies, but beyond nutrition and economics, there are added benefits to using cereal mixtures in the rotation (Entz et al., 1997). In Eritrea, farmers use “Hanfetse”, a mixture of wheat and barley that enables farmers to obtain a crop even through drought and disease pressures (Yahyaoui, 2000). Barley sustains production in dry seasons, and in rainy seasons, wheat performs well, and supports the barley (Yahyaoui, 2000). Disease incidence, specifically leaf rust (*Puccinia triticina*) on wheat, and scald (*Rhyncosporium secalis*), net blotch (*Pyrenophora teres*) and spot blotch (*Bipolaris sorokiniana*) on barley is reduced within these mixtures. By reducing inoculum within the cropping system and slowing disease spread, yields are increased through this practice that farmers have learned from experience will protect them from total crop failure (Yahyaoui, 2000).

Modern conventional agriculture's strategy of employing vertical resistance in cultivars coupled with heavy reliance on fungicides to control pathogens is responsible for producing epidemics (Wolfe et al., 1976; Walther, 1987 cited in Vilich-Meller, 1992). Simulation models (Mundt and Leonard, 1986) show that increasing host genotypes within a mixture will improve the resilience of that mixture to pathogen attacks. The increased genetic heterogeneity found in interspecific cereal mixtures then, should be even more effective than cultivar mixtures or mutilines in suppressing disease (Vilich-Meller, 1992). Such mixtures of cereal species were used widely on marginal land in Germany in the early 1900s to protect against total crop failure (Vilich-Melller, 1992). Modern industrial agriculture required the uniformity of monocultures and standard qualities for milling, however, and cereal mixtures were abandoned (Vilich-Meller, 1992). Such requirements are not applicable to animal feed grains as they are commonly mixed after harvest to provide for a balance of essential nutrients and no variation of quality between field and postharvest grain mixtures has been found (Vilich-Meller, 1992). Tränker (1987, cited in Vilich-Meller, 1992) also provided evidence that field mixtures of grain such as wheat and rye are capable of providing good baking quality flour.

Disease reduction in mixtures is considered to be mainly the result of induced resistance (Chaudhary et al., 1983; Thordal-Christensen and Smedegard-Petersen, 1988) with pre-inoculation experiments to promote induced resistance in cereals bringing about a 30-40% reduction in susceptibility to powdery mildew (Vilich-Meler and Weltzien, 1990). Induced resistance occurs when avirulent spores land on the tissue of a host plant and subsequently cause a resistance reaction in the tissue to spores that would have been otherwise virulent to the host tissue (Lannou and Pope, 1997). Interspecific mixtures also provide genetic barriers to the spread of pathogens as they contain non-host plants and limit pathogen spread even in early stages of disease development through spore trapping on non-host plants (Vilich-Meller, 1992).These mechanisms of disease suppression and compensation in growth by unaffected plants contributes to a stabilization and potential increase of yields within the cereal mixture (Taylor 1978; Burdon and Whitbread, 1979).

2.3.5 Wheat and Other Seed Intercropping

In the selection of potential intercrop partners for wheat, many factors can be considered such as the economic benefit of diversifying the crop, if plant architecture will provide varied canopies and rooting depths thereby affecting resource utilization, and the potential nitrogen benefits if a nitrogen-fixing crop is included. Intercropping may also resolve production issues that arise with monocultures of some crops (Carr et al., 1993). For example, a crop considered a weak competitor, such as flax (*Linum usitatissimum* L.), may benefit from being intercropped with wheat as wheat may ease its emergence from crusted soil, provide a cool, humid canopy and compete with weeds for resources (Carr et al., 1993).

Tropical agriculture routinely uses cereal-pulse mixtures to obtain increased total seed production (Rao et al., 1987; Clark and Myers, 1994), but this practice is seldom used in temperate conventional agriculture (Carr et al., 1995). A legume intercrop can release nitrogen into the soil that can be taken up by a non-legume crop and subsequently increase its yield to more than would be possible in monoculture (Clark and Myers, 1994). There are many studies demonstrating the ability of legume intercrops to overyield (Kass, 1978; Davis et al., 1986; Amador and Gliessman, 1990). This overyielding can be attributed not only from the association with *Rhizobium* bacteria that fix atmospheric nitrogen into a plant-available form, but also from associations with vesicular-arbuscular mycorrhizae (Hayman, 1986).

A study conducted in Denmark (Hauggard-Nielsen et al., 2001) found that an intercrop of barley-pea resulted in higher total grain yields than would result from pea or barley monocultures. Another European cereal-legume intercrop study by Haymes and Lee (1999) found that in an intercrop of wheat-field bean, an overyielding of grain of up to 40% was achieved. In the Canadian prairies and northern Great Plains, results have been mixed. Carr et al. (1995) found a possible slight yield benefit to intercropping wheat and lentil while Izauralde (1990) found no grain yield advantage in intercropping barley and field pea although grain N was higher in the intercrop treatments. Szumigalski and Van Acker (2005) found that in the absence of herbicides, the wheat-canola (*Brassica napus* L.) intercrop treatment had the greatest overall grain yield stability compared to the wheat-canola-pea, wheat-pea, wheat-canola and wheat and pea sole crop treatments, while the wheat-canola-pea treatment achieved repeated overyielding in crop biomass. Both wheat-canola and wheat-canola-pea treatments also tended to have enhanced weed suppression compared to the sole crop treatments.

2.3.6 Wheat and Cover Crops

A cover crop can be defined as "any living ground cover that is planted into or after a main crop and then commonly killed before the next crop is planted" (Hartwig and Ammon, 2002). Cover crops are typically utilized as green manure or forage crops, but may not be considered as an ideal option in areas where producers can continuously grain crop (Thiessen Martens et al., 2001). Intercropping of cover crops and corn and other crops has been studied within the USA and Canada (DeHaan et al., 1997; Adbin et al., 1998; Hesterman et al., 1992) but information on intercropping systems which utilize cover crops and are suited to the Canadian prairies is sparse. Thiessen Martens et al. (2001) found that relay cropped (red clover/alfalfa) or double cropped (chickling vetch (*Lathyrus cicera* L.)/black lentil (*Lens culinaris* Medik. Subsp. *culinaris*) legumes in winter wheat and spring rye did not significantly reduce crop yields and could be a viable cropping system in southern Manitoba. Reynolds et al. (1994) intercropped wheat with the cover crops common vetch (*Vicia sativa* L.) hairy vetch (*Vicia villosa* Roth), berseem clover (*Trifolium alexandrium* L.), crimson clover (*Trifolium incarnatum* L.), New Zealand white clover (*Trifolium repens* L. New Zealand) and Ladino white clover (*Trifolium repens* L. Ladino) and found that the cover crops did not significantly affect wheat yields. Although yield was not increased, hairy vetch and berseem clover increased wheat grain protein by 18 and 11% respectively over the control treatment when green manured (Reynolds et al., 1994).

Nitrogen-fixing cover crops release nitrogen into the cropping system, with subsequent crops greatly benefiting from this nitrogen source (Ebelhar et al., 1984; Hargrove, 1986; Mitchell and Teel, 1977). The total nitrogen contribution of the cover crop is determined from its total dry matter (Fribourg and Johnson, 1955; Holderbaum et al., 1990); hairy vetch being an example of a cover crop that has achieved the highest nitrogen content and productivity in numerous studies (Holderbaum et al., 1990; Nelson, 1944; Frye et al., 1988; Pridham and Entz, unpublished). Although the main cover crop species used are nitrogen-fixing legume species, grasses and crucifers are also utilized for cover cropping purposes (Liebman et al., 2001).

A wide range of cover crop species can be effective in achieving the main purpose of cover crops, that of soil and water retention (Hartwig and Ammon, 2002). Both the above-ground and below-ground biomass of cover crops protect against erosion by rain and wind, increases organic matter, improves soil structure, tilth, water-holding capacity and can also be effective for weed control (Hartwig and Ammon, 2002). Cover crops can aid in the prevention of escape weeds and new weeds entering the cropping system (Hartwig, 1988; 1989) and in some cases can suppress weeds to near perfect weed control (Else and Ilnicki, 1989; Degregorio and Ashley 1985; 1986). Cover crops have also been shown to increase the potential for mycorrhizal fungi colonization of subsequent crops, which benefit the crop plant through aiding in nutrient acquisition (Sorensen et al., 2005; Kabir and Koide, 2000).

Although cover crops were largely abandoned with the advent of production systems based upon chemical fertilizer and herbicide supports, environmental concerns and the rising cost of inputs are renewing interest in the use of cover crops in the production system.

2.4 Cultivar Mixtures

Cultivar mixtures were used on a large scale in the former German Democratic Republic in the 1980's for the majority of spring barley, and in Poland in the 1990's on 60,000 ha of spring barley and is used in Denmark, Switzerland and the USA for the purposes of reducing pesticide inputs while maintaining yield and quality (Newton, 1997).

When monocultures of disease-resistant varieties are grown across large areas it often results in a rapid breakdown of the disease resistance due to high selection for pathogens able to overcome the resistance (Newton, 1997). These "boom-and-bust" cycles have been observed extensively in cereal crops, but few options outside single race-specific resistant cultivars are available (Mundt, 2002b). Modern agriculture has seen the demise of the practice of using local bulk-selected landraces that contain varied disease resistances (van Leur et al., 1989; Broers and Dehaan, 1994). Although genetically diverse landraces are no longer available in industrialized countries, the principle of diversity can still be implemented to reduce disease spread through the use of cultivar mixtures.

Cultivar mixtures are mixtures of cultivars that are agronomically compatible, but have no additional breeding for phenotypic uniformity (Mundt, 2002b). Using cultivar mixtures as a strategy of disease suppression was first academically proposed by Jensen (1952) for use in oats while Borlaug (1959) and Frey et al. (1973) chose to promote multilines for this purpose in wheat and oats. While multilines, a method using backcrossing to develop cultivars with variant race-specific disease resistance genes, have had success, cultivar mixtures are being considered as a more practical and superior alternative to this approach (Akanda and Mundt, 1997). Cultivar mixtures present an agronomic advantage to multilines as they can be selected from already existing cultivars which eliminates the need for the additional breeding required by multilines (Akanda and Mundt, 1997). In addition, the increased levels of genetic diversity in cultivar mixtures, in comparison to multilines, can provide for resistance against non-target diseases and halt the progression of pathogens with multiple virulence genes (Akanda and Mundt, 1997; Mundt, 1994).

The control of polycyclic foliar pathogens by cultivar mixtures has been repeatedly demonstrated but little is known about the effects on other pathogen types (Garrett and Mundt, 1999; Wolfe, 1985). Wheat cultivar mixtures have been shown to be effective at reducing the severity of tan spot (*Pyrenophora tritici-repentis*), a residue-borne pathogen with a steep dispersal gradient (Cox et al., 2004). The same study also demonstrated that the cultivar mixtures were most effective against leaf rust (*Puccinia triticina*), a windborne, specialized, polycyclic pathogen with a shallow dispersal gradient (Cox et al., 2004). There have been few studies addressing diseases other than wind-dispersed pathogens and most of the studies that do exist have produced inconsistent results (Cox et al., 2004). Cultivar mixtures targeting wind-dispersed pathogens however, can be quite successful and in some cases can provide nearly complete disease suppression when the components chosen for the mixture are relevant to the pathogen pressures (Mundt, 2002b). A study by Zhu et al. (2000) on blast disease in rice (*Oryzae sativa*) showed a blast disease severity reduction on the susceptible varieties of 94%

within the cultivar mixtures of susceptible and resistant varieties and the yield was increased by 89% compared to monocultures of the varieties.

The major diseases affecting wheat production in the Canadian prairies include leaf rust, Septoria leaf and glume blotch (*Stagnospora nodorum, Septoria tritici*) and tan spot (*Pyrenophora tritici-repentis*). Cultivar mixtures have been proven effective against the spread of rust pathogens (Mahmood et al., 1991; Hartleb et al., 1986; Leonard, 1969) and tan spot (Cox et al., 2004) but only inconsistent disease reductions have been observed for Septoria tritici blotch resultant from the causal agent *Mycosphaerella graminicola* in cereals (Cowger and Mundt, 2002). The mechanisms for the reduction of residue and soil-borne diseases in cultivar mixtures are not clearly understood (Cox et al, 2004; Mundt, 2002b; Mundt et al., 1995) and further research is required in order to exploit optimal functioning of cultivar mixtures in reducing these types of pathogens.

2.4.1 Yield and Crop Ecology

Cultivar mixtures are a relatively quick and cheap method of incorporating diverse disease resistances into a crop and achieving yield stability and increases without having to greatly alter production methods (Newton, 1997). Under disease pressure, cultivar mixtures have been shown to yield more than the means of the monocultures of their components (Finckh and Mundt, 1992a; Czembor and Gacek, 1996; Gacek et al., 1996a,b). Disease control is not the sole reason for yield increases; yield increases can also be attributed to competition and compensation between the cultivars in the mixture (Allard, 1960; Finckh and Mundt, 1992a,b). Complementary use of resources and divergent niches may also play a role in higher yields, as in intercropping systems (Gallandt et al., 2001). Intragenotypic competition must be greater than intergenotypic competition for the yield to be increased and mixtures should be chosen for their suitability to specific environments (Newton, 1997).

Apart from disease resistance considerations, cultivars should also be chosen for their "ecological combining ability": their ability to increase in yield when bordered by other genotypes moreso than when bordered by their own genotype in addition to increasing the yield of a neighbouring genotype (Finkh and Mundt, 1992). Wheat mixtures have been shown to alter in the proportions of their components due to competitive effects (Khalifa and Qualset, 1974; Tapaswi et al., 1991). However, wheat cultivars similar in yield and environmental adaptation have been shown to establish equilibrium and some mixtures actually improve upon their performance as they are adapted to particular farm environments and are resown (Finckh and Mundt, 1993). Although yield results of cultivar mixtures can be quite variable, a 1996 summary of data by Smithson and Lennè, from over 60 studies involving cultivar mixtures of cereals (barley, wheat and oats), showed that the cereal mixtures that exhibited the greatest yield advantage over monocultures of their components were wheat mixtures.

Cultivar mixtures may require additional production efforts over that of monocultures, but with adequate planning, variations between cultivars may actually become benefits to harvesting (e.g. reducing lodging) (Mundt, 2002b). Mixtures can be acquired from some of the largest companies in the United States and can be a valuable niche market for producers (Mundt, 1994). Although some quality and agronomic qualities must be adhered to, this is not an impossible issue – 13-18% of Oregon and Washington winter wheat is grown within cultivar mixtures without difficulties in production or marketing (Oregon Department of Agriculture, 2000; Washington State Department of Agriculture, 2000 cited in Mundt, 2002b).

Diversifying organic spring wheat production in western Canada is of critical importance. Dependence on a "limited number of progenitors and …intensive backcrossing" to adhere to quality standards has resulted in a base of genetic diversity that is "dangerously narrow" for Canada Western Red Spring wheat [CWRS] (Lamari et al., 2005). With such little genetic diversity, the crop is susceptible to devastating epidemics (Lamari et al., 2005).

2.4.2 Disease Suppression

Studies in wheat mixtures have presented many mechanisms to explain the disease severity reduction of windborne polycyclic foliar pathogens that occurs within cultivar mixtures (Mundt, 2002b). Cultivar mixtures, and the positive impact diversity has on wheat yellow rust (*Puccinia striiformis*), wheat brown rust (*Puccinia recondita*) and barley powdery mildew (*Erysiphe graminis*) has been repeatedly demonstrated (Calonnec et al., 1996; van Asch et al., 1992; Finckh et al., 1999).What is considered a major mechanism responsible for such decreased disease severity is the reduction of disease inoculum due to the increased distance between plants of the same genotype (Mundt, 2002b). Resistant/non-host varieties can also provide a "barrier effect" by blocking the movement of spores between susceptible plants (Newton, 1997). Modifications of the physical environment as a result of morphological differences in cultivars (i.e. a denser stratified canopy), may also reduce disease incidence within the mixture through limiting air and vertical splash dispersed spore movement (Newton, 1997). Another mechanism believed to affect disease suppression is that of induced resistance due to the production of avirulent races or varied pathogen populations (Lannou et al., 1995; Zhu et al., 2000). Disease suppression can also be achieved through race nonspecific resistance to the target disease, varied resistances to non-target diseases and reduced selection for a race that has virulence to all cultivars in the mixture (Finckh and Mundt, 1992).

The efficacy of cultivar mixtures in suppressing the spread of disease is determined by the underlying cause of the epidemic. For example, if a monoculture is experiencing an epidemic due to an outside source of inoculum, then a cultivar mixture cannot provide reliable suppression under a severe epidemic (Mundt, 2002b). Cultivar mixtures tend to be most effective under circumstances where the epidemic is initiated by successive pathogen generations as has been demonstrated repeatedly in the case of rusts and powdery mildews (Browning and Frey, 1969; Mundt and Browning, 1985; Wolfe, 1985; Mundt, 2002b).

Disease suppression is achieved most effectively by cultivar mixtures when the pathogen's host is marginal within the mixture, there is a shallow dispersal gradient of the pathogen, the pathogen is highly specialized towards the host, lesion sizes are small, and there are many pathogen generations (Garrett and Mundt, 1999). Reductions of soil-borne and residue-borne pathogens within cultivar mixtures have still not been sufficiently explained by any specific mechanism, although environment and secondary spread of the disease could greatly influence whether the cultivar mixture will be effective against the pathogen (Mundt, 2002b; Mundt et al., 1995; Cox et al., 2004).

The main non-chemical defence against pathogen attack is disease-resistant varieties, but this strategy cannot provide long-term pathogen protection. Breeding for disease-resistant varieties also requires significant infrastructure and expense that is not possible for minor crops. Cultivar mixtures, however, have shown potential in slowing the rapid progression of host resistance breakdown (Manthey and Fehrmann, 1993; Wolfe and Barrett, 1980; Wolfe, Barrett and Jenkins, 1981). In 1975, Kilpatrick found that on average, race-specific resistance to rust was effective only for about 5 years, and more recently Mundt (1994) reported that resistance in club wheat cultivars in Oregon only maintained resistance to yellow rust pathogens for 2-3 years. In western Canada, AC Barrie, a CWRS wheat representing 38.4% of hard red spring acreage in 2001, was completely resistant to leaf rust (*Puccinia triticina*) when released in 1994, but by 2001 had "poor" resistance (McCallum, 2001). Manthey and Fehrmann (1993) observed successful disease reduction against powdery mildew and stripe rust particularly under mixtures of three cultivars as opposed to two and under management with no fungicide, which suggests increased diversity and low input environments are the optimal conditions for implementation of cultivar mixtures.

Despite the potential benefits of cultivar mixtures on disease suppression and yield stability, yields from mixtures can be lower or marginally higher than component monoculture yields due to the lack of diversity available in disease resistances in cultivars as well as competitive effects between cultivars (Newton, 1997; Finckh and Mundt, 1992). Also, if the resistance genes are not varied, then pathogen populations are able to overcome the components of the mixture (Newton, 1997). Although disease suppression is the primary goal of cultivar mixtures, agronomic uniformity in planting dates, harvesting and standard quality is also desired which then limits the range of resistance genes that can be utilized (Newton, 1997). For CWRS wheat in western Canada, a new variety has to match the reference variety in terms of quality, agronomic and disease performance, while also adhering to the kernel visual distinguishability of the wheat class (Canadian Wheat Board, 2006). This desire for uniformity conflicts with studies that show that with increasing diversity comes increasing resilience against the spread of disease; there have been significant correlations found between additional cultivars in a mixture and improving disease reduction and yields (Newton et al., 1997).

2.4.3 Weed Suppression

Disease suppression is the primary benefit of implementing cultivar mixtures, but weed suppression is also expected to be enhanced in cultivar mixtures over monocultures due to morphological differences in the cultivars and increased competition. Currently, the intergovernmental European scientific cooperative research initiative, COST860 (SUSVAR), which focuses on sustainable low-input cereal production, has discussed weed suppression by cultivar mixtures as a future research interest (COST860, 2005). As there is a lack of past and current research on this topic, it is believed that the literature on intercropping can be considered applicable to cultivar mixtures (COST860, 2005).

Competition studies involving cultivar mixtures can also be of benefit when considering components to include within a mixture that will be effective against weed pressures. A study of perennial grass mixtures in northern Tibet found that certain grass species were more competitive than others in the mixtures, and the mixture which included all of the varieties of grass species was the most productive regardless of weed presence (Dong et al., 2004). Evaluating a cultivar's performance within the mixture is essential as studies of competitive ability of cereals in mixtures found that the genotype that obtained the highest yield in monoculture did not translate into superior competitive ability in a mixture (Jokinen 1991a, 1991b; Jedel et al. 1998).

2.5 Heritage and Modern Varieties in Organic Production

2.5.1 Competitive Traits

Among some organic producers, there is the belief that heritage varieties of wheat (those in use between 1880 and 1950) will be better suited to organic production. The rationale is that these varieties were in use before the advent of high input agriculture, and would therefore be better suited to a low input environment. The variety of wheat that was responsible for turning Canada into "the grain elevator of the British Empire" (Buller, 1919) was Red Fife, a landrace which is believed to have originated from the Ukraine (Symka, 1999). Red Fife was introduced to Canada in 1842 and by 1880 it had been the choice of growers for 20 years and was considered the world's best spring wheat with exceptional milling and baking qualities (Symka, 1999). In 1904, in response to the Canadian farmers' need for an earlier maturing variety, Marquis was created by Charles Saunders as a cross between Red Fife and the earlier maturing Indian wheat Hard Red Calcutta (Symka, 1999). Marquis became the "greatest practical triumph of Canadian agriculture" (Bulson, 1919) due to its early ripening, high yield and superior quality grain and flour and it nearly replaced all of the spring wheat varieties grown in the United States and Canada (Symka, 1999). Marquis however proved to be susceptible to stem rust during a rust infestation in 1915, and repeated severe crop losses forced the government to pursue the development of rust resistant varieties (Agriculture and Agri-Food Canada, 2001).

An evaluation of certain heritage and modern wheat varieties under a high fertility organic regime in Atlantic Canada found that the heritage variety Red Fife had the highest grain yield and harvest index in plots which contained weeds (Evans et al., 2004). In the weed-free plots, Red Fife had the lowest harvest index, and the modern cultivar had the highest harvest index, indicating Red Fife's suitability for weedy and possibly less fertile areas while modern varieties perform best under conditions that are high fertility and weed free (Evans et al., 2004).

One of the most important features of modern wheat cultivars is short stature (Cox et al., 1988). Modern varieties have been bred to exhibit a shorter stature in an effort to increase yield (i.e., higher harvest index, less lodging). However, questions remain about whether short-statured varieties are as competitive as tall varieties. Valentine (1982) and Jedel et al. (1998) found that a barley genotype with a tall, erect phenotype had the competitive advantage over genotypes with prostrate, short phenotypes and Khalifa and Qualset (1974) concluded the short stature of certain components in their wheat mixtures yielded less due to reduced competitive ability in comparison to the taller components. In Khalifa and Qualset's (1974) study, they believed that light interception by the taller varieties was responsible for giving them a competitive advantage and hence increased yields in comparison to the shorter statured varieties. A study conducted in Australia corroborates these findings in a test of 250 wheat varieties including heritage and modern varieties which demonstrated the competitive advantage of taller varieties (Lemerle et al. 1996). Heritage varieties, which are typically taller than modern varieties, were found to be more effective at suppressing weeds than modern varieties due to traits such as their tall growth habit, vigorous early growth, tillering, and expansive leaf area (Lemerle et al. 1996).

Heritage varieties may also be more responsive to mycorrhizal colonization than modern varieties of wheat. In a study of modern bread wheat cultivars, older cultivars and wheat ancestors, there was a trend in older cultivars towards a greater reliance on mycorrhizal symbiosis than the modern cultivars (Hetrick et al., 1992). This increase in reliance suggests that modern breeding techniques have reduced mycorrhizal responsiveness in wheat cultivars (Hetrick et al., 1992). A pot experiment conducted on old and modern wheat cultivars also showed that mycorrhizal reponsiveness in terms of shoot P concentrations was reduced in modern wheat cultivars in comparison to old wheat cultivars (Zhu et al., 2001). Although research in this area is limited, the suggested increased mycorrhizal responsiveness in older wheat varieties would make them more adapted to the lower fertility regimes characteristic of organic production than modern varieties.

2.6 The Economics of Organic Production

2.6.1 The Organic Market

Within the global food industry, the organic food sector has undergone dramatic growth within the past two decades, rapidly progressing from a niche market to a $23 billion industry (Macey, 2004). Within Canada, the organic sector has been growing by an estimated 20% each year for the past decade, with organic retail sales predicted at $3.1 billion for 2005 and the export market valued at $63 million in 2003 (AAFC, 2003; Macey, 2004). Consumer demand is outpacing supply and in 2003, it was estimated that $74 million of fresh produce and $82 million of grocery items were imported for the retail market (Macey, 2004). Canadian organic production supplies only 22% of fresh produce and 10% of organic grocery items (Macey, 2004).

2.6.2 Organic Production Benefits and Constraints

Organic production may experience lower yields than that of conventional systems, but reductions in terms of fertilizer and pesticide costs as well as the addition of price premiums allow for a profitable enterprise (Lockeretz et al., 1981; Stanhill, 1990; Smith et al., 2004). Organic enterprises encounter lower fixed costs associated with depreciation and interest charges on expenditures such as machinery and equipment, while costs are further reduced for purchased feed, veterinary bills and replacement livestock (COG, 2001). A U.S. study could not find any evidence that organic operations were less profitable than their conventional counterparts (Dimitri and Greene, 2002). Price premiums, however, can fluctuate greatly from year to year, necessitating risk management measures by producers (Smith et al., 2004). Organic producers often have to deal with additional marketing costs, may not be sufficiently covered by crop insurance, and may experience losses due to their crop rotation (Smith et al., 2004). Other factors that can affect profitability are labour, soil building costs and level of experience (Smith et al., 2004; Hanson et al., 1997). As organic agriculture expands, many new to the practice may have little to no experience in the methods and their profitability will reflect this (COG, 2001). Especially difficult are the transition years of organic production, as yields will be lowered while the agroecosystem adapts to a management system that functions without the control of synthetic fertilizers, herbicides and pesticides (COG, 2001). Price premiums are not applicable during transition, and the productivity of the system can take anywhere from 3-10 years depending upon how reliant the system previously was on chemical control (COG, 2001).

When making the decision to transition to organic production, a producer will have little support from the traditional modes of production information: other farmers, chemical salespeople and governmental agricultural agencies (Duram, 1999). Fortunately, information is now more readily available than it was a decade ago; organic farming organizations provide support to producers across the country, COG provides information to growers and works to protect their interests, the Organic Agriculture Centre of Canada was established in 2001 specifically for research and education focused on organic agriculture and university research regarding organic agriculture has also been increasing (AAFC, 2003; Entz et al., 2001; Barberi, 2002; Jawson and Bull, 2002). Although information and awareness regarding organic agriculture is increasing, there is still not an adequate infrastructure available to handle the distribution and marketing of organic products, and federal and provincial regulations hinder this process further while credit agencies are hesitant to finance organic production (Hill, 1992; COG, 1990; MacRae et al., 1990; Henning et al., 1990a;b; MacRae et al., 1990a). These obstacles can be surmounted, however, and organic farms have shown themselves to be capable of profitability amidst the "bankruptcies and abandonments" experienced by conventional farmers (Cleary and Martin, 1990).

2.7 Literature Review Summary

Organic agriculture has progressed from a niche market into a recognizable presence in the retail sector. Although organic production practices are generally considered a marginal proportion of agriculture, it has become an increasingly supported and profitable alternative amidst mounting public concerns over environmental and human health. Natural ecosystems and historical agriculture systems have shown that diversity is the key component to the long term stability of a system, which is why organic agriculture, as the "sustainable agriculture" option for the developed world, should strive to increase the diversity of its production practices.

Having an effective crop rotation can improve crop and soil quality and work to break weed and pest cycles, but this practice still relies on the uniform monocultures of conventional agriculture. Intercropping and cultivar mixtures have been used before the advent of high-input agriculture, and to sustain the diet and livelihoods of subsistence farmers around the world, and they should once again be considered as methods to enhance the biodiversity of an agroecoystem and naturally suppress the weeds and diseases within the crops. The genotypic and phenotypic diversity that can be present within intercrops allows for more efficient use of resources while providing competition against weeds and providing a non-host barrier to pathogens. Cultivar mixtures can also benefit from these same processes, though to a lesser extent, as genotypic and phenotypic differences are not as varied as those of intercrops, but there are few production constraints using this practice.

Many farmers and scientists may argue against the implementation of intercropping due to difficulties that would be encountered with seeding and harvesting, but such problems are just engineering questions, and can be solved. North America lacks the local knowledge that many tropical countries have in regards to what crop mixtures can succeed in their local environments, and the benefits of reduced chemical use, improved soil quality, stable yields and suppression of weeds, diseases and pests should no longer be ignored (Hartwig and Ammon, 2002).

3.0 MATERIALS AND METHODS

3.1 Background

Intercropping and cultivar mixture trials were conducted at the University of Manitoba Plant Science research station located at Carman, Manitoba in 2004 and 2005 and on a certified organic farm at Clearwater, Manitoba in 2004. Climate data was obtained from the weather monitoring station at Carman in 2004 and 2005 and for Clearwater, Manitoba data was obtained from the nearest Environment Canada station at Pilot Mound, 17km northwest of Clearwater. (Table 3.1, 3.2).

Table 3.1. Mean monthly temperature in Celsius for Carman 2004, Clearwater 2004 and Carman 2005 sites.

Month	Clearwater[a] 2004	Carman[b] 2004	Carman[b] 2005	Long Term[c] Mean Carman	Long Term[d] Mean Clearwater
April	3.5	4.2	7.1	4.4	3.5
May	6.9	7.8	10.2	12.4	11.3
June	13.2	14.6	17.4	17.2	15.8
July	16.9	18	19.7	19.7	18.7
August	13.3	14	17.6	18.1	17.9
September	13.3	14.1	14.3	12.2	11.6
October	4.9	6	6.6	5.7	5.1

[a] Source: Environment Canada data for Pilot Mound, Manitoba.
[b] Source: Environment Canada data for the University of Manitoba Carman Research Station.
[c] Source: Environment Canada 30 year average from 1971-2000 for Graysville, Manitoba.
[d] Source: Environment Canada 30 year average from 1971-2000 for Pilot Mound, Manitoba.

Table 3.2. Total monthly precipitation in millimetres for Clearwater 2004, Carman 2004 and Carman 2005 sites.

Month	Clearwater[a] 2004	Carman[b] 2004	Carman[b] 2005	Long Term[c] Mean Carman	Long Term[d] Mean Clearwater
April	45.2	21.0	19.0	38.4	35.9
May	235.4	116.6	88.6	61.1	58.2
June	86.4	32.4	139.8	75.5	82.1
July	137.4	50.2	89.6	73.5	63.6
August	33.6	76.6	23.6	66.8	69.6
September	21.8	87.0	31.2	59.9	56.0
October	13.6	35.2	26.8	43.8	37.7

[a] Source: Environment Canada data for Pilot Mound, Manitoba.
[b] Source: Environment Canada data for the University of Manitoba Carman Research Station.
[c] Source: Environment Canada 30 year average from 1971-2000 for Graysville, Manitoba.
[d] Source: Environment Canada 30 year average from 1971-2000 for Pilot Mound, Manitoba.

In 2004, the soil from the Clearwater experimental site was randomly sampled before any field operations from 0-15 cm and 15-60 cm with a hand auger and sent to Norwest Labs for analysis of plant available nutrients (Table 3.3). For Carman 2004, a soil test was used from soil samples taken from plots in the same block and submitted to Agvise Labs for analysis of plant available nutrients. At Carman in 2005, the randomly sampled soil from the experimental site was also sent to Agvise Labs for analysis of plant available nutrients.

Table 3.3. Soil nutrient analysis from Clearwater in 2004 and Carman in 2004 and 2005.

Site-year	Soil type	N*	P**	K	S***
		----------	---------- ppm	----------	----------
Clearwater 2004	clay loam	32	8	256	28
Carman 2004	Winkler clay	77	33	534	54
Carman 2005	Hibsin fine sandy loam	62	21	346	26

* Nitrate-N **Carman 2004 and 2005 Phosphorus analyzed as Olsen Bray Phosphorus by Agvise ***Sulphate-S

All of the experimental trials were randomized complete block designs with four replicates. Seeding operations were undertaken using a Fabro plot seeder with a no-till disc drill (Fabro Enterprises Ltd., Swift Current, SK) with 15 cm row spacing. Experimental plots for the intercrop trial were 4 metres x 8 metres while the cultivar mixture trial plots were 2 metres x 8 metres. Seeding and harvesting information are provided in Table 3.4.

Table 3.4. Seeding dates, weed and crop emergence counts, staging, biomass harvests, disease assessment and harvests from Clearwater 2004, Carman 2004 and Carman 2005.

Site-year	**Seeding**	**Emergence counts**		**Staging**	**Disease**	**Biomass harvest**		**Harvest**
		Crop	**Weed**			**Anthesis**	**Maturity**	
Clearwater 2004								
Cultivar Mixtures	May 28	June 16	June 28	June 29	Aug. 27	--	Aug. 24	Sept. 16
Intercrop Systems	May 28	June 16	June 29	June 30	Aug. 18	July 22	Aug. 24	Sept.16
Carman 2004								
Cultivar Mixtures	June 3	June 18	June 25	July 5	Aug. 20	--	Sept. 1	Sept. 27
Intercrop Systems	June 3	June 18	June 25	July 5	Aug. 17	July 20, 21	Aug. 23	Sept. 27?
Carman 2005								
Cultivar Mixtures	May 17	June 6	June 10	June 23	Aug. 5	July 19	Aug. 9	Aug. 30
Intercrop Systems	May 17	June 6	June 10	June 23	Aug. 4	July 13	Aug. 9	Aug. 18

3.2. Intercrop Trial

The intercrop trial was established at Clearwater in 2004 on land which had previously grown alfalfa for three years and at Carman in 2004 on land that had previously grown oats in 2003. This trial was also established at Carman in 2005 on land that in 2004 had an oats and field pea green manure crop and in 2003 grew wheat. Intercrops requiring a deeper seeding depth and wheat were seeded at the same time in the 4m x 8m plots at 15 cm row spacing at approximately 2.5 - 3.8 cm in depth, but small intercrops requiring shallower seeding depths (flax, oriental mustard (*Brassica juncea* L.), red clover, hairy vetch, annual ryegrass (*Lolium multiflorum* Lam.)) were planted in a second seeder pass which was slightly offset from the initial pass and approximately 0.6 - 1.3 cm in depth. All plots were driven over twice with seeders to provide for equal disturbance. At Clearwater in 2004, the spinner of the seeding equipment was not engaged during the wheat and barley intercrop treatment seeding which resulted in the barley being distributed only in two rows of the plots. The wheat and barley intercrop treatment plots were then tilled and reseeded but not included in the measurements or analyses of the trial.

The intercrop trial consisted of three intercropping systems, the first of which was a wheat and cereal intercrop system comprised of a wheat and oat treatment, a wheat and barley treatment, and a wheat and spring rye treatment. The second system was a wheat and other seed intercrop system which contained a wheat and flax treatment, a wheat and field pea treatment and a wheat and oriental mustard treatment. The third system was a wheat and cover crop system which included wheat and red clover, wheat and hairy vetch and wheat and annual ryegrass treatments. The wheat in each of these treatments was AC Barrie and it was seeded at 150 viable seeds m^{-2}. Also included in this trial was a half-rate wheat treatment and a full-rate wheat treatment. The half-rate wheat treatment was also seeded at 150 viable seeds m^{-2} while the full-rate wheat treatment was seeded at 300 viable seeds m^{-2} to simulate a normal seeding rate of wheat in monoculture. The intercrop components were seeded at half of their recommended seeding rate, except in the case of flax where it was seeded at the initial site at its full seeding rate and it was decided to maintain this across all site years. The varieties, when certified seed was used, and seeding rates were as follows: Ronald Oats, 115 plants m^{-2}, Robust Barley, 125 plants m^{-2}, Spring Rye, 120 plants m^{-2}, Bethune Flax, 560 plants m^{-2}, DS Stalwarth field peas, 40 plants m^{-2}, Forge Oriental mustard, 60 plants m^{-2}, Red clover, 6 kg ha^{-1}, Hairy vetch, 16.85 kg ha^{-1}, and Annual ryegrass, 11 kg ha^{-1}. Red clover, field peas and hairy vetch were all inoculated prior to seeding with appropriate inoculant which was approved for use under organic certification.

3.3 Cultivar Mixture Trial

The cultivar mixture trial was located adjacent to the intercrop trial in all site years, and so the cropping histories were identical for the cultivar mixture trial and intercrop trial. The cultivar mixture trial included two cultivars of Canada Western Red spring wheat, 5602HR and AC Barrie, and two heritage spring wheat cultivars, Red Fife and Marquis. These cultivars were used in treatments of sole varieties, treatments of all combinations of two varieties together, treatments of all combinations of three varieties together, and a treatment of all four varieties together for a total of fifteen treatments. The treatments were seeded proportionally to achieve a final seed population of 300 viable seeds m^{-2}.

The varieties of spring wheat included within this trial possessed a variety of disease resistances and phenotypic characteristics. Red Fife and Marquis are presumed to be susceptible to disease, but were included for their taller habit and to test the assumption that they are more adapted to an organically managed system as they were used before the advent of high-input cropping systems. A new cultivar, 5602HR, developed by Agricore United, was included for its moderate *Fusarium* head blight resistance, as well as its resistance to leaf rust, stem rust, and loose smut. The fourth wheat in the cultivar mixture trial was AC Barrie, which has been the standard variety within Manitoba for over a decade and has good resistance to stem rust, lodging, loose smut, and bunt.

3.4 Measurements

Crop emergence density was determined by counting plants two to three weeks after seeding. Plants were counted in a 1 m length of two adjacent rows of wheat twice in each plot. These density values were then converted into plants m^{-2}. Weed emergence was determined approximately three weeks after seeding by counting individual species within two ¼ m^2 quadrats in each plot.

Wheat, intercrop and weed biomass was determined at anthesis and maturity of the wheat crop by harvesting all aboveground plant biomass in two ¼ m^2 quadrats in each plot. In the cultivar mixture trial, wheat and weed biomass was sampled from one ¼ m^2 quadrat in each plot only at maturity in 2004 but at anthesis and maturity in 2005. All samples were separated into crop and weed samples except for the cultivar mixture trial in 2004. The samples were then dried at 70°C for at least 48 hours, and then the dried samples were weighed.

Wheat height and development stage and height of the intercrops was assessed once or twice throughout the growing season to determine if there was an effect on maturation exerted by the intercrops on the wheat and vice versa. Disease levels within the wheat crop were obtained during grain filling by a visual assessment of the percentage of leaf area covered by disease of 20 randomly selected flag leaves within each plot (Lamari, personal communication). In 2004, disease levels in the intercrop field experiment were evaluated only in certain treatments that were determined to be representative of an intercrop system grouping (wheat and cereal intercrop, wheat and other seed intercrop or wheat and cover crop). In the cultivar mixture trial in 2004, only the sole variety treatments were evaluated for disease levels. In 2005, all treatments in both trials were evaluated for disease levels.

Grain yield was obtained in the intercrop trial by harvesting two 1m x 6 rows in each plot. Only the wheat and field pea treatment was separated before threshing. The samples were then cleaned with a dockage tester using 5 ½ 64″ slotted and round screens. Subsamples from the wheat and cereal intercrops were taken, 10 grams from the cleaned grain above 5 ½ 64″ slotted and 7 grams from the grain above 5 ½ 64″ round. These subsamples were then separated by hand into wheat and other cereal samples which were then reweighed and used to determine what fraction of the initial grain sample was wheat and what fraction was the other cereal which was then extrapolated into kg ha^{-1}. All samples were then reweighed after cleaning. In the cultivar mixture trial, at Clearwater in 2004, 1m x 6 rows were harvested in each plot, while at Carman in 2004 and 2005, all plots were harvested by a plot combine. The samples were then weighed after being cleaned.

3.5 Economic Analysis

Net returns for the intercrop treatment field experiment trial were calculated using Manitoba Agriculture and Agri-Food's "Guidelines for Estimating 2005 Crop Production Costs" (Manitoba Agriculture and Agri-Food, 2005) using the operating and fixed costs for wheat minus the fertilizer and herbicide costs and using the University of Saskatchewan's Organic Information website for organic seed prices (University of Saskatchewan, 2005). A general seed cleaning cost for the separation of intercrops was obtained from Manness Seed of Domain, Manitoba. The net return then consisted of the estimated average organic market price for wheat and the intercrop per bushel less the seed costs, seed cleaning costs and operating and fixed costs in terms of Canadian dollars per acre. An ANOVA was performed on the net returns, with one extreme outlier removed from the intercrop field experiment net returns from Carman at 2005 in order to obtain normality and homogeneity within the data set.

3.6 Statistical Analysis

Treatment effects were tested for significance using analysis of variance (ANOVA) in the PROC GLM procedure of the SAS Institute Inc. (SAS version 8, 1999) in a randomized complete block design. Significance was indicated at $P < 0.05$ unless otherwise indicated, and if significance was determined, mean comparisons were subjected to least significant difference (LSD) tests (Gomez and Gomez, 1984). Normality through heterogeneity of variance was assessed with Bartlett's test and a plot of the residuals. Orthogonal polynomial contrasts were also undertaken on certain treatments. When the conditions of homogeneous variance or normality were not met, log, square root or arcsine transformations of the data were undertaken for the data to conform to the assumptions of ANOVA analyses. In the cultivar mixture trial, homogeneity of variance was assessed with Bartlett's test except for the disease evaluation data, which was assessed with Levene's test.

4.0 RESULTS AND DISCUSSION

4.1 Climate and Soil Background

In all three site-years, there was excessive precipitation during parts of the growing season (Table 3.2). For the growing season from April-October, Clearwater in 2004 had 142% of the normal mean precipitation. For May alone, Clearwater in 2004 had over 4 times the long-term mean precipitation and Carman in 2004 and 2005 had approximately 2 times and 1.5 times the long-term mean precipitation respectively. Carman in 2005 continued to have excessive precipitation, and in June there was 1.85 times the normal mean precipitation for that month. Temperatures for the growing season from April-October were lower than the normal long-term mean temperatures in two of the three site-years (Table 3.1). At Clearwater in 2004 and at Carman in 2004, the temperatures were 85.8% and 87% of the normal long-term mean temperatures, respectively.

The soil test results for the three site-years indicated that although the Clearwater site had grown alfalfa for three years before the trial was implemented, it was still considered in the marginal zone for nitrogen at 32 ppm, and deficient in phosphorus at 8 ppm (Table 3.3). Although the alfalfa green manure can supply nitrogen to the subsequent crop over the growing season, it only continues to remove phosphorus from the available pool. The Carman sites, which were not previously under organic management, contained adequate nutrients for a wheat crop with the soil tests showing 77 ppm of nitrogen and 33 ppm of phosphorus in 2004 and 62 ppm of nitrogen and 21 ppm of phosphorus in 2005.

4.2 Influence of Intercropping Systems on Wheat

4.2.1 Crop Stand Density

The recommended wheat plant densities for Manitoba are 250-300 plants m^{-2} (Manitoba Agriculture and Food, 2001) but little information is available on optimal plant densities for intercropped wheat under organic management. As expected, wheat plant densities were significantly higher in the full-rate wheat treatment in all site-years than the half-rate wheat treatment (Table 4.1). Wheat stand density was generally not significantly affected by intercropping. An exception was at Clearwater in 2004 where the wheat-flax treatment had a significantly higher wheat stand density than the half-rate wheat treatment. These results show that among half-rate seeding rate treatments, intercrops never negatively affected wheat stand establishment.

Total crop density was shown to be strongly affected by intercrop type. The cereal intercrop treatments were not significantly different than the full-rate wheat treatment except for wheat-spring rye at Carman in 2005 which was significantly lower than the other cereal intercrop treatments and full-rate wheat. As the wheat-flax treatment had a full flax seeding rate, it resulted in a total crop stand density significantly higher than all of the other treatments in all site-years. Besides the wheat-flax treatment, the wheat-annual ryegrass treatment also had a significantly higher total crop stand than the other treatments, except for the wheat-red clover treatment in both Carman site-years. As expected, the half-rate wheat treatment was significantly lower in plant population density than most of the treatments due to its reduced seeding rate. At Clearwater in 2004 and Carman in 2005, the half-rate wheat treatment was not significantly different than the wheat-oriental mustard treatment possibly due to the flea beetle damage sustained by the oriental mustard crop during emergence.

Table 4.1. The effect of intercrop treatment on plant population density over three site-years for the intercrop field experiment.

Treatment	Clearwater 2004		Carman 2004		Carman 2005	
	wheat	total	wheat	total	wheat	total
	plants m^{-2}					
Wheat-Oats	133 bc[a]	272 c	105 b	234 cd[b]	108 b[b]	209 bc[b]
Wheat-Barley	--	--	104 b	210 de	118 b	228 bc
Wheat-Spring Rye	131 bc	219 de	101 b	184 ef	102 b	148 def
Wheat-Flax	153 b	597 a	89 b	528 a	109 b	501 a
Wheat-Field pea	144 bc	176 ef	104 b	131 hi	110 b	144 ef
Wheat-Oriental Mustard	145 bc	161 fg	117 b	170 fg	109 b	125 fg
Wheat-Red Clover	127 bc	220 de	102 b	274 bc	111 b	282 b
Wheat-Hairy Vetch	145 bc	178 ef	99 b	148 gh	114 b	183 cde
Wheat-Annual Ryegrass	151 bc	349 b	112 b	302 b	102 b	404 a
Half-rate wheat	123 c	123 g	112 b	112 i	102 b	102 g
Full-rate wheat	262 a	262 cd	215 a	215 de	199 a	199 cd

[a] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

[b] Data was log-transformed for the ANOVA with untransformed means displayed in the table with Bartlett's test for homogeneity not significant at $p > 0.01$.

4.2.2 Crop Development

Typical height for AC Barrie wheat at maturity is 98 cm (Parent Seed Farms Ltd., 2000). Each site-year had variations in the height and maturity of wheat plants, with intercrops often significantly reducing height and delaying maturity compared to the monoculture wheat treatments (Table 4.2). Cereal intercrops with wheat, however, did not reduce wheat height or delay maturity in any site-year compared to the full-rate wheat control. In some site-years, the cereal treatments actually had an increase in height over the full-rate wheat treatment. At Carman in 2004, the wheat-spring rye treatment resulted in significantly taller wheat on July 5 than the full-rate wheat treatment. The wheat-barley treatment also resulted in significantly taller wheat than the full-rate wheat and half-rate wheat treatments at Carman on June 23, 2005. This increased height may be due to the competitive pressures exerted by the cereal intercrops on the wheat, which enhances the wheat's own competitive ability. In studies of barley-oat mixtures, the oats had a higher final height and dry matter, but the barley in the mixture had greater early growth and was ultimately more competitive (Syme and Bremner, 1968; Taylor, 1978; Juskiw et al., 2000). Wheat is considered less competitive than barley and oats, and although it may have had increased height in the cereal mixtures, it would nevertheless be impacted by the other cereal intercrops' increased leaf area, dry matter and tillers (Taylor, 1978).

The full-rate wheat treatment had significantly taller wheat plants than the wheat-flax, wheat-red clover, wheat-hairy vetch, wheat-annual ryegrass and half-rate wheat treatments at Clearwater on June 30, 2004. At this date and location, the wheat-field pea treatment showed a significant delay in development (4.4 Haun units vs. 5.1- 5.4 Haun units) than all other treatments except the wheat-flax and wheat-annual ryegrass treatments, but developmental delay was not observed in the other two site-years. The wheat-flax treatment had significantly lower height than all of the other treatments at Carman on July 5, 2004 and was also significantly less developed, by 0.6 Haun units, than the cereal intercrop treatments and the wheat-field pea treatment. Decreased height/developmental delay of wheat plants was not observed for the wheat-flax treatment at Carman in 2005 however, demonstrating how varying environmental conditions in site-years can greatly impact the dynamics of intercrop components.

Table 4.2. The effect of intercrop treatment on the height[a] and maturity[b] of the wheat crop over three site-years in the intercrop field experiment.

Treatment	**Clearwater 2004**			**Carman 2004**			**Carman 2005**	
	Height I (June 30)	Stage (June 30)	Height II (August 13)	Height I (July 5)	Stage (July 5)	Height II (August 17)	Height (June 23)	Stage (June 23)
Wheat-Oats	26.68 ab[c]	5.36 a	92.27 ab	23.83 ab	5.26 a	83.11[d]	35.41 abcd	5.61[d]
Wheat-Barley	--	--	--	23.13 ab	5.26 a	85.19	39.88 a	5.65
Wheat-Spring Rye	26.33 abc	5.35 ab	90.56 abc	25.17 a	5.17 ab	82.76	38.53 ab	5.69
Wheat-Flax	24.56 bcd	4.72 bc	86.69 c	18.85 c	4.67 c	79.91	37.25 abc	5.70
Wheat-field pea	24.63 abcd	4.39 c	89.06 abc	24.99 ab	5.20 a	84.39	35.63 abcd	5.74
Wheat-Oriental Mustard	26.40 ab	5.36 a	89.31 abc	23.74 ab	5.03 abc	85.05	31.78 d	5.74
Wheat-Red Clover	23.99 cd	5.21 ab	89.59 abc	22.76 ab	4.86 abc	80.49	33.88 bcd	5.72
Wheat-Hairy Vetch	24.53 bcd	5.09 ab	94.34 a	23.76 ab	4.69 bc	85.98	34.97 bcd	5.59
Wheat-Annual Ryegrass	23.62 d	4.76 abc	86.97 bc	22.83 ab	5.09 abc	81.57	36.25 abcd	5.71
Half-rate wheat	24.31 bcd	5.22 ab	91.38 abc	22.56 ab	4.92 abc	86.06	33.44 cd	5.62
Full-rate wheat	27.00 a	5.16 ab	91.16 abc	21.95 b	5.12 abc	84.84	34.09 bcd	5.73

[a] Height measurements are reported in centimetres

[b] Wheat staging is reported in Haun (1973) stages.

[c] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

[d] Means are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

4.2.3 Weed Population Density

Weeds are a major obstacle to successful organic production, and evaluating the effectiveness of intercropping treatments on suppressing weed emergence and growth was one of the key objectives of this study. Weed recruitment was shown to be influenced by location and site-year. For example, there was no significant difference in weed recruitment at Carman in 2005, but in 2004, the half-rate wheat treatment had significantly more weeds than several other treatments (wheat-barley, wheat-spring rye, wheat-hairy vetch, and the full-rate wheat treatments (Table 4.3). At Clearwater in 2004, the wheat-red clover treatment had significantly more weeds than the wheat-flax, wheat-oats, wheat-oriental mustard and the full-rate wheat treatments. The half-rate wheat treatment tended to have higher levels of weeds than many of the intercrop treatments in all three site-years. These observations demonstrate that even at the seedling stage, the competitive pressures exerted by the intercrops and the full seeding rate of wheat created conditions of high population pressure which were generally less favourable to weeds than the half-rate wheat treatment similar to observations reported by Altieri and Liebman (1986).

Table 4.3. The effect of intercrop treatment on weed population density over three site-years for the intercrop field experiment.

Treatment	Clearwater 2004	Carman 2004	Carman 2005
	------------------------weeds m^{-2}-------------------		
Wheat-Oats	287 cd[a][b]	195 ab	118[c]
Wheat-Barley	--	153 b	90
Wheat-Spring Rye	674 a	116 b	93
Wheat-Flax	261 d	203 ab	95
Wheat-Field Pea	414 abcd	215 ab	91
Wheat-Oriental Mustard	254 cd	227 ab	98
Wheat-Red Clover	503 ab	205 ab	88
Wheat-Hairy Vetch	323 abcd	132 b	98
Wheat-Annual Ryegrass	472 abc	233 ab	115
Half-rate wheat	406 abcd	386 a	95
Full-rate wheat	268 bcd	73 b	99
Contrasts			
Half-rate wheat vs. all treatments	0.4684	0.0128	0.8118
Full-rate wheat vs. all treatments	0.2053	0.1054	0.9288

[a] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

[b] Data was log-transformed for the ANOVA with untransformed means displayed in the table.

[c] Means are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

4.2.3.1 Clearwater 2004 Major Weed Species

As the Clearwater site in 2004 was a certified organic farm, it was expected that it would have a higher abundance of weeds and a greater diversity of weeds (Entz et al., 2001). There was indeed a broader spectrum of weeds at Clearwater in 2004 than at Carman, but the major weed species were limited to redroot pigweed, foxtail/barnyard grass, wild buckwheat and wild mustard with foxtail and barnyard grass being the dominant weed in the system (Table 4.4). Foxtail and barnyard grass were grouped together in order to facilitate faster weed enumeration. Wild mustard was not observed in Carman at the levels it was at Clearwater. This result is not surprising as wild mustard has been shown to be a weed characteristic of organic production systems (Entz et al., 2001).

At Clearwater, the dominant weed foxtail/barnyard grass was significantly more abundant in the wheat-red clover treatment than the wheat-oats, wheat-flax, wheat-oriental mustard and the full-rate wheat treatments. As Boyd and Van Acker (2003) showed an increase in green foxtail emergence when seeds were slightly buried in the soil, the high levels of foxtail in the system may be partially due to the two passes required for seeding operations which would drive the weed seeds further into the soil. Wild mustard recruitment levels were significantly higher in the wheat-hairy vetch treatment compared to the wheat-oats, wheat-flax, wheat-field pea, and the full-rate wheat treatment possibly due to the slower establishment of the hairy vetch compared to the other intercrops.

Table 4.4. The major weed species (RRPW = redroot pigweed, FT/BYG = foxtail/barnyard grass, WBW= wild buckwheat, WM = wild mustard) present in the intercrop field experiment at Clearwater in 2004.

Treatment	RRPW	FT/BYG	WBW	WM
	--------------------------------weeds m^{-2}	----------------------------		
Wheat-Oat	8.67^{a}	217.00 c^{bc}	11.33 b	7.00 bc
Wheat-Spring Rye	9.33	592.30 a	13.00 ab	14.33 ab
Wheat-Flax	6.67	189.67 c	12.00 ab	8.00 b
Wheat-Field pea	9.00	332.34 abc	12.67 ab	8.67 b
Wheat-Oriental Mustard	15.00	161.67 c	20.00 ab	--
Wheat-Red Clover	6.67	425.33 a	12.00 ab	11.33 ab
Wheat-Hairy Vetch	12.33	233.67 bc	15.00 ab	16.67 a
Wheat-Annual Ryegrass	5.33	393.33 ab	9.67 b	11.00 ab
Half-rate wheat	6.67	322.67 abc	13.67 ab	10.67 ab
Full-rate wheat	11.33	171.00 bc	14.67 ab	7.34 bc

[a] Means are not significantly different ($P > 0.05$) according to Fischer's protected LSD.
[b] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.
[c] Data was log-transformed for the ANOVA with untransformed means displayed in the table.

4.2.3.2 Carman 2004 Major Weed Species

The major weed species present at Carman in 2004 were redroot pigweed and foxtail/barnyard grass (Table 4.5). Foxtail, like at Clearwater in 2004, was the dominant weed in the cropping system, again possibly due to the slight burying in the soil provided by the two passes for the seeding operations in each plot. The half-rate wheat treatment had significantly more redroot pigweed plants than the wheat-barley, wheat-spring rye and full-rate wheat treatments. The half-rate wheat treatment also had significantly higher numbers of foxtail/barnyard grass than the wheat-red clover and full-rate wheat treatments. These weed levels were expected for the half-rate wheat treatment as its reduced seeding rate translates into less competitive pressure towards weed emergence and establishment.

Table 4.5. The major weed species (RRPW = redroot pigweed, FT/BYG = foxtail/barnyard grass) in the intercrop field experiment at Carman in 2004.

Treatment	RRPW	FT/BYG
	-----------------weeds m^{-2}---------	
Wheat-Oats	55.34 abc[ab]	109.00 ab
Wheat-Barley	18.67 bc	97.33 ab
Wheat-Spring Rye	14.00 c	68.33 ab
Wheat-Flax	37.67 abc	130.00 ab
Wheat-Field pea	50.00 ab	131.00 ab
Wheat-Oriental Mustard	52.33 ab	140.00 ab
Wheat-Red Clover	25.33 abc	147.55 ab
Wheat-Hairy Vetch	39.00 abc	56.33 ab
Wheat-Annual Ryegrass	44.00 abc	152.34 ab
Half-rate wheat	52.67 a	293.00 a
Full-rate wheat	14.00 c	19.00 b

[a] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

[b] All data were log-transformed for the ANOVA analyses with non-transformed values presented in the table.

4.2.3.3 Carman 2005 Major Weed Species

There appeared to be no discernable treatment effect for weed recruitment in the intercrop field experiment at Carman in 2005 (Table 4.6). An exception was the wheat-barley treatment which had significantly less foxtail/barnyard grass than the wheat-oats and wheat-spring rye treatment and the wheat-field pea treatment having significantly fewer wild buckwheat plants than the wheat-oriental mustard treatment. These observations demonstrate that barley was more competitive than the other cereals in this study confirming previous observations by Frick (2000). The wheat-barley treatment was not observed to have significantly lower levels of foxtail/barnyard grass in the other site-years however, which suggests site-year had more of an effect on the presence of foxtail/barnyard grass than did intercrop treatment.

Table 4.6. The major weed species (RRPW = redroot pigweed, FT/BYG = foxtail/barnyard grass, WBW = wild buckwheat) in the intercrop field experiment at Carman in 2005.

Treatment	RRPW	FT/BYG	WBW
	--------------------------weeds m^{-2}------------------------		
Wheat-Oats	89.00[a]	11.50 a[b,c]	15.50 ab
Wheat-Barley	60.50	8.00 b	18.00 ab
Wheat-Spring Rye	68.00	13.00 a	10.00 ab
Wheat-Flax	67.50	11.00 ab	14.00 ab
Wheat-field pea	67.50	10.50 ab	9.00 b
Wheat-Oriental Mustard	60.50	10.00 ab	25.00 a
Wheat-Red Clover	66.00	6.00 ab	14.50 ab
Wheat-Hairy Vetch	66.50	14.50 ab	12.00 ab
Wheat-Annual Ryegrass	87.00	10.00 ab	16.50 ab
Half-rate wheat	67.00	5.50 ab	17.00 ab
Full-rate wheat	66.50	11.50 ab	19.50 ab

[a] Means were not significantly different ($P > 0.05$) according to Fischer’s protected LSD.
[b] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer’s protected LSD.
[c] Data was log-transformed for the ANOVA analyses with untransformed values presented in the table.

4.2.4 Clearwater 2004 Biomass

4.2.4.1 Crop Biomass at Anthesis

The proportions of wheat, intercrop and weed biomass within the treatments provide a representation of the productivity and the competitiveness of each within the cropping system. Biomass levels can indicate whether the intercrop is suppressing the wheat crop and/or the weed populations. Wheat biomass was generally more negatively affected by cereal intercrops and flax than the other treatments (Table 4.7). The full-rate wheat treatment, as expected, produced the largest amount of wheat biomass, with the exception of the wheat-oriental mustard treatment. The wheat plants in the wheat-oriental mustard treatment may have compensated for the loss of the oriental mustard when it was largely destroyed by flea beetles early in the growing season. The flea beetles may have also reduced the weed populations through feeding on such weeds as wild mustard, stinkweed, and lamb's quarters (Manitoba Agriculture, Food and Rural Initiatives, 2006), thereby allowing the wheat crop to more freely access nutrients and grow. The oat and flax intercrops appeared to be the strongest competitors with wheat as the wheat-oats and wheat-flax treatments were the only treatments which were significantly lower in wheat biomass than the half-rate wheat treatment. Possible reasons for this are that oats may have been more successful at capturing resources, perhaps due to larger leaf area, than the wheat crop. Also, cool, moist summers, as were experienced in this site-year, are the optimal growing conditions for oat, as it cannot withstand hot, dry summers as well as wheat, barley or rye (Coffman, 1977; Miller, 1984). Being especially suited for cool, moist environments, it follows that oats would perform better during such a season than wheat which is more adaptable to variant environmental conditions. In the wheat-flax treatment, the flax intercrop was seeded at a full monoculture rate, while the wheat crop was at a half-seeding rate. This higher flax population density limited the amount of resources available to the wheat crop and thereby suppressed its growth. This contradicts Carr et al.'s (1993) study which concluded that flax has little influence on wheat dry matter in moist environments.

The contribution the intercrop makes to the final crop stand is reflected in the total crop biomass. At anthesis, total crop biomass is statistically similar between intercrops, excepting flax, while cover crops are lower in biomass (Table 4.7.). As previously mentioned, the oats and flax intercrops significantly suppressed the biomass of the wheat crop, but when total crop biomass was evaluated, both intercrop treatments were comparable to the treatments with the highest biomass (full-rate wheat, wheat-oriental mustard, wheat-spring rye, wheat-field pea) with wheat-oats having greater total biomass than all other treatments. Although wheat biomass was reduced by competition with the intercrops, total crop biomass was not negatively affected.

4.2.4.2 Crop Biomass at Maturity

By wheat maturity, the cereal intercrop treatments and the wheat-flax treatment continued to suppress the wheat crop, resulting in significantly lower wheat biomass levels than all treatments except for the wheat-red clover treatment (Table 4.7). Pfleeger and Mundt (1998) showed that increasing the proportion of wild oat (*Avena fatua* L.) in a mixture with wheat reduced the number of culms per wheat plant. It appears that the domesticated oat in the wheat-oat treatment elicited a similar response. The remaining treatments now possessed comparable wheat biomass levels to the full-rate wheat treatment, which indicates that wheat plants can compensate for a reduced seeding rate and fill in spaces in the canopy (e.g. through tillering) if those spaces are not being filled by a more competitive intercrop. These results are supported by previous work which showed the ability of wheat to produce compensatory growth under variant growing conditions (Frederick and Marshall, 1985).

Total crop biomass, as in anthesis, again showed the benefits of competitive crops in enhancing biological productivity. The cereal intercrop treatments were among the treatments with the highest total crop biomass levels. The wheat-oats treatment specifically had the largest amount of biomass and was significantly higher in total crop biomass than many treatments (wheat-flax, wheat-red clover, wheat-hairy vetch, half-rate wheat). This does not appear to correspond with earlier literature which characterized oat as having less dry matter than barley, wheat or rye, with cereal rye having more early spring and fall growth than oat (Miller, 1984). The wheat-flax treatment was now significantly less in total crop biomass than all other treatments, even though it had been comparable to full-rate wheat at anthesis. This decline in biomass can be attributed to the killing frost undergone by the flax crop at Clearwater. The cover crop treatments, now established, were comparable to the full-rate wheat treatment in total crop biomass, although hairy vetch and annual ryegrass contributed more biomass than red clover.

4.2.4.3 Weed Biomass at Anthesis

Crop biomass shows us the productivity and competition levels of the intercrops, but weed biomass is another key indicator of whether the competitive force exerted by weeds will reduce the eventual grain yield of the crop(s). At anthesis, it appears that the competitive cereal treatments of wheat-oats and wheat-spring rye were also competitive against weeds, as they tended to have less weed biomass than treatments which added nitrogen to the system or were slow to establish and/or non-competitive (wheat-field pea, wheat-red clover, wheat-hairy vetch, wheat-annual ryegrass, half-rate wheat) (Table 4.7). The wheat-oriental mustard treatment was also significantly lower in weed biomass than the previously listed treatments excepting wheat-red clover. This reduction in weed growth may be due to the wheat crop's increased biomass, and hence competition, while compensating for the loss of the oriental mustard intercrop, and/or from the physical damage suffered by weeds from the flea beetles concentrated in these plots.

The reason for greater weed growth in the cover crop system may be attributed to the slower establishment of cover crops at this location. All of the cover crops used in this system are characteristically slower to establish than cover crops such as buckwheat (Pennsylvania State University, 2006). Without early vigorous growth, the cover crops provided little initial competition to the weeds and were therefore not as effective at suppressing their growth within the system as the cereal intercrops or full-rate wheat.

4.2.4.4 Weed Biomass at Maturity

Although the wheat-spring rye, wheat-field pea, wheat-red clover and wheat-hairy vetch treatments all had high levels of weed biomass, the wheat-hairy vetch treatment was the only treatment which had significantly more weed biomass than the remainder of the treatments (Table 4.7). It is widely used as a cover crop in the United States, but is known to require fall establishment (Pennsylvania State University, 2006), which is not possible in Manitoba, and which presents a further disadvantage over red clover or annual ryegrass in terms of speed of establishment. The wheat-oats treatment retained its competitiveness against weeds as it demonstrated during anthesis, resulting in among the lowest weed biomass levels. Oats appear to be an ideal intercrop for weed suppression, as was also found in a previous study (Lanini et al., 1999) which found that oats interseeded into alfalfa provided weed control benefits comparable to that of paraquat while also increasing forage yield. The wheat-annual ryegrass treatment was much more effective at suppressing weeds by the time of wheat maturation. This suppressive effect can be attributed to its large increase in biomass since anthesis and, unlike the other cover crops in the system, it does not fix nitrogen which could stimulate weed growth. The wheat-flax treatment was also surprisingly low in weeds, even with the frost damage undergone by the flax crop. The high population density created early on in this treatment appears to have been effective at suppressing weeds throughout the growing season and into wheat maturity.

Table 4.7. The effect of intercrop treatment on wheat, crop and weed biomass production in the field intercrop experiment during anthesis at Clearwater in 2004.

	Anthesis			Maturity		
Treatment	**Wheat**	**Total Crop**	**Weed**	**Wheat**	**Total Crop**	**Weed**
	biomass (kg ha $^{-1}$)					
Wheat-Oats	2047.0 de[a]	3851.5 a	666.5 abcd	3103.5 de	5923.0 a	700.0 d
Wheat-Spring Rye	2142.0 cde	3432.5 abc	477.0 cd	3293.0 cd	4880.0 abc	1349.0 abc
Wheat-Flax	1494.5 e	2896.0 bcd	565.5 abcd	2259.5 e	3384.5 d	749.5 d
Wheat-Field pea	2486.5 bcd	3221.5 abcd	824.5 abc	4447.0 ab	5112.0 ab	1184.0 abcd
Wheat-Oriental Mustard	3087.0 ab	3143.5 abcd	408.0 d	5068.0 a	5191.0 ab	883.0 cd
Wheat-Red Clover	2789.5 bc	2854.5 bcd	795.5 abcd	3907.0 bcd	4005.5 cd	1556.0 ab
Wheat-Hairy Vetch	2761.5 bc	2859.5 bcd	1026.0 a	4648.0 ab	4863.5 bc	1578.0 a
Wheat-Annual Ryegrass	2259.0 cd	2608.0 d	1003.5 a	4203.0 abc	4910.0 abc	771.0 d
Half-rate wheat	2806.0 bc	2806.0 cd	880.5 abc	4756.5 ab	4756.5 bc	992.5 cd
Full-rate wheat	3588.5 a	3588.5 ab	520.7 bcd	4987.5 a	4987.5 abc	1056.0 bcd

[a] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

4.2.5 Carman 2004 Biomass

4.2.5.1 Crop Biomass at Anthesis

As in Clearwater, the full-rate wheat treatment also had significantly more wheat biomass than the other treatments at anthesis at Carman in 2004 (Table 4.8). The only other treatment comparable in wheat biomass was the wheat-hairy vetch treatment. The nitrogen that the hairy vetch contributed to the system may have assisted in the growth of the wheat crop in this site-year. As it was observed that the cover crops were quicker to establish at this location than at Clearwater, possibly due to higher mean temperatures, the hairy vetch was then more vigorous and may have been more capable of fixing and utilizing nitrogen to foster growth than the less vigorous plants at Clearwater. As hairy vetch has also been shown in many studies to be the highest in nitrogen content compared to other cover crops (Holderbaum et al., 1990; Nelson, 1944; Frye et al., 1988), this may be why the other nitrogen-fixing crops did not also provide the same benefit to the wheat crop as hairy vetch. As was witnessed at Clearwater in 2004, the cereal intercrops and the wheat-flax treatment reduced wheat biomass, but only the most competitive treatment, wheat-barley, had significantly less wheat biomass than the half-rate wheat treatment, confirming the very competitive nature of barley (Frick, 2000).

Except for wheat-flax, in which flax suppressed the wheat crop and itself, and wheat-red clover, which contributed little red clover biomass to the system, the intercrop treatments were statistically comparable in total crop biomass to the full-rate wheat treatment. Cereal intercrop treatments, however, tended to be higher, with wheat-barley, barley being the most competitive crop, having the highest total crop biomass.

4.2.5.2 Crop Biomass at Maturity

Wheat crop biomass reflected the competitiveness of the intercrops again at Carman in 2004, with the wheat-oats and wheat-barley treatments having significantly lower wheat biomass than most of the treatments with the exception of the wheat-oriental mustard treatment (Table 4.8). This was the only site-year in which oriental mustard was not affected by flea beetles, and it proved to be a competitive intercrop, similar to canola which is known to be quite competitive when established (Ontario Ministry of Agriculture, Food and Rural Affairs, 2002). Also, as witnessed at Clearwater in 2004, less competitive treatments (half-rate wheat, wheat-annual ryegrass, wheat-hairy vetch, wheat-red clover, wheat-field pea) had comparable wheat biomass to the full-rate wheat treatment, indicating the wheat plant's capability to compensate for spaces in the canopy.

Cereal intercrops were shown to be competitive against the wheat crop, but this was the only site-year, anthesis or maturity, where the wheat-spring rye treatment did not significantly reduce the wheat crop compared to the full-rate wheat treatment while also being significantly greater in total crop biomass the full-rate wheat treatment. It follows with Miller's (1984) assessment of rye as having more biomass than oat, but contradicts Frick's (2000) assessment of spring rye being more competitive than oat. All other treatments were significantly comparable in total crop biomass to the full-rate wheat treatment, which was also not observed in any other site-year, anthesis or maturity. The full-rate wheat treatment presented no advantage in total crop biomass in this site-year.

4.2.5.3 Weed Biomass at Anthesis

Among the treatments with high levels of weed biomass (wheat-spring rye, wheat-field pea, wheat-hairy vetch, wheat-annual ryegrass) only the half-rate wheat treatment was significantly greater in weed biomass than all of the remaining treatments (Table 4.8). The half-rate wheat treatment does not have the benefit of an intercrop to exploit the niches that weeds would otherwise occupy, so it is not surprising that it has a high weed biomass. Wheat-oats and full-rate wheat had the lowest levels of weeds, again highlighting oats' impressive capability to suppress weed populations. Although oat possesses rapid germination which can assist in smothering plants, weed suppression is also due to allelopathic chemicals in the root exudates of oat seedlings which can hinder weed and wheat growth for weeks (Kato-Noguchi et al., 1994; Valenzuela and Smith, 2002). This may explain why although barley is more competitive, oats was more effective at suppressing weed biomass at anthesis.

4.2.5.4 Weed Biomass at Maturity

By the time of wheat maturity, as total crop biomass differed so little between treatments, it is not surprising that the weed biomass levels were only significantly higher than the full-rate wheat treatment in the half-rate wheat treatment. Though the half-rate wheat treatment was comparable in total crop biomass to all treatments, it did not possess the diversity that intercrops bring to a system, and therefore could not benefit from enhanced weed suppression attributable to divergent niche exploitation.

Table 4.8. The effect of intercrop treatment on wheat, crop and weed biomass production in the field intercrop experiment during anthesis and maturity at Carman in 2004.

	Anthesis			Maturity		
Treatment	**Wheat**	**Total Crop**	**Weed**	**Wheat**	**Total Crop**	**Weed**
	biomass (kg ha $^{-1}$)					
Wheat-Oats	1243.3 de[a]	2552.6 ab	56.7 c[b]	2589.5 e	5087.5 d	323.5 ab[c]
Wheat-Barley	1019.2 e	2751.8 a	139.6 abc	2453.0 e	5921.0 bcd	434.0 ab
Wheat-Spring Rye	1261.5 de	2564.0 ab	157.0 abc	4252.0 cd	7730.5 a	319.0 ab
Wheat-Flax	1352.3 cde	1850.4 c	120.7 abc	4381.0 cd	5911.5 bcd	322.5 ab
Wheat-Field Pea	1670.6 bcd	2235.0 abc	169.4 abc	5417.5 abcd	7293.5 ab	511.5 ab
Wheat-Oriental Mustard	1638.7 bcd	2283.4 abc	153.3 abc	3933.5 de	6197.0 abcd	509.0 ab
Wheat-Red Clover	1803.3 bc	1859.5 c	326.0 abc	5140.0 abcd	5633.0 bcd	486.5 ab
Wheat-Hairy Vetch	2007.8 ab	2059.1 bc	159.0 abc	6009.5 ab	6899.5 abc	406.0 ab
Wheat-Annual Ryegrass	1836.0 abc	2165.3 abc	268.0 ab	4581.5 bcd	5367.0 cd	781.5 ab
Half-rate wheat	2028.3 ab	2028.3 bc	323.7 a	6575.0 a	6575.0 abcd	1066.0 a
Full-rate wheat	2433.2 a	2433.2 abc	85.9 bc	5582.0 abc	5582.0 bcd	96.5 b

[a] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.
[b] Data was log-transformed for the ANOVA with untransformed means displayed in the table.
[c] Data was log-transformed for the ANOVA analyses with untransformed values presented in the table.

4.2.6 Carman 2005 Biomass

4.2.6.1 Crop Biomass at Anthesis

As witnessed in the other two site-years, the full-rate wheat treatment again had significantly higher wheat biomass than the treatments containing intercrops, but unlike the other site-years, the half-rate wheat treatment also had significantly higher wheat biomass than the treatments containing intercrops (Table 4.9). This may be due to the intercrops being better adapted to the extremely wet conditions of this season than wheat, which led to their subsequent inhibiting of the wheat crop. Oats, for example, requires more moisture than the other small grains (McLeod, 1982; Valenzuela and Smith, 2002) and would thus tolerate wet soils better than them.

As at Carman in 2004, barley's competitive ability was reflected in the total crop biomass, which was significantly higher in total crop biomass than all other treatments. The other cereal intercrops also produced comparable if not greater (wheat-spring rye) total crop biomass than the full-rate wheat treatment.

4.2.6.2 Crop Biomass at Maturity

Unlike the other two site-years, by maturity wheat biomass was still significantly higher in the full-rate wheat treatment than all other treatments (Table 4.9). This suggests that due to the environmental conditions in this year, specifically excess precipitation, the wheat crop was not as capable of compensating for reduced seeding rates or competing against crops which were previously observed as uncompetitive against the wheat crop. Barley, the most competitive and suppressant of the wheat crop, has only 29% of the wheat biomass that the half-rate wheat treatment has. This illustrates how dynamic an intercropping system is, and how the components of the system can alter in proportions in response to environmental conditions.

Total crop biomass showed that the cereal intercrops, although greatly reducing the wheat crop biomass, were again comparable to the treatments highest in total crop biomass (full-rate wheat, wheat-hairy vetch, wheat-annual ryegrass) which was also the case in every site year at anthesis and maturity except for Carman at maturity in 2004. The wheat-hairy vetch and wheat-annual ryegrass were observed to be overly competitive with the wheat crop in this site-year, to the extent that the cover crops became the main crops of the treatments, and were therefore undesirable as intercrop partners for wheat. This was the only site-year where annual-ryegrass had the highest level of total crop biomass, composed primarily of annual ryegrass, but it is known to be more tolerant of poorly drained wet soils than cereals (Stanley et al., 2005). In addition, wheat seedlings are known to produce allelochemicals that suppress annual ryegrass (Wu et al., 2002), but as wheat was less competitive and vigorous in this site-year than the previous site-years, it stands to reason that fewer allelochemicals were being released to suppress the annual ryegrass.

4.2.6.3 Weed Biomass at Anthesis

The half-rate wheat treatment, like the two previous site-years, was among the treatments with highest levels of weed biomass (Table 4.9). These consistently higher levels of weed biomass demonstrate the half-rate wheat treatments' lessened ability to compete with weeds in comparison to the majority of the other treatments. The wheat-red clover treatment also had significantly higher weed biomass which is due to the extremely small amount of red clover biomass contributed to the system, coupled with significantly reduced wheat biomass that resulted in the lowest level of biomass. This was simply not enough to compete with the weeds in the system, with a total biomass 69% of the half-rate wheat treatment. This is the only site-year where it was less effective than the other treatments of the cover crop system (wheat-hairy vetch, wheat-annual ryegrass) in suppressing weeds. This suggests that hairy vetch and annual ryegrass may be more effective in suppressing weeds than red clover in conditions of normal mean temperatures but excess precipitation, which was expected due to their significantly higher total crop biomass measurements. Annual ryegrass was extremely effective against weeds in this site-year due to its much increased biomass which effectively smothered weeds. This copious biomass may be resultant not only from a tolerance for wet soils and reduced competition from wheat, but also from more nitrogen being available to the annual ryegrass from a green manure crop in the previous year.

As observed in the previous two site-years, oats again had low levels of weeds at anthesis, showing that its allelopathic effect on weeds was not hindered by the excessive precipitation in this site-year.

4.2.6.4 Weed Biomass at Maturity

All biomass levels were higher in this site-year, and this included weed biomass levels (Table 4.9). The half-rate wheat treatment, with the exception of the wheat-oriental mustard treatment, had significantly higher weed biomass levels than the other treatments. High weed biomass levels were expected due to the lack of an intercrop to exert more competitive pressure on weeds and especially as wheat was not as competitive under conditions of excess precipitation. The half-rate wheat treatment was observed to be amongst the treatments with the highest weed biomass levels in all site-years at anthesis and maturity except for Clearwater 2004 at maturity. The wheat-oriental mustard treatment, like at Clearwater in 2004, underwent damage to the oriental mustard from flea beetles. However, lower weed levels were not observed here as in Clearwater, as weeds that flea beetles attack such as wild mustard, stinkweed and lamb's quarters were not present at Carman in the levels they were at Clearwater.

This was the only site-year where increasing competition of intercrops provided increasing suppression of weeds to correspond with Woolley and Davis' (1991) assertion that the more vigorous the crop growth, the more competition is exerted against weeds. Barley, shown to be the most competitive intercrop whenever it was implemented, and reported as more competitive than wheat in the literature (Frick, 2000), had significantly lower weed biomass than the full-rate wheat treatment.

The cover crop treatments of wheat-hairy vetch and wheat-annual ryegrass smothered the wheat crop in this site-year, but only the wheat-annual ryegrass treatment significantly reduced weed biomass in comparison to the full-rate wheat treatment. Annual ryegrass covered the soil surface with vegetation, and when the vegetation was pushed back to reveal the soil surface, it was observed to be a dense mat of fine roots. Such root masses and vegetation cover were very effective at suppressing weed emergence and the acquisition of nutrients by already established weeds. The wheat-hairy vetch treatment, however, although dense, viney, and seemingly effective at intercepting light that would reach wheat or weeds, also contributed nitrogen to the system that could stimulate weeds. Neither wheat-hairy vetch nor wheat-red clover significantly reduced weed biomass in comparison to full-rate wheat. This appears to contradict the findings of

Reynolds et al. (1994) which found “substantial effects” in intercropping systems containing vetch and clover towards suppressing weed populations.

Table 4.9. The effect of intercrop treatment on wheat, crop and weed biomass production in the field intercrop experiment during wheat anthesis and maturity at Carman in 2005.

	Anthesis			Maturity		
Treatment	**Wheat**	**Total Crop**	**Weed**	**Wheat**	**Total Crop**	**Weed**
	biomass (kg ha $^{-1}$)					
Wheat-Oats	2081.0 cd[a]	5634.5 bc	140.5 f[b]	2506.5 ef[b]	7754.5 abc	767.0 def
Wheat-Barley	1685.5 de	6881.0 a	368.0 cde	1852.0 f	8491.5 ab	621.5 ef
Wheat-Spring Rye	2937.5 b	5837.0 b	645.5 bcd	3909.0 cd	8757.0 a	1270.0 cde
Wheat-Flax	1932.0 de	5337.0 bcd	353.0 de	2454.5 ef	6904.0 bcde	804.5 def
Wheat-Field pea	3089.0 b	4588.5 de	1073.0 ab	4070.0 cd	5937.5 de	1814.0 bc
Wheat-Oriental Mustard	2844.0 b	3145.0 fg	1050.5 ab	4814.0 bcd	5259.0 e	2570.5 ab
Wheat-Red Clover	2791.5 bc	2835.5 g	1675.0 a	5122.0 bc	5590.0 e	1972.0 bc
Wheat-Hairy Vetch	3289.5 b	4033.5 ef	842.0 abc	3127.0 de	7522.0 abcd	1224.5 cde
Wheat-Annual Ryegrass	1231.5 e	4252.0 e	168.5 ef	3596.5 cd	8879.0 a	278.5 f
Half-rate wheat	4119.0 a	4119.0 e	1349.0 ab	6305.0 ab	6305.0 cde	2814.0 a
Full-rate wheat	4718.0 a	4718.0 cde	720.5 abcd	7835.0 a	7835.0 abc	1408.5 cd

[a] Means within the same site year followed by the same letter within a column are not significantly different (P > 0.05) according to Fischer's protected LSD.

[b] Data was log-transformed for the ANOVA analyses with untransformed values presented in the table.

4.2.7 Disease Development

Without fungicides to bolster the system in the event of an epidemic, monocultures in organic systems could rapidly succumb to fungal disease pressures. By increasing the level of diversity in the system through intercropping, non-host plants in the mixture could effectively slow the spread of disease (Vilich-Meler, 1992; Jensen et al., 2005). As the plots in this experiment were small and the treatments were not intentionally exposed to inoculum, it was unclear whether disease suppressive effects from the intercropping treatments would be tangible. Also, very little research is available on the effects of intercropping on disease levels, or the mechanisms involved if disease suppression occurs.

Disease level evaluations were only taken from representative treatments at Clearwater in 2004 and Carman in 2004, but evaluations from all treatments were taken at Carman in 2005. In all three site-years, it was observed that the full-rate wheat treatment had significantly higher levels of foliar disease on the wheat crop than the wheat-field pea treatment (Table 4.10). This result suggests that the field pea intercrop, with its viney habit, was acting as a physical barrier towards spores that would have otherwise landed on the wheat host crop. The field pea vines were observed to bunch wheat plants together, possibly shielding inner leaves from wind and splash dispersed spores. These results support a study of disease incidence in barley-legume intercrops on organic farms which showed that barley-pea intercrops reduced ascochyta blight (*Ascochyta pisi*) on peas and only the barley-pea intercrop, amongst the other legumes used in the study, significantly reduced net blotch on barley (Kinane and Lyngkjaer, 2002). They concluded that the varying spatial arrangements of wheat-pea, as found in intercrops of wheat-clover (Bannon and Cooke, 1998), and alteration of microclimate, as observed in intercrops of corn-bean (Boudreau, 1993), may have affected disease dispersal and development in wheat-pea as well (Kinane and Lyngkjaer, 2002).

All intercrop treatments tended to have lower disease levels than the full-rate wheat treatment, although the treatments evaluated were only statistically lower at Carman in 2004. This would suggest that as non-hosts, and by altering the structure and climate of the canopy, intercrops were capable of slowing the spread of disease at least partially within the canopy. However, half-rate wheat also tended to have lower levels of disease. This may be explained by the higher levels of weeds within the half-rate wheat treatments which carried out the same function as intercrops by slowing the spread of disease within the wheat crop. Also, the decreased population of wheat plants in the half-rate wheat treatment meant fewer host plants for wheat diseases and thus less inoculum spreading throughout the crop.

Although no conclusions can be made from the full disease evaluation at Carman in 2005, it is interesting to note that the wheat-flax treatment had significantly lower levels of foliar disease on the wheat crop than the other treatments. It was observed in 2005 that the flax crop was quite lush and had a dense canopy, which would greatly reduce wind speed and raise the relative humidity of the canopy thereby influencing disease development as witnessed in corn-bean intercropping (Boudreau, 1993). This dense canopy was only observed in 2005, however, so disease suppression in wheat-flax in previous site-years may not have been so significant in effect. Research in crop rotations found that wheat crops after flax had less disease than after a wheat monoculture (Fernandez et al., 1998). This indicates that flax is a suitable choice as an intercrop with wheat for the reduction of wheat diseases as it did not encourage the persistence of wheat diseases in the system for the year studied.

These disease evaluations, though limited in scope, demonstrate that intercrops are capable of consistently and significantly reducing wheat foliar disease levels in comparison to a monoculture of wheat at a normal seeding rate. Such reduction of disease not only safeguards the system against crop failure, but it could allow for the wheat plant to achieve higher quality grain as more resources could be directed towards grain filling.

Table 4.10. The effect of intercrop treatment on disease levels in the field intercrop experiment during grain filling over three site-years.

Treatment	Clearwater 2004	Carman 2004	Carman 2005
	---------------------------% leaf area covered by disease--------------------		
Wheat-Oats	75 ab[a]	41 b	89 ab
Wheat-Barley	--	--	91 a
Wheat-Spring Rye	--	--	86 ab
Wheat-Flax	--	--	39 c
Wheat-field pea	70 b	28 b	78 b
Wheat-Oriental Mustard	--	--	94 a
Wheat-Red Clover	76 ab	35 b	91 a
Wheat-Hairy Vetch	--	--	95 a
Wheat-Annual Ryegrass	--	--	95 a
Half-rate wheat	74 ab	32 b	87 ab
Full-rate wheat	81 a	69 a	96 a

[a] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

4.2.8 Grain Yield

Total crop biomass may have been higher or comparable to full-rate wheat treatments, but it was unclear as to whether this increased competitiveness would translate into an increase in total yields as well.

For wheat yield alone, the highest yielding treatments were generally those which also possessed the highest levels of wheat crop biomass at maturity. Hence, the highest wheat yielding treatments were the full-rate and half-rate wheat treatments along with wheat-hairy vetch at Carman in 2004 and wheat-oriental mustard treatments at Clearwater in 2004 (Table 4.11). Hairy vetch established better at Carman in 2004 than at Clearwater, but did not outcompete the wheat as at Carman in 2005. Therefore, hairy vetch provided optimal benefits of added nitrogen and weed suppression in this year without reducing wheat yield. The high wheat yield observed for the wheat-oriental mustard treatment at Clearwater in 2004 was attributed to the largely devastating effects to the oriental mustard by flea beetles. This event allowed the oriental mustard to exert competition towards weeds during emergence, but then this competitive force was removed, thereby allowing the wheat crop to more fully establish itself. The concentration of flea beetles within these plots may also have consumed some of the weeds in the plots as well, which appeared to be confirmed by the low weed biomass levels present when measured at anthesis and maturity (Table 4.7). This lower level of weeds would also assist in boosting the yield potential of the wheat crop.

As expected from the increased levels of total crop biomass previously observed, for total yield (wheat+intercrop), the cereal mixtures of wheat-barley and wheat-spring rye were comparable or higher than the full-rate of wheat in all site-years (Table 4.11). This result indicates that these intercrop mixtures are not only highly competitive but also high yielding. Wheat-oats, wheat-field pea, and wheat- oriental mustard were also high yielding, and never yielded less than the half-rate wheat treatment. The moderately successful yields of the wheat-field pea treatment contradicts previous studies which found field peas to be too competitive as an intercrop with wheat, and only valuable for their contribution to increased protein in the cereal crop (Berkenkamp and Meeres, 1987;

Walton, 1975) but corresponds with Szumigalski and Van Acker's (2005) study which showed wheat-pea in unsprayed treatments to be comparable to wheat and pea monocultures in four of five site-years. Wheat-pea overyielded in two site-years but underyielded in one site-year during their study (Szumigalski and Van Acker, 2005), demonstrating that, as in our study, environment will influence the success of this mixture, but it is capable of high yields. Perhaps under the lower nitrogen, fungicide-free conditions of organic management, the disease reduction (Table 4.10) and nitrogen that field peas contributes to this intercrop system are significantly more beneficial than if undertaken under high-input conditions. The discrepancy in the results from this study and the study of Szumigalski and Van Acker (2005) compared to studies conducted under high-input conditions further illustrates the importance of conducting research under organic management.

The wheat-flax treatment was observed to significantly reduce the wheat crop with the competitive pressure of its high population density, but in only one site-year, Carman 2004, was it able to have comparable total yields to the full-rate wheat treatment (Table 4.11). In the other two site-years, it had significantly lower total yields than both full-rate wheat and half-rate wheat treatments. In the Clearwater 2004 site-year, this result can be explained by the frost damage suffered by the flax at this location which destroyed the majority of the seed bolls. At Carman in 2005, the observed lush and vigorous flax crop, better adapted to the wet soils than wheat, reduced the wheat crop to the point where a high total crop yield could not be achieved. The wheat grain yields appeared to be significantly more affected than in the Carr et al. (1993) study which found that wheat grain yield was reduced by almost 25% by intercropping with flax in one year of their study while flax grain yield suffered yield reductions of more than 90%. Numerous historical studies, which utilized much lower seeding rates than the monoculture seeding rates utilized in Carr's study, concluded that a wheat-flax intercrop could provide for a relative yield advantage over monocultures as well as improved wheat grain yield and reduced wheat populations (Arny et al., 1929, Arny, 1923; 1924; Martin, 1922; McKee, 1927). The high flax seeding rate used in the present trial appeared to be too competitive for use with the half-rate seeding rate used in the intercrop treatment. Carr et al. (1993) demonstrated that seeding at normal monoculture rates for wheat and flax was also too competitive for the two intercrops. Further studies on wheat-flax should employ reduced seeding rates of both wheat and flax as although flax is characterized as a weak competitor, it is capable of greatly reducing wheat yields at a high seeding rate.

Competitive intercrops with wheat, such as the cereals, are capable of producing higher total yields than that of high-rate wheat treatments, but at the cost of reducing wheat yield. Nitrogen-fixing crops can provide nitrogen benefits to the system or at least to themselves, making them more productive, but intercrops with lower competitive effects on the wheat such as field peas or red clover may be better choices for implementation than hairy vetch. Hairy vetch was observed to undergo extreme variations in establishment in the site-years, providing significantly higher wheat yields in one year, but totally overwhelming the wheat crop in the next. As the purpose of this experiment was to provide consistent benefit to the wheat crop, hairy vetch was not an ideal cover crop, unless the producer is willing to accept high nitrogen contributions for the next year in exchange for a marginal wheat yield in the present year. Such a result demonstrates the relative adaptation of wheat and intercrops to varying environmental conditions. As such, when choosing intercropping components, producers should be aware of the intercrops' possible responses in different environments, and how this could affect profitability in order to manage risk within their cropping system. Ultimately, it is the decision of the producer in the contemplation of the needs of his system as to whether intercrops should be implemented for higher total yields, higher wheat yields, or their nitrogen contribution to the system. The intercrops utilized in this experiment exhibited benefits in all of these areas and show promise for use in wheat-based intercropping systems in Manitoba.

Table 4.11. The effect of intercrop treatment on grain yield in the field intercrop experiment over three site-years.

Treatment	Clearwater 2004		Carman 2004		Carman 2005	
	wheat	total crop	wheat	total crop	wheat	total crop
	($kg\ ha^{-1}$)					
Wheat-Oats	957.0 f[a]	1635.2 bc	1126.2 d	3264.6 a	800.0 de[b]	1623.4 cd
Wheat-Barley	--	--	1078.0 d	3244.5 a	661.3 ef	2943.9 a
Wheat-Spring Rye	1183.1 ef	1824.9 abc	1519.0 cd	2680.1 abc	903.8 cde	2233.8 b
Wheat-Flax	883.7 f	901.4 d	1786.8 bc	2259.2 bcd	433.0 fg	1042.0 ef
Wheat-Field pea	1400.1 de	1583.9 bc	1977.8 bc	2996.1 ab	1415.3 bc	1458.3 de
Wheat-Oriental Mustard	1842.3 ab	1858.1 ab	1535.6 cd	2356.2 bcd	1233.3 bcd	1356.3 de
Wheat-Red Clover	1611.0 bcd	1611.0 bc	2044.0 bc	2044.0 cd	1322.3 bc	1322.2 de
Wheat-Hairy Vetch	1719.2 bcd	1719.2 abc	2373.6 ab	2373.6 bcd	278.3 g	278.1 g
Wheat-Annual Ryegrass	1486.1 cde	1486.1 c	1871.4 bc	1871.4 d	773.5 ef	773.6 f
Half-rate wheat	1731.7 bc	1731.7 abc	2311.8 ab	2311.8 bcd	1744.8 ab	1744.6 cd
Full-rate wheat	2073.8 a	2073.8 a	2761.5 a	2761.5 abc	2081.3 a	2081.3 bc
Contrasts						
half-rate wheat vs. all	0.0324	0.4659	0.0308	0.3163	0.0012	0.1732
full-rate wheat vs. all	<.0001	0.0013	<.0001	0.4156	<.0001	0.0011
wheat-oats vs. half-rate wheat	<.0001	0.5956	0.0004	0.0132	0.0006	0.5951
wheat-oats vs. full-rate wheat	<.0001	0.0216	<.0001	0.1744	<.0001	0.0513
wheat-barley vs. half-rate wheat	--	--	0.0003	0.0150	0.0001	<.0001
wheat-barley vs. full-rate wheat	--	--	<.0001	0.1917	<.0001	0.0006
wheat-spring rye vs. half-rate wheat	0.0020	0.6084	0.0130	0.3166	0.0022	0.0381
wheat-spring rye vs. full-rate wheat	<.0001	0.1777	0.0003	0.8233	<.0001	0.5038
wheat-flax vs. half-rate wheat	<.0001	<.0001	0.0904	0.8853	<.0001	0.0040
wheat-flax vs. full-rate wheat	<.0001	<.0001	0.0029	0.1750	<.0001	<.0001
wheat-field pea vs. half-rate wheat	0.0486	0.4182	0.2745	0.0681	0.3558	0.2139
wheat-field pea vs. full-rate wheat	0.0003	0.0112	0.0139	0.5215	0.0019	0.0097
wheat-mustard vs. half-rate wheat	0.4969	0.4880	0.0148	0.9030	0.0825	0.0954
wheat-mustard vs. full-rate wheat	0.1610	0.2408	0.0003	0.2713	0.0002	0.0031
wheat-red clover vs. half-rate wheat	0.4587	0.5076	0.3792	0.4647	0.1784	0.0708
wheat-red clover vs. full-rate wheat	0.0077	0.0159	0.0232	0.0564	0.0005	0.0021
wheat-hairy vetch vs. half-rate wheat	0.9382	0.9447	0.8382	0.8655	<.0001	<.0001
wheat-hairy vetch vs. full-rate wheat	0.0359	0.0589	0.2058	0.2919	<.0001	<.0001
wheat-annual ryegrass vs. half-rate wheat	0.1377	0.1831	0.1526	0.2329	0.0124	0.0002
wheat-annual ryegrass vs. full-rate wheat	0.0011	0.0029	0.0059	0.0198	<.0001	<.0001

[a] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

[b] Data was square root-transformed for the ANOVA analyses with untransformed values presented in the table.

4.2.9 Economics

Yield results can demonstrate biological productivity of intercrops, but an economic analysis is required to determine which treatments would be most profitable. Table 4.12 shows net returns based on 2004 average price data for organic crops, less a general seed cleaning cost, seed cost, operating cost and fixed cost (Appendix 8.1). Wheat-barley and wheat-spring rye treatments are generally comparable to the full-rate wheat treatment. Riskier treatments such as wheat-flax and wheat-mustard however, are the treatments which can increase the profitability of the system. Treatments incorporating legumes, although perhaps not immediately profitable, will be valuable in the long term for their soil nitrogen contributions.

Table 4.12. Net returns from Carman 2004 and 2005 and Clearwater 2004.

Treatment	Net Return $/acre (Carman 05)	Net Return $/acre (Carman 04)	Net Return $/acre (Clearwater 04)
Wheat-oat	66.05 c[a]	227.34 bcd	72.53 d
Wheat-barley	191.82 a	233.13 bc	--
Wheat-spring rye	122.87 bc	185.35 cd	96.98 bcd
Wheat-flax	111.00 bc	315.55 b	5.61 e
Wheat-field pea	66.19 bc	243.59 bc	79.67 cd
Wheat-mustard	134.15 ab	655.29 a	136.70 ab
Wheat-red clover	62.84 c	156.41 cd	100.29 bcd
Wheat-hairy vetch	-82.08 e	189.57 cd	104.74 bcd
Wheat-annual ryegrass	-18.30 d	124.02 d	74.06 cd
Half-rate wheat	120.81 bc	194.34 cd	119.15 abc
Full-rate wheat	156.53 ab	244.71 bc	155.56 a

[a] Means within columns followed by the same letter are not significantly different according to Fisher's LSD test ($P < 0.05$).

4.2.10 Conclusions

Each intercropping system elicited a different response from the wheat crop, with quite variant effects exerted from intercrops even within a system group. The wheat-cereal intercrop system was observed to influence the cropping system consistently throughout the site-years and in nearly every measured parameter compared to the other system groupings which varied in each site-year. The cereal intercrops were comparable in plant population density to the full-rate wheat treatment, and did not negatively affect the wheat crop's height or stage of development. Biomass measurements of the wheat and total crop reveal that the cereal intercrops may be strongly competing for resources in the same niche as the wheat crop and in some cases being more successful than the wheat in accessing nutrients and exploiting the niche. In all three site-years at anthesis and maturity, at least one of the cereal intercrops reduced the wheat crop biomass to significantly less than the half-rate wheat treatment. These same treatments, however, resulted in comparable or higher total crop biomass than the full-rate wheat treatment. In addition, these treatments tended to be among the lowest in weed biomass. Cereal intercrops also negatively affect wheat grain yield, but total crop yields were generally comparable to the full-rate wheat treatment as were the net returns. Cereal intercrops do not present an immediate significant advantage in terms of yield or profitability over full-rate monoculture wheat. However, the benefits of low weed levels and the protection against total crop failure in the event of a disease epidemic may be enough to recommend it for use within an organic wheat production system.

Within the other seed intercrop system, the high population density of flax elicited negative effects towards height and developmental stage, as well as wheat biomass, while providing no benefit towards weed suppression over that of full-rate wheat. There was a benefit observed, however, towards the suppression of disease at Carman in 2005. Total grain yield was also significantly reduced compared to full-rate wheat in half-rate wheat treatments in two of three site-years, which suggests that there was an overall negative effect on total grain yield with this intercrop treatment. Even with these reductions, net returns of the wheat-flax treatment were comparable to that of the full-rate wheat treatment except at Clearwater where it was largely destroyed by frost damage. It appears then that a flax intercrop with wheat may lower disease levels within a wheat crop while providing for a profitable yield. The wheat-oriental mustard and wheat-field pea treatments were generally comparable or lower to the full-rate wheat treatment in total crop biomass, and did not provide any benefit over full-rate wheat in reducing weed biomass. The wheat-field pea did provide significant disease suppression compared to the full-rate wheat treatment in each of three site-years. Both wheat-field pea and wheat-oriental mustard were never significantly greater in total crop yield than the full-rate wheat treatment. Although wheat-oriental mustard and wheat-field pea were comparable in net returns to the full-rate wheat treatment in two of three site-years, wheat-oriental mustard tended to have higher net returns than wheat-field pea, and had significantly greater net returns than all treatments in the one site-year that the oriental mustard treatment was not affected by flea beetles. Wheat-oriental mustard appears to be a profitable choice even with flea beetle damage, while the wheat-field pea treatment reduces disease and contributes nitrogen to the system.

In the cover crop system, the treatments were generally comparable to the wheat monoculture treatments in total crop biomass at maturity, except for Carman 2005 when the hairy vetch and annual ryegrass significantly reduced the wheat crop biomass and comprised the majority of the total biomass. Wheat-annual ryegrass had the lowest levels of weed biomass in the cover crop system. Grain yields were comparable to the half-rate wheat treatment, except for Carman 2005 when hairy vetch and annual ryegrass suppressed the wheat crop. The profitability reflected the grain yields, with the cover crop treatments being comparable to the half-rate wheat treatment, except for when the hairy vetch and annual ryegrass outcompeted the wheat crop at Carman 2005 which resulted in a net loss. However, these calculations only focus on short-term profitability and do not factor in the contribution of nitrogen that hairy vetch and red clover would make to the subsequent crop.

4.3 Influence of Cultivar Mixtures on Wheat

4.3.1 Plant Stand Density

As mentioned previously, the optimal plant stand density for a spring wheat crop in Manitoba is between 250-300 plants m^{-2} (Manitoba Agriculture and Food, 2001). Crop densities in all treatments were lower than the recommended density only at Carman in 2004 (Table 4.13). Cultivar mixture treatment did not appear to have an overall significant effect on plant density over the three site-years. At Carman in 2004, the Red Fife-Marquis-AC Barrie-5602HR treatment had significantly higher plant population density than the Red Fife, Red Fife-AC Barrie-5602HR, Marquis-5602HR and the AC Barrie treatments. At Carman in 2004, however, the Red Fife-Marquis-AC Barrie and the Marquis-AC Barrie treatments were significantly higher in wheat stand density than the AC Barrie treatment. At Carman in 2005, however, there was no significant difference in wheat stand density between treatments. This suggests that cultivar mixture treatment generally had no effect on crop stand density.

Table 4.13 The effect of cultivar mixture treatment on wheat plant population density in the cultivar mixture field experiment over three site-years.

Treatment	Clearwater 2004	Carman 2004	Carman 2005
	-------------------------------	plants m^{-2}	------------------------
Red Fife	226 d[a]	194 ab	217[b]
Red Fife-Marquis	260 abcd	225 ab	247
Red Fife-5602HR	256 abcd	202 ab	219
Red Fife-AC Barrie	267 abcd	202 ab	232
Red Fife-Marquis-5602HR	270 abcd	217 ab	233
Red Fife-Marquis-AC Barrie	256 abcd	238 a	247
Red Fife-AC Barrie-5602HR	244 bcd	201 ab	238
Red Fife-Marquis-AC Barrie-5602HR	299 a	217 ab	234
Marquis	260 abcd	219 ab	241
Marquis-5602HR	242 bcd	231 ab	231
Marquis-AC Barrie	281 ab	234 a	227
Marquis-5602HR-AC Barrie	276 abc	203 ab	252
5602HR	285 ab	210 ab	261
5602HR-AC Barrie	260 abcd	212 ab	245
AC Barrie	228 cd	178 b	243
Contrasts			
Red Fife vs. all treatments	0.0451	0.3178	0.1864
5602HR vs. all treatments	0.1547	0.9224	0.1375
Marquis vs. all treatments	0.9003	0.7300	0.8353
AC Barrie vs. all treatments	0.0586	0.0736	0.7346

[a] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

[b] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

4.3.2 Weed Population Density

As weeds are the major limiting factor to organic production, determining whether a cultivar mixture or heritage variety of wheat was effective at suppressing weeds would be valuable information for organic wheat production systems. Generally, there appeared to be no significant reduction in weed population density throughout the site-years (Table 4.14). At Clearwater in 2004 there was no significant difference between the treatments. At Carman in 2004, Marquis-5602HR and 5602HR-AC Barrie had significantly more weed recruitment than Red Fife-Marquis and Red Fife-Marquis-AC Barrie-5602HR treatments. At Carman in 2005, the Marquis-5602HR treatment was again significantly higher in weed population density, but only in comparison to the Red Fife-5602HR and 5602HR-AC Barrie treatments, both of which had higher weed populations at Carman in 2004. As there was little consistency in weed recruitment among treatments throughout the site-years, it is evident that the site is more of a determining factor for weed recruitment than is the cultivar mixture treatment. Heritage varieties do not appear to have any advantage or disadvantage in suppressing weed recruitment compared to the modern varieties in this study.

Table 4.14. The effect of cultivar mixture treatment on weed recruitment in the cultivar mixture field experiment over three site-years.

Treatment	Clearwater 2004	Carman 2004	Carman 2005
	--------------------------weeds m^{-2}---------------------		
Red Fife	120[a]	170 abc[b][c]	81 ab
Red Fife-Marquis	107	73 c	87 ab
Red Fife-5602HR	124	212 abc	71.5 b
Red Fife-AC Barrie	123	328 ab	104 ab
Red Fife-Marquis-5602HR	119	243 ab	81 ab
Red Fife-Marquis-AC Barrie	87	186 abc	107 a
Red Fife-AC Barrie-5602HR	116	225 abc	79 ab
Red Fife-Marquis-AC Barrie-5602HR	116	132 bc	85 ab
Marquis	104	293 abc	80 ab
Marquis-5602HR	106	357 ab	107 a
Marquis-AC Barrie	143	182 abc	82 ab
Marquis-5602HR-AC Barrie	152	303 ab	101 ab
5602HR	148	229 abc	103 ab
5602HR-AC Barrie	125	376 a	73 b
AC Barrie	99	191 abc	77 ab

[a] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

[b] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

[c] Data was log-transformed for the ANOVA with untransformed means displayed in the table.

4.3.3 Carman 2005 Biomass

Crop and biomass data could be useful in providing an indication of the productivity of the cultivar mixture treatments as well as their suppressive abilities towards weeds. Unfortunately, there was only one site-year of separated crop and weed biomass data. However, the data provides an indication of the productivity the treatments experienced in the environmental conditions of 2005 as well as their effectiveness towards weed populations in this site-year. At anthesis, wheat biomass levels were significantly higher in the Marquis-5602HR-AC Barrie treatment than the Red Fife, Red Fife-5602HR, Red Fife-Marquis-AC Barrie, Marquis, and Marquis-AC Barrie treatments (Table 4.15). The weed biomass during anthesis showed no significant difference between treatments suggesting that higher wheat biomass levels were not also indicative of increased weed suppressive ability at anthesis.

At maturity, the only significant differences in wheat biomass were that one heritage cultivar, Marquis, and one modern cultivar, AC Barrie had significantly lower biomass levels than the Red Fife-AC Barrie mixture. As Marquis and AC Barrie were observed to be the varieties most affected by disease, it follows that they would be the most reduced in biomass by maturity. By maturity, only two treatments, Red Fife-Marquis-AC Barrie and 5602HR, had significantly greater weed biomass than many other treatments (Red Fife-Marquis, Red Fife-5602HR, Red Fife-Marquis-5602HR, Red Fife-AC Barrie-5602HR, Red Fife-Marquis-5602HR-AC Barrie, 5602HR-AC Barrie and AC Barrie). Little can be concluded from these results, except that 5602HR appeared to be the least competitive sole variety against weeds. This is not surprising as modern breeding focuses on increasing yield potential, not a variety's competitiveness against weeds.

Overall, there were few significant differences between the treatments in terms of wheat and weed biomass. Although modern cultivars have a reduced height compared to heritage cultivars, modern cultivars actually produce higher biomass in ideal environmental conditions and are generally comparable in biomass over varying growing seasons (Austin et al., 1989). Advances in wheat breeding allowed for biomass that was previously allocated in the plant towards culm height to instead be used to provide for a greater number of grains/m^2 (Borrell et al., 1991). In regards to weed biomass, the trial in this year was stressed by excess precipitation, and all treatments appeared to be uncompetitive with the weeds in the presence of this added stress.

Table 4.15. The effect of cultivar mixture treatment on wheat and weed biomass in the cultivar mixture field experiment at wheat anthesis and maturity at Carman in 2005.

	Anthesis		**Maturity**	
Treatment	**wheat**	**weeds**	**wheat**	**weeds**
	biomass (kg ha^{-1})			
Red Fife	4703.0 c	535.0	7089 ab	1226.7 ab
Red Fife-Marquis	5226.0 abc	397.0	7792 ab	693.0 b
Red Fife-5602HR	4502.0 c	399.0	6811 ab	847.0 b
Red Fife-AC Barrie	5142.0 abc	368.0	8883 a	1151.0 ab
Red Fife-Marquis-5602HR	5168.0 abc	365.0	7470 ab	719.0 b
Red Fife-Marquis-AC Barrie	4738.0 c	482.0	6619 ab	1604.0 a
Red Fife-AC Barrie-5602HR	5282.0 abc	318.0	7018 ab	701.0 b
Red Fife-Marquis-AC Barrie-5602HR	5326.0 abc	331.0	7253 ab	795.0 b
Marquis	4986.0 bc	320.0	6214 b	1107.0 ab
Marquis-5602HR	5174.0 abc	374.0	6420 ab	1361.0 ab
Marquis-AC Barrie	4527.0 c	462.0	6683 ab	995.0 ab
Marquis-5602HR-AC Barrie	6496.0 a	652.0	6460 ab	917.0 ab
5602HR	6284.0 ab	634.0	7259 ab	1683.0 a
5602HR-AC Barrie	5729.0 abc	436.0	6772 ab	733.0 b
AC Barrie	5694.0 abc	453.0	5996 b	654.0 b

[a] Means are not significantly different (P > 0.05) according to Fischer's protected LSD.

[b] Means within the same site year followed by the same letter within a column are not significantly different (P > 0.05) according to Fischer's protected LSD.

4.3.4 Disease Development

Cultivar mixtures are implemented mainly for their ability to slow the spread of disease within a crop, thereby stabilizing yield. As heritage cultivars were utilized in this study, it was important to determine whether they could remain resilient in the presence of disease or whether they would present susceptibilities far greater than that of modern cultivars, rendering them a hindrance within cultivar mixtures.

During grain filling, when the flag leaves were being evaluated for disease levels, it appeared that AC Barrie was susceptible to the rust races present, as well as

Septoria/tan spot. 5602HR appeared to have rust resistance, but was susceptible to Septoria/tan spot. AC Barrie and Marquis appeared to be the cultivars that succumbed the quickest to the spread of disease.

In all three site-years, Red Fife was the cultivar which had the lowest level of disease (Table 4.16). In 2005, when a full disease evaluation of all treatments occurred, it was observed that the lowest levels of disease were found in mixtures with contained Red Fife, even when it was in a mixture with treatments that in monoculture had high levels of disease. These results do not suggest that Red Fife was disease resistant, but its slower development may have allowed it to avoid disease for an extended period compared to the earlier maturing varieties. This phenomenon supports numerous studies that showed increased disease severities occurring in cultivars with shorter stature and earlier heading dates (Eyal et al., 1983; Eyal et al., 1987; van Beuningen & Kohli, 1990; Jlibene et al., 1992; Camacho-Casas et al., 1995). Heading date, however, has been shown to have more of an effect on disease susceptibility than height (Arama et al., 1994) and specifically in the case of Septoria tritici blotch on wheat, Arama et al. (1999) found that disease severity was much greater in cultivars with earlier heading dates. Implementing varieties with varying heading dates and heights into cultivar mixtures may be an effective method of slowing disease spread through the wheat crop, and Red Fife, with its late heading date, appeared to be effective in this regard.

Table 4.16. The effect of cultivar mixture treatment on disease severity as a percentage of leaf area covered by disease in the cultivar mixture field experiment over three site-years.

Treatment	Clearwater 2004	Carman 2004	Carman 2005
	----------------------% leaf area covered by disease---------		
Red Fife	89 b[a,b]	22 b[a,b]	79 de[a,b]
Red Fife-Marquis	--	--	83 cde
Red Fife-5602HR	--	--	73 e
Red Fife-AC Barrie	--	--	72 e
Red Fife-Marquis-5602HR	--	--	80 de
Red Fife-Marquis-AC Barrie	--	--	82 cde
Red Fife-AC Barrie-5602HR	--	--	73 e
Red Fife-Marquis-AC Barrie-5602HR	--	--	91 bcd
Marquis	100 a	89 a	99 a
Marquis-5602HR	--	--	98 a
Marquis-AC Barrie	--	--	94 abc
Marquis-5602HR-AC Barrie	--	--	97 ab
5602HR	98 a	61 a	93 abc
5602HR-AC Barrie	--	--	98 ab
AC Barrie	99 a	89 a	97 ab

[a] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

[b] Data was arcsine-transformed for the ANOVA analyses with untransformed values presented in the table.

4.3.5 Wheat Grain Yield

Cultivar mixtures provide mainly for stability in grain yield, but if an overyielding mixture results, that could be of great benefit to the wheat production system. The cultivar mixtures remained generally stable as expected, with no significant difference between treatments at Clearwater in 2004, and the Red Fife-Marquis-AC Barrie-5602HR only significantly greater in grain yield than the 5602HR-AC Barrie treatment at Carman in 2004 (Table 4.17). At Carman in 2005, however, 5602 HR had significantly greater grain yield than the majority of the treatments (Red Fife, Red Fife-Marquis, Red Fife-5602 HR, Red Fife-Marquis-5602HR, Red Fife-AC Barrie-5602HR, Red Fife-Marquis-AC Barrie-5602HR, Marquis, Marquis-5602HR, Marquis-AC Barrie, 5602HR-AC Barrie, and AC Barrie). In this site-year, the plots underwent flooding stress, suggesting that 5602HR may be better suited to flooding conditions than the other cultivars.

In all site-years, heritage varieties had comparable grain yields to the modern varieties in the study. In the one site-year where a modern variety, 5602HR, had a higher grain yield than Red Fife and Marquis sole varieties, mixtures containing Red Fife and Marquis without 5602HR were comparable in grain yield to 5602HR.

These results demonstrated that although modern varieties have been bred to have a higher harvest index than heritage varieties, heritage varieties, specifically Red Fife, are competitive enough under organic management to produce comparable grain yields. Such high yields for heritage wheat under organic management is supported by Evans et al.'s (2004) study in which heritage wheat had overall higher yields in plots with weeds than newer cultivars. However, the performance of 5602HR demonstrated that modern cultivars are also capable of maintaining high yields under organic production. Although not the same throughout the site-years, the highest yielding treatments tended to be mixtures, even when containing cultivars which produced lower yields in monoculture.

No sole variety or mixture was significantly higher in yield than all other treatments in the trial. This corresponds to previous research which has found that although mixtures can provide 1 to 5% yield increases or greater in the absence of significant disease pressures (Mundt, 2002b; Finkh and Mundt, 1992b; Smithson and Lenne, 1996; Wolfe and Barrett, 1980) their greatest and most consistent benefit is that of yield stability (Kessler, 1997; Mundt, 2002a; Pfahler and Linskens, 1979; Smithson and Lenne, 1996; Wolfe, 1985).

As there were few significant differences within the site years, yields from all of the site-years were combined to provide for a representation of how the cultivar mixture treatments yielded overall. Again, there appeared to be little significant differences except for 5602HR yielding significantly more than the Marquis, Marquis-5602HR and AC Barrie treatments. As explained previously, Marquis and AC Barrie appeared to be most affected by disease in all site-years, so it follows then that their grain yield would be reduced compared to all of the other treatments.

Table 4.17. The effect of cultivar mixture treatment on wheat grain yield in the cultivar mixture field experiment over three site-years.

Treatment	Clearwater 2004	Carman 2004	Carman 2005	Combined (all site-years)
	--------------------	--------(kg ha^{-1})--------	--------------------	
Red Fife	2474.0[a]	2368.1 ab[b]	1695.7 b	2179.3 ab
Red Fife-Marquis	2419.5	2334.3 ab	1711.3 b	2155.0 ab
Red Fife-5602HR	2290.0	2356.3 ab	1553.7 b	2066.7 ab
Red Fife-AC Barrie	2769.0	2251.1 ab	1872.6 ab	2297.6 ab
Red Fife-Marquis-5602HR	2332.8	2487.3 ab	1528.5 b	2166.2 ab
Red Fife-Marquis-AC Barrie	2341.3	2250.4 ab	1872.7 ab	2154.8 ab
Red Fife-AC Barrie-5602HR	2762.1	2273.9 ab	1846.8 b	2294.2 ab
Red Fife-Marquis-AC Barrie-5602HR	2490.2	2622.6 a	1446.0 b	2186.3 ab
Marquis	2295.1	1988.6 ab	1345.3 b	1876.3 b
Marquis-5602HR	2452.3	2041.7 ab	1531.6 b	2008.5 b
Marquis-AC Barrie	2438.1	2234.5 ab	1538.7 b	2070.4 ab
Marquis-5602HR-AC Barrie	2586.8	2272.6 ab	1900.1 ab	2253.1 ab
5602HR	2526.9	2456.6 ab	2477.5 a	2487.0 a
5602HR-AC Barrie	2729.8	1869.4 b	1785.8 b	2128.3 ab
AC Barrie	2306.3	2154.5 ab	1640.1 b	2033.6 b

[a] Means are not significantly different ($P > 0.05$) according to Fischer's protected LSD.
[b] Means within the same site year followed by the same letter within a column are not significantly different ($P > 0.05$) according to Fischer's protected LSD.

4.3.6 Conclusions

Cultivar mixture treatment generally did not influence crop or weed population density. Little difference was observed in the one site-year of biomass measurements, although Marquis and AC Barrie had the lowest levels of wheat biomass, due to disease damage, and 5602HR had among the highest levels of weed biomass. In regards to disease, the main reason for implementing cultivar mixtures, Red Fife had less foliar disease than did the other sole varieties, and in the one site-year of full disease evaluation, the mixtures containing Red Fife also had lower levels of foliar disease. Grain yield also exhibited little variation among the treatments, except for 5602HR yielding significantly more than many other treatments in one site-year. These results demonstrate that cultivar mixtures are indeed suited for maintaining yield stability, while Red Fife and 5602HR, a heritage and a modern variety, are two varieties which can perform well under organic management in Manitoba.

5.0 GENERAL DISCUSSION AND CONCLUSIONS

5.1 Intercropping Systems Trial

A primary objective of this research was to identify intercrop partners with wheat that would provide effective competition against weeds, superior to that of a full-rate wheat monoculture. No intercropping treatment clearly provided a consistent advantage over full-rate wheat in suppressing weeds. However, the competitive, non nitrogen-fixing intercrops of oats, barley, flax and annual ryegrass did present a benefit in suppressing weed biomass over full-rate wheat in certain site-years. These results suggest that an intercrop which provides a full canopy and/or aggressively competes for resources in a similar niche as the major weed (e.g. foxtail) is optimal for weed suppression.

Another objective of this study was to identify intercrop pairings which would reduce wheat foliar disease levels. Unfortunately, the intercrop partner which reduced wheat foliar disease in all three site-years (wheat-field pea) did not also provide a benefit in weed suppression in comparison to full-rate wheat. The benefits provided by a full canopy towards weed suppression appeared as a disadvantage in the context of disease suppression. This was further evidenced by the half-rate wheat treatment having a generally lower level of foliar disease than the full-rate wheat treatment. The only exception to this, wheat-flax, was due to the severe reduction of wheat biomass in the mixture by the high density of flax plants. Thus, at least for the intercrop pairings evaluated in this trial, intercrop mixtures can be successful at reducing weed or disease levels, but do not effectively achieve both objectives.

Grain yield of the intercrop mixtures was expressed in terms of wheat grain yield and total grain yield. The study was limited as land equivalent ratios could not be determined, but grain yield provided information on how negatively or positively an intercrop influenced wheat grain yield, as well as how the intercrop affected the total grain yield of the mixture. The cereal intercrop system exerted strong competition against the wheat crop as they occupied a similar niche, and this resulted in significant reductions of the wheat grain yield. Despite this inhibition of the wheat crop's yield potential, a comparable total grain yield to full-rate wheat was generally reached by the system although certain treatments could be higher (wheat-barley) or lower (wheat-oat) in yield. No dramatic yield increase was witnessed from this system, due to similar niche exploitation, but its consistently strong yields were more reliable and less affected by environmental pressures than the other systems in the trial.

The other seed intercrop system contained intercrops in which further research on optimal seeding rates and management is required in order for them to become successful components of a cropping system. The high seeding rate of flax elicited a competitive force which negatively affected yields of both wheat and flax, while wheat-field pea yielded comparably to full-rate wheat only under certain environmental conditions. Wheat-oriental mustard was damaged by flea beetles in two of three site-years, but only when under the excessive precipitation of 2005 could wheat not compensate for this loss. Until production methods are developed which can provide for improved success of both intercrops, these mixtures are "risky" within a cropping system.

The cover crop system was not included in this study to elicit gains in wheat grain yields, but for its potential benefits in weed/disease suppression. The nitrogen-fixing cover crops, however, demonstrated the capability to maintain and even increase (hairy vetch) wheat grain yield under certain conditions. This capability is possible as hairy vetch and red clover can fix their own nitrogen and therefore are not as aggressive competitors for nutrient resources with wheat as are other intercrops. Before implementing such intercrops, attention must be paid to their environmental adaptations, as they can also be capable of overwhelming the main crop under certain environmental conditions.

Although intercropping may work to improve the resiliency and functioning of an agroecosystem in the long-term, short-term profitability is an important factor for producers when designing a successful cropping system. The cereal intercrop system, as it contains cereals, will not provide a great increase of profitability over full-rate wheat. However, it may stabilize net returns when the wheat crop is adversely affected by environmental pressures, or wheat grain quality is poor. The other seed intercrop system provided the most opportunity for short-term profitability, but it cannot be relied upon to provide stable net returns. Altering proportions of the intercrops in the other seed intercrop system may improve the mixtures' stability and economic performance. The cover crop system did not provide value in terms of short-term profitability. Despite this lack of short-term gain, cover crops should still be considered as valuable for long-term financial gain through their capacity to reduce soil erosion, and, for nitrogen-fixing crops, their soil nitrogen contributions which benefits subsequent crops.

5.1.1 Considerations for Wheat Intercropping in an Organic System

The cereal intercropping mixtures were high yielding in both biomass and grain yield, but they are the most difficult of the intercrop treatments to separate from wheat. This added production difficulty will most likely limit their adoption unless producers are able to sell their mixtures as mixtures, and seed cleaning is done by a separate entity.

Wheat-oats and wheat-barley were effective at weed suppression, but wheat-barley could achieve higher yields under excess precipitation and was more profitable. Wheat-spring rye could also achieve high total yields, but it was not as profitable as wheat-barley and demonstrated no other benefits to the system, and in every site-year the crop contained ergot (*Claviceps purpurea*). Wheat-barley appeared to be the treatment that would be most profitable and competitive as a mixture with wheat.

The flax intercrop inhibited the wheat crop to unacceptable levels. If wheat and flax are to be intercropped, neither crop should be sown at monoculture seeding rates or there will be too much suppression of the crops. Flax is highly profitable as an organic crop, which makes it a valuable part of a rotation and intercropping is a wise choice to manage risk in case of a flax crop failure due to frost.

Wheat-field pea was shown to reduce disease levels in all three site-years, most likely due to the physical barrier they presented towards the spread of spores. Field peas resulted in increased total crop biomass in two of three site-years but higher total grain yield in only one site-year. This may have been due to shattering as was observed during separation of the crops prior to threshing. Harvesting should occur promptly in order to minimize this occurrence. This mixture displays potential for use in an organic system with its contribution of nitrogen to the system, disease suppression, increased biological productivity and the potential for high total grain yields.

The wheat-oriental mustard treatment suffered flea beetle damage in two of three site-years, indicating that without seed treatments, oriental mustard is a risky crop to have in the rotation. Intercropping with wheat however, did protect the treatment from total crop failure, and it remained profitable. Although profitable, it would not be advisable to have this mixture too often in the rotation in order to avoid flea beetle damage.

Red clover was the least competitive of the cover crops used in this study, contributing the least amount of biomass to the mixture. As a nitrogen-fixer, however, it contributed nitrogen to the system. This treatment also had lower levels of disease than full-rate wheat, although significantly lower only in one site-year which suggests that it may reduce splash dispersed spores. This treatment also remained comparable in grain yield and net returns to the half-rate wheat treatment. While this treatment will not provide nitrogen contributions as high as hairy vetch, or disease suppression as effective as field peas, this is a good cover crop choice for producers that want a cover crop which will not greatly inhibit the wheat crop while providing moderate nitrogen and disease suppression benefits.

Hairy vetch established slowly in the spring, but could produce large amounts of biomass later in the summer and into the fall. Its later establishment meant that it was not effective as a physical barrier against disease early in the season as field peas were, nor did it provide early competition against weeds. It was capable of maintaining wheat yields comparable to that of full-rate wheat, but smothered the wheat crop during a warm, high precipitation growing season. As hairy vetch showed great variation in response to environmental conditions, it may not be a suitable choice if a producer is relying on having a profitable wheat crop. However, hairy vetch sown with a nurse crop would provide for an excellent green manure crop.

Annual ryegrass was also slow to establish, similar to hairy vetch. When it successfully established, however, it provided very effective weed control. It also suppressed the wheat crop, producing yields that were always lower than that of the half-rate wheat treatment. As annual ryegrass did not contribute nitrogen to the system and suppressed the wheat crop, it is not an ideal choice for a cover crop.

5.2 Cultivar Mixtures Trial

Cultivar mixtures are implemented for their benefits in suppressing disease through genetic diversity, but it was anticipated that the phenotypic differences provided by cultivar mixtures and heritage cultivars would provide weed suppressive benefits greater than that of a modern wheat monoculture. Heritage cultivars generally have larger leaf area and taller habits than that of modern cultivars and this may aid in shading weeds and inhibiting their growth, but there was insufficient evidence to suggest a benefit from heritage cultivars or mixtures from the present study. Further research is needed however, into what characteristics of a wheat plant should be emphasized through plant breeding to enhance the weed competitive ability of the wheat crop.

Genetic diversity within the cultivar mixture may present more of a substantial disease suppressive effect during an epidemic, but phenological differences appeared to be the greatest factor in reducing disease in the present study. The delayed development exhibited by Red Fife appeared to allow this cultivar and the mixtures it was included in to escape a portion of the disease which impacted earlier maturing cultivars. Genetic improvement did allow for the most recently developed cultivar, 5602HR, to maintain high yields despite higher disease levels than Red Fife and site-years with excess precipitation. Hence, both genetic and phenological diversity are important components in achieving effective disease suppression in cultivar mixtures.

5.2.1 Considerations for Implementing Cultivar Mixtures of Wheat

Red Fife is not a registered variety recognized by the Canadian Grain Commission. This limits its inclusion in organic wheat production to direct marketing to buyers. This would be a major drawback to producers in Western Canada as their wheat would not be accepted or marketed by the Canadian Wheat Board. However, as Red Fife is gaining international recognition through the Slow Food Movement, and is in high demand from artisan bakers, the obstacle of marketing Red Fife may be worth the financial gain. As for its use in cultivar mixtures, this would also have to be marketed directly by the producer, and may be a more difficult sell as it is not solely Red Fife.

Marquis did not prove to be a variety suitable for use in organic production or cultivar mixtures. This cultivar succumbed to disease more readily than Red Fife, and over the site-years had a significantly lower yield. Marquis lacks the recognition for use in artisan baking garnered by Red Fife, and as it is also not recognized as a registered variety by the Canadian Grain Commission, there is no advantage to utilizing this cultivar within the organic wheat production system.

AC Barrie, the standard of western Canadian spring wheat production for the past decade, performed poorly and was observed to be susceptible to rust. It had comparably low yields across the site-years to the heritage variety Marquis. AC Barrie is no longer an appropriate variety to use within organic production, as its resiliency to disease pressures has been compromised.

5602HR would benefit organic wheat production, especially in wet seasons as proven by its high yields in all site-years. It also proved to be resistant to rust while Marquis and AC Barrie were greatly affected by it. For the short term at least, this would be a valuable variety of organic wheat, as well as a strong component in a cultivar mixture.

6.0 RECOMMENDATIONS

Based on the results of this study, the following recommendations are given to producers that wish to implement intercropping and/or cultivar mixtures into their organic cropping system:

- wheat-barley should be chosen if a cereal intercrop is desired that will be both competitive and profitable
- wheat-flax should utilize less than full monoculture seeding rates for both crops
- wheat-field pea can be implemented for disease suppression to the wheat crop
- promptly harvest wheat-field pea to avoid shattering
- wheat-oriental mustard should not be grown too frequently to avoid flea beetle infestations
- wheat-hairy vetch and wheat-annual ryegrass are not suitable as wheat intercrops in wet seasons
- Marquis and AC Barrie should not be used in organic production due to their disease susceptibility
- 5602HR is a suitable high yielding modern cultivar for use in organic production

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8.0 APPENDICES

Appendix 8.1. Costs used in the calculation of net returns for the intercropping field experiment.

2004 Price Data/Seed Cost Average Prices in $/bu[a]	Seed Cleaning Cost	Operating Cost[b] (wheat)	Fixed Cost[b] (wheat)
Wheat - $8.72 Oats- $3.53 Barley - $5.43 Flax - $29.28 Field Pea - $7.60 Mustard - $39.06	$0.25/bu	$39.77/acre	$57.64/acre

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[a] Prices taken from http://organic.usask.ca/pricedata.htm and also used as the seed cost for each treatment

[b] Operating costs and Fixed Costs taken from the 2004 Guidelines for Estimating Crop Production costs minus fertilizer, fungicide and herbicide costs with seed costs also calculated separately. The 2005 version is online at: http://www.gov.mb.ca/agriculture/financial/farm2005/cac40s01.html