University of Alberta

Wheat cultivar and cereal species mixture use in organic and conventional agriculture

by

Amelia Helena Erika Elizabeth Kaut ©

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Abstract

Mixtures of wheat cultivars and cereal species may be more competitive, produce higher yields and provide greater environmental stability than growing sole crop wheat. We conducted two 8 site-year studies on both organic and conventionally managed land; testing a) 16 modern wheat cultivar mixtures with and without simulated weed pressure, and b) 18 wheat:spring cereal (barley, oats or triticale) mixtures, between 2003 and 2005. A 1:1 mixture of a vigorous semi-dwarf (Superb) and an early maturing (Intrepid) wheat cultivar performed well in both conventional and organic systems. Sole-crop Superb produced high yields but was not as stable as some mixtures. Barley:wheat and oat:wheat mixtures yielded well and suppressed weeds in both systems. Barley often suppressed wheat (and weeds) in mixtures due to its greater competitive ability. Wheat cultivar and cereal species mixtures may be useful for both organic and conventional producers in western Canada.

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Table of Contents

List of Tables

List of Figures

List of Appendices

The potential of wheat cultivar and cereal species mixture use in organic and conventional agriculture: a review of literature

1.0 Abstract

Wheat is the most widely grown crop in the world and second only to maize in production. Spring bread wheat is the most common type of wheat grown in Canada, amounting to 76% of total production area. Organic agriculture is a system of production that excludes the use of pesticides, herbicides, chemical fertilizer, irradiation and genetically-modified organisms in crop production. Wheat is a major crop on many organic farms in Canada, but yields are depressed by heavy weed pressure and other biotic and abiotic stress factors. Wheat cultivar mixtures and cereal species mixtures may be more competitive, produce higher yields and provide better disease resistance and increased environmental buffering or stability than sole crop wheat. Cereal species mixtures may also be used as forage or feed for organic animal production. Many of the benefits of mixed grain cropping can be utilized by producers across Canada, making them useful for organic, conventional and integrated grain producers.

1.1 Introduction

Competitive ability, yield and disease resistance of wheat are important for grain producers across the world. Integrated crop management (ICM) – a system that seeks to replace widespread and broad-spectrum pesticide use with cultural control methods and economic thresholds – and organic agriculture are gaining popularity worldwide. With the rise of these alternative crop production regimes comes the need for alternative methods of weed and disease control in cereal production.

Wheat cultivar mixtures have been studied extensively around the world for their disease mitigating potential. In addition, their yield, competitive ability and quality have been explored. Cultivar mixtures provide an option for producers wishing to decrease or eliminate their dependence on chemical disease and weed control. Cereal species mixtures represent a relatively unexplored area of research which may be considered an alternative to sole-crop grain production, especially for animal feed and forage.

The following literature review outlines the importance of wheat in global and Canadian agriculture, the rise of organic agriculture in modern grain production, and the potential of wheat cultivar mixtures and cereal species mixtures in both organic and conventional cereal production.

1.2 Wheat (*Triticum aestivum* L.)

1.2.1 General Introduction and World Production

The three most important grain crops in the world are wheat, maize and rice. Of these, wheat is by far the most widespread (grown on 215 million ha in over 120 countries) (Food and Agriculture Organization of the United Nations [FAO] 2005) and second only to maize in terms of production (721 MMT maize versus 627 MMT wheat in 2004) (Food and Agriculture Organization of the United Nations Statistics Database [FAOSTAT] 2005).

Wheat is a member of the grass family (Poaceae) and the genus *Triticum*; a group which also includes species such as einkorn, emmer, club and durum wheat (Peterson 1965). It is thought that modern bread wheat descends from ancient species that grew in the Fertile Crescent: einkorn wheat (*T. monococcum* L., AA) combined with a diploid wild grass (*Aegilops speltoides* Tausch) to form emmer wheat (*T. turgidum* L., AABB), which combined with the wild grass *Aegilops tauschii* Coss. to become hexaploid bread wheat, or *T. aestivum* L. (AABBDD) (Peterson 1965; Bonjean and Angus 2001). The most common wheats grown today are bread and durum wheat (AABB), which accounted for 92% and 7% of world wheat production in 1999, respectively (Aquino et al. 1999). There are two wheat growth habits, winter and spring, which accounted for approximately two-thirds and one-third of total wheat production in 1999, respectively (Aquino et al. 1999). Spring wheat is a C_3 plant with an optimal growing temperature of 25°C, although it can grow in temperatures ranging from 3 to 32°C (Curtis 2002). Optimum yields occur when annual rainfall is between 300 and 1000 mm, but rainfall distribution throughout the growing season may be more important than total moisture (Stoskopf 1985; DePauw and Hunt 2001).

In Canada, spring wheat is further divided into classes by visual and tactile characteristics, which are related to end use. Canada Western Red Spring (CWRS) and Canada Prairie Spring (CPS) are the two most common classes of hexaploid Canadian wheat grown on the Prairies. CWRS wheat is visually characterized by medium size oval grain with a pronounced reddish tinge. The kernels are hard and have protein content and gluten quality highly desirable for making leavened bread (DePauw and Hunt 2001). CPS wheat has larger kernels than CWRS, elliptical in shape and possessing 1-2% less protein and weaker gluten strength. These wheats yield 25-30% more than CWRS cultivars and were developed in response to changes in properties required by international markets (DePauw and Hunt 2001).

1.2.2 Canadian Wheat Production

In 2005, Canada produced 25.5 MMT of wheat on 10.1 million ha (Statistics Canada 2005), with an average yield of 2.4 t/ha. Of the wheat produced, 8.7 MMT were exported, mostly to Japan, Algeria, the United States and Mexico (FAOSTAT 2005). Canada ranks sixth in world wheat production, behind China, the United States, India, Russia and Kazakhstan (Curtis 2002). Many countries use high protein Canadian wheat in blends to improve the baking properties of poorer quality soft wheats. The most common type of wheat grown in Canada is spring wheat, due to the short growing season and extremely cold winters on the Prairies, the main wheat-producing area (Curtis 2002). Bread, durum and winter wheat account for 76%, 20% and 4% of total Canadian wheat production area, respectively (Statistics Canada 2001).

Wheat is grown on 30% of all crop production area in Alberta (Alberta Agriculture, Food and Rural Development [AAFRD] 2001), making it the most widely grown crop in the province. In 2001, 2.77 million ha were sown to wheat in Alberta, with 85% being spring wheat, 14% durum and only 1% winter wheat (Statistics Canada 2001).

1.3 Organic Agriculture

1.3.1 Introduction

Until approximately 60 years ago, all agriculture of the previous 8 to 10 millennia was, by definition, organic (Pimental et al. 2005). Only after the advent of chemical fertilizers, herbicides, fungicides and insecticides did the words "conventional agriculture" take on a meaning dissimilar to organic agriculture (Vos 2000). The International Federation of Organic Agriculture Movements (IFOAM) definition of organic farming is as follows:

> "...a system that excludes the use of synthetic inputs, such as synthetic fertilizers and pesticides, veterinary drugs, genetically modified seeds and breeds, preservatives, additives and irradiation. Organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity." (IFOAM 2005)

At present, organic agriculture is often perceived as an ideology or way of life (Hill and MacRae 1992; Lotter 2003), whereas conventional agriculture is seen as a profit-based business (Ulbricht 1980). Nevertheless, there are examples of farmers who became organic for monetary reasons (Rigby and Cáceres 2001; Willick 2004). Often, organic agriculture is considered synonymous with words such as alternative, regenerative or sustainable (Vandermeer 1995; Vos 2000). In fact, "sustainability" has become part of the modern organic agriculture ideology in an attempt to maintain long-term productivity without degrading the resource base (Smolik et al. 1995; Norman et al. 2000), such as occurs in conventional farming methods (Oelhaf 1978; Vandermeer 1995) or even historical, chemical-free, low-input systems that were "organic by neglect" (Carter and Dale 1974).

1.3.2 Organic versus Conventional Agriculture

Organic agriculture often differs from its conventional counterpart in many ways. These may include: lower nutrient inputs (Hansen et al. 2001), higher numbers and diversity of weed species (Rasmussen et al. 2000; van Elsen 2000; Mäder et al. 2002; Hyvönen et al. 2003; Lotter 2003; Boguzas et al. 2004), higher efficiency of production (Pimental et al. 1983; Loomis and Connor 1992; Dalgaard et al. 2001; Reganold et al. 2001; Mäder et al. 2002; Stokstad 2002), more complex crop rotations (Reganold et al. 1987; Hill and MacRae 1992; Smolik et al. 1995; Fernandez-Cornejo et al. 1998; Derksen et al. 2002), higher soil organic matter levels (Reganold et al. 1987; Rynk 2002; Lotter 2003; Pimental et al. 2005), lower fossil energy use (Berardi 1978; Smolik et al. 1995; Pimental et al. 2005), increased environmental buffering and stability (Smolik et al. 1995; Pimental et al. 2005), smaller farm size (Fernandez-Corejo 1998; Klonsky and Tourte 1998; Lotter 2003) and the prohibition of chemical fertilizers and synthetic pesticides (Lockeretz and Wernick 1980; Greene 2000; Trewavas 2001).

Many studies have demonstrated the lower yield potential of organic management systems (Berardi 1978; Lockeretz and Wernick 1980; Vereijken 1989; Nguyen and Haynes 1995; Warman and Havard 1998; Clark et al. 1999; Tamis and van den Brink 1999; Mäder et al. 2002; Lotter 2003), ranging from 8 (Reganold et al. 1987) to 50% (Entz et al. 2001) lower than conventional agricultural systems. Such yield reductions are compensated for by decreased monetary input per unit land – i.e. no chemical fertilizer or pesticides – and the price premium associated with organic produce (Jukes 1974; Dobbs 1994; Smolik et al. 1995; Tamis and van den Brink 1999; Greene 2000; Lotter 2003). There have also been studies reporting organic yields equal to or greater than conventional counterparts (Stanhill 1990; Drinkwater et al. 1995; Warman and Havard 1997; Walker et al. 1999; Poudel et al. 2002; Nass et al. 2003), especially once farms are past the three-year transition period (Hanson et al. 1997; Lotter et al. 2003) or during periods of drought stress (Sahs and Lesoing 1985; Pimental et al. 2005).

Weed control presents a major agronomic challenge for organic farmers (Klonsky and Tourte 1998). Broad-spectrum applications of herbicides cannot be used to eradicate weeds and farmers therefore rely on the cumulative effect of a series of cultural and mechanical weed control methods. Such methods include tillage, green manure/smother crops, crop rotation, use of competitive crops and cultivars, and the adjustment of row spacing, seeding rates and seeding depth (Klonsky and Tourte 1998; Emmens 2003; Lotter 2003). Dominant weed species differ depending upon locality, and thus cultural methods that work in a given region may not work in another. For example, organic farms in Australia must contend with grassy weeds such as rigid ryegrass (*Lolium rigidum*) and wild oats (*Avena fatua*) (Emmens 2003), while research on the Canadian prairies has suggested that broadleaf weeds such as wild mustard (*Brassica kaber*) and Canada thistle (*Cirsium arvense*) were the most prevalent weeds on organic farms (Entz et al. 2001).

The relative impact of organic versus conventional management on the environment is the subject of much debate. There have been many conflicting studies: some reporting organic farming to reduce fossil fuel use (Berardi 1978; Lockeretz and Wernick 1980; Smolik et al. 1995), lower soil erosion (Lockeretz et al. 1981; Reganold et al. 1987; Smolik et al. 1995; Siegrist et al. 1998; Macilwain 2004) and promote biodiversity (McLaughlin and Mineau 1995; van Elsen 2000; Mäder et al. 2002; Hole et al. 2005); while others report environmental problems associated with organic farming, including runoff/leaching (Loomis and Connor 1992; Entz et al. 2001; Hansen et al. 2001; Trewavas 2001; Pimental et al. 2005), erosion (Derksen et al. 2002) and gas emission (Nelson et al. 2004), and suggest this system is an inefficient use of valuable agricultural land (Loomis and Connor 1992; Trewavas 2001). However, organic proponents regard pollution by conventional agriculture to be even greater due to the inherent problems associated with herbicide, pesticide (Robinson 1991) and chemical fertilizer losses (Ellis and Wang 1997; Vitousek et al. 1997; Pimental et al. 2005).

Some scientists question whether organic food has any real, measurable benefits for humans (Adam 2001). Some studies have reported greater amounts of nutrients such as iron and vitamin C in organic foods (Worthington 2001), while other studies report the opposite effect (Warman and Havard 1997; 1998), especially regarding protein content in organic wheat (Starling and Richards 1993; Storey et al. 1993; Thompson et al. 1993; Nass et al. 2003). Opponents of organic grain production have expressed concerns over contamination by mycotoxins and phytoxins as a result of not using fungicides (Pussemier et al. 2006).

Conversely, many aspects of organic management (such as long crop rotations, the use of resistant cultivars and heavy tillage) may help prevent epidemics of Fusarium head blight (*Fusarium graminearum*), which is responsible for one of the most prevalent mycotoxins found on cereal grains (Pussemier et al. 2006). At the very least, organic produce should not contain pesticide residues on or in the marketable portion (Lotter 2003).

1.3.3 Global Organic Agriculture

Worldwide, there are approximately 26 million ha of agricultural land under organic management (Research Institute of Organic Agriculture [RIOA] 2005), with the greatest portion in Australia (11.3 million ha), Europe (6.3 million ha), South America (6.2 million ha) and North America (1.4 million ha) (Yussefi 2005). These statistics do not take into account subsistence farming, which is often organic and accounts for 60% of global agriculture, producing 15-20% of the world's food (Smithson and Lenné 1996). In 2000, about 3% of agricultural land in Europe was planted to organic crops (Pussemier et al. 2006); as of 2005, the figure had risen to over 3.5% (RIOA 2005). Organic production accounts for 1-1.5% of Australia's total agricultural output. This compares with 2.5% in the USA, 3.7% in Denmark, 7.8% in Switzerland and 10% in Austria (Organic Federation of Australia 2001). Although organic produce remains a niche market, global sales rose by 20% per year between 2000 and 2004 (Nelson et al. 2004). Worldwide, the market value of organic produce has risen to $25 billion US (IFOAM 2005). The United Kingdom, EU and US organic food markets are now worth some $854 million, $7.3 billion and $11 billion US per year, respectively (Lampkin 2000; Adam 2001; IFOAM 2005).

In Canada, there are over 3600 organic producers (1.5% of all Canadian farmers) cultivating almost 600,000 ha of organic land (Macey 2005). There are 72,560 ha of organic land sown to wheat, grown by 941 producers, 72% of whom are in Saskatchewan. The value of organic wheat grown on the Prairies is over $27 million (Macey 2005).

In Alberta, there are 245 organic producers (0.4% of total producers) cultivating 95,375 ha of organic land. There are 13,809 ha of organic land sown to wheat on over 40 farms (Macey 2005). In 2004, organic wheat sold for $7.38-$7.79/bu, and production was 33-38 bu/acre, on average (Agriculture, Food and Rural Revitalization [AFRR] 2004). This translates to a 30% price premium for organic flour (Macey 2004).

1.4 Wheat Cultivar Mixtures

1.4.1 Introduction to Wheat Cultivar Mixtures

Conventional industrialized agriculture is very dependent on external outputs such as chemical fertilizer, herbicides and fungicides. As the implementation of integrated crop management increases, producers often strive to engage in more ecological methods to reduce disease and weeds and maintain yields. At present, subsistence agriculture (the production of food primarily for personal sustenance instead of for cash profit) is still the most common and widespread application of organic farming (Devendra and Thomas 2002). There are many parallels that may be drawn between subsistence farming and modern organic farming. One of these is the use of varietal and species mixtures (Smithson and Lenné 1996). Both agricultural systems employ species mixtures for similar reasons: to reduce insect and disease damage (Emmens 2003), stabilize yield, minimize risk, and maximize exploitation of limited resources such as water, nutrients or space (Smithson and Lenné 1996) without resorting to expensive external inputs. Crop mixtures are also used in organic farming for green manure or plowdown. If crop or cultivar mixtures utilize available space and nutrients more efficiently than monocrops (Sarandon and Sarandon 1995), thereby out-competing weeds and increasing yield, they represent a valuable multi-faceted tool for farmers using organic, conventional and integrated crop management (ICM) techniques.

Cultivar mixtures may be any combination of two or more cultivars of a given crop in any ratio. They are easily developed by producers using locally adapted and available cultivars (Georgeson et al. 1891; Finckh et al. 2000), and may decrease requirements for external inputs such as fertilizer (Sarandon and Sarandon 1995), provide resistance to multiple diseases (Ram et al. 1989; Mundt et al. 1995a; Akanda and Mundt 1996; Cox et al. 2004), reduce lodging (Reddy and Prasad 1977; Rajeswara Rao and Prasad 1984; Finckh et al. 2000) and produce yields equal to or better than monocultures (Wolfe 1985; Manthey and Fehrmann 1993; Mundt et al. 1995a; Jackson and Wennig 1997). Additionally, there are other potential benefits for mixture use in organic agriculture, including yield buffering against unpredictable environmental variation (Shaalan et al. 1966), lowering economic and environmental costs (Sarandon and Sarandon 1995), and maintaining grain quality (Finckh et al. 2000) as well as soil organic matter levels (Sarandon and Sarandon 1995).

The use of cultivar mixtures is becoming more widespread, and not just in organic or subsistence farming. About 12% of the wheat area in Switzerland is planted to mostly two-way cultivar mixtures (Finckh et al. 2000), while in the United States, 10 and 13% of soft white winter wheat area in Oregon and Washington and 76% of club wheat area in Washington is sown to cultivar mixtures (Garrett and Mundt 1999). In Kansas, the area sown to two- and three-way wheat mixtures increased from 7 to 13% of the total wheat acreage from 2001 to 2003 (Cox et al. 2004). An impressive example of cultivar mixture use occurred in East Germany, where the percentage of barley sown to varietal mixtures increased from 0 to 92% between 1980 and 1990, while powdery mildew incidence and fungicide use declined by 80% over the same time period (Finckh et al. 2000).

1.4.2 Wheat Cultivar Mixtures and Disease

The greatest amount of research conducted on wheat cultivar mixtures has been in the area of disease control. This is likely because of two simultaneous events: the evolution of new disease races and the development of popular cultivars over time and between locations. Researchers must therefore constantly search to discover the correct combination of cultivars and ratios that work best against a given disease in a given area (Wolfe 1985). Many diverse methods are employed by crop breeders to increase crop disease resistance, including pyramiding multiple resistance genes into one cultivar (Jones et al. 1995, Pedersen and Leath 1998) or the development of multilines (mixtures of nearly isogenic lines that vary only in disease resistance) (Dubin and Wolfe 1994). However, these are time and resource intensive methods, providing vertical resistance to only a few pathogen races for a limited time (Sharma and Dubin 1996). More feasible, especially in areas of subsistence or organic farming, is the use of cultivar mixtures. Mixtures are an ecologically sound disease control method and can reduce disease through mechanisms such as the reduction in the percentage of susceptible plants present (Klages 1936; Wolfe 1985; Finckh and Mundt 1992); the barrier effect of resistant plants (Chin and Wolfe 1984; Loomis and Connor 1992; Finckh et al. 2000); altering morphology and timing of phenological events (Sharma and Dubin 1996); facilitating escape of susceptible plants by diluting the amount of inoculum present (Ram et al. 1989; Mundt 2002a); and induced resistance caused by non-virulent pathogens (Calonnec et al. 1996). Some producers will not grow mixtures due to variations in cultivar height, heading, maturity, or seed size/appearance. This may be overcome by employing mixtures with just two or three components, chosen for similar appearance and maturity, but with differing disease resistances (Wolfe 1985). Generally, however, farmers pay little heed to physical differences as long as high yields are maintained (Sharma and Dubin 1996).

1.4.2.1 Effectiveness of Wheat Cultivar Mixtures Against Disease

Many experiments conducted worldwide have reported that wheat cultivar mixtures effectively reduce airborne disease. Diseases reduced by wheat cultivar mixtures include leaf rust (*Puccinia recondita* f. sp. *tritici*) (Ram et al. 1989; Brophy and Mundt 1991; Mahmood et al. 1991; Aslam and Fischbeck 1993; Manthey and Fehrmann 1993; Dubin and Wolfe 1994; Jackson and Wennig 1997; Cox et al. 2004), stem rust (*Puccinia graminis* f. sp. *tritici*) (Alexander et al. 1986), stripe rust (*Puccinia striiformis* West.) (Ram et al. 1989; Brophy and Mundt 1991; Finckh and Mundt 1992; Aslam and Fischbeck 1993; Finckh and Mundt 1993; Manthey and Fehrmann 1993; Dubin and Wolfe 1994; Mundt et al. 1995a; Akanda and Mundt 1996; Akanda and Mundt 1997; Garrett and Mundt 2000), powdery mildew (*Erysiphe graminis* f. sp. *tritici*) (Ram et al. 1989; Manthey and Fehrmann 1993; Strzembicka et al. 1998), Helminthosporium leaf blight (caused by a complex of *Drechslera tritici-repentis* Shoem. and *Bipolaris sorokiniana* Shoem.) (Dubin and Wolfe 1994), septoria tritici blotch (*Mycosphaerella graminicola*) (Mundt et al. 1995b; Jackson and Wennig 1997; Cowger and Mundt 2002) and spot blotch of wheat (*Cochliobolus sativus*) (Sharma and Dubin 1996). Cultivar mixtures have reduced the incidence of leaf rust and spot blotch by 57% (Sharma and Dubin 1996; Cox et al. 2004), powdery mildew by 94% (Strzembicka et al. 1998) and stripe rust by 96% (Finckh and Mundt 1992).

In addition to polycyclic airborne diseases such as stripe rust, leaf rust and powdery mildew, cultivar mixtures have also proven effective against soil- and residue-borne pathogens. Hariri et al. (2001) studied the use of two-way mixtures against the wheat mosaic virus, which has a soil-borne vector (*Polymyxa graminis*). When researchers combined one susceptible and one resistant cultivar, there was a reduction in both the number of infected plants and the virus concentration compared to the susceptible plant in pure stand. Reduction of disease could not be attributed to the barrier effect, decreased frequency of susceptible plants or induced resistance, because wheat mosaic virus is not an airborne disease. Thus, the researchers hypothesized that disease reduction was caused by root development, root exudates of the resistant cultivar or the sensitivity of the virus to heat. Cox et al. (2004) examined the effect of mixing one susceptible and one resistant cultivar on tan spot (*Pyrenophora tritici-repentis*), a splash-dispersed, residue-borne pathogen of wheat. As the proportion of the susceptible cultivar in the mixture decreased to 25%, tan spot decreased by 23-37% and leaf rust decreased by 38-57% on the susceptible cultivar. Eyespot of wheat (*Pseudocercosporella herpotrichoides*) is another residue-borne disease for which mixtures have been effectively employed. Mundt et al. (1995a) reported that mixtures caused a 6%

reduction in eyespot severity, while Vilich-Meller (1992) observed 50% reductions in eyespot due to mixture effects. These researchers postulated that the dichotomy in results stemmed from differences in environment between the two experiments. These results contradicted the previously held belief that cultivar mixtures had no effect on soil-borne diseases (Wolfe 1985).

1.4.2.2 Factors Affecting Mixture Efficacy Against Disease

An important characteristic of cultivar mixing is that diseases become less prevalent with each successive pathogen generation, as decreasing availability of uninfected host tissue in the isolated susceptible pure stands limits epidemic progression (Leonard 1969; Mundt and Finckh 1993; Garrett and Mundt 1999; Mundt 2002a). Cultivar mixtures are effective in mitigating severe disease epidemics if pathogen increase is driven by the number of pathogen generations in-crop, but not if a large influx of outside inoculum is causing the epidemic (Wolfe and Barrett 1980; Garrett and Mundt 1999; Mundt 2002a).

Pathogen dispersal mechanisms may also affect mixture efficacy in preventing the spread of disease. In general, mixtures are less effective against airborne pathogens with steep dispersal gradients (e.g. splash-dispersed) than shallow dispersal gradients (e.g. wind-dispersed) (Jeger et al. 1981; Mundt et al. 1995a; Garrett and Mundt 1999; Cowger and Mundt 2002). Generally, a shallower dispersal gradient moves propagules further away from the susceptible host and reduces autoinfection (Cox et al. 2004). However, two-component wheat cultivar mixtures reportedly reduced Septoria tritici blotch, caused by the splash-dispersed pathogen *Mycosphaerella graminicola*, by ~9% under conditions of severe disease (Mille and Jouan 1997; Cowger and Mundt 2002).

Inoculum reduction in cultivar mixtures is affected by the ratio of autoinfection to alloinfection: the higher the level of autoinfection, the less effective the mixture (Lannou et al. 1994), since this cancels the barrier effect of resistant plants (Wolfe and Barrett 1980). Lesion size can affect this: diseases with large lesions (e.g. stripe rust) saturate their host more quickly than those with small lesions (e.g. leaf rust), canceling the effect of inoculum dilution onto resistant plants (Lannou et al. 1994).

There are several methods of cultivar mixing that may be used in the field by producers, including random mixtures, alternating rows or alternating swaths. Disease reduction is highest in random mixtures because isolation of susceptible plants is maximized, preventing the spread of disease (Brophy and Mundt 1991; Garrett and Mundt 2000). Cultivar mixtures with larger contiguous areas occupied by a single cultivar are less effective than more fragmented mixtures (Mundt and Leonard 1986; Brophy and Mundt 1991; Garrett and Mundt 1999).

Overall plant density may also influence disease reduction potential of wheat cultivar mixtures. Some studies reported increased disease in cereal monocultures as seeding rates increase (Burdon and Chilvers 1976; Burdon and Chilvers 1982; Krupinsky et al. 2002), but the opposite effect also occurs (Pfleeger and Mundt 1998; Finckh et al. 1999). Garrett and Mundt (2000) reported conflicting results when they used two-way mixtures, with disease increasing with density in one study year and opposite results the following year. Overall, disease reduction was greatest at an intermediate seeding rate of 250 seeds m^{-2}, normal for that area.

1.4.2.3 Composing Effective Cultivar Mixtures

Disease reaction is altered by the number of component cultivars, cultivar selection and cultivar proportion in the mixture. In general, increasing the number of component cultivars tends to increase disease control and slow pathogen evolution by increasing a given mixture's durability (Ralph 1987; Mundt et al. 1995a; Strzembicka et al. 1998). Selection of cultivars is based on local availability (Finckh et al. 2000) and mixing ability – i.e. their performance, competitiveness and disease resistance when they are part of a mixture (Knott and Mundt 1990). A cultivar with a high genotypic performing ability (performs well in pure stand) but a low total general mixing ability (ability of a given cultivar to affect yield and disease reduction when mixed with other cultivars) is not as desirable for use in cultivar mixtures as one with opposite characteristics (Knott and Mundt 1990). Unfortunately, this distinction cannot be made by merely observing the performance of a cultivar in monoculture. Even cultivars with proven disease resistance and high yielding ability must be tested for mixing ability (Finckh et al. 2000). Statistical approaches for choosing mixture components based on field analysis of two-component mixtures and the local pathogen population have been proposed (Yong and Zadoks 1992; Lopez and Mundt 2000). Nevertheless, most cultivar mixtures currently in use are created by producers or seedsmen from cultivars considered competitive, high-yielding, and similar in quality and maturity (Finckh et al. 2000; Mundt 2002b). Disease levels decrease with increasing proportions of resistant plants in the mixture (Klages 1936; Alexander et al. 1986). Studies have found equiproportional mixtures of cultivars to have the greatest disease reduction (Manthey and Fehrmann 1993; Strzembicka et al. 1998), especially as the number of component cultivars increases, since this separates similar genotypes as much as possible and maximizes barrier effects (Akanda and Mundt 1996; Akanda and Mundt 1997; Garrett and Mundt 1999). However, the opposite recommendation was made by Gupta and Virk (1984), who observed that a 1:1 ratio is not always the optimal composition for a cultivar mixture.

1.4.3 Wheat Cultivar Mixtures and Yield

Despite the potential of wheat cultivar mixtures to mitigate disease, they will likely not be widely adopted if they cause significant yield reductions. However, if mixtures are proven to yield higher than pure stands, they may be used solely on the basis of their yielding ability rather than primarily for disease mitigation (Baker 1977).

1.4.3.1 Yield Potential of Wheat Cultivar Mixtures

Previous studies have shown that mixtures yield approximately 4-18% more than the mean of their components (Georgeson et al. 1891; Sage 1971; Ralph 1987; Cheema et al. 1988; Mahmood et al. 1991; Chowdhry et al. 1992; Finckh and Mundt 1992; Manthey and Fehrmann 1993; Akanda and Mundt 1997; Jackson and Wennig 1997; Finckh et al. 2000) and sometimes even perform better than the highest-yielding component (Sage 1971; Ralph 1987; Cheema et al. 1988; Chowdhry et al. 1992). However, Baker (1977) found that wheat cultivar mixtures yielded greater than pure stands in one study year and less in another year due to environmental variation. This is just one example of the difficulties in procuring dependable, repeatable results in mixture studies.

1.4.3.2 Factors Affecting Yield of Cultivar Mixtures

The yield of a mixture can be affected by the inherent yielding ability of each cultivar, the effect of plant competition on each component of the mixture, the number of component cultivars, the effect of mixture composition on disease, and the severity of disease events throughout the growing season (Alexander et al. 1986; Finckh et al. 2000).

Cultivar yielding ability is highly correlated with competitive ability; that is, the strain with the highest yield in pure stand imposes the greatest yield depression on neighboring cultivars (Jensen and Federer 1965). However, Finckh and Mundt (1993) reported that a cultivar's performance in pure stand had no correlation with their performance in mixtures.

Intergenotypic competition usually causes one cultivar to decrease and another to increase, but these changes may not always be equivalent (Klages 1936; Akanda and Mundt 1997). However, Khalifa and Qualset (1974) reported that competition affected the performance of the individual component cultivars without influencing the overall performance of the mixtures. There is a general consensus that taller cultivars are more competitive and will yield greater in mixture (Rajeswara Rao and Prasad 1982b, 1987). Interference between cultivars in mixtures can be reduced by altering mixture design and seeding rate. For example, planting mixtures in alternating swaths of resistant and susceptible cultivars may be more advantageous than using random mixtures because the susceptible cultivar, although exposed to higher disease pressure in the alternating swathes, is not exposed to the double pressure of disease and competition from the resistant cultivar (Brophy and Mundt 1991). Similarly, cultivars can be planted in alternating rows to achieve the same effect (Prasad and Sharma 1980). Planting mixtures at low seeding rates will space plants farther apart and minimize direct competition between taller, more competitive cultivars and shorter, higher-yielding cultivars (Sage 1971).

In general, the more components in the mixture, the greater the overall yield (Mundt et al. 1995a), perhaps due to better resource exploitation above and below ground (Finckh et al. 2000), or disease mitigation effects.

When Mundt (2002b) examined the effects of cultivar mixtures on the residue-borne pathogen *Cephalosporium graminearum*, the causal agent of Cephalosporium stripe of wheat, the highest yields were obtained from mixtures of moderately resistant cultivars even though there was no observable decrease in disease. Cox et al. (2004) suggested the shape of the yield versus disease severity curve may be important. If the curve is concave for a given mixture or pure stand, disease reduction does result in a large yield advantage. For yield in diseased plots, general mixing ability (the average performance of a cultivar over all mixtures) was more important than specific mixing ability (the deviation of a mixture from its estimated performance based on its average performance in mixtures) (Knott and Mundt 1990).

Mixtures generally exhibit a yield advantage under high disease pressure (Finckh and Mundt 1992; Dubin and Wolfe 1994; Akanda and Mundt 1997; Strzembicka et al. 1998; Cowger and Mundt 2002). However, many mixtures do not outyield their component monocultures when no disease is present (Ralph 1987; Manthey and Fehrmann 1993). Mixture yield advantage can result from compensation by different cultivars under different environments (Sage 1971; Wolfe 1985; Mundt et al. 1995b; Mundt 2002a) or complementation between cultivars (Sage 1971; Wolfe 1985; Brophy and Mundt 1991).

1.4.4 Yield Stability in Wheat Cultivar Mixtures

Even more than possible yield benefits, wheat cultivar mixtures have been explored for their yield stabilizing effects. For practical purposes, stability is the ability of a mixture to consistently produce high yields, regardless of biotic (disease, insects) or abiotic (drought, frost) stress (Dubin and Wolfe 1994). Yield stability is very important for organic and subsistence farmers due to the wide variation in moisture, soil nutrients and weed populations across these systems. It is also important in conventional agriculture due to high input costs (Mundt 2002a) and may be more important than disease mitigation potential (Finckh et al. 2000). Wheat mixtures offer the benefits of each component's strengths while compensating for each cultivar's weaknesses (Ciha 1984). The mixture advantage results from increased adaptability to, and buffering of, unpredictable environmental variation (Jensen 1965; Frey and Maldonado 1967; Rajeswara Rao and Prasad 1982a; Gates et al. 1986; Finckh et al. 2000). Many studies have shown that mixtures have superior stability to pure stands (Rajeswara Rao and Prasad 1982a; Rajeswara Rao and Prasad 1984; Aslam and Fischbeck 1993; Sharma and Dubin 1996), with stability increasing with the number of mixture components (Marshall and Brown 1973; Mundt et al. 1995a). Since cultivars behave differently in mixtures than in monoculture, greater gains in stability would occur from a systematic search for components that exhibit a high degree of buffering capacity when mixed, rather than composing mixtures based on yield capacity alone (Marshall and Brown 1973; Gupta and Virk 1984).

1.4.5 Grain Quality in Wheat Cultivar Mixtures

An important goal in wheat breeding has been to increase grain yield and grain protein simultaneously, which is difficult because of the negative correlation between these traits (Löffler et al. 1985). There have been few studies conducted on the effect of cultivar mixtures on wheat quality, perhaps because producers often mix low and high quality wheat themselves to increase profitability. Jackson and Wennig (1997) and Sarandon and Sarandon (1995) grew two component mixtures of one high and one low quality wheat and found that the mixture had quality equivalent to the high quality component. Protein content in mixtures may also be related to the competitive ability of the components. Rajeswara Rao and Prasad (1987) grew a three-way mixture of tall, semidwarf and dwarf wheat cultivars. Protein content was highest in the tallest cultivar in pure stand; protein increased in the dwarf and semi-dwarf cultivars and decreased in the tall cultivar in mixture. The increase in protein content of the two shorter cultivars in mixed stands might possibly be due to better or more efficient translocation of nitrogen into grain, prompted by intercultivar competition. Given that cultivar mixtures usually produce wheat grain and flour with quality equal to or better than the mean of the components grown alone, there should be no difficulty selling mixtures containing cultivars that produce acceptable quality when grown alone (Jackson and Wennig 1997; Finckh et al. 2000; Mundt 2002).

1.4.6 Competitive Ability of Cultivar Mixtures

It is a reasonable proposition that a competitive mixture may consist of cultivars with high yield potential in pure stands (Wolfe and Barrett 1980). Gupta and Virk (1984) reported that the competitive ability of a cultivar was a reliable predictor of grain yield. However, developing high-yielding, competitive cultivar mixtures is difficult due to the complex factors influencing plant growth and yield in a competitive environment. The most prevalent theory is that plant height confers competitive ability due to shading effects (Rajeswara Rao and Prasad 1984; Finckh and Mundt 1993). Thus, some researchers believe that mixtures of tall and semidwarf cultivars will not be productive (Baker and Briggs 1984). However, there is ample evidence to the contrary. Sarandon and Sarandon (1995) theorized that variation in wheat cultivar morphology, canopy structure or physiology results in greater utilization of available resources. In a mixture of genotypes, timing and intensity of resource requirement may differ and total potential resource availability may increase. This also applies to root characteristics, since differences in patterns of root distribution within the soil have been found among old tall and modern semi-dwarf wheat cultivars (Sarandon and Sarandon 1995). Knott and Mundt (1990) found a tall: semidwarf wheat mixture with both high yield potential and high specific mixing ability. Likewise, they reported a semidwarf: semidwarf mixture with low yield potential, despite previous predictions that this mixture would exhibit high yield potential due to complementary competitive ability.

Another factor influencing the development of competitive cultivar mixtures is a phenomenon known as the Montgomery effect, after E. G. Montgomery (1912), who was the first to document it. The Montgomery effect occurs when the species or cultivar which yields the greatest in monoculture is outcompeted when mixed with a lower-yielding, more competitive rival (De Wit 1960; Loomis and Connor 1992). This dominance of low-yielding species is a common occurrence in low productivity environments such as organic systems (van Ruijven and Berendse 2003). This effect may stem from cultivars being selected as pure lines in early crossing generations and therefore not exposed to intergenotypic competition throughout the breeding and selection process (Finckh and Mundt 1993). Several studies have reported the Montgomery effect in cultivar mixtures (Laude and Swanson 1942; Suneson and Wiebe 1942; Wolfe 1985; Alexander et al. 1986).

1.4.7 Wheat Cultivar Mixtures in Organic Farming

Organic producers cannot use herbicides, fungicides or chemical fertilizers, and the crop's inherent ability to compete and extract nutrients from soil is very important. Thus, wheat cultivar mixtures may be useful for organic producers only insofar as they are competitive against weeds, can resist or reduce disease and extract/contribute high levels of nutrients from or to the soil.

One common viewpoint is that plant height confers competitive ability against weeds due to shading effects (Reddy and Prasad 1977; Rajeswara Rao and Prasad 1984; Finckh and Mundt 1993), but Jensen and Federer (1965) reported that, in the most aggressive wheat cultivar they observed, height was not the dominant characteristic influencing competitive ability. In their study, plant vigor had the greatest impact on a given cultivar's competitive ability. The importance of rapid early growth in competitive stands of weeds and cereals has been emphasized by Pavlychenko (1937). In his experiments, wild oats were noticeably more aggressive and damaging in wheat than in barley, which has more rapid early growth (Suneson and Wiebe 1942). Harlan and Martini (1938) reported that the relative dominance of cultivars varies with environment; thus, there is conceivably a mixture of genotypes that is extremely competitive and will dominate specifically under organic or low-input management systems.

Fungicide use seldom results in yield increases because of the great ability of wheat cultivar mixtures to buffer against yield loss due to disease (Manthey and Fehrmann 1993), making the use of fungicides less practical (Finckh et al. 2000). Sarandon and Sarandon (1995) reported that wheat cultivar mixtures had a low harvest index, with more resources allocated to competitive structures like stems and leaves. Because of the importance of soil organic matter in an organic agriculture system, the greater biomass production of mixtures as found in their study is an important benefit. In addition, Sarandon and Sarandon (1995) reported mixture yields similar to the highest-yielding component in pure stand when no chemical fertilizer was applied, suggesting that there may be no yield advantage to growing monocrops under organic management.

1.5 Cereal Species Mixtures

1.5.1 Introduction to Cereal Species Mixtures

Cereal species mixtures are a relatively unexplored area of intercropping. Cereal-legume or cultivar mixtures are much more commonly used and researched. However, mixtures of cereals may be useful for reducing weed pressure (Francis 1989), increasing yield stability (Simmonds 1962; Wilson 1988; Francis 1989; Davidson et al. 1990; Juskiw et al. 2000c), increasing yield through complementary niche utilization (Simmonds 1962; Taylor 1978; Juskiw et al. 2000c), increasing crop rotation flexibility (Walton 1975), pest and disease buffering, and increasing animal feed value (Stoskopf 1985). The use of small grain mixtures is promising for both conventional and organic growers, albeit for different reasons. Yield advantages for cereal mixtures over sole crops have been noted under both high (Jokinen 1991b; Gallandt et al. 2001; Sobkowicz and Tendziagolska 2005) and low (Jokinen 1991b; Sarandon and Sarandon 1995) input environments.

1.5.2 Cereal Species Mixtures for Forage and Silage

A great deal of research has concentrated on the use of cereal mixtures for forage or silage production. In general, barley (*Hordeum vulgare* L.) has the highest silage feed quality and yield, followed by oat (*Avena sativa* L.), triticale (× *Triticosecale* Wittmack) and wheat (Walton 1975; Cherney and Marten 1982; Baron et al. 1992; Maloney et al. 1999). Oats, however, may outyield barley under certain conditions (Kirk et al. 1934; Walton 1975). Semi-dwarf barley lines generally have lower proportions of stem material and more leaf material than taller cultivars (Capper 1988; Sheaffer et al. 1994). This tends to render barley more desirable for use in cereal silage mixtures due to increased feed quality and lower competition for light between components. To maximize yield and quality, barley and oat are harvested at the soft dough stage, while rye and triticale exhibit peak quality and yield at the boot to milk stage (Juskiw et al. 2000a, b). This may lead to complementarity in cereal species mixtures, as rye and triticale are generally slower growing than barley and oat, and therefore a mixture may be at the optimal stage for all species at harvest. The slower growing species will generally increase feed quality because of their high proportion of leaf biomass compared to the more mature components (Juskiw et al. 2000b). Mixtures can yield more than monoculture silage crops and may have higher quality (Baron et al. 1992; Jedel and Salmon 1994; Jedel and Salmon 1995; Juskiw et al. 2000a). Combining species may also extend the silage harvest window or provide both a fall and spring forage harvest, important in areas with unpredictable weather patterns (Davidson et al. 1990; Maloney et al. 1999; Juskiw et al. 2000a).

1.5.3 Composing Effective Cereal Mixtures

There are several obstacles to developing successful cereal mixtures, such as differences in height, early season vigor, lodging resistance, rooting depth, nutrient requirements and maturation rates of the components (Loomis and Connor 1992). Many studies have reported height to be a major determining factor in a component's competitive ability in mixture (Valentine 1982; Jedel et al. 1998). This doesn't always occur, however, since barley can outcompete oats in mixtures even though the oats are often taller at harvest (Taylor 1978). Barley is generally a fast-maturing crop while triticale matures quite slowly (Maloney et al. 1999); thus, a mixture of these two species would be ill-advised. However, this difference in maturation times may increase yield due to staggered timing of resource requirements (i.e. complementarity) (Sobkowicz and Tendziagolska 2005). Also, early season vigor has a large impact on the competitiveness of each component (Sobkowicz and Tendziagolska 2005) and whether a mixture maintains its ratio from planting to harvest. Vigorous species may outcompete the other components in the mixture, resulting in almost a monoculture at harvest (Fejer et al. 1982; Juskiw et al. 2000c). A producer must account for this by using a ratio and seeding rate that maximizes yield while minimizing interspecific competition (Stoskopf 1985) and being aware of how environmental conditions will affect each component (Klages 1936).

1.5.4 Pests and Disease in Cereal Species Mixtures

There are several mechanisms by which cereal species mixtures may affect crop pests and diseases. The quality and quantity of crop residue from both host and non-host crops can influence pathogen growth, sporulation, and survival through the release of fungicidal compounds during residue breakdown (Bailey and Lazarovits 2003). For example, sporulation of *Cochliobolus sativus*, which causes common root rot of cereals, occurs on cereals in the following order: barley > wheat > triticale > oat. Thus, mixing these crops together may decrease the severity of this disease. A break of at least one year is considered necessary to control soil- and residue-borne pathogens, but mixtures may decrease host tissue density enough to provide an alternative means of disease control (Vilich 1993). Cereal mixtures have also been shown to decrease cereal cyst nematode (*Heterodera avenae*) damage in wheat and barley (Rajvanshi et al. 2002), cereal leaf beetle (*Oulema* spp.) damage in oats (Wenda-Piesik and Piesik 1998), *Septoria* glume blotch of wheat (Michalski et al. 1996), barley mildew (*Blumeria graminis*) (Burdon and Chilvers 1977) and eyespot of wheat and barley (Vilich-Meller 1992). Mixtures can also decrease pathogen infection on subsequent crops (Vilich 1993). Similar to wheat cultivar mixtures, researchers have noted that disease mitigation of cereal mixtures is prevented or skewed by the small size of experimental plots (Stoskopf 1985). Vilich-Meller (1992) reported that wheat-barley mixtures provided greater disease reduction on wheat than did applications of fungicide, illustrating the potential of cereal mixtures for use in organic agriculture.

1.5.5 Yield of Cereal Species Mixtures

Conventional production emphasizes high yield as its primary goal (Sobkowicz and Tendziagolska 2005) and crop mixtures have been shown more often than not to increase relative yields of the component crops (Jolliffe 1997). Most mixtures yield less than the highest-yielding component in monoculture, but may offer small yield increases over the mean component yield in sole crop (Taylor 1978; Stoskopf 1985; Jokinen 1991a; Jedel and Salmon 1995; Maloney et al. 1999; Juskiw et al. 2000c; Singh and Singh 2000).

Inconsistency of mixture yield advantages is probably due to the similarity between cereal crop species growth habits and requirements for limiting resources (Rao 1986; Pandey et al. 1999; Sobkowicz and Tendziagolska 2005). Cereal mixtures of winter and spring growth types are multifunctional, providing at least two forage harvests (fall and spring) and one grain harvest (summer) (Davidson et al. 1990; Maloney et al. 1999).

1.5.6 Potential of Cereal Mixtures in Organic Agriculture

Crop mixtures are used chiefly on subsistence farms with limited resource availability and little new technology (Francis 1989), making them directly applicable to modern organic farms. Crop mixtures are often employed as a non-chemical means of disease and weed control rather than strictly for yield increase (Fukai 1993). In a management regime which cannot use broad-spectrum herbicides to control weeds, any competitive advantage that can be employed will help organic producers (Cousens 1996, Davidson et al. 1990). As well, mixtures of grain may be fed directly to organic livestock, or the biomass may be harvested for silage production (Jedel and Salmon 1995).

1.5.7 Strategies for Employing Mixtures

If a given mixture is used season after season in the same location, it is reasonable to assume that any disease mitigation capability will be lost and mixture ratios will skew towards the most competitive component. This can be prevented through the simple expedient of not overusing a given cultivar or species mixture and resynthesizing the mixtures every 3-4 years (Wolfe and Barrett 1980). Once a mixture is found to work reasonably well, it is easy enough to add new, superior genotypes as they are developed (Mundt 2002a). It is unlikely that any mixture, regardless of how beneficial it turns out to be, can be used over such a large area that disease problems become widespread. Every agro-ecosystem has its own crops and cultivars that suit the climate and soils; it is from these that effective mixtures must be developed. Mixture development is a very localized mechanism that can be fine tuned to suit a given farm's soil, topography and crop rotation.

1.6 Conclusions

Wheat is an integral part of agriculture in Canada and across the world. As producers continue their attempts to decrease dependence on chemical pest control methods, alternative methods of disease and weed management will become increasingly important. Wheat cultivar mixtures and cereal species mixtures have potential for increasing crop competitiveness and decreasing disease, but relatively little research has been conducted on this area, especially in Canada. As the popularity of organic and ICM production methods continues to rise, cereal and wheat mixtures may become an important tool in maintaining yields and yield stability in unpredictable environments. However, research is required to determine optimal cultivar, crop and ratio combinations that will maximize yield and stability, as well as provide weed suppression and disease mitigation.

1.7 Statement of Purpose

The current Canadian body of knowledge pertaining to organic cereal production is relatively small. Information about the performance of wheat cultivar mixtures and cereal species mixtures under organic and conventional production may clarify whether they are an appropriate agronomic practice for organically managed or low-input environments. Local producers may benefit by being able to choose suitable cultivar and species mixtures using locally developed and available cultivars. The identification of specific mixtures that confer competitive ability under low input management would assist organic producers in developing competitive mixtures for use on their own farms. Canadian research pertaining to the performance of wheat cultivar and cereal species mixtures has thus far dealt with a relatively small number of genotypes and has generally been conducted only on conventionally managed land. Additional knowledge of agronomic traits in specific wheat cultivar and cereal species mixtures will contribute to existing knowledge in this area.

The objectives of this thesis research are:

1. To evaluate the performance of wheat cultivar and cereal species mixtures grown under organic and conventional management systems.
2. To evaluate the effect of height and tillering capacity of wheat cultivars on the competitive ability of wheat cultivar mixtures grown under organic and conventional management systems.
3. To determine the effect of component ratio on the competitive ability of wheat cultivar and cereal species mixtures grown under organic and conventional management systems.
4. To establish which, if any, agronomic and/or yield component traits affect the competitive ability and performance of wheat cultivar and cereal species mixtures.
5. To determine whether wheat cultivar and cereal species mixtures exhibit different capabilities when grown under organic and conventional management systems.

The underlying null hypotheses tested were:

1. There are no differences in the performance of wheat cultivar and cereal species mixtures when grown under organic and conventional management systems.
2. Height and tillering capacity of wheat cultivar mixtures have no effect on the competitive ability of mixtures grown under organic and conventional management systems.
3. Component ratio has no effect on the competitive ability of wheat cultivar and cereal species mixtures grown under organic and conventional management systems.
4. Wheat cultivar and cereal species mixtures have similar agronomic and/or yield component traits.
5. Wheat cultivar and cereal species mixtures do not differ when grown under organic and conventional management systems.

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Spring wheat (*Triticum aestivum* L.) cultivar mixtures in organic and conventional management systems in western Canada

2.0 Abstract

Wheat cultivar mixtures represent a relatively unexplored avenue for maintaining and stabilizing yield for both organic and conventional producers. We examined the response of Canada western red spring wheat cultivar mixtures to varying degrees of simulated and natural competition and environmental stress at three sites in central Alberta, Canada. Three modern hard red spring wheat cultivars [Superb (semi-dwarf), AC Intrepid (early maturing) and 5600HR (tall)], along with thirteen two- and three-way mixtures, were planted on organic and conventional land under two levels of simulated weed competition over eight site years between 2003 and 2005. The *Brassica juncea* weed competition treatment decreased yields at all sites. Overall yield was lowest at the certified organic farm and highest under conventional management. Sole-crop, semi-dwarf Superb and all three Superb-Intrepid entries (1:1, 1:2 and 2:1) consistently yielded the greatest, regardless of management system. In addition, 1:1 and 1:2 Superb-Intrepid entries were the most stable of all entries tested. This mixture combined the semi-dwarf, elevated (5.6) leaf area index (LAI) characteristics of Superb, with the early maturing, medium height, low (3.8) LAI characteristics of Intrepid. Early season vigor was the trait most strongly associated with yield, with the strongest correlation occurring under low moisture, low nutrient, high competition conditions at the certified organic farm.

This chapter will be submitted as: Kaut, A. H. E. E., O'Donovan, J., Navabi, A. and Spaner, D. Spring wheat (*Triticum aestivum* L.) cultivar mixtures in organic and conventional management systems in western Canada to the Journal of Sustainable Agriculture.

2.1 Introduction

Certified organic agriculture is a relatively new practice in western Canada, with only 1.4% of total cropland in Alberta, Saskatchewan and Manitoba currently registered organic (Statistics Canada 2001; Macey 2005). A dichotomy exists between the extensive nature of Prairie grain farming (average farm size = 424 ha) (Statistics Canada 2001; Macey 2005) and the more intensive nature of organic farming (average farm size in North America = 82 ha) (United States Department of Agriculture (USDA) 2002; Macey 2005). Organic grain producers on the Canadian Prairies (average farm size = 132 ha) (Macey 2005) must employ many non-chemical agronomic techniques to remain viable. Wherever possible, every operation has more than one function. For example, spring tillage is used to loosen the soil, prepare the seedbed and kill weeds before planting (Bond and Grundy 2001; Rasmussen 2004). Crop species and cultivars are chosen not only for yield potential, but also as part of complex crop rotations to control weeds, insects and diseases (Teasdale et al. 2004).

Strategies for producers to reduce chemical inputs include the breeding of several disease resistance genes into a single cultivar (Jones et al. 1995), crop rotations, and agronomic practices to diminish the prevalence of disease organisms. The use of cultivar mixtures may be an additional practical alternative because of their simplicity and ease of implementation (Finckh et al. 2000). They have been reported to prevent disease outbreaks (Finckh et al. 2000) and buffer against extreme environmental stress (Shaalan et al. 1966), which may occur in low-input agriculture. Wheat cultivar mixtures have also been reported to reduce insect and disease damage (Emmens 2003), minimize risk, and maximize exploitation of limited resources such as moisture, nutrients or space (Smithson and Lenné 1996). Additional benefits of mixture use include increased stability (Shaalan et al. 1966) and increased soil organic matter levels through greater aboveground biomass production (Sarandon and Sarandon 1995). Such characteristics may render cultivar mixtures useful for both organic and conventional producers.

Wheat cultivar mixtures may involve any combination of two or more cultivars, in any ratio. They have been reported to yield equal to or more than monocultures (Manthey and Fehrmann 1993). Characteristics generally associated with successful wheat cultivar mixtures include equiproportional mixture ratios (Manthey and Fehrmann 1993); the use of tall or competitive cultivars (Klages 1936; Finckh and Mundt 1993) with good mixing ability (Knott and Mundt 1990); and more, rather than fewer components (Mundt et al. 1995). Studies have reported many mixtures that yield greater than their mid-component average (the mean of their components) and, occasionally, greater than their highest yielding component (Sage 1971; Finckh and Mundt 1992; Akanda and Mundt 1997).

Use of wheat cultivar mixtures may result in improved yield stability over environments. For practical purposes, stability is the ability of a mixture to consistently produce high yields, despite biotic or abiotic stress (Dubin and Wolfe 1994). Yield stability is very important for organic and subsistence farmers to help ensure a crop can be harvested regardless of environmental variation or stress. Wheat mixtures may offer the benefits of each component's strengths while compensating for each cultivar's weaknesses (Ciha 1984). The mixture advantage results from increased adaptability to, and buffering of, unpredictable environmental variation (Gates et al. 1986; Finckh et al. 2000). Several studies have shown that mixtures have superior stability to pure stands (Aslam and Fischbeck 1993; Sharma and Dubin 1996). Since cultivars behave differently in mixtures than in monoculture, greater gains in stability would occur from a systematic search for components that exhibit a high degree of buffering capacity when mixed, rather than composing mixtures based on yield capability alone (Gupta and Virk 1984). If wheat cultivar mixtures are to be profitably employed by organic producers, they must be competitive enough to suppress weeds to the same degree as, or preferably more than, sole-crop wheat.

The objectives of the present study were: 1) to determine the potential of wheat cultivar mixtures on the northern Canadian prairies under both organic and conventional management, and 2) to establish which agronomic traits contribute to the yield potential and weed suppression of successful wheat cultivar mixtures. We endeavored to identify specific wheat cultivar mixtures that could be implemented by producers immediately, and to determine characteristics that could be used to compose effective wheat cultivar mixtures in the future.

2.2 Materials and Methods

Field trials were conducted at the University of Alberta Edmonton Research Station in Edmonton, Alberta, Canada (53° 34′ N, 113° 31′ W) from 2003 to 2005 and at a certified organic farm near New Norway, Alberta, Canada (52° 52′ N, 112° 56′ W) in 2004 and 2005 (Table 2.1). The soils in Edmonton are classified as Orthic Black Chernozemics (horizon sequence Ah, Bm, Ck), typical of central Alberta, and soils at New Norway were classified as an Eluviated Black Chernozem (horizon sequence Ah, Aej, Btj, Ck) (AAFRD 2005). Soil fertility levels for all fields over all years are presented in Table 2.2. The conventionally managed land at the Edmonton Research Station (Edmonton Conventional) had fertilizer added as urea (46-0-0: N-P_2O_5-K_2O) broadcast to give 67 – 73 kg ha^{-1} total N in 2003; at a rate of 45 kg ha^{-1} N and 20 kg ha^{-1} P, as urea and ammonium phosphate (11-52-0) in the seed row in 2004; and at 28 kg ha^{-1} as ammonium phosphate banded with the seed in 2005. The organically managed land at the Edmonton Research Station (Edmonton Organic) had compost (comprised of dairy manure, sawdust, wood chips and straw) added at a rate of 50 – 62 t ha^{-1} each year. The certified organically managed land in New Norway (Certified Organic) had no external inputs of fertilizer, but the fields had plowdown crops containing legumes on them the previous year. Moisture was sufficient in Edmonton in 2004 and 2005, but there was a mild drought in 2003 in Edmonton and in 2005 in New Norway (Table 2.1).

Trials were seeded into cultivated and harrowed soil that was tilled both in the autumn and spring prior to seeding. Organically managed land had an additional tillage operation (cultivation and harrowing) performed to kill weeds immediately before seeding. In 2003, the plots were four rows wide (23 cm row spacing) and 4m long, seeded with a self-propelled, double-disk plot drill (Fabro Enterprises Ltd., Swift Current, SK, Canada), while in 2004 and 2005 plots were six rows wide (23 cm row spacing) and 4m long, and seeded with a self-propelled, no-till, double-disk plot seeder (Fabro Enterprises Ltd., Swift Current, SK, Canada).

The experiment was planted as a strip-plot arrangement of a randomized complete block design, with four blocks. Horizontal and vertical factors were mixture entries and competition treatments, respectively. Mixture entries (thirteen two- and three-way wheat cultivar mixtures) and the three cultivars used to comprise the mixtures (Table 2.3) were randomized into four blocks, with each block comprising two identical tiers of the 16 entries planted to plot sizes described above. One randomly chosen tier within each block was cross-seeded with Oriental mustard (*Brassica juncea* L.) at a rate of 60 seeds m^{-2}, and one was not. Entries were composed on a kernel-number basis of pure seed to plant at a standard rate of 300 seeds m^{-2}. The three component cultivars were chosen on the basis of contrasting height, time to maturity, yield potential and tillering capacity, and all were registered in Canada after 1990 (Table 2.3).

The experiment was grown for three years at the three sites – Edmonton Conventional and Edmonton Organic in 2003 and Edmonton Conventional, Edmonton Organic and Certified Organic in 2004 and 2005 - for a total of 8 site-years containing 4 blocks of 32 entries each - 16 entries with imposed *B. juncea* competition (competition) and 16 without (non-competition) - representing a continuum of increasing competition from the non-competition treatment at Edmonton Conventional (almost no weed pressure) to the competition treatment at the Certified Organic Farm (extreme weed pressure). Non-competition plots on conventional land were the only ones to receive any herbicide application. They were treated with Dyvel (active ingredients MCPA and dicamba) applied at 1235.5 mL ha^{-1} at the recommended crop (2-4 leaf) and weed (emergence to 3 leaf) stage (AAFRD 2006).

2.2.1 Data Collection

Emergence counts of both crop and *B. juncea* were taken before the onset of tillering (1-3 leaf stage) and the plots were scored for early season vigor on a scale of 1 (low vigor) to 5 (highly vigorous) one month after seeding. At Edmonton Conventional and Edmonton Organic in 2004 and 2005, heading and maturity were recorded when 75% of a given plot was fully headed and at physiological maturity, respectively. Light interception readings were recorded with a LI-191 Line Quantum Sensor (LI-COR Environmental, Lincoln, Nebraska) as close to June 21 (the longest day of the year) as possible. Leaf area index was measured at this time as well, using a LAI-2000 Plant Canopy Analyzer (LI-COR Environmental, Lincoln, Nebraska). Weed and *B. juncea* samples were collected separately from each plot using 25 cm × 25 cm quadrats when the crop had reached physiological maturity. All samples were taken between the third and fourth row, 60 cm into the plot. Disease ratings were recorded for leaf spot disease on a scale from 0 (no leaf spot disease present) to 5 (flag leaf riddled with disease), and powdery mildew (*Erysiphe graminis* f. sp. *tritici*) and stripe rust (*Puccinia striiformis* Westend. f. sp. *tritici*) were scored following the modified Cobb's scale (Peterson et al. 1948). Stripe rust ratings were recorded in 2005 only, as that was the only year to have a measurable infestation of stripe rust. A single tiller count and height measurement per plot was taken once stem elongation was completed. Lodging ratings were recorded throughout the season, particularly in 2004, when heavy winds and an early snowfall caused widespread lodging. Lodging was rated from 0 (no lodging present) to 9 (plot completely flat). Once the entries were fully mature, but prior to harvest, ten spikes were randomly collected from each plot to determine kernels per spike and kernel weight.

A Wintersteiger plot combine harvested the entire plot for yield, which was determined after each sample was cleaned and dried to 13-14% moisture. *B. juncea* and other small weed seeds were removed from the plot yields using a 2mm sieve and a fan, which also removed chaff. In 2004, plot yields from the certified organic farm in New Norway were infested with wild oats to such a degree that they had to undergo hand cleaning on a sub-sample of 150g. Test weight was determined using a dry pint sub-sample and protein content of the grain was determined using a FOSS 6500 spectrometer (FOSS NIRSystems 6500, Silver Springs, Maryland) and WinISI II software (FOSS NIRSystems 6500, Silver Springs, Maryland).

2.2.2 Data Analysis

To initially examine differences among the eight environments, a preliminary combined analysis of variance over all environments was performed using the MIXED procedure (Littell et al. 1996) of SAS (version 8.2; SAS Institute 1999), where environment, entry and competition were considered fixed, and replication and replication interactions were considered random. In this analysis, the eight environments differed ($P<0.01$) for grain yield (Appendix 5.1). Mean yields at the Certified Organic Farm were low (1.27 t ha^{-1} in 2004 and 0.89 t ha^{-1} in 2005), compared to Edmonton Organic (3.62, 3.24, 3.39 t ha^{-1} in 2003, 2004 and 2005 respectively) and Edmonton Conventional (3.36, 4.46 and 5.51 t ha^{-1} in 2003, 2004 and 2005 respectively). Due to the large differences among site soils and climate (Tables 2.1 and 2.2), yield potential and management characters, analyses and results for yield and agronomic indices were conducted and are presented by site combined over years.

Analyses of variance for each of the three sites (Edmonton Organic, Edmonton Conventional, and Certified Organic farm) were done separately, and performed using the MIXED (Littell et al. 1996) procedure of SAS, where year, replication within year and replication interactions within a strip plot analysis of variance were considered random. Entry, competition and their interactions were considered fixed. The mid-component average yield of a mixture is the combined average for the sole-crop yield of the components in that mixture, weighted according to ratio (see Appendix 5.2 for example). Single degree of freedom contrasts, weighted by proportion seeded (eg. 1:1, 2:1 or 1:2) were conducted to compare mixture means with mid-component averages. Pearson's coefficients of correlation were computed within each site using the least squared means of entries from each of the sites with the CORR procedure of SAS (SAS Institute 1999).

For each entry, a stability regression statistic was computed following the method described by Finlay and Wilkinson (1963). The eight location-years × two competition levels were considered as 16 environments for the purposes of stability analysis. Linear regression coefficients (*b*) of individual entry yields on environmental average yields were calculated in the REG Procedure of SAS (SAS Institute 1999).

2.3 Results

The main effects of entry and competition were significant (P<0.01) for grain yield at all three sites, while the interaction of competition × entry was not (P>0.05) (Table 2.4). No mixture yielded greater (P>0.05) than its respective mid-component average, but neither did any of the sole-crops yield significantly more grain than their respective mixtures (Table 2.4). Sole-crop Superb, the three Superb-Intrepid mixtures and 5S12 were the highest yielding entries over all environments (Table 2.4). When analyzed through single degree of freedom contrasts, these five entries yielded more grain than all other entries combined (P<0.01). Sole-crop 5600HR had the lowest average yield over all environments (Table 2.4), and it yielded less grain than all entries except for 5I11, 5I21 and 5SI111.

The artificial competition treatment reduced yield at all sites (Table 2.4). Total weed biomass did not differ significantly between entries at any site (Table 2.4). This may have been the result of large inherent variation in weed biomass in the field. Although mixtures varied for grain yield, they did not suppress weeds better than their sole-crop components (P>0.05) at any site. The highest yielding entries (Superb and the Superb-Intrepid mixtures) sometimes had among the highest weed biomasses.

The eight location-years × two competition levels were considered as 16 environments for the purposes of stability analysis. The Certified Organic Farm under competition in 2005 was the lowest mean yielding site (0.99 t ha^{-1}), while Edmonton Conventional in 2005 was the highest mean yielding site (4.81 t ha^{-1}). Entries responded differently to the yielding ability of the environments. Over the 16 environments, sole-crop Superb, SI11 and SI21 were the highest yielding entries, and sole crop 5600HR and 5I21 were the lowest yielding entries (Figure 2.1). Linear regression coefficients (b) of individual entry yields on mean site yields were calculated. Entries with a coefficient of regression close to unity (± confidence interval) were grouped as entries with average stability or good general adaptability, while those with higher or lower regression coefficients were grouped as entries with below or above average stability, respectively. Regression coefficients for the highest yielding sole-crop Superb (b = 1.06) and the mixture SI21 (b = 1.06) were greater than 1.05 (indicating responsive entries), while the high yielding SI11 (b = 1.00) and SI12 (b = 1.02) had regression coefficients near unity (suggesting stable entries). These entries, in addition to higher-than-average yield in all environments, had stable performance over all environments. The sole crop 5600HR (b = 0.94) and the mixture 5I21 (b = 0.91) were the lowest yielding entries, with the lowest regression coefficients (Figure 2.1).

Mean emergence was 125 plants m^{-2} at the Certified Organic site compared to 163 and 203 plants m^{-2} at the Edmonton Organic and Conventional sites, respectively (Table 2.5). Entries differed ($P<0.01$) for emergence at the Edmonton Conventional site, with Superb, and the mixtures 5S12 and SI21, exhibiting the greatest emergence percentage. The entry × competition interaction was significant for emergence at Certified Organic. Some entries exhibited decreased emergence in the competition treatment (e.g. 5S11 and sole-crop Intrepid), while others increased (e.g. sole-crop Superb and SI12). Under competition, both 5S11 and 5S21 had significantly lower emergence than their mid-component averages at the Certified Organic Farm. Early season vigor (ESV) was 65% higher at Edmonton Conventional than at Edmonton Organic, with Superb and SI21 generally having the highest ESV (Table 2.5). Early season vigor had a significant entry × competition interaction at the Certified Organic farm, with most entries exhibiting decreased vigor in the competition treatment. However, sole-crop Superb and the three Superb:Intrepid mixtures exhibited increased vigor in the competition treatment.

Entries differed ($P<0.01$) for spikes m^{-2} at the Edmonton Organic site only (Table 2.6). Competition reduced spikes m^{-2} ($P<0.01$) at Edmonton Conventional and Certified Organic, but not at Edmonton Organic. Mean spikes m^{-2} at the Certified Organic site was roughly half that of the Edmonton Conventional site. Only two mixtures had significantly fewer tillers than their mid-component average: 5S21 at Certified Organic ($P<0.05$) and 5SI112 at Edmonton Organic ($P<0.01$). Entries growing at Edmonton Organic matured 13 days later than Edmonton Conventional plants. Intrepid matured earliest and Superb the latest, regardless of site or management (Table 2.6). Competition did not alter ($P>0.05$) days to maturity at any site. SI11, 5I11 and 5SI211 all matured later ($P<0.05$) than their mid-component averages.

Mean lodging was negligible at the Certified Organic Farm, with site averages of 4 on a 0-9 rating scale at both Edmonton sites. The main effects of entry and competition from *B. juncea* were not significant ($P>0.05$) for lodging at any site and data are not provided. Lodging may have been negligible at the Certified Organic farm because of overall lower growth and yield potential of this site. Mean plant height was 82 cm, 101 cm and 102 cm at the Certified Organic, Edmonton Organic and Edmonton Conventional sites, respectively. There were no differences in disease rating between entries on any of the sites (data not shown). Overall disease was lowest at Certified Organic (dry, low nutrient conditions) and highest at Edmonton Conventional (moist, high nutrient conditions). Disease tended to be greater under competition, but the increase was significant at Edmonton Conventional only ($P<0.05$).

Mean grain protein was lowest at the Edmonton Organic site (13.6%) compared to the Edmonton Conventional (14.4%), and the Certified Organic Farm (15.1%) (Table 2.6). Among the cultivars tested, Intrepid generally had high protein regardless of location and Superb had low protein. At the Certified Organic and Edmonton Conventional sites, no mixture differed from their mid-component averages, but at Edmonton Organic, 5I11 and SI11 both had significantly lower protein levels ($P<0.05$) than their mid-component averages, perhaps because of the high protein content of sole-crop Intrepid at that location.

Leaf area index (LAI) and light interception data are presented from the non-competition treatment plots at Edmonton Conventional so that values are not altered by the presence of weeds. Entries differed in LAI (Table 2.5). However, even though the three sole-crops differed (Superb 5.6 vs. Intrepid 3.8) for LAI, the 13 mixtures had statistically similar LAI values (Table 2.5).

Early season vigor (ESV) was positively correlated with yield at all sites, with the correlation increasing as competition and stress increased from the Edmonton Conventional site to the Certified Organic farm (Table 2.7). There was a negative correlation between *B. juncea* biomass and total weed biomass and yield at every site, indicating the important effect competition has on yield. On the Certified Organic farm, ESV had the strongest negative correlation with both weed and *B. juncea* weight, suggesting early season vigor is associated with weed suppression under organic management. At the Edmonton Conventional site, however, spikes m^{-2} and maturity had the strongest negative correlation with weed and *B. juncea* weight.

2.4 Discussion

The three cultivars chosen for this experiment were registered within the last 10 years in Canada (Table 2.3). The semi-dwarf Superb yielded well in all environments, even under severe competition, and was among the highest yielding of the entries. Other studies have reported decreased yield in semi-dwarfs when mixed with tall cultivars, or otherwise placed under competition (McKenzie and Grant 1980). In the present study, each cultivar responded differently when mixed. 5600HR yielded less than at least three of its mixtures at every site. Superb did not yield more grain than the three Superb:Intrepid mixtures at any site, and Intrepid yielded similarly to most of its mixtures. Mixtures did not resist lodging or disease any better than the sole-crop cultivars in this study. Wheat cultivar mixtures are often used for disease mitigation and control (Strzembicka et al. 1998). Many studies use at least one resistant cultivar to obtain noticeable disease reduction (Wolfe and Barrett 1980; Cox et al. 2004), while we chose cultivars based on agronomic potential which differed slightly in leaf spotting disease resistance potential.

One of the goals of mixing wheat cultivars is to combine cultivars with differing morphology and rooting structure in a ratio that will minimize intraspecific competition, and produce yields higher than the components in monoculture (Sarandon and Sarandon 1995). Of all the entries tested, the Superb:Intrepid mixtures were consistently the highest yielding. The 1:1 and 1:2 Superb:Intrepid entries were the most stable of all entries tested. These mixtures combined the semi-dwarf, elevated (5.6) leaf area index (LAI) characteristics of Superb, with the early maturing, medium height, low (3.8) LAI characteristics of Intrepid. They never yielded significantly less than sole-crop Superb, and did yield more grain than sole-crop Intrepid under low-input conditions at the certified organic farm.

For a mixture to be considered viable by producers, it should yield as well, or better than its mid-component average (Sage 1971). No mixture in the current experiment yielded more grain than its mid-component average. Thus, no cultivar tested exhibited elevated mixing ability. The general consensus in the literature is that the more components a cultivar mixture has, the higher yielding it will be (Mundt et al. 1995; Strzembicka et al. 1998). In the present experiment, the two-way mixtures yielded more than the three-way mixtures at one organic site, but were not different at the other two sites. In addition to yielding well, organic producers require crops that are highly competitive and can suppress weeds (Bàrberi 2002), but we found no particular mixture or sole-crop that suppressed weeds significantly better than any of the others. Even though none of the entries suppressed weeds, Superb and the Superb-Intrepid mixes could be classified as tolerant to weed competition, since they maintained their yield even under severe competition (Coleman et al. 2001). This is a potential detriment to the adoption of these particular entries by organic producers, since they cannot risk intensification of weed infestations from growing crops that do not actively suppress weeds.

Sage (1971) suggested that mixture competitiveness against weeds would be greatest when phenotypic differences in height and earliness are great between component cultivars (e.g. when one component is tall and the other is early maturing). This may explain why mixtures of Superb (late-maturing cultivar, semi-dwarf, elevated LAI and early season vigor) and Intrepid (early-maturing cultivar, average height, low LAI and moderate early season vigor) exhibited elevated yield, high stability and tolerated weed pressure. Superb also consistently yielded the highest of all the sole-crops, regardless of weed pressure or soil nutrient status. Of all the entries, sole-crop Superb had the highest LAI, which may contribute to this cultivar's high yield under both organic and conventional management (Lemerle et al. 1996).

The highest yielding and most stable mixtures were of Superb and Intrepid, two cultivars which vary widely in maturity, height, LAI and early season vigor. In this experiment, a 1:1 mixture of a highly vigorous semi-dwarf and an early-maturing average height variety combined high yield and stability the best out of all entries tested, and could be recommended for both organic and conventional producers.

Tillering capacity and height are often considered important competitive traits in wheat, particularly in organic systems (Bond and Grundy 2001). In the present experiment, tillering, height and yield all decreased from conventional to organic production, presumably from increased competition and decreased soil moisture. Because of the need for multiple tillage operations to control weeds, seeding dates on organic land are usually later than on conventional land (Bond and Grundy 2001). Delayed seeding seemed to affect maturation times for the organic crops, causing them to reach maturity almost two weeks later than conventional crops. This is most likely due to the fact that the conventional crops were in their most rapid growth stage (tillering to stem elongation) around June 21st, when day length (and thus, photosynthetic activity) was at its maximum (Slafer et al. 2001).

Overall grain protein content increased from Edmonton Organic to Edmonton Conventional to Certified Organic. The highest yielding sole-crop (Superb) had the lowest protein content. The strong negative correlation between protein and yield has been well documented (Kibite and Evans 1984). The mixtures (particularly the Superb:Intrepid mixes) generally had greater protein content than Superb, but not often as high as Intrepid in monoculture. This is one aspect of mixtures that holds promise for both conventional and organic producers, as high protein wheat is worth more under the Canadian grading system. Mixtures with yield not significantly different than the highest-yielding component but with significantly higher protein levels would give producers a better economic return, all other aspects remaining equal.

Although disease mitigation is one of the primary reasons cultivar mixtures are used around the world, there were no significant differences in disease between the monocultures and mixtures in the present experiment. One reason might be the high level of similarity in disease resistance bred into many Canadian wheat breeding programs. The component cultivars used in this experiment may not have differed in resistance to the extent required to provide a measurable difference in yield, given the overall level of disease in the experiment.

Lemerle et al. (1996) reported that competitive wheat cultivars shared certain characteristics, including above-average height, high early biomass accumulation (early season vigor), a large tillering capacity and high LAI. Of the agronomic traits we examined, early season vigor appeared to be the most important for yield production, especially in heavily stressed environments. Sole-crop Superb had high early season vigor ratings at all sites, and was not tall or high tillering. Of all agronomic traits observed, early season vigor was the only one to be positively correlated with yield at all three sites. In addition, early season vigor was the one trait associated with weed suppression on organic land. Most of the higher yielding entries also had comparatively high emergence on all sites, indicating the importance of a well-prepared seedbed (Nasr and Selles 1995), high quality seed (Xue and Stougaard 2002), and high seeding rates (Gooding et al. 2002) to overcome weed pressure.

2.5 Conclusions

Organic and conventional management should be considered separately when recommending cultivar mixtures. On conventionally managed land, the sole-crop semi-dwarf cultivar was the highest yielding entry, but had low protein content. Protein could therefore be improved through the use of mixtures with early maturing, tall, higher protein content cultivars, such as Intrepid. On organic land, competition has the largest negative effect on yield, and thus both weed suppression and high yield must be considered when choosing a cultivar mixture. Of the mixtures that had both above-average yield and high stability, the 1:1 mixture of a highly vigorous semi-dwarf and an average height, early maturing variety also had among the lowest total weed biomass in its plots, and thus may be the most suitable for organic production. If conventional producers are concerned about unpredictable environmental variation causing yield loss, these mixtures could also be considered.

2.6 Tables and Figures

Table 2.1. Planting and harvesting dates, and environmental data[a] for field trials conducted in north-central Alberta from 2003 to 2005.

Year	Site	Planting Date	Harvest Date	Precipitation (mm)						Temperature (°C)				
				May	June	July	Aug	Sept	Total	May	June	July	Aug	Sept
2003	Edmonton Conventional	May 15	Sept 9	33	59	72	56	15	235	9.1	14.1	17.6	17.4	10.3
2003	Edmonton Organic	May 15	Sept 13											
2004	Edmonton Conventional	May 10	Sept 15	48	27	256	44	39	414	8.5	13.9	16.7	14.6	8.8
2004	Edmonton Organic	May 18	Oct 6											
2004	Certified Organic	May 26	Sept 22	27	24	118	69	42	280	8.4	13.0	16.3	14.0	9.3
2005	Edmonton Conventional	May 10	Sept 8	39	62	60	97	27	285	10.6	14.3	16.4	13.7	8.9
2005	Edmonton Organic	May 27	Oct 4											
2005	Certified Organic	June 3	Oct 12	18	79	38	32	33	200	10.3	13.5	16.0	13.4	9.3
	Average Precipitation (mm)		Edmonton	45	87	91	69	42	334	11.7	15.5	17.5	16.6	11.3
			New Norway	44	87	88	62	42	323	10.7	14.6	16.5	15.8	10.3

[a] Environment Canada (2004)

Table 2.2. Soil nutrient content and physical characters recorded before planting on conventional and organic land in Edmonton, AB and New Norway, AB from 2003 to 2005. Soil samples were taken from a depth of 0 to 12 inches (0 to 30 cm).

		Soil Nutrient Analysis ($kg\ ha^{-1}$)					EC[c]	OM[d]
Year	Site	N[a]	P	K	S[b]	pH	($dS\ m^{-1}$)	(%)
2003	Edmonton Conventional	153	86	>1347	26	6.8	1.09	10.1
2003	Edmonton Organic	72	>135	921	>45	6.6	0.62	9.9
2004	Edmonton Conventional	300	73	817	65	6.0	0.75	12.1
2004	Edmonton Organic	147	113	1114	64	6.3	0.59	10.3
2004	Certified Organic	65	47	730	22	6.5	0.37	5.4
2005	Edmonton Conventional	272	192	1462	>90	7.3	0.99	7.2
2005	Edmonton Organic	199	260	1582	>90	6.1	0.91	10.3
2005	Certified Organic	122	77	2208	64	6.1	0.44	5.4

[a] Nitrate-N only [b] Sulphate-S only
[c] Electrical conductivity [d] Organic matter content

Table 2.3. Wheat cultivar mixtures and sole-crop cultivars used in trials conducted in north-central Alberta from 2003 to 2005.

Entry (year of release)	Seed Ratio[a]	Abbreviation	Protein[b]	Height	Maturity
Superb (2000)	Sole-crop	-	14.0%	83 cm	112 days
AC Intrepid (1997)	Sole-crop	-	14.1%	91 cm	109 days
5600HR (1999)	Sole-crop	-	13.6%	96 cm	112 days
5600HR-Intrepid	1:1	5I11			
5600HR-Intrepid	1:2	5I12			
5600HR-Intrepid	2:1	5I21			
5600HR-Superb	1:1	5S11			
5600HR-Superb	1:2	5S12			
5600HR-Superb	2:1	5S21			
Superb-Intrepid	1:1	SI11			
Superb-Intrepid	1:2	SI12			
Superb-Intrepid	2:1	SI21			
5600HR-Superb-Intrepid	1:1:1	5SI111			
5600HR-Superb-Intrepid	1:1:2	5SI112			
5600HR-Superb-Intrepid	1:2:1	5SI121			
5600HR-Superb-Intrepid	2:1:1	5SI211			

[a] Mixtures were composed on a kernel number basis to achieve a standard seeding rate of 300 seeds m^{-2}.
[b] Agronomic data for the cultivar descriptions are adapted from Varieties of Cereal and Oilseed Crops for Alberta 2005. Agdex 100/32, Alberta Agriculture, Food and Rural Development, Edmonton, Alberta, Canada.

Table 2.4. Least square means of grain yield and weed biomass for three wheat cultivars and thirteen resulting mixtures grown with and without *B. juncea* competition at three locations in north-central Alberta between 2003 and 2005.

	Certified Organic				Edmonton Organic				Edmonton Conventional			
		B. juncea Competition		Non-competition		*B. juncea* Competition		Non-competition		*B. juncea* Competition		Non-competition
Entry	Yield t ha^{-1}	Juncea g m^{-2}	Total Weeds g m^{-2}	Total Weeds g m^{-2}	Yield t ha^{-1}	Juncea g m^{-2}	Total Weeds g m^{-2}	Total Weeds g m^{-2}	Yield t ha^{-1}	Juncea g m^{-2}	Total Weeds g m^{-2}	Total Weeds g m^{-2}
Superb	1.43[a]	80	240	155	3.61	45	135	290	4.93	35	50	0
Intrepid	1.00	65	250	250	3.53	140	210	150	4.45	35	50	30
5600HR	0.80	115	280	240	3.11	115	290	155	4.09	25	45	15
5I11	0.91	105	270	270	3.27	110	210	175	4.29	10	20	0*
5I12	0.92	220**	430*	245	3.33	80	290	190	4.46	45	60	15
5I21	0.88	80	330	265	3.17	135	285	155	4.00	50	55	10
5S11	1.09	115	240	250	3.44	150	240	115	4.59	50	60	5
5S12	1.28	125	270	250	3.68	50	195	120	4.43	20	50	25
5S21	0.97	85	280	220	3.35	215	355	215	4.38	30	40	20
SI11	1.31	90	215	190	3.82	65	150	90	4.61	80	100	10
SI12	1.23	95	290	260	3.53	175	270	165	4.69	85	90	0
SI21	1.18	70	200	170	3.78	140	265	190	4.63	35	45	15
5SI111	0.99	65	290	270	3.22	125	195	180	4.25	85*	110*	10
5SI112	1.12	45	290	235	3.23	120	260	90	4.38	50	70	25
5SI121	1.12	110	270	235	3.30	85	265	100	4.52	30	50	20
5SI211	1.11	180	375	195	3.31	150	315	145	4.38	55	60	10
Mean	**1.08**	**105**	**280**	**230**	**3.42**	**110**	**245**	**160**	**4.44**	**45**	**60**	**15**
Non-comp	1.17				3.67				4.81			
Comp	0.99				3.16				4.07			
F-values[b]												
Entry	**	ns	ns	ns	**	ns	ns	ns	**	ns	ns	ns
Comp	*	-	ns	ns	*	-	ns	ns	**	-	**	**
Entry*Comp	ns	-	ns	ns	ns	-	ns	ns	ns	-	ns	ns
SE (entry)[c]	0.14	50.7	73.0	77.8	0.15	66.4	82.1	83.5	0.16	36.1	37.0	11.9
SE (comp)[d]	0.07	-	26.0	26.0	0.19	-	50.3	50.3	0.19	-	11.0	11.0
SE (ent*comp)	0.14	-	53.7	53.7	0.15	-	62.3	62.3	0.16	-	20.1	20.1

[a] * or ** in the main entry columns indicate significant difference from the mid-component average at P=0.05 and P=0.01, respectively.

[b] ns = not significant, * = significant at $P<0.05$, ** = significant at $P<0.01$. [c] Standard error of the difference between two means.

[d] Standard error of the difference between competition and non-competition main effects.

Table 2.5. Least-square means of plant emergence, early season vigor (ESV), leaf area index (LAI) and light interception for three wheat cultivars and thirteen resulting mixtures grown with and without *B. juncea* competition at three locations in north-central Alberta between 2003 and 2005.

	Certified Organic				Edmonton Organic		Edmonton Conventional			
	Emergence m^{-2}		ESV (1-5)							
Entry	Non-Comp	Comp	Non-Comp	Comp	Emerg. m^{-2}	ESV (1-5)	Light Int. (%)	Emerg. m^{-2}	ESV (1-5)	LAI[a]
Superb	125[b]	155	4.6	4.9	195	3.0	94	230	4.9	5.6
Intrepid	120	100	4.0	3.9	170	3.1	86	190	4.2	3.8
5600HR	140	130	3.6	3.0	145	2.3	90	190	3.8	4.3
5I11	115	120	3.4	3.8	150	2.2	91	190	3.8	4.2
5I12	120	90	3.8	3.2	160	2.6	90	195	3.9	4.0
5I21	135	115	3.5	3.4	120*	1.9*	89	200	3.9	4.1
5S11	115	60**	4.1	3.1**	175	2.6	96	210	4.3	4.5*
5S12	130	135	4.4	3.9	160	2.9	93	240	4.6	4.8
5S21	165	95*	4.0	3.5	155	2.4	91	200	4.4	4.7
SI11	115	135	4.0	4.1	175	2.6	91	190	4.6	4.5
SI12	115	155	4.1	4.1	190	2.6	88	210	4.4	4.1
SI21	150	140	4.4	4.6	170	3.1	92	225	4.8	4.6
5SI111	120	125	4.3	3.9	185	2.9	93	195	4.3	4.7
5SI112	120	110	4.0	3.8	160	2.8	90	200	4.4	4.3
5SI121	140	135	4.1	3.6	170	2.6	92	210	4.6	4.6
5SI211	135	105	4.0	3.8	140	2.3	88	175*	4.2	4.3
Mean	**130**	**120**	**4.0**	**3.8**	**165**	**2.7**	**91**	**205**	**4.3**	**4.4**
Non-Comp					165	2.7	-	200	4.3	-
Comp					160	2.6	-	205	4.3	-
F-values[c]										
Entry	ns	**	*	**	ns	**	ns	**	**	**
Comp	*	*	*	*	ns	ns	-	ns	ns	-
Entry*Comp	*	*	**	**	ns	ns	-	ns	ns	-
SE (entry)[d]	25.2	20.9	0.32	0.35	29.4	0.30	2.7	13.7	0.25	0.21
SE (comp)[e]	4.8	4.8	0.07	0.07	5.6	0.15	-	4.4	0.06	-
SE (ent*comp)	18.6	18.6	0.29	0.29	16.9	0.30	-	13.7	0.25	-

[a] LAI and light interception values are from non-competition Edmonton Conventional only.
[b] * or ** in the main entry columns indicate significant difference from the mid-component average at P=0.05 and P=0.01, respectively.
[c] ns = not significant, * = significant at P<0.05, ** = significant at P<0.01.
[d] Standard error of the difference between two least-square means.
[e] Standard error of the difference between competition and non-competition main effects.

Table 2.6. Least-square means of number of tillers m^{-2}, maturity and protein content for three wheat cultivars and thirteen resulting mixtures grown with and without *B. juncea* competition at three locations in north-central Alberta between 2003 and 2005.

	Certified Organic		Edmonton Organic			Edmonton Conventional		
Entry	Tillers m^{-2}	Protein (%)	Tillers m^{-2}	Protein (%)	Maturity (days from seeding)	Tillers m^{-2}	Protein (%)	Maturity (days from seeding)
Superb	340[a]	14.6	370	13.2	123	595	13.9	110
Intrepid	325	15.2	405	14.4	111	545	14.8	100
5600HR	280	15.3	460	13.3	117	550	14.3	109
5I11	275	15.4	445	13.5*	121**	580	14.6	105
5I12	320	15.7	405	14.0	117	565	14.6	103
5I21	285	15.5	440	13.4	119	550	14.5	105
5S11	315	14.6	445	13.3	121	590	14.1	109
5S12	270	14.5	455	13.3	120	590	14.1	109
5S21	230*	14.7	420	13.2	119	580	14.4	108
SI11	330	15.1	410	13.4*	122*	570	14.4	106
SI12	370	15.3	370	14.0	117	590	14.5	103
SI21	295	14.9	420	13.7	119	560	14.2	106
5SI111	315	15.3	410	13.8	118	580	14.5	106
5SI112	270	15.5	340**	13.9	115	560	14.6	105
5SI121	330	15.2	395	13.6	118	590	14.3	107
5SI211	265	15.2	375	13.5	122*	590	14.4	106
Mean	**300**	**15.1**	**410**	**13.6**	**119**	**575**	**14.4**	**106**
Non-Comp	315	15.2	425	13.5	120	595	14.4	107
Comp	285	15.1	395	13.7	118	555	14.4	105
F-values[b]								
Entry	ns	**	**	**	**	ns	**	**
Comp	**	ns	ns	ns	ns	ns	ns	ns
Entry*Comp	ns	ns	ns	ns	ns	ns	ns	ns
SE (entry)[c]	39	0.27	33	0.17	2.8	26	0.12	1.3
SE (comp)[d]	11	0.12	31	0.13	2.3	13	0.07	1.4
SE (ent*comp)	39	0.27	33	0.13	2.8	26	0.12	1.3

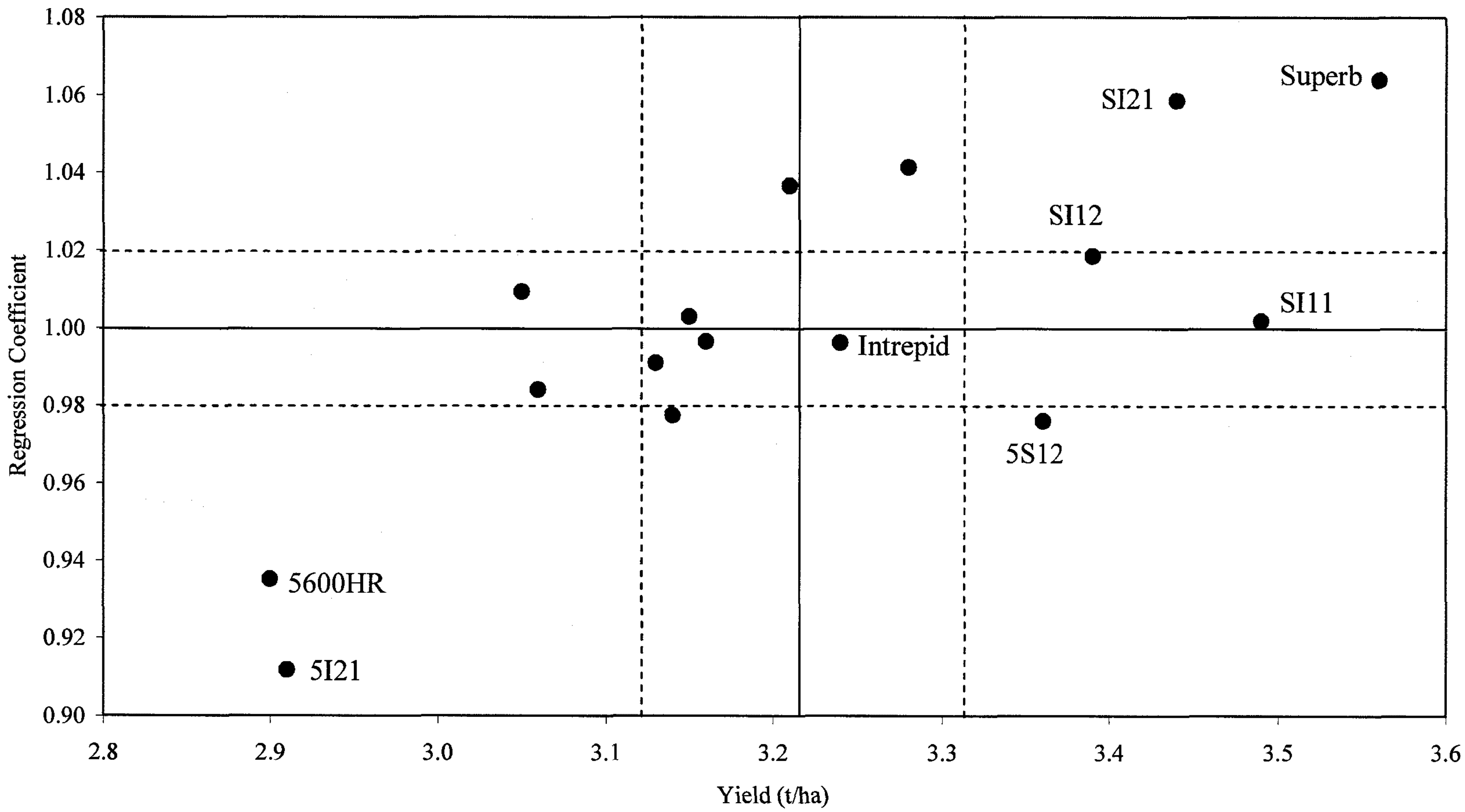
[a] * or ** in the main entry columns indicate significant difference from the mid-component average at P=0.05 and P=0.01, respectively.
[b] ns = not significant, * = significant at P<0.05, ** = significant at P<0.01.
[c] Standard error of the difference between two least-square means.
[d] Standard error of the difference between competition and non-competition main effects.

Table 2.7. Pearson's coefficients of correlation ($P<0.05$) among grain yield, weed biomass and various agronomic characters for sixteen entries grown at Edmonton Conventional (top), Edmonton Organic (middle) and Certified Organic (bottom) sites between 2003 and 2005.

	Emergence	Early Season Vigor	Spikes m^{-2}	Grain yield
Grain Yield	-[a]	0.38	0.69	
	0.38	0.52	-	
	-	0.72	0.49	
B. juncea Weight	-	-	-0.47	-0.68
	-	-	-	-0.75
	-	-0.39	-	-0.41
Total Weed Weight	-	-	-0.47	-0.68
	-	-	-	-0.63
	-0.37	-0.56	-	-0.61

[a] Correlation coefficient not significant ($P>0.05$).

Figure 2.1. The relationship between cultivar adaptation and cultivar mean yield for three wheat cultivars and thirteen resulting mixtures grown in 16 environments. Solid lines indicate mean values and dotted lines represent 95% confidence limits.



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Wheat (*Triticum aestivum* L.) based spring cereal species mixtures in organic and conventional management systems on the northern Prairies of Canada

3.0 Abstract

Cereal species mixtures represent a relatively unexplored avenue for maintaining and stabilizing yield for both organic and conventional producers. We examined the response of small grain mixtures containing wheat, oats, barley and triticale to varying degrees of natural competition and environmental stress at three locations in central Alberta, Canada. One modern and one heritage hard red spring wheat cultivar, along with one cultivar each of oats, barley and triticale and eighteen two-way mixtures, were planted on organic and conventional land over seven location years between 2003 and 2005. Overall yield was lowest at the certified organic farm and highest under conventional management. Sole-crop barley consistently yielded the highest under organic management and mixtures of Park wheat and barley yielded the most grain under conventional management. Triticale yield decreased rapidly as weed competition and abiotic stress increased. Mixtures of wheat and oats gave high yield at all locations and also had final harvest ratios very close to the original ratios seeded. Overall, mixtures of wheat with either barley or oats represent the best opportunity for organic producers to suppress weeds and have high yield of a feed crop and a high-value cash crop.

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3.1 Introduction

Cereal species mixtures are a relatively unexplored area of intercropping, as cereal-legume or cultivar mixtures are more commonly employed and researched. However, mixtures of cereals may be useful for reducing weed pressure (Francis 1989), increasing yield stability (Simmonds 1962; Wilson 1988; Francis 1989; Davidson et al. 1990; Juskiw et al. 2000c), increasing yield through complementary niche utilization (Simmonds 1962; Taylor 1978; Juskiw et al. 2000c), increasing crop rotation flexibility (Walton 1975), pest and disease buffering, minimizing soil variability, and increasing animal feed value (Stoskopf 1985).

Certified organic agriculture is a relatively new practice in western Canada, with only 1.4% of total cropland in Alberta, Saskatchewan and Manitoba currently registered organic (Statistics Canada 2001, Macey 2005). A dichotomy exists between the extensive nature of Prairie grain farming (average farm size = 424 ha) (Statistics Canada 2001, Macey 2005) and the more intensive nature of organic farming (average farm size in North America = 82 ha) (United States Department of Agriculture (USDA) 2002, Macey 2005). Organic grain producers on the Canadian Prairies (average farm size = 132 ha) (Macey 2005) must employ many non-chemical agronomic techniques to remain viable. Crop species and cultivars are chosen not only for yield potential, but also as part of complex crop rotations to control weeds, insects and diseases (Teasdale et al. 2004).The use of small grain mixtures is promising for both conventional and organic growers, albeit for different reasons. Yield advantages for cereal mixtures over sole crops have been reported under both high (Jokinen 1991b; Gallandt et al. 2001; Sobkowicz and Tendziagolska 2005) and low (Jokinen 1991b; Sarandon and Sarandon 1995) input environments.

A great deal of research has concentrated on the use of cereal mixtures for forage or silage production. To maximize yield and quality, barley and oats are harvested at the soft dough stage, while rye and triticale exhibit peak quality and yield at the boot to milk stage (Juskiw et al. 2000a, b). This may lead to complementarity in cereal species mixtures, as rye and triticale are generally slower growing than barley and oats, and therefore a mixture may be at the optimal stage for all species at harvest. The slower growing species will generally increase feed quality because of their high proportion of leaf biomass compared to the more mature components (Juskiw et al. 2000b). There have also been several studies conducted testing the grain yield potential of cereal mixtures on conventional land (Juskiw et al. 2000b, c), but none on organic land.

There are several obstacles to developing successful cereal mixtures, such as differences in height, vigor, lodging resistance, rooting depth, nutrient requirements and maturation rates of the component species (Loomis and Connor 1992). Many studies have reported height to be a major determining factor in a component's competitive ability in mixture (Valentine 1982; Jedel et al. 1998). This doesn't always occur, however, as barley can outcompete oats in mixtures, even though the oats are often taller at harvest (Taylor 1978). Barley is generally a fast-maturing crop while triticale matures quite slowly (Maloney et al. 1999). However, this difference in maturation times may increase yield due to staggered timing of resource requirements (i.e. complementarity) (Sobkowicz and Tendziagolska 2005). Also, early season vigor has a large impact on the competitiveness of each component (Sobkowicz and Tendziagolska 2005) and whether a mixture maintains its ratio from planting to harvest. Vigorous species may outcompete the other components in the mixture, resulting in almost a monoculture at harvest (Fejer et al. 1982; Juskiw et al. 2000c). A producer must account for this by using a ratio and seeding rate that maximizes yield while minimizing interspecific competition (Stoskopf 1985).

There are several mechanisms by which cereal species mixtures may affect crop pests and diseases. The quality and quantity of crop residue from both host and non-host crops can influence pathogen growth, sporulation, and survival through the release of fungicidal compounds during residue breakdown (Bailey and Lazarovits 2003). Mixtures can also decrease pathogen infection on subsequent crops (Vilich 1993). Similar to wheat cultivar mixtures, researchers have noted that disease mitigation of cereal mixtures can be prevented or skewed by the small size of experimental plots (Stoskopf 1985). Vilich-Meller (1992) reported that wheat-barley mixtures provided greater disease reduction on wheat than did applications of fungicide, illustrating the potential of cereal mixtures for use in organic agriculture.

Conventional production emphasizes high yield as its primary goal (Sobkowicz and Tendziagolska 2005). Most mixtures yield less than the highest-yielding component in monoculture, but may offer small yield increases over the mean component yield in sole crop (Taylor 1978; Stoskopf 1985; Jokinen 1991a; Jedel and Salmon 1995; Maloney et al. 1999; Juskiw et al. 2000c; Singh and Singh 2000). Inconsistency of mixture yield advantages may be due to the similarity between cereal crop species growth habits and requirements for limiting resources (Rao 1986; Pandey et al. 1999; Sobkowicz and Tendziagolska 2005).

Crop mixtures are used chiefly on subsistence farms with limited resource availability and little new technology (Francis 1989), making them directly applicable to modern organic farms. Crop mixtures are often employed as a non-chemical means of disease and weed control rather than strictly for yield increase (Fukai 1993). In a management regime that cannot use broad-spectrum herbicides to control weeds, any competitive advantage that can be employed will aid organic producers (Cousens 1996; Davidson et al. 1990). As well, mixtures of grain may be fed directly to organic livestock, or the biomass may be harvested for silage production (Jedel and Salmon 1995).

It is unlikely that any mixture, regardless of how beneficial it turns out to be, can be used over such a large area that disease problems become widespread. Every agro-ecosystem has its own crops and cultivars that suit the climate and soils; it is from these that effective mixtures must be developed. Mixture development is a localized mechanism that can be fine-tuned to suit a given farm's soil, topography and crop rotation.

The objectives of the present study were to: 1) determine the potential of various wheat-based spring cereal mixtures on the northern Canadian prairies under both organic and conventional management, and 2) to establish the competitive abilities of the various cereal mixtures to establish protocols for the growing of cereal mixtures on organic farming systems on the northern Canadian prairies. We endeavored to identify specific cereal species mixtures that could be implemented by producers immediately, and to determine characteristics that could be used to compose effective spring cereal mixtures in the future.

3.2 Materials and Methods

Field trials were conducted at the University of Alberta Edmonton Research Station in Edmonton, Alberta, Canada (53° 34′ N, 113° 31′ W) from 2003 to 2005 and at a certified organic farm near New Norway, Alberta, Canada (52° 52′ N, 112° 56′ W) in 2004 (Table 2.1). The soils in Edmonton are classified as Orthic Black Chernozems (horizon sequence Ah, Bm, Ck), typical of central Alberta, and soils at New Norway were classified as an Eluviated Black Chernozems (horizon sequence Ah, Aej, Btj, Ck) (AAFRD 2005). Soil fertility levels for all fields over all years are presented in Table 2.2. The conventional land at the Edmonton Research Station (Edmonton Conventional) had fertilizer added as urea (46-0-0: N-P_2O_5-K_2O) broadcast to give 67 – 73 kg ha^{-1} total N in 2003; at a rate of 45 kg ha^{-1} N and 20 kg ha^{-1} P, as urea and ammonium phosphate (11-52-0) in the seed row in 2004; and at 28 kg ha^{-1} as ammonium phosphate banded with the seed in 2005. The organic land at the Edmonton Research Station (Edmonton Organic) had compost (comprised of dairy manure, sawdust, wood chips and straw) added at a rate of 50 – 62 t ha^{-1} each year. The certified organic land in New Norway (Certified Organic) had no external inputs of fertilizer, but the fields had plowdown crops containing legumes the previous year. Moisture was sufficient in Edmonton in 2004 and 2005, but there was a mild drought in 2003 in Edmonton (Table 2.1).

Trials were seeded into cultivated and harrowed soil that was tilled both in the autumn and spring prior to seeding. Organically managed land had an additional tillage operation performed to kill weeds immediately before seeding. In 2003, the plots were four rows wide (23 cm row spacing) and 4m long, seeded with a self-propelled, double-disk plot drill (Fabro Enterprises Ltd., Swift Current, SK, Canada), while in 2004 and 2005 plots were six rows wide (23 cm row spacing) and 4m long, and seeded with a self-propelled, no-till, double-disk plot seeder (Fabro Enterprises Ltd., Swift Current, SK, Canada).

The experiment was grown for three years at the three locations – Edmonton Conventional and Edmonton Organic in 2003 to 2005 and Certified Organic in 2004 – for a total of 7 location-years of data. The seven experimental trials were planted as randomized complete block designs (RCBD) with four blocks. Mixture entries included eighteen two-way cereal species mixtures and the five cultivars used to comprise the mixtures. Entries were composed on a kernel-number basis of pure seed to plant at a standard rate of 300 seeds m^{-2}. One cultivar each of barley, oats and triticale was chosen to combine with two cultivars of hard red spring wheat to form the mixture entries. One wheat cultivar (McKenzie) is a modern, high-yielding cultivar registered in 1997, and the other is a taller, early-maturing cultivar (Park), registered in 1963 but still favored by some organic producers in Alberta (Fu et al. 2005). Plots on conventional land were the only ones to receive any herbicide application. They were treated with Dyvel (active ingredients MCPA and dicamba) applied at 1235.5 mL ha^{-1} at the recommended crop (2 to 4 leaf) and weed (emergence to 3 leaf) stage (AAFRD 2006).

3.2.1 Data Collection

Emergence counts were taken before the onset of tillering (1-3 leaf stage) and plots scored for early season vigor on a scale of 1 (low vigor) to 5 (highly vigorous) one month after seeding. At Edmonton Conventional and Edmonton Organic in 2004 and 2005, heading and maturity were recorded when 75% of each species exhibited emerged heads and was physiologically mature, respectively. Weed samples were collected from each plot using 25 cm × 25 cm quadrats when the crop had reached physiological maturity. All samples were taken between the third and fourth row, 60 cm into the plot. Height measurements were taken for each species separately once stem elongation was completed. Lodging ratings were recorded throughout the season, particularly in 2004, when heavy winds and an early snowfall caused widespread lodging. Lodging was rated from 1 (no lodging present) to 9 (plot completely flat). Once the entries were fully mature, but prior to harvest, ten spikes were randomly collected from each species in each plot to determine kernels per spike and kernel weight.

A Wintersteiger plot combine harvested the entire plot for yield, which was determined after each sample was cleaned and dried to 13-14% moisture. Small weed seeds were removed from plot yield samples using a 2mm sieve and a fan, which also removed chaff. In 2004, plot yields from the certified organic farm in New Norway were infested with wild oats (*Avena fatua* L.) to such a degree that they had to undergo hand cleaning on a sub-sample of 150g. Final mixture ratios were calculated by separating 100g samples of plot yield into its respective species in 2003, and through the harvest of randomly chosen 1m-row of plot and subsequent separation in 2004 and 2005. The grain samples were analyzed for thousand kernel weight, which was used to calculate the relative mixture ratios back to a kernel number basis in the same way the mixtures were originally synthesized.

3.2.2 Data Analysis

For the purposes of examining differences in the seven environments, a preliminary combined analysis of variance over all environments was performed using the MIXED procedure (Littell et al. 1996) of SAS (version 8.2; SAS Institute 1999); where environment and entry were considered fixed, and replication and replication interactions were considered random. In this analysis, the seven environments differed ($P<0.01$) for grain yield (data not shown). Mean yield at the Certified Organic Farm was low (1.34 t ha^{-1} in 2004), compared to Edmonton Organic (3.36, 3.22, 3.36 t ha^{-1} in 2003, 2004 and 2005 respectively) and Edmonton Conventional (3.42, 4.29 and 5.37 t ha^{-1} in 2003, 2004 and 2005 respectively). Due to the large differences in location soils and climate (Tables 2.1 and 2.2), yield potential and management characters, analyses and results for yield and agronomic indices were conducted and are presented by location, combined over years. Thus, analyses of variance for each of the three locations (Edmonton Organic, Edmonton Conventional, and Certified Organic) were performed separately using the MIXED (Littell et al. 1996) procedure of SAS, where year, replication within year and replication interactions were considered random. Entry was considered fixed. The mid-component average yield of a mixture is the combined average for the sole-crop yield of the components in that mixture, weighted according to ratio. Single degree of freedom contrasts, weighted by proportion seeded (e.g. 1:1, 3:1 or 1:3) were conducted to compare mixture means with mid-component averages for yield and the percent seed composition outcome of the final harvest. The final mixture ratios were compared to their originals using the TTEST procedure of SAS (SAS Institute 2003). Weed biomass was generally the lowest under barley treatments and barley has been reported to be strongly competitive with weeds (O'Donovan et al. 2000). We therefore conducted single degree of freedom contrasts comparing the weed biomass of all other entries with sole-crop barley. Significance levels for total weed biomass were calculated using a square-root transformation to reduce variability (Steel et al. 1996).

3.3 Results

The five sole-crop and 18 mixture entries differed ($P<0.05$) for early season vigor, grain yield and final grain mixture ratio at all three locations (Table 3.1, 3.2, 3.3). At Edmonton Conventional, triticale, barley and oats yielded more grain than both wheat cultivars. Under higher competition conditions at Edmonton Organic and Certified Organic locations, barley and oats yielded the most grain of all sole-crops planted and triticale and the wheat cultivars yielded the least (Tables 3.2 and 3.3). No mixture yielded greater ($P>0.05$) than its respective mid-component average at Edmonton Organic, but two did at both Edmonton Conventional (Park wheat:Barley 1:1 and McKenzie wheat:Barley 1:1) and Certified Organic (McKenzie wheat:Oats 1:1 and 1:3). Under low competition conditions at Edmonton Conventional, mixture entries yielded similarly; between 4.0 and 4.9 t ha^{-1} (Table 3.1). As weed competition and abiotic stress levels increased, there were greater yield differences among the mixtures (Tables 3.2 and 3.3). Mixtures of wheat with barley or oats tended towards yield improvements and greater weed suppression over sole-crops grown under organic management at the Edmonton Organic and Certified Organic locations (Tables 3.2 and 3.3).

Final grain mixture ratios differed ($P<0.01$) from the original planted ratios in all Wheat:Barley mixtures at all locations (Tables 3.1, 3.2 and 3.3). Barley was more competitive than either wheat cultivar. In environments with high weed competition levels and high abiotic stress (Edmonton Organic and Certified Organic), wheat competed more strongly when mixed with triticale and oats than at Edmonton Conventional. In general, a 50:50 mixture of wheat and barley resulted in a 25:75 ratio harvest, while mixtures seeded as 75:25 resulted in a 50:50 harvest, and a 25:75 seeded ratio was harvested as a 10:90 ratio (Table 3.1, 3.2 and 3.3). Conversely, both cultivars of wheat were more competitive than triticale. Oats competed slightly better than wheat. The mean final wheat ratio decreased as environmental stress increased from Edmonton Conventional to Certified Organic, indicating barley and oats were more stress tolerant and competitive in general than the two wheat cultivars.

Final weed biomass differed ($P<0.01$) between entries at Edmonton Organic only (Table 3.2). Final weed biomass was uniformly high (average = 190 g m^{-2}) at Certified Organic and uniformly low (average = 5 g m^{-2}) at Edmonton Conventional. At Edmonton Organic, sole-crop triticale and triticale mixtures generally had the highest final weed biomass, indicating this crop does not compete with or suppress weeds. Sole-crop barley had among the lowest weed biomass levels at all locations, indicating this crop competes with and suppresses weeds, especially on organically managed locations (Tables 3.2 and 3.3). Although mixtures varied for grain yield, they did not suppress weeds more than their mid-component average ($P>0.05$) at any location. Barley had high early season vigor ratings, high yield, and low weed biomass levels at all locations, making it the most competitive crop planted. We conducted single degree of freedom contrasts comparing the weed biomass of all other entries with sole-crop barley (Table 3.1, 3.2 and 3.3). Due to the uniformly low weed biomass levels at Edmonton Conventional, barley did not suppress weeds better than any other entry. At Edmonton Organic, sole-crop triticale had the highest weed biomass levels of any entry, significantly ($P <0.05$) greater than barley. Two mixtures (Park wheat:Triticale 25:75 and McKenzie wheat:Oats 50:50) also had higher ($P<0.05$) weed biomass than barley. At Certified Organic, sole-crop McKenzie had higher ($P<0.05$) weed levels than barley, and was also the lowest yielding entry. Two mixtures (McKenzie wheat:Barley 75:25 and McKenzie wheat:Triticale 50:50) also had higher ($P<0.05$) weed levels than barley. Average weed biomass levels in Park wheat:Barley mixtures at Certified Organic were 138 g m^{-2}, compared to 258 g m^{-2} in McKenzie wheat:Barley mixtures.

Sole-crop triticale had lower mean emergence ($P<0.05$) than all other sole-crops at both Edmonton Conventional and Edmonton Organic (Table 3.4). Early season vigor (ESV) was 30% higher at Edmonton Conventional than at Edmonton Organic, with sole-crop barley and Park wheat:Barley mixtures generally having the highest ESV (Table 3.1). Sole-crops growing at Edmonton Organic matured an average of 6 days later than Edmonton Conventional plants. Barley matured earliest and triticale the latest, regardless of location, even though the two crops reached the heading stage at about the same time. Even though it had the lowest emergence and ESV and latest maturity of all crops tested, triticale still had the highest yield under low competition levels at Edmonton Conventional. However, its yield dropped by over half as competition stress increased at the organic locations. This indicates that triticale has low competitive ability, despite its drought tolerance.

Sole-crop entries lodged almost twice as much at Edmonton Conventional than Edmonton Organic. Triticale had the lowest lodging rating at both locations (Table 3.4). Mean wheat height was higher at Edmonton Conventional than Edmonton Organic, while crop height was the opposite (Table 3.4).

Mean wheat kernel weight was lowest at Certified Organic compared to Edmonton Conventional and Edmonton Organic (Tables 3.1, 3.2 and 3.3). Among the crop (i.e. non-wheat) species tested, triticale generally had high kernel weight regardless of location. The crop component of each mixture did not differ ($P>0.05$) from its mid-component average at any location, but wheat had lower kernel weight in several mixtures at Edmonton Conventional and Edmonton Organic, particularly when combined with oats. The two wheat cultivars tested responded differently at each location. In the low-stress, low competition environment of Edmonton Conventional, Park yielded more grain than McKenzie, and also had higher ESV and was taller (Table 3.1 and 3.4). Under high competition, high moisture conditions at Edmonton Organic, McKenzie yielded more grain than Park and had higher ESV, emergence and lodging (Table 3.2 and 3.4). Under extreme competitive and moisture stress at Certified Organic, Park yielded almost twice as much grain as McKenzie, possibly due to much higher ESV, early maturity and fewer weeds than McKenzie (Table 3.3).

3.4 Discussion

3.4.1 Crop Competitive Ability

There are many differences between modern conventional and organic farming systems, the most prominent being the use of synthetic chemicals such as fertilizers, herbicides and pesticides (Vos 2000). While conventional producers rely on one or more applications of herbicide to control weeds, organic producers must depend upon multiple agronomic practices to overcome weed pressure (Lotter 2003). We evaluated the competitive ability of two wheat cultivars, and one cultivar each of barley, oats and triticale, alone and in mixtures under organic and conventional management. Barley was the most competitive crop evaluated, exhibiting high early season vigor, emergence, yield, and low weed biomass. Many studies report plant height at maturity to be positively associated with competitive ability (Lemerle et al. 1996; O'Donovan et al. 2000). Barley was the shortest crop we evaluated, but was the most competitive with both weeds and other cereals in mixture. This suggests that plant characters other than height at maturity play important roles in a plant's competitive ability. Barley also exhibited the greatest early season vigor (Rasmussen and Rasmussen 2000), and was almost twice as tall as triticale one month after planting, thereby competing strongly with weeds for light, space, moisture and nutrients (Sobkowicz and Tendziagolska 2005).

Triticale had poor emergence and very poor early season vigor, and was the least competitive crop grown in this trial. This was not anticipated, as triticale was originally bred as a drought tolerant, competitive crop for use in marginal areas (Giunta et al. 1993; Quarrie et al. 1999). Current Canadian research on triticale centers around its potential as an animal feed and fodder crop under conventional management (Clayton et al. 2003; Ross et al. 2004). This suggests the need for location-specific evaluation within highly competitive or organic environments, and not extrapolating recommendations based on results from conventional, high-input trials (Schwarte et al. 2006; Manero de Zumelzú et al. 2002). Oats were slightly more competitive than wheat, significantly outcompeting wheat in mixture about half the time, while wheat never significantly outcompeted oats in mixture. The two wheat cultivars examined, Park and McKenzie, also differed in competitive ability between environments. The heritage cultivar Park yielded more grain than the modern cultivar McKenzie under low stress conditions at Edmonton Conventional and under extreme stress at Certified Organic. Overall, in the present experiment, the crop competitive ability of the different grains grown in central Alberta could be rated in order as barley being greater than oats, followed by wheat and then triticale. This is similar to comparisons made in the literature, which rate barley and oats as the most competitive, followed by wheat (Mason and Spaner 2006).

3.4.2 Recommendations for Organic and Conventional Production

Cereal mixtures may prove a valuable tool for organic producers wishing to capitalize on the inherent competitive ability of certain crops (e.g. barley), while still garnering price premiums for high-value crops (e.g. wheat). Many organic producers have their own on-farm means of cleaning weed seeds from their crops to allow for direct marketing to consumers (Born 2005); it would not be difficult for them to adjust their methods to allow for separation of grain crops from each other. Due to its low competitive ability, triticale would not be recommended for use on organic farms. Rye (*Secale cereale*) may be a more competitive and higher yielding choice (Creamer et al. 1996), although we did not evaluate this species in the present experiment. Depending on how much the producer requires of each crop, one of the Park wheat:Barley mixtures may allow for yield maintenance under high abiotic (e.g. drought) and biotic (e.g. competition) stress. Such a mixture may simultaneously serve to provide barley as organic animal feed and wheat for sale into the premium organic flour market. A mixture of Park wheat and oats may be an alternative choice based on our present results.

When choosing cultivars for use in mixtures or on organic land, it is important to consider their individual characteristics. Park wheat and Manny barley work well together because, even though the barley exhibits has higher early season vigor and competes to the extent of yielding greater grain percentage in the final mixture ratio, the wheat is taller and, following stem elongation, has access to sunlight at the top of the crop canopy. Using a shorter wheat cultivar with a taller barley cultivar may not be as complementary. This also applies to mixtures of oats and wheat. In the present trial, the oats were taller than either wheat cultivar, which may have allowed oats to outcompete wheat in mixtures. Producers can formulate different species mixtures until they discover a combination and ratio that works best for their farming operation (Finckh et al. 2000).

Despite the fact that three of the top four entries on conventional land were Wheat:Barley mixtures, it is unlikely that conventional Canadian grain producers will adopt cereal mixtures. At the present time, low herbicide prices preclude the need for alternate weed control methods. Until chemical prices rise or weed resistance becomes rampant, conventional producers will continue to use herbicides as their main, and often only, weed control method.

3.5 Conclusions

Organic and conventional management should be considered separately when recommending cereal species mixtures. On conventionally managed land, wheat:barley mixtures exhibited potential for yield maintenance and weed suppression. If conventional producers are concerned about weed competition causing yield loss and the development of herbicide resistance in weed populations, these mixtures should be considered. On organically managed land, competition with weeds had a large negative effect on yield, and thus both weed suppression and high yield may be considered when choosing a species mixture. The two 25:75 mixtures of wheat and oats and mixtures of Park wheat and barley exhibited high yield potential and barley mixtures exhibited weed suppressive capabilities. However, further studies are needed to determine which specific cultivars commonly used on the Canadian prairies have good mixing ability and will consistently provide above average yield potential when combined.

3.6 Tables

Table 3.1. Least-square means for yield, early season vigor (ESV), weeds, kernel weight and final grain mixture ratios for 23 entries grown at the Edmonton Conventional location from 2003 to 2005.

Mixture Components	Mixture Ratio	ESV	Grain Yield t ha^{-1}	Yield Rank	Final Grain Mixture Ratio (%) Wheat	Crop	Sig.[b]	Kernel Weight (mg) Wheat	Crop	Weed Biomass[c] g m^{-2}
Park (HRS wheat)	Sole-crop	3.9[a]	3.99	21	-	-		34	-	10
McKenzie (HRS wheat)	Sole-crop	4.5	3.65	22	-	-		34	-	10
Barley (Manny)	Sole-crop	5.0	4.48	8	-	-		-	37	5
Oats (Grizzly)	Sole-crop	3.6	4.67	6	-	-		-	40	5
Triticale (AC Alta)	Sole-crop	2.8	4.68	5	-	-		-	49	0
Park-Barley	50:50	4.9	4.89*	1	27	73	**	32	36	10
Park-Barley	25:75	5.0	4.73	2	10	90	**	33	38	15
Park-Barley	75:25	4.4	4.48	8	50	50	**	33	37	10
McKenzie-Barley	50:50	4.8	4.69*	4	26	74	**	32	37	5
McKenzie-Barley	25:75	4.5	4.44	10	10	90	**	31*	39	15
McKenzie-Barley	75:25	4.4	4.16	16	54	46	**	32	38	0
Park-Oats	50:50	4.4*	4.31	13	40	60	**	32*	38	5
Park-Oats	25:75	3.9	4.45	9	20	80		32*	39	15
Park-Oats	75:25	3.9	4.09	17	67	33	**	34	39	10
McKenzie-Oats	50:50	4.3	4.51	7	38	62	*	33	37	5
McKenzie-Oats	25:75	4.1	4.72	3	20	80		30**	39	5
McKenzie-Oats	75:25	4.0	4.25	15	71	29		32	37	20
Park-Triticale	50:50	3.6	4.36	12	62	38	*	33	48	5
Park-Triticale	25:75	3.5	4.41	11	31	70	**	33	49	0
Park-Triticale	75:25	3.5	4.01	19	80	20		34	50	0
McKenzie-Triticale	50:50	3.6	4.00	20	67	33	**	32	48	5
McKenzie-Triticale	25:75	3.1	4.26	14	34	66	*	33	52	5
McKenzie-Triticale	75:25	3.5	4.06	18	87	14	**	32	47	0
	Mean	**4.0**	**4.36**		**44**	**56**		**33**	**42**	**5**
	F-value (entry)[d]	**	**		**	**		*	**	ns
	SE (entry)	0.35	0.29		4.6	4.6		1.12	1.69	6.8
	LSD (entry) P=0.05	0.73	0.60		9.5	9.5		2.32	3.51	14.1

[a] Main column entries significantly different from their mid-component average P<0.05 (*) and P<0.01 (**), respectively.

[b] * , ** indicate final grain mixture ratio differs from original planted ratio at P<0.05 and P<0.01, respectively.

[c] None of the entry weed biomass values were significantly different from sole-crop barley.

[d] ns = not significant, * = significant at P<0.05, ** = significant at P<0.01

Table 3.2. Least-square means for yield, early season vigor (ESV), weeds, kernel weight and final mixture ratios for 23 entries grown at the Edmonton Organic location from 2003 to 2005.

Mixture Components	Mixture Ratio	ESV	Grain Yield[a] $t\ ha^{-1}$	Yield Rank	Final Grain Mixture Ratio (%) Wheat	Crop	Sig.[c]	Kernel Weight (mg) Wheat	Crop	Weed Biomass $g\ m^{-2}$	Contrast (Barley)[d]
Park (HRS wheat)	Sole-crop	2.6[b]	2.45	16	-	-		34	-	240	
McKenzie (HRS wheat)	Sole-crop	3.0	2.60	15	-	-		33	-	90	
Barley (Manny)	Sole-crop	3.5	4.71	2	-	-		-	38	90	
Oats (Grizzly)	Sole-crop	3.4	4.35	3	-	-		-	35	120	
Triticale (AC Alta)	Sole-crop	1.5	2.11	22	-	-		-	42	440	**
Park-Barley	50:50	3.1	4.23	4	16	84	**	32	40	215	
Park-Barley	25:75	3.8	4.23	4	7	93	**	32	40	40	
Park-Barley	75:25	3.0	3.51	9	41	59	**	32	38	170	
McKenzie-Barley	50:50	3.0	3.95	6	25	75	**	32	37	60	
McKenzie-Barley	25:75	3.0	4.81	1	11	89	**	33	38	110	
McKenzie-Barley	75:25	2.9	3.31	11	47	53	**	31	38	100	
Park-Oats	50:50	3.1	3.35	10	29	71	*	30**	36	160	
Park-Oats	25:75	3.1	3.62	8	16	84	*	30**	36	190	
Park-Oats	75:25	2.9	3.13	13	57	43	*	32	36	105	
McKenzie-Oats	50:50	2.9	3.83	7	38	62		30**	35	345*	*
McKenzie-Oats	25:75	2.8	4.07	5	19	81		28**	34	110	
McKenzie-Oats	75:25	2.2**	3.20	12	68	32		33	35	155	
Park-Triticale	50:50	2.2	2.22	21	56	44		33	41	240	
Park-Triticale	25:75	1.8	2.44	17	32	68		32	41	430	**
Park-Triticale	75:25	3.0*	2.63	14	78	22		34	42	300	
McKenzie-Triticale	50:50	2.5	2.43	18	71	29	**	32	38	315	
McKenzie-Triticale	25:75	2.3	2.36	20	46	54	**	33	43	300	
McKenzie-Triticale	75:25	2.5	2.37	19	84	16	**	33	41	240	
	Mean	**2.8**	**3.30**		**41**	**59**		**33**	**38**	**200**	
	F-value (entry)[e]	**	**		**	**		**	**	*	
	SE (entry)	0.32	0.37		6.9	6.9		1.21	1.97	127.9	
	LSD (entry) P=0.05	0.66	0.77		14.3	14.3		2.51	4.09	265.3	

[a] LS means from analysis of covariance with total weed biomass as covariable (P<0.01)

[b] Main column entries significantly different from their mid-component average P<0.05 (*) and P<0.01 (**), respectively.

[c] * , ** indicate final grain mixture ratio differs from original planted ratio at P<0.05 and P<0.01, respectively.

[d] * , ** indicate entry weed biomass differs from sole-crop barley at P<0.05 and P<0.01, respectively.

[e] ns = not significant, * = significant at P<0.05, ** = significant at P<0.01

Table 3.3. Least-square means for yield, early season vigor (ESV), weeds, kernel weight and final mixture ratios of 23 entries grown at the Certified Organic location in 2004.

Mixture Components	Mixture Ratio (%)	ESV	Grain Yield t ha^{-1}	Yield Rank	Final Grain Mixture Ratio (%) Wheat	Crop	Sig.[b]	Kernel Weight (mg) Wheat	Crop	Weed Biomass g m^{-2}	Contrast (Barley)[c]
Park (HRS wheat)	Sole-crop	4.3[a]	1.37	11	-	-		31	-	210	
McKenzie (HRS wheat)	Sole-crop	2.8	0.75	19	-	-		31	-	275	*
Barley (Manny)	Sole-crop	4.0	1.55	5	-	-		-	31	120	
Oats (Grizzly	Sole-crop	3.5	1.38	10	-	-		-	38	160	
Triticale (AC Alta)	Sole-crop	4.0	1.11	16	-	-		-	42	115	
Park-Barley	50:50	4.5	1.61	3	30	70	**	29	29	170	
Park-Barley	25:75	4.8*	1.56	4	13	87	**	29	31	110	
Park-Barley	75:25	4.5	1.44	9	56	44	*	28	31	135	
McKenzie-Barley	50:50	4.0	1.19	15	22	78	**	29	31	250	
McKenzie-Barley	25:75	4.5*	1.31	13	9	91	**	29	29	240	
McKenzie-Barley	75:25	3.3	0.98	17	44	56	**	29	30	285	*
Park-Oats	50:50	4.0	1.37	11	43	57		31	40	155	
Park-Oats	25:75	4.3	1.71	2	17	83		32	39	200	
Park-Oats	75:25	3.8	1.19	15	75	25		30	41	180	
McKenzie-Oats	50:50	3.3	1.48*	7	32	68		31	40	225	
McKenzie-Oats	25:75	3.0	2.21**	1	11	89	*	31	40	125	
McKenzie-Oats	75:25	3.0	1.20	14	49	51	**	32	41	180	
Park-Triticale	50:50	4.0	1.46	8	52	48		30	43	150	
Park-Triticale	25:75	3.8	1.50	6	27	73		34	39	165	
Park-Triticale	75:25	4.0	1.32	12	80	20		32	44	240	
McKenzie-Triticale	50:50	3.5	0.98	17	48	52		31	44	270	*
McKenzie-Triticale	25:75	3.5	1.19	15	21	79		31	45	225	
McKenzie-Triticale	75:25	3.0	0.90	18	67	33		31	43	230	
	Mean	**3.8**	**1.34**		**38**	**62**		**30**	**38**	**190**	
	F-value (entry)[d]	**	**		**	**		ns	**	ns	
	SE (entry)	0.35	0.22		5.3	5.3		1.77	2.28	70.3	
	LSD (entry) P=0.05	0.73	0.46		11.0	11.0		3.67	4.73	145.8	

[a] Main column entries significantly different from their mid-component average P<0.05 (*) and P<0.01 (**), respectively.
[b] * , ** indicate final grain mixture ratio differs from original planted ratio at P<0.05 and P<0.01, respectively.
[c] * indicates entry weed biomass differs from sole-crop barley at P<0.05. [d] ns = not significant, * = significant at P<0.05, ** = significant at P<0.01

Table 3.4. Least-square means for emergence, early season vigor (ESV), days to heading, days to maturity, height and lodging of sole-crop varieties grown under Organic (Org) and Conventional (Conv) management in Edmonton in 2004 and 2005.

		Emergence (plants m^{-2})[a]		ESV (1-5)		Days to Heading		Days to Maturity		Height (cm)		Lodging (1-9)	
Species	Cultivar	Conv	Org	Conv	Org	Conv	Org	Conv	Org	Conv	Org	Conv	Org
HRS Wheat	Park	212ab[b]	164a	4.3ab	3.5c	56c	56c	101b	105c	97bc	97bc	2.3b	2.3b
HRS Wheat	McKenzie	218ab	190a	3.4c	4.6a	56c	54c	99b	103c	92c	92c	3.6a	3.6a
Barley	Manny	232a	190a	4.5a	4.9a	64b	64b	93c	97d	82d	82d	3.6a	3.6a
Oats	Grizzly	247a	172a	3.1c	4.1b	68a	66ab	100b	111b	113a	113a	1.2b	1.2b
Triticale	AC Alta	176b	81b	3.6bc	2.0d	67a	67a	124a	131a	101b	101b	1.0b	1.0b
	Mean	**217**	**159**	**3.8**	**3.8**	**62**	**61**	**103**	**109**	**97**	**97**	**2.3**	**2.3**
	F-value (entry)[c]	*	**	**	**	**	**	**	**	**	**	**	**
	SE (entry)	22.1	15.0	0.38	0.22	0.85	1.5	2.0	2.4	3.2	3.2	0.7	0.7
	LSD (entry) P=0.05	45.8	31.1	0.79	0.46	1.76	3.1	4.1	5.0	6.6	6.6	1.5	1.5

[a] Column means with the same letter behind them are not significantly different at P=0.05.
[b] Means separation was achieved using single degree of freedom contrasts.
[c] ns = not significant, * = significant at P<0.05, ** = significant at P<0.01

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4.0 General Discussion and Conclusions

There are large differences between modern conventional and organic farming. Organic farming uses no synthetic chemical pesticides, fertilizers or genetically-modified organisms, replacing them with agronomic practices designed to reduce weed, disease and insect problems over time, such as crop rotation, variety selection and plowdown crops. This indicates the need for research pertaining directly to modern organic farming; it is incorrect to draw conclusions for both organic and conventional management systems based on results from conventional systems only.

Mixtures of crops have several potential advantages over strict monocultures; the increase in variability helps control disease and insect outbreaks, as well as suppress weeds. With wheat being the most widely grown crop in Canada, it is important to develop agronomic strategies to help producers maximize yield potential while simultaneously reducing their dependence on external inputs, such as herbicide.

Development of successful species or cultivar mixtures can be done by producers themselves. However, there are known plant traits that may make certain mixtures more successful than others. Developing guidelines for successful mixture development formed the basis of this thesis, with the following objectives:

1. To evaluate the performance of wheat cultivar and cereal species mixtures grown under organic and conventional management systems.

2. To evaluate the effect of height and tillering capacity of wheat cultivars on the competitive ability of wheat cultivar mixtures grown under organic and conventional management systems.

3. To determine the effect of component ratio on the competitive ability of wheat cultivar and cereal species mixtures grown under organic and conventional management systems.

4. To establish which, if any, agronomic and/or yield component traits affect the competitive ability and performance of wheat cultivar and cereal species mixtures.

5. To determine whether wheat cultivar and cereal species mixtures exhibit different capabilities when grown under organic and conventional management systems.

The following are summary points from each of the chapters developed from these objectives:

Spring wheat (*Triticum aestivum* L.) cultivar mixtures in organic and conventional management systems in western Canada

- All spring wheat cultivar mixtures yielded more grain under conventional management than under organic management.
- Sole-crop Superb and Superb:Intrepid 1:1 and 2:1 were the highest yielding and most stable entries over all locations.
- Overall, out of all the mixtures tested, a 1:1 mixture of a highly vigorous semidwarf wheat and an early maturing, average height variety had the highest yield and weed suppression under both organic and conventional management systems.
- Currently, there are two other varieties of CWRS wheat that are semidwarfs – CDC Go and AC Abbey. These two varieties provide alternatives for wheat cultivar mixtures that might be more compatible in maturity than Superb.
- Of all traits recorded, early season vigor had the strongest and most consistent correlation with increased yield. Any future research should take this into account.

Wheat (*Triticum aestivum* L.) based spring cereal species mixtures in organic and conventional management systems on the northern Prairies of Canada

- All cereal species mixtures yielded more grain under conventional management than under organic management.
- Under conventional management, wheat:barley mixtures provided the best yield and weed suppression.
- Under an organic regime, both wheat:barley and wheat:oat mixtures combined high yield with weed suppression.
- Triticale – both alone and in mixture – lost yield quickly as competition increased. This crop may not be the best choice for organic production. However, new, more vigorous varieties of spring and winter triticale should be tested.
- Whereas the highly vigorous barley outcompeted wheat when grown in mixture, wheat and oats generally maintained their original planted ratios. This makes it easier for producers to predict what their final yields will be and to plan accordingly.

4.0.1 Recommendations for Future Research

Both of the experiments conducted during this thesis research are highly variety-dependent. Altering the crops or varieties used would likely change the results quite significantly. We drew broad conclusions regarding which varietal characteristics may combine to produce successful mixtures, but more research is required to corroborate and expand on these general conclusions. In particular, this research should be conducted using modern, high yielding varieties of all crops commonly grown on the Canadian prairies – barley, oats, forages, etc. Once basic mixture analysis of several high-yielding, competitive crops and varieties is complete, this knowledge can be put into practice by producers themselves and used to provide long-term disease, insect and weed control under both organic and integrated pest management regimes. As input costs (fuel, fertilizer, chemical, etc.) continue to rise, producers will be required to streamline their operations to maintain economic viability. This research may provide a base upon which further studies can be conducted to broaden our understanding of how crop and variety mixtures may fit into a sustainable agricultural management system.

5.0 Appendices

Appendix 5.1. Analysis of variance results for yield over eight site-years of wheat cultivar mixtures grown at three locations in north-central Alberta.

Location	Year	Mean Site Yield ($t\ ha^{-1}$)[a]	Significance Level[b]		
			Entry	Competition	Entry*Comp
Edmonton Conventional	2003	3.36c	**	**	ns
Edmonton Conventional	2004	4.46b	ns	ns	ns
Edmonton Conventional	2005	5.51a	**	**	ns
	Mean	**4.44**			
Edmonton Organic	2003	3.62c	**	**	ns
Edmonton Organic	2004	3.24c	*	**	ns
Edmonton Organic	2005	3.39c	ns	ns	ns
	Mean	**3.42**			
Certified Organic	2004	1.27d	**	**	ns
Certified Organic	2005	0.89d	ns	ns	ns
	Mean	**1.08**			

[a] values with different letters behind them are significantly different at $P<0.01$

[b] ns = not significant, * = significant at $P<0.05$, ** = significant at $P<0.01$

Appendix 5.2. Two-way G x E table for yield (t ha^{-1}) of sixteen wheat cultivar mixtures across sixteen environments.

Entry	Cert-Org[a] 2005 Comp	Cert-Org 2005 Non-Comp	Cert-Org 2004 Comp	Cert-Org 2004 Non-Comp	Ed-Org 2004 Comp	Ed-Org 2003 Comp	Ed-Conv 2003 Comp	Ed-Org 2005 Non-Comp	Ed-Org 2005 Comp	Ed-Conv 2003 Non-Comp	Ed-Org 2004 Non-Comp	Ed-Org 2003 Non-Comp	Ed-Conv 2004 Comp	Ed-Conv 2004 Non-Comp	Ed-Conv 2005 Comp	Ed-Conv 2005 Non-Comp	**Mean**	Mid-component Average[b]	Reg. Coeff.
Superb	1.45	1.30	1.15	1.83	3.15	3.57	3.63	3.08	3.70	4.00	3.53	4.62	4.75	4.47	5.18	7.53	**3.56**	-	1.06
Intrepid	0.78	0.85	1.08	1.30	2.78	3.70	3.48	3.35	3.58	3.93	3.45	4.35	4.05	4.62	4.45	6.18	**3.24**	-	1.00
5600HR	0.73	0.82	0.75	0.90	2.05	2.95	3.03	3.10	3.48	3.35	3.08	4.00	4.15	4.57	4.23	5.20	**2.90**	-	0.94
5I11	0.67	0.62	0.95	1.38	2.63	2.97	3.23	3.30	3.08	3.29	3.75	3.90	4.40	4.75	4.18	5.85	**3.06**	3.07	0.99
5I12	0.80	0.80	0.97	1.10	2.63	3.10	3.30	3.65	3.33	3.45	3.78	3.50	4.83	5.02	4.28	5.88	**3.15**	3.13	1.00
5I21	0.65	0.85	0.92	1.08	2.45	3.22	3.30	3.38	2.98	3.18	3.03	3.97	3.98	3.70	4.15	5.70	**2.91**	3.01	0.91
5S11	0.92	0.75	1.10	1.58	2.75	3.22	3.20	3.85	3.75	3.50	3.28	3.77	4.78	4.76	4.73	6.60	**3.28**	3.23	1.04
5S12	1.10	1.00	1.43	1.58	3.20	3.42	3.05	3.53	3.78	3.48	3.63	4.50	4.03	4.40	5.10	6.50	**3.36**	3.34	0.98
5S21	0.87	0.97	0.87	1.15	2.55	3.37	3.23	3.35	3.33	3.80	3.40	4.10	4.33	4.55	4.45	5.90	**3.14**	3.12	0.98
SI11	1.10	1.03	1.33	1.80	3.75	3.70	3.35	3.28	3.63	3.78	4.08	4.47	4.23	4.40	5.15	6.78	**3.49**	3.4	1.00
SI12	0.80	0.87	1.40	1.85	3.03	3.35	3.33	3.48	3.10	3.88	3.88	4.35	4.88	4.67	4.95	6.43	**3.39**	3.35	1.02
SI21	0.98	1.10	1.15	1.50	3.13	3.35	3.38	3.55	4.15	3.70	3.93	4.55	4.15	4.33	5.08	7.05	**3.44**	3.45	1.06
5SI111	0.70	0.82	1.23	1.20	2.85	2.67	2.80	3.10	3.10	3.25	3.75	3.85	4.13	4.40	4.38	6.58	**3.05**	3.23	1.01
5SI112	0.67	0.87	1.20	1.73	2.95	2.67	2.63	3.00	3.70	3.28	3.88	3.17	4.53	4.82	4.70	6.33	**3.13**	3.24	0.99
5SI121	0.92	0.97	1.18	1.40	2.95	2.60	2.93	2.98	3.53	3.45	3.75	3.97	4.35	4.70	5.05	6.65	**3.21**	3.32	1.04
5SI211	0.90	0.92	1.07	1.55	2.85	2.95	2.98	3.43	3.05	3.30	3.70	3.84	4.43	4.50	4.60	6.50	**3.16**	3.15	1.00
Mean	**0.88**	**0.91**	**1.11**	**1.43**	**2.85**	**3.18**	**3.18**	**3.34**	**3.45**	**3.54**	**3.62**	**4.06**	**4.37**	**4.54**	**4.66**	**6.35**			

[a] Cert-Org = Certified Organic; Ed-Org = Edmonton Organic; Ed-Conv = Edmonton Conventional

[b] The mid-component average is the average of the yield of a given mixture's components weighted to fit the mixture ratio (e.g. 5I12 = (2.9+3.24+3.24)/3)

Appendix 5.3. Two-way tables of yield components: a) kernel weight (mg), b) kernels spike^{-1}, and c) spikes m^{-2} of wheat cultivar mixtures grown in north-central Alberta.

a)

Entry	Cert-Org 2005 Comp	Cert-Org 2005 Non-Comp	Cert-Org 2004 Comp	Cert-Org 2004 Non-Comp	Ed-Org 2004 Comp	Ed-Org 2003 Comp	Ed-Conv 2003 Comp	Ed-Org 2005 Non-Comp	Ed-Org 2005 Comp	Ed-Conv 2003 Non-Comp	Ed-Org 2004 Non-Comp	Ed-Org 2003 Non-Comp	Ed-Conv 2004 Comp	Ed-Conv 2004 Non-Comp	Ed-Conv 2005 Comp	Ed-Conv 2005 Non-Comp	**Mean**
Superb	36.4	37.8	36.2	36.5	35.8	38.6	40.1	39.9	47.5	48.8	34.6	35.1	38.6	41.0	44.5	46.0	**39.8**
Intrepid	36.4	36.3	37.9	35.6	38.8	39.3	40.4	40.7	46.2	45.7	35.9	38.4	39.8	40.8	43.4	45.8	**40.1**
5600HR	35.0	34.2	34.3	32.4	34.4	34.0	35.8	33.9	42.0	41.2	33.4	33.3	36.8	37.2	38.3	38.6	**35.9**
5I11	37.1	37.1	35.4	33.7	35.8	35.5	36.4	37.8	42.9	42.7	32.8	34.3	39.7	38.5	40.9	40.9	**37.6**
5I12	35.9	36.3	39.8	35.6	36.4	33.9	38.5	39.0	42.0	43.6	33.8	34.4	38.9	40.7	40.3	41.1	**38.1**
5I21	37.3	33.2	36.4	35.3	33.5	36.3	35.8	35.8	40.9	41.4	32.9	33.1	36.2	36.7	40.3	40.2	**36.6**
5S11	34.6	36.6	37.9	34.6	34.8	35.3	37.7	35.8	43.0	43.2	33.4	34.1	37.6	39.0	38.4	39.4	**37.2**
5S12	37.7	36.9	37.0	38.0	35.4	33.8	40.2	36.0	44.2	43.5	32.0	35.3	37.0	40.1	38.0	39.3	**37.8**
5S21	35.4	36.7	38.1	37.9	34.9	34.4	37.1	36.5	43.0	41.0	31.8	33.3	36.3	38.9	38.3	38.5	**37.0**
SI11	39.6	38.7	38.0	39.1	36.6	36.3	40.2	37.4	46.2	47.7	35.1	36.0	37.5	40.0	44.7	45.0	**39.9**
SI12	36.6	37.5	36.0	33.4	35.5	38.0	40.0	39.7	44.7	46.0	35.0	36.1	39.8	41.0	45.2	44.9	**39.3**
SI21	39.3	35.3	37.2	35.5	39.9	38.1	39.4	37.3	46.7	46.3	33.9	38.4	39.9	38.1	44.1	45.0	**39.6**
5SI111	36.6	36.3	37.2	37.2	33.6	33.9	41.1	35.6	44.5	45.2	34.5	34.6	37.8	39.0	42.2	43.6	**38.3**
5SI112	36.3	35.9	36.5	38.1	35.9	35.3	38.2	37.9	45.8	45.5	33.6	34.9	39.2	39.6	43.9	44.1	**38.8**
5SI121	37.8	34.6	37.1	35.1	36.1	37.8	38.1	38.2	45.5	46.8	32.5	33.5	36.3	40.4	41.2	41.9	**38.3**
5SI211	34.8	34.4	36.8	36.9	36.4	33.4	39.1	37.4	44.3	45.2	34.0	36.9	38.1	39.6	40.7	41.6	**38.1**
Mean	**36.7**	**36.1**	**37.0**	**35.9**	**35.8**	**35.8**	**38.6**	**37.4**	**44.3**	**44.6**	**33.7**	**35.1**	**38.1**	**39.4**	**41.5**	**42.2**	

b)

Entry	Cert-Org 2004 Comp	Cert-Org 2004 Non-Comp	Cert-Org 2005 Comp	Cert-Org 2005 Non-Comp	Ed-Org 2004 Comp	Ed-Org 2004 Non-Comp	Ed-Org 2005 Comp	Ed-Org 2005 Non-Comp	Ed-Conv 2004 Comp	Ed-Conv 2004 Non-Comp	Ed-Conv 2005 Comp	Ed-Conv 2005 Non-Comp	**Mean**
Superb	16	20	27	26	23	27	26	26	28	22	33	37	**26**
Intrepid	15	17	25	24	23	27	33	33	30	30	32	35	**27**
5600HR	18	18	23	23	24	28	30	31	29	29	30	33	**26**
5I11	18	19	23	24	24	27	31	30	30	30	34	36	**27**
5I12	17	19	24	24	26	26	33	32	31	31	34	34	**27**
5I21	17	18	21	24	28	27	31	33	29	30	32	36	**27**
5S11	18	19	24	26	23	24	28	30	27	25	35	38	**26**
5S12	19	21	25	26	25	24	30	30	28	25	33	37	**27**
5S21	17	19	23	26	25	26	31	31	29	26	34	37	**27**
SI11	18	20	23	24	24	24	30	31	26	29	32	35	**26**
SI12	18	22	26	24	26	25	27	31	30	26	32	36	**27**
SI21	18	21	24	25	26	24	31	32	27	27	33	35	**27**
5SI111	17	18	24	25	26	27	31	31	27	28	34	35	**27**
5SI112	17	18	22	25	24	25	33	31	29	26	32	36	**26**
5SI121	17	19	25	26	25	24	29	30	27	25	31	33	**26**
5SI211	15	20	25	24	27	28	28	32	29	27	33	36	**27**
Mean	**17**	**19**	**24**	**25**	**25**	**26**	**30**	**31**	**28**	**27**	**33**	**35**	

c)

Entry	Cert-Org 2004 Comp	Cert-Org 2004 Non-Comp	Cert-Org 2005 Comp	Cert-Org 2005 Non-Comp	Ed-Org 2003 Comp	Ed-Org 2003 Non-Comp	Ed-Org 2005 Comp	Ed-Org 2005 Non-Comp	Ed-Conv 2003 Comp	Ed-Conv 2003 Non-Comp	Ed-Conv 2004 Comp	Ed-Conv 2004 Non-Comp	Ed-Conv 2005 Comp	Ed-Conv 2005 Non-Comp	**Mean**
Superb	401	488	255	228	379	454	333	312	460	378	805	878	515	525	**458**
Intrepid	444	506	187	160	465	437	380	335	346	390	723	726	447	633	**441**
5600HR	258	361	252	261	491	503	363	489	347	448	627	739	579	573	**449**
5I11	398	417	133	153	428	534	415	408	339	489	741	731	574	595	**454**
5I12	464	409	204	200	367	460	389	408	394	381	632	784	576	624	**449**
5I21	345	420	161	219	375	532	423	434	386	384	686	703	500	649	**444**
5S11	473	407	177	203	423	484	477	396	351	393	807	917	507	580	**471**
5S12	309	384	190	194	512	519	400	394	316	360	890	803	595	589	**461**
5S21	363	259	117	167	354	462	385	484	325	425	752	801	593	577	**433**
SI11	386	498	225	212	461	485	368	333	376	354	759	750	586	578	**455**
SI12	526	528	221	214	425	458	269	327	444	406	815	738	518	612	**464**
SI21	330	431	203	215	411	492	464	307	357	396	762	792	510	543	**444**
5SI111	431	445	222	164	388	474	389	382	375	405	766	798	537	611	**456**
5SI112	352	500	88	131	264	370	401	322	324	312	718	798	551	661	**414**
5SI121	431	460	192	230	406	468	338	360	366	379	842	786	519	642	**459**
5SI211	278	483	148	147	399	421	342	335	320	426	844	828	515	600	**435**
Mean	**387**	**437**	**186**	**194**	**409**	**472**	**383**	**376**	**364**	**395**	**760**	**786**	**539**	**599**	

Appendix 5.4. Phenotypic correlations of all variables for sixteen wheat cultivar mixtures at Edmonton Conventional (top) and Edmonton Organic (bottom) significant at P<0.05.

	Yield	Height	Total Weeds	Juncea	LAI	Light Int.	ESV	Emerg.	Leaf Spot Disease	Stripe Rust	Powdery Mildew	Lodging	Heading	Maturity
Yield		-0.302	-0.215	-0.102		-0.377	0.273	-0.369	-0.178		0.20	-0.503	0.222	
Height					-0.16		-0.209	0.204				0.200		
Total Weeds	-0.466			0.919	0.324			-0.146				-0.169		
Juncea	-0.272		0.458		0.313			-0.124				-0.144		
LAI[a]			0.166	-0.127		-0.172	0.394	-0.217			0.382	-0.459	0.275	0.511
Light Int.	-0.142	0.189	0.161		0.493		-0.162	0.391			-0.398	0.508	-0.124	
ESV	0.251			-0.189	0.468	0.256					0.192	-0.343		0.172
Emerg.			-0.194		-0.294		0.147		0.129		-0.415	0.618	-0.352	
Leaf Spot Disease						0.162	0.161	0.239						-0.137
Stripe Rust		0.290			-0.196		-0.249	-0.216						0.207
Powdery Mildew								-0.189				-0.611	0.493	0.236
Lodging				0.290	-0.862	-0.352	-0.454	0.371					-0.501	
Heading	-0.126	0.132		0.138	-0.733	-0.328	-0.664	0.198		0.298		0.698		0.425
Maturity	0.146	0.178	-0.221		-0.343		-0.518			0.373		0.312	0.591	

[a] LAI = leaf area index; light int. = light interception; ESV = early season vigor; emerg. = emergence

Appendix 5.5. Phenotypic correlations of all agronomic traits for sixteen wheat cultivar mixtures grown at Certified Organic significant at P<0.05.

	Yield	Height	Total Weeds	Juncea	ESV	Emerg.	Lodging
Yield							
Height	0.386						
Total Weeds		0.310					
Juncea	-0.135	0.191	0.527				
ESV	0.317			-0.188			
Emerg.	0.248		-0.198	-0.195	0.508		
Lodging					0.229	0.201	

Appendix 5.6. Phenotypic correlations (P<0.05) for yield components with all agronomic traits for sixteen wheat cultivar mixtures at three locations in north-central Alberta.

	Edmonton Conventional			Edmonton Organic			Certified Organic		
	Kernel Wt	Kernels $spike^{-1}$	Spikes m^{-2}	Kernel Wt	Kernels $spike^{-1}$	Spikes m^{-2}	Kernel Wt	Kernels $spike^{-1}$	Spikes m^{-2}
Yield	0.715	0.569	0.388		0.183	0.548	0.330		0.496
Kernel Weight		0.375	0.392		0.503	-0.278		0.188	
Kernels $spike^{-1}$	0.375		-0.567	0.503			0.188		-0.534
Spikes m^{-2}	0.392	-0.567		-0.278				-0.534	
Height	-0.248	-0.188			0.165	0.309	0.146	-0.600	0.543
Total Weeds			-0.279	0.265		-0.498		-0.368	0.189
Juncea Weight	0.110		-0.121		-0.250			-0.239	
LAI	0.210	0.269	-0.403	0.720	0.588	-0.291			
Light Int.	-0.358	-0.413	0.261	0.333	0.245	-0.228			
ESV	0.289	0.183	-0.133	0.463	0.349				0.208
Emerg.	-0.333	-0.576	0.542	-0.206	-0.331				0.285
LS Disease	-0.218								
Stripe Rust				-0.381		0.242			
Powdery Mildew		0.491	-0.417	-0.161	0.140				
Lodging	-0.473	-0.713	0.707	-0.758	-0.665				
Heading		0.390	-0.357	-0.657	-0.534	0.243			
Maturity				-0.276	-0.315	0.286			

Appendix 5.7a. Genotypic correlations ($P<0.05$) for sixteen wheat cultivar mixtures grown at Edmonton Conventional (top) and Edmonton Organic (bottom) from 2003 to 2005.

	Emg	ESV	Harv Ind.	Head	Ht	Junc Ct	Junc Wt	Kern spk^{-1}	LAI	LS Dis	LI	Lodg	Mat	PM	Spk m^{-2}	Str Rust	Test Wt	TKW	Tot Wds	Yield
Emerg[a]		0.55			-0.47				0.56		0.45		0.40							
ESV	0.65			-0.34	-0.66			-0.49	0.48					-0.68						0.38
Hrv Ind	0.38																			
Heading	-0.39	-0.58					-0.40						0.58	0.76			0.52	-0.62	-0.38	
Height	-0.55	-0.56		0.70				0.40	-0.70			-0.42	-0.50	0.46						-0.42
Junc Ct			-0.53	-0.38			0.87	-0.42	0.39		0.61		-0.38		-0.66		-0.69		0.82	-0.81
Junc Wt			-0.47			0.89		-0.40		0.36	0.43		-0.40		-0.47		-0.69		0.96	-0.68
Kn/spk	-0.52				0.55				-0.58		-0.41								-0.43	
LAI			-0.47	-0.53	-0.37	0.79	0.72	-0.41			0.75	0.47	0.51							
LS Dis											0.22								0.37	
LI			-0.46	-0.42		0.69	0.64	-0.37	0.81			0.36	0.33					-0.42		-0.38
Lodging			-0.45			0.49	0.57		0.38		0.52									
Maturity				0.35											0.44		0.62		-0.41	0.35
PM	-0.59	-0.55	-0.35	0.64	0.56													-0.71		
Spk m^{-2}				0.43	0.49									0.59			0.44		-0.47	0.69
Str Rst	-0.41	-0.52		0.60	0.47								0.38	0.56	0.35					
Test Wt								-0.37					0.36		0.41				-0.67	0.64
TKW	0.60	0.60	0.39	-0.70	-0.64									-0.82	-0.45	-0.72				0.60
Tot Wds			-0.35			0.67	0.75		0.56		0.56	0.56								-0.68
Yield	0.38	0.52	0.61			-0.76	-0.75		-0.54		-0.57	-0.47					0.45		-0.63	

[a] Emerg = emergence; ESV = early season vigor; Hrv Ind = harvest index; Junc Ct = Juncea count (plants m^{-2}); Junc Wt = Juncea biomass; Kn/spk = kernels per spike; LAI = leaf area index; LS Dis = leaf spot disease rating; LI = light interception; PM = powdery mildew rating; Spk m^{-2} = spikes m^{-2}; Str Rst = stripe rust rating; Test Wt = test weight; TKW = thousand kernel weight; Tot Wds = total weed biomass.

Appendix 5.7b. Genotypic correlations (P<0.05) of sixteen cultivar mixtures grown at Certified Organic in 2004 and 2005.

	Emerg	ESV	Height	Juncea Count	Juncea g m^{-2}	Kernels $spike^{-1}$	Lodg	Spikes m^{-2}	Test Weight	Kernel Weight	Total Weeds	Weeds g m^{-2}	Yield
Emerg													
ESV	0.53												
Height		-0.65											
Juncea Count			0.46										
Juncea g m^{-2}		-0.39	0.37	0.84									
Kernels $spike^{-1}$	0.37	0.57	-0.72	-0.69	-0.54								
Lodg.	0.40	0.46	-0.43			0.43							
Spikes m^{-2}			-0.35	-0.35		0.45							
Test Weight		0.68	-0.67			0.62	0.50						
Kernel Weight									0.46				
Total Weeds	-0.37	-0.56	0.48	0.52	0.69	-0.56	-0.42		-0.47				
Weeds g m^{-2}				-0.51	-0.51				-0.41	-0.42			
Yield		0.72	-0.58	-0.46	-0.41	0.77	0.44	0.49	0.74		-0.61		

Appendix 5.8. Least-square means of agronomic traits measured on 16 spring wheat cultivar mixtures with (1) and without (0) simulated competition at Edmonton Conventional (2003).

Entry	Comp	Yield t ha^{-1}	Rank	TKW (g)	Test Wt kg hL^{-1}	Spk m^{-2}	Harv Index	Weeds g m^{-2}	Juncea g m^{-2}	Tot Wds g m^{-2}	Protein (%)
Superb	0	4.00	1	35	81.2	378	0.39	7.0	-	-	14.7
Intrepid	0	3.93	2	38	79.9	390	0.43	61.2	-	-	15.1
5600HR	0	3.35	10	33	80.0	448	0.40	46.6	-	-	15.1
5I11	0	3.29	12	34	79.4	489	0.42	3.1	-	-	14.8
5I12	0	3.45	9	34	79.6	381	0.40	39.4	-	-	15.1
5I21	0	3.18	15	33	79.9	384	0.40	30.4	-	-	15.4
5S11	0	3.50	7	34	79.9	393	0.41	7.7	-	-	15.0
5S12	0	3.48	8	35	80.4	360	0.42	78.9	-	-	14.9
5S21	0	3.80	4	33	80.8	425	0.40	53.4	-	-	15.0
SI11	0	3.78	5	36	80.3	354	0.42	18.0	-	-	15.6
SI12	0	3.88	3	36	79.9	406	0.43	5.1	-	-	14.8
SI21	0	3.70	6	38	80.8	396	0.43	40.4	-	-	14.9
5SI111	0	3.25	14	35	80.4	405	0.41	23.0	-	-	15.1
5SI112	0	3.28	13	35	79.7	312	0.40	61.7	-	-	15.1
5SI121	0	3.45	9	34	80.3	379	0.42	32.3	-	-	14.7
5SI211	0	3.30	11	37	80.3	426	0.42	21.3	-	-	15.1
Mean		**3.54**	-	**35**	**80.1**	**395**	**0.41**	**33.1**	-	-	**15.0**
Superb	1	3.63	1	35	80.4	460	0.42	16.5	13.1	29.6	14.7
Intrepid	1	3.48	2	36	79.3	346	0.41	35.9	4.1	40.0	15.1
5600HR	1	3.03	10	33	79.8	347	0.37	59.0	23.9	83.0	15.0
5I11	1	3.23	7	33	79.3	339	0.59	12.5	13.9	26.4	15.4
5I12	1	3.30	6	34	79.3	394	0.40	24.1	16.0	40.1	15.4
5I21	1	3.30	6	33	79.6	386	0.40	19.4	17.6	37.0	15.2
5S11	1	3.20	8	33	79.9	351	0.40	11.1	20.1	31.2	15.2
5S12	1	3.05	9	32	79.8	316	0.39	81.7	50.2	132.0	15.0
5S21	1	3.23	7	32	80.0	325	0.40	21.4	22.0	43.4	15.3
SI11	1	3.35	4	35	79.6	376	0.41	46.2	6.4	52.6	15.2
SI12	1	3.33	5	35	79.1	444	0.41	16.1	10.7	26.8	15.1
SI21	1	3.38	3	34	79.3	357	0.40	24.0	16.2	40.2	15.0
5SI111	1	2.80	13	35	79.3	375	0.40	70.6	10.8	81.3	15.5
5SI112	1	2.63	14	34	79.4	324	0.41	55.9	111.5	167.4	15.2
5SI121	1	2.93	12	33	79.8	366	0.41	43.3	27.8	71.1	15.4
5SI211	1	2.98	11	34	80.1	320	0.40	7.9	87.7	95.6	15.3
Mean		**3.18**	-	**34**	**79.6**	**364**	**0.41**	**34.1**	**28.3**	**62.3**	**15.2**
F-value[a]	Comp	**		ns	*	*	ns	ns	-	*	**
	Entry	**		**	*	ns	ns	*	*	*	ns
	C*E	ns		ns	ns	ns	ns	ns	-	ns	ns
	SE (entry)[b]	0.20		1.15	0.35	40.8	0.03	20.1	15.21	27.02	0.18
	SE (comp)[c]	0.042		0.60	0.14	14.4	0.01	9.6	-	8.02	0.047

[a] ns = not significant; * = significant at P<0.05, ** = significant at P<0.01

[b] Standard error of the difference between two means.

[c] Standard error of the difference between competition and non-competition treatments.

Appendix 5.9. Least-square means of agronomic traits measured on 16 spring wheat cultivar mixtures with (1) and without (0) simulated competition at Edmonton Conventional (2004).

Entry	Comp	Yield t ha^{-1}	Rank	TKW (g)	Ker spk^{-1}	Test Wt kg hL^{-1}	Spk m^{-2}	ESV	Emerg	Head	Mat	Weeds g m^{-2}	Juncea g m^{-2}	TotWds g m^{-2}	Juncea plt m^{-2}	Height (cm)	LS Dis	PM (%)	LI (%)	LAI	Prot (%)	Lodg
Superb	0	4.48	11	41	22	76.5	878	5	278	56	110	0	-	-	-	94	2.3	0.0	97.7	5.62	14.4	9
Intrepid	0	4.63	7	41	30	77.8	726	4	183	58	101	0	-	-	-	106	2.3	1.3	96.0	3.68	14.7	6
5600HR	0	4.58	8	37	29	79.1	739	3	191	63	109	0	-	-	-	109	1.8	6.3	96.7	3.52	14.5	7
5I11	0	4.75	4	39	30	78.6	731	3	198	59	105	0	-	-	-	111	2.0	2.5	96.9	3.76	14.8	7
5I12	0	5.03	1	41	31	78.1	784	4	201	57	102	0	-	-	-	106	2.3	2.5	96.0	3.79	14.5	7
5I21	0	3.70	14	37	30	76.1	703	3	232	58	103	0	-	-	-	103	2.8	5.0	96.5	3.40	14.5	8
5S11	0	4.76	3	39	25	77.7	917	4	276	60	108	0	-	-	-	103	2.7	2.1	97.2	3.88	14.1	7
5S12	0	4.40	12	40	25	77.7	803	4	271	60	112	0	-	-	-	105	2.8	0.0	97.3	4.39	14.0	8
5S21	0	4.55	9	39	26	77.8	801	4	224	63	112	0	-	-	-	105	2.3	1.3	97.0	4.27	14.4	7
SI11	0	4.40	12	40	29	77.9	750	5	233	58	105	0	-	-	-	104	3.0	0.0	97.3	4.26	14.3	7
SI12	0	4.68	6	41	26	77.7	738	4	266	57	103	0	-	-	-	106	2.5	0.0	96.3	3.92	14.3	7
SI21	0	4.33	13	38	27	77.3	792	4	269	58	106	0	-	-	-	100	3.3	0.0	97.2	4.36	14.2	9
5SI111	0	4.40	12	39	28	77.5	798	4	246	58	109	0	-	-	-	105	2.5	1.3	97.2	4.44	14.2	9
5SI112	0	4.83	2	40	26	77.5	798	5	237	58	108	0	-	-	-	106	2.5	0.0	97.5	4.62	14.6	8
5SI121	0	4.70	5	40	25	77.8	786	5	275	58	108	34.0	-	-	-	103	3.0	0.0	97.3	4.42	14.3	7
5SI211	0	4.50	10	40	27	77.9	828	5	204	59	107	0	-	-	-	105	2.0	1.3	97.3	4.17	14.2	8
Mean		**4.54**	-	**39**	**27**	**77.7**	**786**	**4**	**236**	**59**	**107**	**2.1**	-	-	-	**104**	**2.5**	**1.5**	**97.0**	**4.16**	**14.4**	**7**

Appendix 5.9. Continued...

Entry	Comp	Yield t ha^{-1}	Rank	TKW (g)	Ker spk^{-1}	Test Wt kg hL^{-1}	Spk m^{-2}	ESV	Emerg	Head	Mat	Weeds g m^{-2}	Juncea g m^{-2}	TotWds g m^{-2}	Juncea plt m^{-2}	Height (cm)	LS Dis	PM (%)	LI (%)	LAI	Prot (%)	Lodg
Superb	1	4.75	4	39	28	75.1	805	5	270	56	108	0	0	0	13	99	3.3	0.0	97.7	4.80	13.8	9
Intrepid	1	4.05	13	40	30	77.2	723	4	238	57	100	0	0	0	20	107	2.3	0.0	95.8	3.83	14.6	6
5600HR	1	4.15	11	37	29	79.0	627	3	205	62	108	0	0	0	27	106	2.0	10.0	96.9	3.66	14.3	8
5I11	1	4.40	7	40	30	78.3	741	3	237	58	102	0	0	0	12	109	2.3	3.1	96.3	3.74	14.6	8
5I12	1	4.83	2	39	31	78.1	632	3	247	56	100	0	7.6	7.6	12	109	2.3	0.0	96.5	3.89	14.3	7
5I21	1	3.98	15	36	29	77.7	686	3	231	58	101	0	94.8	94.8	28	105	2.8	1.3	96.9	3.91	14.2	7
5S11	1	4.78	3	38	27	78.1	807	4	254	59	108	0	68.8	68.8	33	103	2.8	0.0	98.1	4.71	14.2	7
5S12	1	4.03	14	37	28	78.3	890	5	273	58	107	0	0	0	13	104	2.8	0.0	97.6	4.41	14.0	9
5S21	1	4.33	9	36	29	78.3	752	4	195	61	107	0	0	0	15	104	2.8	1.3	97.8	3.92	14.2	9
SI11	1	4.23	10	37	26	77.2	759	5	221	58	104	0	0	0	15	106	3.3	0.0	97.5	4.46	13.6	6
SI12	1	4.88	1	40	30	77.3	815	5	240	56	102	0	93.6	93.6	36	105	3.0	0.0	97.9	4.28	14.1	9
SI21	1	4.15	11	40	27	77.5	762	5	271	58	106	0	0	0	22	104	3.3	0.0	96.8	4.44	14.0	8
5SI111	1	4.13	12	38	27	76.5	766	4	237	57	105	0	42.0	42.0	21	105	2.5	1.3	96.5	4.10	14.3	9
5SI112	1	4.53	5	39	29	77.5	718	5	226	58	104	0	9.2	9.2	11	106	3.0	1.3	96.6	3.91	14.5	8
5SI121	1	4.35	8	36	27	76.7	842	4	227	58	107	0	0	0	17	105	2.8	1.3	97.2	4.23	14.3	8
5SI211	1	4.43	6	38	29	77.9	844	4	207	59	107	0	0	0	14	106	2.8	3.8	96.2	3.97	14.1	9
Mean		**4.37**	-	**38**	**28**	**77.5**	**760**	**4**	**236**	**58**	**105**	**0**	**19.8**	**19.8**	**19**	**105**	**2.7**	**1.4**	**97.0**	**4.14**	**14.2**	**8**
F-value[a]	Comp	ns		ns	*	ns	ns	ns	ns	*	*	ns	-	ns	-	ns	ns	ns	ns	ns	ns	ns
	Entry	ns		ns	**	*	**	**	**	**	**	ns	ns	ns	ns	**	*	**	ns	**	**	ns
	C*E	ns		ns	**	ns	ns	*	ns	**	ns	ns	-	*	-	ns	ns	ns	ns	**	ns	ns
	SE (entry)[b]	0.31		1.34	1.08	0.68	47.6	0.3	22.2	0.96	1.60	6.0	18.6	19.6	4.6	2.0	0.36	1.37	0.61	0.19	0.15	0.91
	SE (comp)[c]	0.15		0.46	0.30	0.37	34.6	0.08	7.4	0.17	0.41	2.2	-	9.9	-	1.4	0.09	0.06	0.38	0.10	0.14	0.48

[a] ns = not significant; * = significant at P<0.05, ** = significant at P<0.01
[b] Standard error of the difference between two means.
[c] Standard error of the difference between competition and non-competition treatments.

Appendix 5.10. Least-square means of agronomic traits measured on 16 spring wheat cultivar mixtures with (1) and without (0) simulated competition at Edmonton Conventional (2005).

Entry	Comp	Yield t ha^{-1}	Rank	TKW (g)	Ker spk^{-1}	Test Wt kg hL^{-1}	Spk m^{-2}	ESV	Emerg	Head	Mat	Weeds g m^{-2}	Juncea g m^{-2}	TotWds g m^{-2}	Juncea plt m^{-2}	Height (cm)	LS Dis	Str Rst (%)	PM (%)	LI (%)	LAI	Protein (%)	Lodg
Superb	0	7.53	1	46	37	82.3	525	5	174	60	112	0	-	-	-	90	1.5	6.3	2.0	91.3	5.50	13.0	1
Intrepid	0	6.18	9	46	35	81.1	633	5	190	59	101	28.6	-	-	-	105	3.0	0.0	4.0	76.6	3.87	14.6	1
5600HR	0	5.20	14	39	33	80.9	573	5	175	62	109	0	-	-	-	103	3.0	0.0	50.0	83.1	5.03	13.4	0
5I11	0	5.85	12	41	36	81.3	595	5	160	62	106	2.1	-	-	-	107	2.5	0.0	32.5	85.1	4.62	13.8	0
5I12	0	5.88	11	41	34	81.3	624	4	165	62	105	0	-	-	-	102	2.3	0.0	27.5	83.8	4.30	14.0	0
5I21	0	5.70	13	40	36	81.3	649	5	169	63	109	5.9	-	-	-	104	2.5	1.3	40.0	80.9	4.78	13.7	0
5S11	0	6.60	4	39	38	82.1	580	5	166	60	110	5.9	-	-	-	100	2.5	0.0	32.5	93.4	5.08	13.1	1
5S12	0	6.50	6	39	37	82.1	589	5	193	62	110	0.5	-	-	-	101	2.0	3.8	22.5	88.7	5.22	13.4	0
5S21	0	5.90	10	39	37	81.6	577	5	196	63	108	0	-	-	-	102	2.5	0.0	25.0	85.7	5.11	13.6	0
SI11	0	6.78	3	45	35	82.0	578	5	158	60	108	2.3	-	-	-	99	2.8	2.5	4.3	85.1	4.77	13.8	1
SI12	0	6.43	7	45	36	81.7	612	5	161	60	105	0	-	-	-	104	2.5	0.0	6.3	80.3	4.30	14.2	0
SI21	0	7.05	2	45	35	82.3	543	5	171	60	109	2.7	-	-	-	101	2.0	1.3	4.3	86.3	4.86	13.5	0
5SI111	0	6.58	5	44	35	81.8	611	5	151	61	108	1.1	-	-	-	100	2.5	2.5	20.0	88.2	4.91	13.8	0
5SI112	0	6.33	8	44	36	81.6	661	4	163	61	105	13.8	-	-	-	100	2.8	0.0	18.8	83.1	4.07	13.9	1
5SI121	0	6.65	3	42	33	82.0	642	5	176	61	107	0	-	-	-	99	3.0	0.0	19.0	86.7	4.70	13.5	0
5SI211	0	6.50	6	42	36	81.5	600	4	121	60	107	0	-	-	-	101	2.3	0.0	27.5	78.2	4.52	13.6	1
Mean		**6.35**	-	**42**	**35**	**81.7**	**599**	**5**	**168**	**61**	**107**	**3.9**	-	-	-	**101**	**2.5**	**1.1**	**21.0**	**84.8**	**4.72**	**13.7**	**0**

Appendix 5.10. Continued...

Entry	Comp	Yield t ha^{-1}	Rank	TKW (g)	Ker spk^{-1}	Test Wt kg hL^{-1}	Spk m^{-2}	ESV	Emerg	Head	Mat	Weeds g m^{-2}	Juncea g m^{-2}	TotWds g m^{-2}	Juncea plt m^{-2}	Height (cm)	LS Dis	Str Rst (%)	PM (%)	LI (%)	LAI	Protein (%)	Lodg
Superb	1	5.18	1	45	33	81.6	515	5	193	60	109	18.7	97.6	116.3	44	93	2.0	1.3	0.7	96.2	5.78	13.3	2
Intrepid	1	4.45	10	43	32	80.3	447	4	141	58	99	13.6	96.7	110.3	51	103	2.3	0.0	5.0	86.9	5.06	14.7	1
5600HR	1	4.23	13	38	30	80.8	579	5	196	61	109	0.0	50.3	50.3	38	106	2.8	0.0	42.5	95.1	5.56	13.7	0
5I11	1	4.18	14	41	34	80.4	574	4	169	62	108	7.7	22.8	30.4	42	104	2.8	0.0	30.0	91.8	5.46	14.0	0
5I12	1	4.28	12	40	34	80.3	576	4	166	61	106	12.2	114.5	126.6	41	106	2.8	1.3	25.0	91.5	5.18	14.2	1
5I21	1	4.15	15	40	32	80.5	500	5	158	61	109	2.1	29.4	31.5	36	102	3.0	10.0	32.5	94.6	5.33	13.9	0
5S11	1	4.73	7	38	35	81.2	507	5	155	60	109	5.4	65.8	71.1	42	99	2.5	0.0	25.0	95.7	5.60	13.4	0
5S12	1	5.10	3	38	33	81.5	595	5	216	61	107	1.9	13.3	15.2	33	102	2.3	0.0	16.3	89.1	5.55	13.5	1
5S21	1	4.45	10	38	34	80.7	593	5	195	62	107	1.5	67.2	68.7	33	103	2.8	5.0	25.0	92.5	5.33	13.8	2
SI11	1	5.15	2	45	32	81.4	586	5	149	59	105	9.1	231.3	240.4	41	100	2.3	1.3	3.0	84.6	5.01	13.7	1
SI12	1	4.95	6	45	32	80.5	518	4	174	60	103	7.5	145.9	153.4	47	102	2.3	0.0	5.0	90.4	4.91	14.2	1
SI21	1	5.08	4	44	33	81.5	510	5	183	60	105	9.4	88.6	98.0	35	99	2.8	1.3	5.0	92.8	5.30	13.6	1
5SI111	1	4.38	11	42	34	80.6	537	4	143	59	103	16.3	195.3	211.6	42	102	2.8	0.0	18.8	88.0	5.33	13.8	2
5SI112	1	4.70	8	44	32	81.2	551	4	171	59	103	12.3	23.3	35.5	40	104	2.3	0.0	17.5	88.3	5.18	14.2	1
5SI121	1	5.05	5	41	31	81.0	519	5	152	59	106	4.4	68.9	73.2	36	102	2.5	2.5	13.8	88.4	5.07	13.6	1
5SI211	1	4.60	9	41	33	80.7	515	4	159	60	104	7.4	72.3	79.7	35	97	3.3	0.0	21.3	92.4	5.22	13.9	1
Mean		**4.66**	-	**42**	**33**	**80.9**	**539**	**5**	**170**	**60**	**106**	**8.1**	**86.4**	**94.5**	**40**	**101**	**2.6**	**1.4**	**17.9**	**91.1**	**5.30**	**13.8**	**1**
F-value[a]	Comp	**		ns	**	*	**	ns	ns	ns	ns	ns	-	*	-	ns	ns	ns	ns	ns	ns	**	ns
	Entry	**		**	*	**	ns	**	**	**	**	ns	ns	ns	ns	**	ns	ns	**	ns	**	**	ns
	C*E	ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	-	ns	-	ns	ns	ns	ns	ns	ns	ns	ns
	SE (entry)[b]	0.18		0.77	1.24	0.18	41.7	0.2	13.5	0.6	1.7	8.4	47.8	47.1	4.2	2.1	0.34	2.3	5.0	3.8	0.22	0.14	0.59
	SE (comp)[c]	0.29		0.38	0.44	0.21	16.8	0.07	4.8	0.5	3.0	5.3	-	19.7	-	2.2	0.12	0.97	1.4	3.7	0.29	0.04	0.26

[a] ns = not significant; * = significant at $P<0.05$, ** = significant at $P<0.01$

[b] Standard error of the difference between two means.

[c] Standard error of the difference between competition and non-competition treatments.

Appendix 5.11. Least-square means of agronomic traits measured on 16 spring wheat cultivar mixtures with (1) and without (0) simulated competition at Edmonton Organic (2003).

Entry	Comp	Yield t ha^{-1}	Rank	TKW (g)	Test Wt kg hL^{-1}	Spk m^{-2}	Harv Index	Weeds g m^{-2}	Juncea g m^{-2}	Juncea plt m^{-2}	Protein (%)
Superb	0	4.63	1	39	79.5	454	0.43	13.8	-	-	14.0
Intrepid	0	4.35	5	39	78.9	437	0.40	2.3	-	-	15.2
5600HR	0	4.00	7	34	80.1	503	0.38	11.2	-	-	14.7
5I11	0	3.90	9	36	79.2	534	0.39	7.4	-	-	14.8
5I12	0	3.50	13	34	79.4	460	0.40	4.2	-	-	14.9
5I21	0	3.98	8	36	79.5	532	0.38	6.5	-	-	14.7
5S11	0	3.78	12	35	78.8	484	0.40	5.3	-	-	14.4
5S12	0	4.50	3	34	79.4	519	0.39	19.6	-	-	14.2
5S21	0	4.10	6	34	79.8	462	0.40	7.8	-	-	14.1
SI11	0	4.48	4	36	79.6	485	0.42	3.8	-	-	14.2
SI12	0	4.35	5	38	79.0	458	0.43	6.4	-	-	14.6
SI21	0	4.55	2	38	79.1	492	0.43	6.8	-	-	14.3
5SI111	0	3.85	10	34	78.4	474	0.38	9.3	-	-	14.6
5SI112	0	3.18	14	35	78.4	370	0.41	9.8	-	-	14.7
5SI121	0	3.98	8	38	79.5	468	0.40	1.4	-	-	14.3
5SI211	0	3.84	11	33	78.3	421	0.40	15.6	-	-	14.6
Mean		**4.06**	-	**36**	**79.2**	**472**	**0.40**	**8.2**	-	-	**14.5**
Superb	1	3.58	2	36	78.9	379	0.38	26.8	46.7	73.6	14.4
Intrepid	1	3.70	1	39	78.2	465	0.37	36.4	18.6	55.0	15.4
5600HR	1	2.95	9	34	79.6	491	0.36	65.7	37.0	102.7	14.5
5I11	1	2.98	8	36	78.1	428	0.40	62.7	41.1	103.8	15.2
5I12	1	3.10	7	36	77.7	367	0.37	69.0	25.1	94.2	15.0
5I21	1	3.23	6	34	78.5	375	0.37	90.4	39.4	129.8	14.8
5S11	1	3.23	6	35	78.3	423	0.37	55.1	61.2	116.3	14.9
5S12	1	3.43	3	35	79.0	512	0.32	43.4	19.4	62.7	14.4
5S21	1	3.38	4	35	78.8	354	0.37	101.2	22.2	123.4	14.6
SI11	1	3.70	1	36	78.9	461	0.40	54.6	15.0	69.6	14.5
SI12	1	3.35	5	36	77.6	425	0.38	31.4	31.2	62.6	15.1
SI21	1	3.35	5	40	79.3	411	0.42	16.4	20.8	37.2	14.6
5SI111	1	2.68	10	34	77.8	388	0.38	46.3	64.1	110.4	14.6
5SI112	1	2.68	10	36	77.7	264	0.35	143.1	132.0	275.0	15.0
5SI121	1	2.60	11	36	78.5	406	0.39	74.1	3.6	77.6	14.4
5SI211	1	2.95	9	36	78.1	399	0.38	47.5	61.3	108.8	14.7
Mean		**3.18**	-	**36**	**78.4**	**409**	**0.37**	**60.3**	**39.9**	**100.2**	**14.7**
F-value[a]	Comp	**		ns	ns	*	ns	**	-	-	**
	Entry	**		**	**	ns	ns	ns	*	*	**
	C*E	ns		ns	ns	ns	ns	ns	-	-	ns
	SE (entry)[b]	0.21		1.2	0.5	49	0.02	23.9	15.7	26.1	0.20
	SE (comp)[c]	0.11		0.96	0.6	15	0.01	12.3	-	-	0.067

[a] ns = not significant; * = significant at P<0.05, ** = significant at P<0.01

[b] Standard error of the difference between two means.

[c] Standard error of the difference between competition and non-competition treatments.

Appendix 5.12. Least-square means of agronomic traits measured on 16 spring wheat cultivar mixtures with (1) and without (0) simulated competition at Edmonton Organic (2004).

Entry	Comp	Yield t ha^{-1}	Rank	TKW (g)	Ker spk^{-1}	Test Wt kg hL^{-1}	ESV	Emerg	Heading	Maturity	Weeds g m^{-2}	Juncea g m^{-2}	TotWds g m^{-2}	Juncea plt m^{-2}	Height (cm)	LS Dis	PM (%)	LI (%)	LAI	Prot. (%)	Lodg
Superb	0	3.53	8	40	27	77.8	3	250	62	124	88.8	-	-	-	91	2.3	2.5	93.8	2.36	11.7	8
Intrepid	0	3.45	9	41	27	76.3	3	175	63	117	167.6	-	-	-	98	2.5	0.0	88.7	1.76	12.6	6
5600HR	0	3.08	12	34	28	78.4	2	109	67	122	173.2	-	-	-	106	2.3	20.0	92.1	1.98	12.0	7
5I11	0	3.75	5	38	27	78.1	2	153	64	124	210.0	-	-	-	103	2.5	5.0	92.4	1.86	12.1	7
5I12	0	3.78	4	39	26	78.6	2	225	64	121	165.2	-	-	-	102	2.5	0.0	96.3	1.89	13.2	6
5I21	0	3.03	13	36	27	78.0	1	85	67	126	263.2	-	-	-	101	2.3	12.5	89.6	1.35	11.8	7
5S11	0	3.28	11	36	24	79.3	2	226	66	124	173.6	-	-	-	102	2.5	3.8	93.4	1.85	11.5	7
5S12	0	3.63	7	36	24	78.6	3	164	65	126	136.8	-	-	-	99	2.0	2.5	92.0	1.57	11.5	8
5S21	0	3.40	10	37	26	78.7	2	127	67	125	419.2	-	-	-	107	2.0	7.5	91.0	1.74	11.8	7
SI11	0	4.08	1	37	24	78.6	3	194	64	123	175.2	-	-	-	99	2.3	0.0	85.9	1.64	11.8	7
SI12	0	3.88	3	40	25	78.8	3	230	63	124	37.2	-	-	-	100	2.0	0.0	91.8	2.08	12.7	7
SI21	0	3.93	2	37	24	78.2	3	219	64	126	135.2	-	-	-	98	2.8	0.0	92.1	2.06	12.5	8
5SI111	0	3.75	5	36	27	78.4	3	249	64	124	133.2	-	-	-	102	2.8	8.8	96.2	2.49	12.1	7
5SI112	0	3.88	3	38	25	73.7	3	204	63	123	162.8	-	-	-	98	2.5	1.3	92.4	2.09	12.0	6
5SI121	0	3.75	5	38	24	78.9	2	207	65	124	57.6	-	-	-	106	2.8	2.5	94.0	1.95	12.0	8
5SI211	0	3.70	6	37	28	78.3	2	141	63	126	140.0	-	-	-	101	2.3	2.5	93.8	1.93	12.5	8
Mean		**3.62**	**-**	**37**	**26**	**78.0**	**2**	**185**	**64**	**124**	**164.9**	**-**	**-**	**-**	**101**	**2.4**	**4.3**	**92.2**	**1.91**	**12.1**	**7**

Appendix 5.12. Continued…

Entry	Comp	Yield t ha^{-1}	Rank	TKW (g)	Ker spk^{-1}	Test Wt kg hL^{-1}	ESV	Emerg	Heading	Maturity	Weeds g m^{-2}	Juncea g m^{-2}	TotWds g m^{-2}	Juncea plt m^{-2}	Height (cm)	LS Dis	PM (%)	LI (%)	LAI	Prot. (%)	Lodg
Superb	1	3.15	3	40	23	78.8	3	216	61	124	49.6	52.4	102.0	47	92	3.0	0.0	94.8	2.88	11.9	7
Intrepid	1	2.78	8	40	23	78.0	3	191	61	115	82.0	201.2	283.2	39	99	2.8	1.3	95.5	2.80	13.4	8
5600HR	1	2.05	13	36	24	77.4	2	134	64	118	182.8	283.2	466.0	57	101	2.3	7.5	95.9	2.00	12.4	8
5I11	1	2.63	10	36	24	77.2	2	151	63	118	71.2	267.2	338.4	39	102	2.0	3.8	94.3	2.38	12.4	8
5I12	1	2.63	10	39	26	77.8	2	145	63	122	381.2	152.4	533.6	43	104	1.8	2.5	95.8	2.65	13.0	7
5I21	1	2.45	12	36	28	77.8	1	136	64	122	189.2	262.4	451.6	58	100	1.8	12.5	93.4	2.34	12.8	7
5S11	1	2.75	9	38	23	78.8	2	181	63	124	21.6	378.4	400.0	51	97	2.3	8.8	94.3	2.90	12.0	8
5S12	1	3.20	2	40	25	80.1	3	177	63	124	16.8	76.0	92.8	35	99	2.5	1.3	95.7	2.37	12.4	8
5S21	1	2.55	11	37	25	77.9	2	151	64	121	178.8	559.2	738.0	50	108	3.0	1.3	95.7	2.84	12.2	8
SI11	1	3.75	1	40	24	79.9	3	232	62	116	63.2	158.8	222.0	34	100	2.8	0.0	94.7	2.82	12.5	6
SI12	1	3.03	5	40	26	78.6	3	235	61	114	71.2	193.2	264.4	43	96	2.8	0.0	96.0	2.73	13.0	7
SI21	1	3.13	4	39	26	79.1	2	166	63	122	52.8	176.0	228.8	50	99	2.8	0.0	96.4	2.60	12.7	8
5SI111	1	2.85	7	41	26	78.7	3	205	63	124	43.2	308.0	351.2	32	104	2.3	0.0	96.2	2.77	12.5	7
5SI112	1	2.95	6	38	24	78.5	2	182	62	116	50.4	179.6	230.0	33	101	2.3	2.5	95.7	2.38	12.6	7
5SI121	1	2.95	6	38	25	79.3	2	189	62	118	152.8	232.4	385.2	50	104	2.3	0.0	95.8	2.44	12.6	7
5SI211	1	2.85	7	39	27	78.7	2	188	63	118	27.2	338.0	365.2	38	104	3.0	3.8	96.1	2.52	12.5	8
Mean		**2.85**	**-**	**39**	**25**	**78.5**	**2**	**180**	**63**	**120**	**102.1**	**238.7**	**340.8**	**44**	**100**	**2.5**	**2.8**	**95.4**	**2.59**	**12.6**	**7**
F-value[a]	Comp	*		ns	ns	ns	ns	ns	*	ns	ns	-	**	-	ns	ns	ns	ns	*	ns	ns
	Entry	**		**	ns	*	**	**	**	*	ns	ns	*	ns	**	ns	*	ns	ns	*	ns
	C*E	ns		ns	ns	ns	ns	**	ns	ns	ns	-	ns	-	ns	ns	ns	ns	ns	ns	ns
	SE (entry)[b]	0.18		1.28	1.68	0.85	0.30	23.7	0.9	2.5	84.9	78.5	108.1	5.1	2.4	0.39	4.15	1.8	0.24	0.30	0.66
	SE (comp)[c]	0.17		0.70	0.90	0.35	0.13	9.6	0.5	1.3	31.4	-	33.9	-	2.1	0.21	1.31	1.6	0.13	0.19	0.34

[a] ns = not significant; * = significant at $P<0.05$, ** = significant at $P<0.01$

[b] Standard error of the difference between two means.

[c] Standard error of the difference between competition and non-competition treatments.

Appendix 5.13. Least-square means of agronomic traits measured on 16 spring wheat cultivar mixtures with (1) and without (0) simulated competition at Edmonton Organic (2005).

Entry	Comp	Yield t ha^{-1}	Rank	TKW (g)	Ker spk^{-1}	Test Wt kg hL^{-1}	Spk m^{-1}	ESV	Emerg	Head	Mat	Weeds g m^{-1}	Juncea g m^{-2}	TotWds g m^{-2}	Juncea plt m^{-2}	Height (cm)	LS Dis	StRst (%)	PM (%)	LI (%)	LAI	Protein (%)	Lodg
Superb	0	3.08	12	49	26	79.1	312	3	159	55	122	760.7	-	-	-	96	1.8	13.8	1.3	97.7	5.08	13.5	0
Intrepid	0	3.35	8	46	33	78.1	335	4	160	55	108	282.6	-	-	-	104	2.8	1.3	1.5	94.6	5.06	14.6	1
5600HR	0	3.10	11	41	31	77.2	489	3	152	60	113	278.8	-	-	-	108	2.8	30.0	11.3	96.0	4.78	13.1	0
5I11	0	3.30	9	43	30	77.8	408	3	139	58	118	303.9	-	-	-	109	2.3	22.5	8.7	97.0	4.51	13.7	0
5I12	0	3.65	2	44	32	78.1	408	3	121	57	115	393.1	-	-	-	102	2.8	28.8	8.8	94.0	4.65	14.0	0
5I21	0	3.38	7	41	33	77.8	434	3	150	56	115	198.1	-	-	-	109	2.5	16.3	6.3	96.6	4.83	13.4	0
5S11	0	3.85	1	43	30	79.8	396	3	154	55	120	159.3	-	-	-	105	2.5	32.5	3.7	97.4	4.86	13.3	0
5S12	0	3.53	4	43	30	79.7	394	4	146	55	116	212.1	-	-	-	100	2.0	23.8	6.2	96.2	4.92	13.5	0
5S21	0	3.35	8	41	31	78.0	484	3	180	59	116	221.2	-	-	-	109	2.3	22.5	7.5	97.0	5.29	13.2	0
SI11	0	3.28	10	48	31	77.3	333	3	159	60	125	84.3	-	-	-	102	2.3	7.5	2.5	97.7	4.03	13.7	0
SI12	0	3.48	5	46	31	78.2	327	3	160	56	113	452.9	-	-	-	104	2.0	2.8	0.2	95.5	4.71	14.2	0
SI21	0	3.55	3	46	32	78.7	307	4	141	54	115	423.3	-	-	-	95	2.0	17.5	1.3	97.0	4.96	14.1	0
5SI111	0	3.10	11	45	31	79.1	382	4	147	54	110	389.4	-	-	-	101	2.3	15.0	1.3	97.1	5.58	14.3	1
5SI112	0	3.00	13	45	31	78.7	322	4	123	56	109	101.0	-	-	-	103	2.3	15.0	1.3	95.8	4.73	14.3	0
5SI121	0	2.98	14	47	30	79.3	360	3	158	55	118	232.8	-	-	-	104	2.3	7.5	1.2	97.4	5.24	13.9	0
5SI211	0	3.43	6	45	32	78.2	335	3	118	58	120	273.3	-	-	-	108	2.0	30.0	5.0	95.5	4.77	13.8	0
Mean		**3.34**	**-**	**45**	**31**	**78.4**	**376**	**3**	**148**	**56**	**116**	**297.9**	**-**	**-**	**-**	**104**	**2.3**	**17.9**	**4.3**	**96.4**	**4.87**	**13.8**	**0**

Appendix 5.13. Continued...

Entry	Comp	Yield t ha^{-1}	Rank	TKW (g)	Ker spk^{-1}	Test Wt kg hL^{-1}	Spk m^{-1}	ESV	Emerg	Head	Mat	Weeds g m^{-1}	Juncea g m^{-2}	TotWds g m^{-2}	Juncea plt m^{-2}	Height (cm)	LS Dis	StRst (%)	PM (%)	LI (%)	LAI	Protein (%)	Lodg
Superb	1	3.70	4	48	26	79.9	333	3	148	54	122	191.7	36.0	227.7	35	94	2.3	10.0	0.0	98.2	5.81	13.6	0
Intrepid	1	3.58	6	46	33	78.1	380	4	144	52	104	90.3	200.5	290.8	41	103	2.3	2.5	1.3	97.7	5.09	15.0	2
5600HR	1	3.48	8	42	30	78.1	363	3	178	60	117	274.2	22.0	296.1	46	105	2.5	32.5	12.5	97.5	5.70	13.3	1
5I11	1	3.08	11	43	31	76.0	415	2	153	57	124	166.0	28.1	194.1	39	103	2.5	27.5	5.0	96.8	5.41	13.4	0
5I12	1	3.33	9	42	33	78.1	389	3	148	54	111	182.2	56.0	238.2	47	104	2.8	17.5	3.8	96.3	5.28	14.0	1
5I21	1	2.98	13	41	31	77.5	423	3	115	56	113	178.3	99.6	277.9	43	104	2.0	25.0	10.0	97.2	5.15	13.4	1
5S11	1	3.75	3	43	28	79.6	477	4	133	55	117	203.1	8.1	211.1	35	107	2.5	15.0	12.5	98.2	6.04	13.5	0
5S12	1	3.78	2	44	30	79.6	400	3	150	54	115	374.1	54.0	428.1	32	103	2.5	16.3	2.5	96.9	5.85	13.6	1
5S21	1	3.33	9	43	31	78.3	385	3	162	59	116	140.2	65.6	205.8	34	102	2.5	18.8	6.3	97.2	5.79	13.2	1
SI11	1	3.63	5	46	30	78.2	368	3	109	54	124	131.9	23.7	155.5	43	97	2.5	8.8	1.3	96.6	5.59	13.7	0
SI12	1	3.10	10	45	27	76.6	269	2	136	56	117	173.8	299.0	472.7	41	98	2.8	10.3	6.3	97.4	5.63	14.1	2
SI21	1	4.15	1	47	31	79.5	464	4	160	53	115	303.6	229.3	532.8	44	95	2.8	13.8	0.0	96.7	5.46	14.1	0
5SI111	1	3.10	10	44	31	78.3	389	3	144	57	113	116.0	2.8	118.7	41	95	2.5	7.5	3.8	96.9	5.33	14.2	1
5SI112	1	3.70	4	46	33	78.7	401	3	124	55	113	225.6	41.6	267.2	34	95	2.0	8.8	2.5	95.5	5.46	14.4	1
5SI121	1	3.53	7	45	29	79.4	338	3	123	53	113	311.6	23.3	334.8	40	96	2.5	7.5	1.3	96.8	5.57	14.0	0
5SI211	1	3.05	12	44	28	76.7	342	2	123	59	125	414.8	49.0	463.9	43	106	2.8	32.5	0.0	96.2	5.02	13.2	1
Mean		**3.45**	**-**	**44**	**30**	**78.3**	**383**	**3**	**141**	**55**	**116**	**217.3**	**77.4**	**294.7**	**40**	**100**	**2.5**	**15.9**	**4.3**	**97.0**	**5.51**	**13.8**	**1**
F-value[a]	Comp	ns	-	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	ns	-	**	ns	ns	ns	ns	ns	ns	*
	Entry	ns	-	**	**	*	*	ns	ns	ns	*	ns	ns	ns	ns	**	ns	**	**	**	ns	**	*
	C*E	ns	-	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	ns	-	ns	ns	ns	*	ns	ns	ns	ns
SE (entry)[b]		0.28	-	0.92	1.1	0.92	40.0	0.48	14.4	2.4	4.7	125.6	51.2	128.0	2.88	3.0	0.31	6.8	2.6	0.6	0.27	0.26	0.30
SE (comp)[c]		0.38	-	0.27	0.39	0.87	59.6	0.26	6.8	2.2	4.2	147.9	-	141.9	-	1.0	0.11	3.9	0.9	0.3	0.21	0.22	0.16

[a] ns = not significant; * = significant at P<0.05, ** = significant at P<0.01

[b] Standard error of the difference between two means.

[c] Standard error of the difference between competition and non-competition treatments.

Appendix 5.14. Least-square means of agronomic traits measured on 16 spring wheat cultivar mixtures with (1) and without (0) simulated competition at Certified Organic (2004).

Entry	Comp	Yield t ha^{-1}	Rank	TKW (g)	Ker spk^{-1}	Test Wt kg hL^{-1}	Spk m^{-2}	ESV	Weeds g m^{-2}	Juncea g m^{-2}	Tot Wds g m^{-2}	Height (cm)	LS Dis	Prot (%)	Lodging
Superb	0	1.83	2	38	20	78.3	488	5	206.4	-	-	81	2.8	14.9	0
Intrepid	0	1.30	10	36	17	76.8	506	4	358.4	-	-	91	1.8	14.0	0
5600HR	0	0.90	15	34	18	75.8	361	3	342.8	-	-	92	2.3	15.4	0
5I11	0	1.38	9	37	19	77.1	417	3	338.4	-	-	91	2.5	14.6	0
5I12	0	1.10	13	36	19	76.8	409	4	289.2	-	-	86	2.5	15.8	0
5I21	0	1.08	14	33	18	77.0	420	3	244.4	-	-	89	1.5	15.2	0
5S11	0	1.58	5	37	19	79.4	407	4	265.2	-	-	88	1.3	14.3	0
5S12	0	1.58	5	37	21	78.7	384	4	216.4	-	-	85	2.6	14.2	0
5S21	0	1.15	12	37	19	78.7	259	4	241.6	-	-	88	2.2	13.8	0
SI11	0	1.80	3	39	20	78.8	498	4	174.8	-	-	89	3.0	15.2	0
SI12	0	1.85	1	37	22	77.0	528	4	241.2	-	-	91	2.5	14.6	0
SI21	0	1.50	7	35	21	78.4	431	5	150.4	-	-	83	1.6	15.1	0
5SI111	0	1.20	11	36	18	78.0	445	5	311.6	-	-	87	1.3	14.7	0
5SI112	0	1.73	4	36	18	76.9	500	4	195.2	-	-	91	3.0	15.3	0
5SI121	0	1.40	8	35	19	77.8	460	4	278.0	-	-	84	2.0	15.3	0
5SI211	0	1.55	6	34	20	76.7	483	4	198.4	-	-	94	1.5	14.1	0
Mean		**1.43**	-	**36**	**19**	**77.6**	**437**	**4**	**253.3**	-	-	**88**	**2.1**	**14.8**	**0**
Superb	1	1.15	7	36	16	76.7	401	5	256.4	102.8	359.2	85	1.8	14.4	1
Intrepid	1	1.08	9	36	15	74.1	444	4	245.6	60.0	305.6	89	1.5	14.0	1
5600HR	1	0.75	14	35	18	75.5	258	3	225.6	134.8	360.4	98	1.5	14.5	1
5I11	1	0.95	11	37	18	77.5	398	4	218.8	100.0	318.8	94	2.5	14.7	0
5I12	1	0.98	10	36	17	76.7	464	4	362.8	182.4	545.2	89	1.5	15.1	0
5I21	1	0.93	12	37	17	75.6	345	3	391.2	83.6	474.8	91	2.8	14.5	2
5S11	1	1.10	8	35	18	76.2	473	4	144.8	143.2	288.0	95	2.5	14.1	2
5S12	1	1.43	1	38	19	78.8	309	4	195.6	211.2	406.8	92	2.8	13.9	0
5S21	1	0.88	13	35	17	76.4	363	3	238.0	80.4	318.4	93	2.3	14.1	1
SI11	1	1.33	3	40	18	78.1	386	5	179.6	101.6	281.2	88	2.3	14.5	1
SI12	1	1.40	2	37	18	76.8	526	4	312.0	138.4	450.4	90	2.8	14.8	0
SI21	1	1.15	7	39	18	77.9	330	5	178.4	104.8	283.2	82	2.3	13.7	1
5SI111	1	1.23	4	37	17	77.3	431	4	237.2	88.8	326.0	90	1.5	15.0	1
5SI112	1	1.20	5	36	17	76.8	352	4	303.6	40.4	344.0	93	2.0	15.1	1
5SI121	1	1.18	6	38	17	78.3	431	4	179.6	129.6	309.2	87	1.8	15.0	1
5SI211	1	1.08	9	35	15	75.7	278	4	305.6	306.4	612.0	95	2.8	15.4	1
Mean		**1.11**	-	**37**	**17**	**76.8**	**387**	**4**	**248.4**	**125.5**	**374.0**	**90**	**2.2**	**14.5**	**1**
F-value[a]	Comp	**		ns	**	ns	*	ns	ns	-	**	ns	ns	ns	ns
	Entry	**		*	*	*	ns	**	ns	ns	ns	**	ns	ns	ns
	C*E	ns		ns	ns	ns	ns	*	ns	-	ns	ns	ns	ns	ns
SE (entry)[b]		0.19		1.15	0.94	0.88	64.6	0.23	75.9	43.4	89.7	2.9	0.64	0.47	0.45
SE (comp)[c]		0.07		0.58	0.33	0.67	19.8	0.07	26.8	-	31.7	1.4	0.21	0.20	0.70

[a] ns = not significant; * = significant at $P<0.05$, ** = significant at $P<0.01$

[b] Standard error of the difference between two means.

[c] Standard error of the difference between competition and non-competition treatments.

Appendix 5.15. Least-square means of agronomic traits measured on 16 spring wheat cultivar mixtures with (1) and without (0) simulated competition at Certified Organic (2005).

Entry	Comp	Yield t ha^{-1}	Rank	TKW (g)	Ker spk^{-1}	Test Wt kg hL^{-1}	Spk m^{-2}	ESV	Emerg	Weeds g m^{-2}	Juncea g m^{-2}	Tot Wds g m^{-2}	Juncea plt m^{-2}	Height (cm)	LS Dis	Protein (%)	Lodging
Superb	0	1.30	1	36	26	78.5	228	4	123	100.8	-	-	-	70	2.0	14.4	1
Intrepid	0	0.85	9	36	24	75.4	160	4	121	138.1	-	-	-	72	2.0	16.2	0
5600HR	0	0.83	10	32	23	74.0	261	4	137	139.0	-	-	-	73	3.3	15.7	1
5I11	0	0.63	13	34	24	73.9	153	4	113	206.1	-	-	-	73	2.3	16.0	0
5I12	0	0.80	11	36	24	74.3	200	4	121	200.7	-	-	-	71	2.0	15.9	0
5I21	0	0.85	9	35	24	72.5	220	4	134	282.7	-	-	-	77	1.8	16.2	0
5S11	0	0.75	12	35	26	75.0	203	4	115	229.9	-	-	-	66	2.5	15.1	1
5S12	0	1.00	4	38	26	76.9	195	5	128	286.8	-	-	-	69	2.3	15.0	1
5S21	0	0.98	5	38	26	75.8	167	4	164	193.8	-	-	-	74	2.0	15.4	1
SI11	0	1.03	3	39	24	75.3	212	4	113	203.5	-	-	-	75	1.5	15.5	0
SI12	0	0.88	8	33	24	76.3	214	4	116	272.2	-	-	-	75	2.3	15.7	1
SI21	0	1.10	2	35	25	76.4	215	4	150	192.5	-	-	-	74	2.0	15.2	0
5SI111	0	0.83	10	37	25	75.0	164	4	117	231.3	-	-	-	74	2.0	15.8	0
5SI112	0	0.88	8	38	25	74.0	132	4	117	275.2	-	-	-	79	1.8	15.8	0
5SI121	0	0.98	5	35	26	75.8	231	4	141	187.6	-	-	-	73	2.3	15.4	0
5SI211	0	0.93	6	37	24	75.2	148	4	135	193.6	-	-	-	75	2.5	15.6	1
Mean		**0.91**	**-**	**36**	**25**	**75.3**	**194**	**4**	**128**	**208.3**	**-**	**-**	**-**	**73**	**2.1**	**15.6**	**0**
Superb	1	1.45	1	36	27	78.9	255	5	156	57.4	61.5	118.9	71	75	2.0	14.8	1
Intrepid	1	0.78	8	38	25	75.0	187	4	98	134.2	65.6	199.9	58	78	2.8	16.3	0
5600HR	1	0.73	9	34	23	73.3	252	4	132	108.6	94.6	203.2	53	74	2.8	15.8	0
5I11	1	0.68	11	35	23	73.8	134	4	120	111.5	105.6	217.0	75	78	2.3	16.1	0
5I12	1	0.80	7	40	24	74.6	205	3	92	57.7	255.8	313.6	76	77	2.3	16.1	0
5I21	1	0.65	12	36	21	72.3	161	4	113	105.7	77.1	182.8	78	85	1.8	16.0	0
5S11	1	0.93	4	38	24	77.1	178	3	58	107.8	82.9	190.7	63	71	1.8	14.8	0
5S12	1	1.10	2	37	25	76.3	190	4	136	97.0	38.0	135.0	61	71	2.5	15.1	0
5S21	1	0.88	6	38	23	76.7	118	4	95	152.8	87.8	240.6	78	75	1.0	15.3	0
SI11	1	1.10	2	38	23	77.8	225	4	133	77.5	73.3	150.7	73	75	2.0	15.3	1
SI12	1	0.80	7	36	26	74.8	221	4	153	80.2	53.9	134.1	62	67	1.8	15.9	0
SI21	1	0.98	3	37	24	76.6	203	5	138	75.9	38.5	114.4	61	74	2.0	15.5	1
5SI111	1	0.70	10	37	24	75.1	222	4	124	208.1	41.5	249.6	79	80	2.0	15.7	0
5SI112	1	0.68	11	36	22	75.4	88	4	111	186.5	47.2	233.7	78	76	1.8	16.0	0
5SI121	1	0.93	4	37	25	75.5	193	4	133	143.9	91.1	235.0	60	76	1.5	15.4	1
5SI211	1	0.90	5	37	25	76.5	148	4	103	84.7	53.4	138.2	69	74	2.3	15.7	0
Mean		**0.88**	**-**	**37**	**24**	**75.6**	**186**	**4**	**118**	**111.8**	**79.2**	**191.1**	**68**	**75**	**2.0**	**15.6**	**0**
F-value[a]	Comp	ns		ns	ns	ns	ns	ns	ns	**	**	ns	**	ns	ns	ns	ns
	Entry	ns		ns	ns	**	*	ns	ns	ns	*	ns	ns	ns	ns	**	ns
	C*E	ns		ns	ns	ns	ns	ns	*	ns	*	ns	ns	ns	ns	ns	ns
SE (entry)[b]		0.19		1.76	1.14	1.19	38.4	0.49	18.6	54.2	24.9	64.0	4.8	4.1	0.38	0.30	0.36
SE (comp)[c]		0.33		0.80	0.44	0.33	8.1	0.11	4.8	19.1	-	22.4	-	2.2	0.11	0.15	0.22

[a] ns = not significant; * = significant at P<0.05, ** = significant at P<0.01

[b] Standard error of the difference between two means.

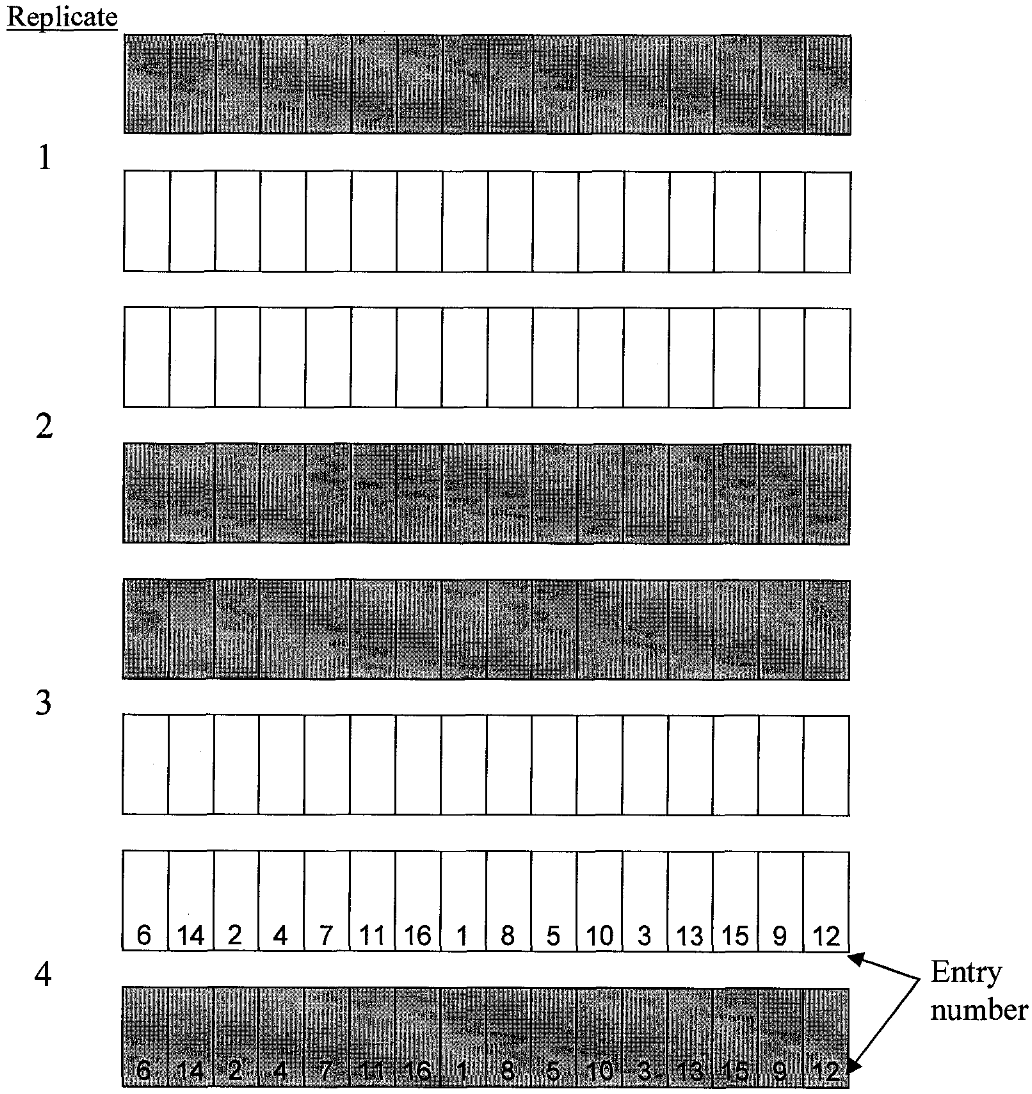
[c] Standard error of the difference between competition and non-competition treatments.

Appendix 5.16. Least-square means for height (cm) of 23 cereal species mixtures grown across north-central Alberta from 2003 to 2005.

Mixture	Mixture	Edmonton Conventional		Edmonton Organic	
Components	Ratio	Wheat	Crop	Wheat	Crop
Park (wheat)	Sole-crop	99[a]	-	97	
McKenzie (wheat)	Sole-crop	92	-	92	
Barley (Manny)	Sole-crop	-	82	-	82
Oats (Grizzly)	Sole-crop	-	113	-	113
Triticale (AC Alta)	Sole-crop	-	94	-	101
Park-Barley	50:50	98	84	95	84
Park-Barley	25:75	97	83	93	79
Park-Barley	75:25	97	81	92	80
McKenzie-Barley	50:50	89	83	86	76
McKenzie-Barley	25:75	89	83	91	81
McKenzie-Barley	75:25	91	84	89	81
Park-Oats	50:50	96	109	89**	113
Park-Oats	25:75	96	112	93	111
Park-Oats	75:25	98	106**	92	115
McKenzie-Oats	50:50	88	113	85*	109
McKenzie-Oats	25:75	90	114	87	113
McKenzie-Oats	75:25	90	112	89	111
Park-Triticale	50:50	98	95	93	102
Park-Triticale	25:75	94*	95	90*	102
Park-Triticale	75:25	102	96	91	98
McKenzie-Triticale	50:50	87	93	89	102
McKenzie-Triticale	25:75	86*	93	88	99
McKenzie-Triticale	75:25	90	93	87	100
	Mean	**93**	**96**	**90**	**98**
	F-value (entry)[b]	**	**	*	**
	SE (entry)	2.6	2.4	3.2	3.1
	LSD (entry) P=0.05	5.4	5.0	6.6	6.4

[a] * , ** indicate height differs from mid-component average at P<0.05 and P<0.01, respectively.
[b] ns = not significant, * = significant at P<0.05, ** = significant at P<0.01

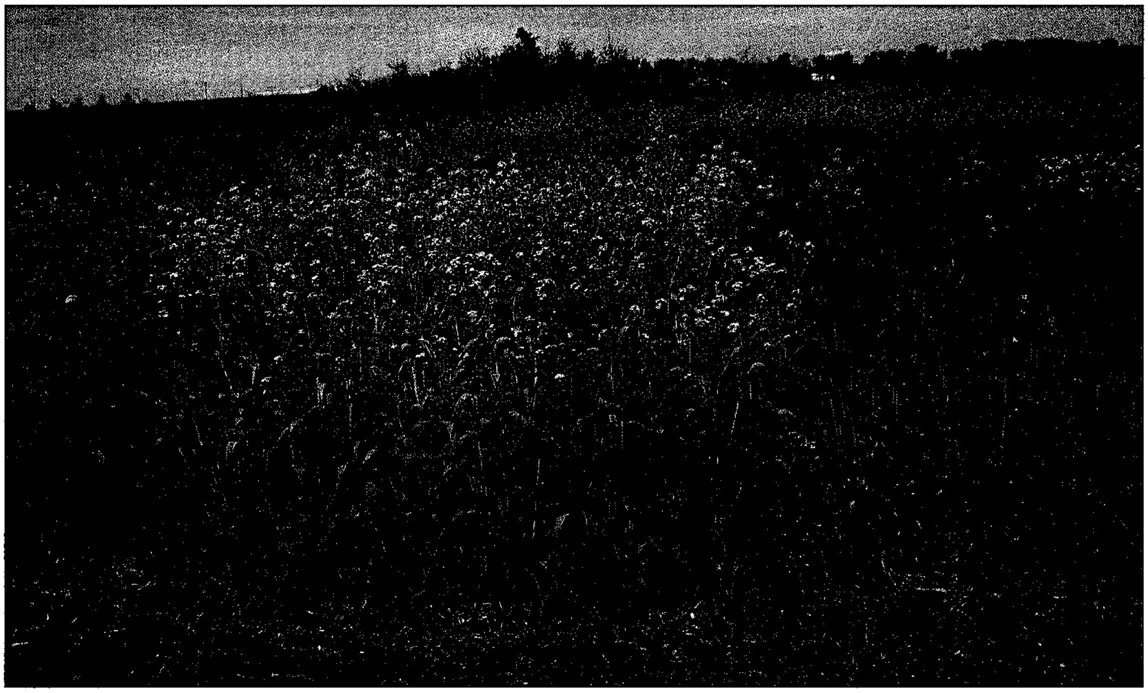
Appendix 5.17. Sample plot layout for two strip-plot trials grown in central Alberta from 2003 to 2005.



= cross-seeded with *Brassica juncea* at 60 seeds m^{-2} as simulated competition.

Appendix 5.18. Comparison of barley (left) and triticale (right) six weeks after planting on organic land in north-central Alberta.

Appendix 5.19. Comparison of oats (left) triticale (center) and barley (right) eight weeks after planting on conventional land in north-central Alberta. Plots are cross-seeded with *Brassica juncea* to simulate weed competition.



Appendix 5.20. Poster presented at Organic Connections in Saskatoon, SK, November 14-16, 2004.

Effect of management and competition on yield of spring wheat cultivar mixtures

A. Kaut[1], A. Navabi[1], J. O'Donovan[2], and D. Spaner[1]
[1] *Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, AB,*
[2] *Agriculture and Agri-Food Canada, Beaverlodge, AB*

Introduction

• Cultivar mixtures may increase yield and yield stability by increasing inherent crop heterogeneity and genetic buffering potential (1, 2).

• Yield increases may be due to agronomic factors such as decreased lodging and disease potential, and increased in crop competitive ability (3, 4).

• Cultivar mixtures may be promising for use in organic or low-input systems, where producers are more reliant on the crop's inherent ability to out-compete biotic and abiotic stressors.

Objectives

• To study the yield response of spring wheat cultivar mixtures under:
  • competition with *B. juncea* versus no competition, and
  • conventional versus organic management

Materials and Methods

• **Mixtures**: One tall (5600HR), one average height (AC Intrepid) and one semi-dwarf (Superb) Hard Red Spring (HRS) wheat cultivar were mixed in 1:1, 1:2, 2:1, 1:1:1, 2:1:1, 1:2:1, and 1:1:2 ratios, and planted at 300 seeds/m² in 2003 and 2004 at two sites: Conventional Michener (CM) and Organic Michener (OM). Pure stands were also included as checks.

• **Competition**: Oriental mustard (*Brassica juncea*) was cross-seeded across designated plots to impose simulated weed competition (Figure 1). Conventional competition plots received no herbicide in either year, while conventional non-competition plots were sprayed with 1.24 l/ha of Dyvel at early tillering. Organic competition and organic non-competition plots on OM received one hand-weeding to remove winter annual weeds in the spring. No other weeding was done on OM in either year.

• **Management**: In both years, conventional plots were planted into tilled summerfallow land previously under alfalfa for 5-6 years. Plots received 45 kg N/ha and 20 kg P/ha banded in the seed row. In both years, OM plots were seeded into organically managed land (greater than 3 years without any chemical input), seeded to fall rye and treated with 100 t/ha composted dairy manure the season prior.

Results and Discussion

• In 2003, both sites experienced drought stress. Moisture conditions were sufficient for crop growth in 2004. Competition × cultivar mixture interactions were not significant (P>0.10) under either management regime. Grain yield (averaged over both years) was lower (P<0.05) with imposed weed competition:

  • 3.76 t/ha with competition versus 4.03 t/ha with no competition (CM)
  • 3.38 t/ha with competition versus 3.93 t/ha with no competition (OM)

• In 2003, organically managed plots yielded greater (P<0.05) than conventional plots, perhaps due to higher soil organic matter content, which may have allowed for greater crop moisture availability.

Table 1. Yield of wheat cultivars in mixtures and pure stands under conventional and organic management averaged over two seasons.

Crop Mixture Treatment	Grain yield (t/ha)	
	Conventional	Organic
Superb	4.21	3.96
Intrepid	3.63	3.45
5600HR	3.80	3.48
5600HR : Intrepid 1:1	3.84	3.57
5600HR : Intrepid 1:2	4.01	3.78
5600HR : Intrepid 2:1	3.78	3.54
5600HR : Superb 1:1	4.12	3.68
5600HR : Superb 1:2	4.05	3.63
5600HR : Superb 2:1	3.72	3.70
Superb : Intrepid 1:1	3.92	3.62
Superb : Intrepid 1:2	3.96	3.65
Superb : Intrepid 2:1	3.91	3.95
5600HR : Superb : Intrepid 1:1:1	4.18	3.91
5600HR : Superb : Intrepid 1:1:2	3.91	3.81
5600HR : Superb : Intrepid 1:2:1	3.52	3.34
5600HR : Superb : Intrepid 2:1:1	3.75	3.38
LSD (α = 0.05)	0.276	0.283

• Superb planted as a sole-crop was the highest yielding entry (on average) under either management regime (Table 1).

• Many mixture treatments performed better than sole-crop Intrepid or 5600HR, and some were equal to Superb.

• When subjected to drought stress (2003), some mixtures performed better than all sole-crop treatments (data not shown), and therefore appeared to exhibit greater stability over environments.

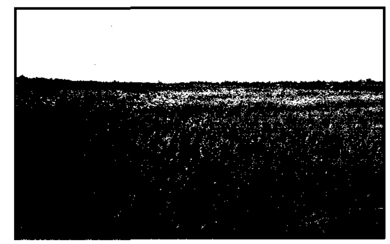


Figure 1. Wheat cultivar mixtures on organic land with no competition (foreground) and interseeded *B. juncea* (background).

• The triple cultivar mixture at a 1:1:1 ratio yielded similar to Superb (on average) under all conditions (Table 1).

• The mixture of Superb:Intrepid 1:1 also had consistently high yields across years and locations (data not shown).

• Other mixtures varied widely between optimal growth with heightened lodging (2004) and drought (2003) conditions.

Conclusions

• Competition had a significant detrimental effect on all cultivars, regardless of mixture type, management or year.

• In pure stands, Superb consistently yielded the most grain. In mixtures, Superb:Intrepid 1:1 and 5600HR:Superb:Intrepid 1:1:1 were the highest yielding and most stable.

• Organic management resulted in higher yields under drought stress than conventional management.

References

(1) Sharma, R. and Dubin, H. (1996) *Field Crops Res.* **48**: 95-101.
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Acknowledgements

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Appendix 5.21. Poster presented at the 25th annual Guelph Organic Conference in Guelph, ON, January 26-29, 2006.

Do spring wheat cultivar mixtures maintain yield and suppress weeds under organic management?

A. Kaut[1], A. Navabi[1], J. O'Donovan[2] and D. Spaner[1]
[1]Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, AB,
[2]Agriculture and Agri-Food Canada, Beaverlodge, AB

Introduction

• Spring wheat (*Triticum aestivum* L.) yields are often lower under organic management (when compared to conventional systems), due to increased competition with weeds (Lotter, 2003).

• The use of spring wheat cultivar mixtures may maintain grain yield and suppress weed growth (Manthey and Fehrmann, 1993; Jackson and Wennig, 1997).

• Cultivar mixtures may alter various competitive traits, such as early season vigour, leaf area index or tillering potential.

Objectives

• To examine the potential of spring wheat cultivar mixtures to maintain yield and suppress weeds under conventional and organic management.

• To identify traits associated with competitive and stable cultivar mixtures.

Materials and Methods

• One tall (5600HR), one average height (AC Intrepid) and one semi-dwarf (AC Superb) hard red spring wheat cultivar were mixed in 1:1, 1:2, 2:1, 1:1:1, 1:1:2, 1:2:1 and 2:1:1 ratios and grown on one conventional and two organic sites from 2003 to 2005.

• The conventional (Conv) site was located on the Edmonton Research Station (ERS) and the two organic sites were on the ERS (Org 1) and on a certified organic farm (Org 2) near New Norway, AB.

• Oriental mustard (*Brassica juncea*) was cross-seeded across designated plots to impose simulated weed competition (Figure 1).

• Early season vigour (ESV), spikes m^{-2}, weed biomass, leaf area index (LAI) and grain yield were recorded.

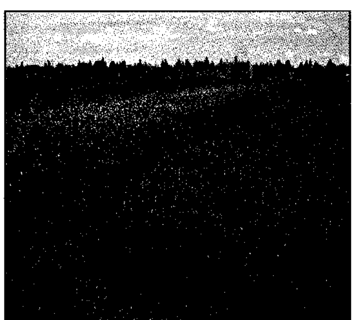

Figure 1. Wheat cultivar mixtures on conventional land in Edmonton, AB with cross-seeded oriental mustard (left) and with no competition (right).

Results

• Average wheat yield decreased in the following order: Conv > Org 1 > Org 2 (Table 1).

• Average weed biomass varied greatly between locations: 36 g m^{-2} (Conv), 201 g m^{-2} (Org 1) and 257 g m^{-2} (Org 2).

• Sole-crop Superb yielded more grain than 5600HR and Intrepid at the Conv and Org 2 locations and 5600HR at the Org 1 location.

• Superb-Intrepid mixtures consistently yielded equal to or better than their sole-crop counterparts, regardless of management.

Table 1. Grain yield of sixteen cultivar mixtures grown under conventional and organic management from 2003 to 2005 in north-central Alberta

Mixture	Yield (t ha^{-1})		
	Conv	Org 1	Org 2
Superb	**4.92**	**3.61**	**1.43**
Intrepid	4.45	3.53	1.00
5600HR	4.09	3.11	0.80
5600HR-Int 1:1	4.28	3.27	0.91
5600HR-Int 1:2	4.46	3.33	0.92
5600HR-Int 2:1	4.00	3.17	0.88
5600HR-Sup 1:1	4.59	3.44	1.09
5600HR-Sup 1:2	4.42	3.68	1.28
5600HR-Sup 2:1	4.38	3.35	0.97
Sup-Int 1:1	**4.61**	**3.82**	**1.31**
Sup-Int 1:2	**4.69**	**3.53**	**1.23**
Sup-Int 2:1	**4.59**	**3.78**	**1.18**
5600HR-Sup-Int 1:1:1	4.25	3.22	0.99
5600HR-Sup-Int 1:1:2	4.38	3.23	1.12
5600HR-Sup-Int 1:2:1	4.52	3.30	1.12
5600HR-Sup-Int 2:1:1	4.38	3.32	1.11
LSD (α = 0.05)	**0.50**	**0.42**	**0.29**

• Cultivar mixtures did not suppress weeds ($P>0.05$) at any location.

• Sole-crop Superb and some Superb-Intrepid mixtures had greater than average early season vigour ratings, but these difference were not statistically significant ($P>0.05$).

• Some Superb-Intrepid mixtures had greater than average spikes m^{-2}, but these values were not statistically significant ($P>0.05$).

• Sole-crop Superb had a significantly higher leaf area index at the Conv location ($P<0.05$) and was above-average at the Org 1 location.

Literature Cited

• Lotter, D. W. 2003. J. Sust. Agric. 21: 59-128.
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Table 2. Means of agronomic traits of selected cultivar mixtures grown under conventional and organic management from 2003 to 2005 in north central Alberta

Location	Mixture	ESV[1]	Spikes m^{-2}	LAI
Conv	Superb	4.9a[2]	593a	5.43a
	Sup-Int 1:1	4.6a	567a	4.35b
	Sup-Int 1:2	4.4a	589a	4.35b
	Sup-Int 2:1	4.8a	560a	4.69ab
	Location Average	**4.3a**	**574a**	**4.58ab**
Org 1	Superb	3.0a	369a	4.03a
	Sup-Int 1:1	2.6a	411a	3.52a
	Sup-Int 1:2	2.6a	370a	3.79a
	Sup-Int 2:1	3.1a	418a	3.77a
	Location Average	**2.6a**	**410a**	**3.72a**
Org 2	Superb	4.8a	343a	-
	Sup-Int 1:1	4.1a	330a	-
	Sup-Int 1:2	4.1a	372a	-
	Sup-Int 2:1	4.5a	295a	-
	Location Average	**3.9a**	**301a**	-

[1]Early season vigour is rated from 1 (low vigour) to 5 (highly vigorous).
[2]Mixtures with the same letter are not significantly different (P<0.05) within their respective management systems.

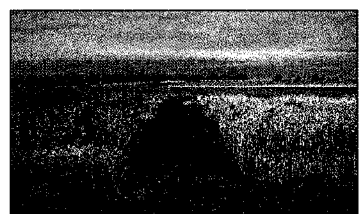

Figure 2. Wheat cultivar mixtures on organic land in Edmonton, AB with cross-seeded oriental mustard (left) and no competition (right).

Conclusions

• Wheat grain yields were lower on organic land due to increased competition from weeds.

• The semi-dwarf cultivar (Superb) out-yielded the tallest cultivar regardless of management system.

• Sole-crop Superb and Superb-Intrepid mixtures had consistently high yields but did not noticeably suppress weeds.

• High-yielding mixtures tended to have above-average early season vigour and spikes m^{-2}.

• An optimal wheat cultivar mixture for organic producers may be a combination of a vigorous semi-dwarf variety and a variety with high tillering capacity.

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