University of Alberta

Aboveground weed competitive ability of spring wheat (*Triticum aestivum* L.) in organic and conventional management systems

by

Heather Elizabeth Mason ©

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

Doctor of Philosophy
in
Plant Science

Department of Agricultural, Food and Nutritional Science

Edmonton, Alberta
Spring 2007

Library and
Archives Canada

Published Heritage
Branch

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque et
Archives Canada

Direction du
Patrimoine de l'édition

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence
ISBN: 978-0-494-29710-0
Our file Notre référence
ISBN: 978-0-494-29710-0

NOTICE:
The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:
L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Abstract

The use of competitive spring wheat (*Triticum aestivum* L.) cultivars may reduce the negative effects of weed competition in organic and conventional systems. A series of studies were conducted to evaluate the agronomic performance and competitive ability of spring wheat cultivars under organic and conventional farming systems, and to identify traits conferring competitive ability in organically grown wheat. Twenty-seven Canada Western Red Spring wheat cultivars, representing 114 years of Canadian wheat breeding, were grown under organic and conventional management in field trials conducted from 2002-2004. Cultivars performed differently in the two management systems, suggesting that there may be some cultivars better suited to organic than conventional management systems. Of the 27 bread wheat cultivars, five were selected to be evaluated for their breadmaking quality when grown in the two management systems. Although differences were detected between the two systems, results suggest that growing high quality bread wheat under organic management systems in north central Alberta is possible. There was no evidence in either of these studies suggesting that older cultivars are better suited to organic production than modern cultivars. An additional set of 11 spring wheat and barley cultivars differing in height, tillering and maturity characters were grown at recommended (300 seeds m^{-2}) and doubled seeding densities, with or without competition from tame oats, under organic management in 2003 and 2004. Cultivars differed in their abilities to achieve and maintain grain yield under competition, and to suppress weeds. Barley was generally more competitive than wheat. Doubling the seeding rate increased grain yield, weed suppression and economic returns, suggesting that it is a suitable strategy for overcoming weed competition in organic grain production. We investigated the stability and adaptation of 9 wheat cultivars in differing natural weed environments. Older cultivars were the most yield stable across a wide range of environments, while semidwarf cultivars were the least weed stable. Height, early season vigour, time to heading and maturity, and tillering were identified as traits related to

cultivar competitive ability. A competitive crop ideotype for organic agriculture would be a tall plant with strong early season vigour, and early heading and maturity.

Acknowledgement

I would like to thank Dean Spaner for everything he has given me throughout the time that I have known him, including his friendship, kindness, support and guidance. I feel very privileged to have had him as my supervisor.

I am grateful to Brenda Frick, John O'Donovan and Lloyd Dosdall for their participation in this project and their valuable suggestions and comments in reviewing this thesis. I would also like to thank Alireza Navabi for the significant contributions that he has made to this thesis and to enriching my graduate experience. Thank you to Byron, Dione, Klaus, Cliff and all the others who gave technical support. I wish to additionally thank Steven, Robert and Rosemary Snider for allowing me to conduct field trials on their land and for welcoming me into their home.

I would like to acknowledge my colleagues for contributing, in various ways, to my getting here. Thank you to Denise, Baxter, Rae, Mike, Alana, Iqbal, Amy, Todd and Alison, for making my school life more rewarding and fun.

I would like to thank my parents, my brother, my little mama, my family, Craig's family, and my close friends Anna, Clara and Caroline for their support and encouragement through the good and bad times. I am indebted to all of you, for your friendship, advice and (often much needed) perspective.

Finally, thank you to Craig for being there every day with love and laughter.

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Competitive ability of wheat in conventional and organic management systems: A review of the literature[1]

1.1 Introduction

The ability of wheat (*Triticum aestivum* L.) to compete against weeds is important in conventional grain production, and may be even more important in organic grain production where producers have fewer and less immediate strategies available for weed control. While there are effective and practical management strategies available to increase crop competitive ability, there is an increasing interest in determining the genetic ability of a wheat variety to overcome weed pressure, either through the maintenance of yield or the suppression of weeds. The identification of a competitive crop ideotype would assist wheat breeders in the selection of competitive wheat varieties.

The increased crop stresses under organic management systems may affect varietal performance to the extent where breeding specifically for organic environments is recommended. Additionally, researchers have hypothesized that older crop varieties may outperform modern crop varieties under the stresses of organic management systems than under the relatively more modern, conventional management systems. The examination of a wide range of historical and modern Canadian wheat germplasm will help to determine if this hypothesis is supported in Canadian wheat.

The following literature review outlines the role of organic agriculture in wheat production, summarizes the history of wheat breeding globally and in Canada, and considers the competitive ability of wheat and the surrounding body of knowledge.

1.2 Organic Agriculture: An overview

1.2.1 Organic Agriculture

The central objective of organic agriculture is to promote ecosystem health through the reduction of external inputs (Bruinsma 2003). As such, organic agriculture refers to a system of production that prohibits, among other things, the use of mineral fertilizers, synthetic pesticides and genetically modified organisms (GMOs) (Bruinsma 2003). Producers have made the transition from conventional to organic production for a number of reasons, including concerns about environmental stewardship, pesticide resistance, grower independence, high input costs,

---

[1] *This chapter (except sections 1.3.1, 1.3.3 and 1.7) has been published in:* Mason, H. and Spaner, D. 2006. Can. J. Plant Sci. 86:333-343.

increasing human health concerns, and rising consumer demand (Entz et al. 2001; Ngouajio and McGiffen 2002).

Production constraints associated with organic agriculture are similar to, but often of a higher magnitude than, those faced in conventional production. Increased weed pressure and soil nutrient deficiencies, particularly in nitrogen and phosphorus, are more common in organic management systems, which may or may not lead to crop yield reductions (Waldon et al. 1998; Clark et al. 1999; Ryan et al. 2004). To overcome such constraints, and in compliance with the regulations set out by organic certification associations, producers make use of farming practices such as crop rotations, changes to seeding dates and rates, intercropping, the use of animal and green manures, and varietal selection (Stopes and Millington 1991; Barberi 2002).

1.2.2 Global Organic Agriculture

Over 24 million ha of the world's land was organically managed in 2004, compared with just over 10 million ha in 2000 (Willer and Yussefi 2000; Yussefi 2004). Less than half of this land is considered arable, with the remaining portion used mainly for the grazing of animals, particularly in Australia (Yussefi 2004). Oceania/Australia, Latin America and Europe are the areas where most of the organically managed land is located, with those continents representing 42%, 24% and 23% of the world's organic land, respectively (Yussefi 2004). Australia comprises only 0.5% of the organic farms worldwide, largely because of the area of land devoted to grazing. Europe has 38% and Latin America has 31% of the world's organic farms (Yussefi 2004). North America represents 2.3% of the world's organic farms situated on ~1.4 million ha; about 5.9% of the world's organically managed land (Yussefi 2004). In 2002, the global organic food market was worth 23 billion USD; North America and Western Europe were the biggest consumers of organic products, with sales in that year reaching 11.75 and 10.5 billion USD, respectively (Sahota 2004).

1.2.3 Organic Agriculture in Canada

Canada has over 3 500 organic farms on almost 480 000 ha, which is about 1.5% of the total agricultural area in the country (Yussefi 2004). The Canadian market comprises only 6.5% of the North American market for organic food and drink, however the growth in demand for such products is estimated at 15-20% per year since the late 1990's and is expected to maintain that level of growth in the near future (Sahota 2004).

In the 2001 Canadian Census of Agriculture, 65% of Canada's organic farms reported the production of field crops including wheat and barley (*Hordeum vulgare* L.) and to a lesser extent, legume and oilseed crops (Agriculture and Agri-Food Canada 2000; Statistics Canada 2004b).

Nearly 30% of organic farms produced fruits, vegetables and greenhouse products, close to 20% produced animal or animal products and 15% produced other goods (e.g. maple syrup, herbs) (Statistics Canada 2004b). The Prairie provinces account for most of Canada's grain production while British Columbia and the Maritime provinces produce mainly fruits and vegetables; Ontario and Quebec produce both grain crops and fruits and vegetables (Statistics Canada 2004b).

1.2.4 Organic Grain Production

Grain yields in organically managed fields are commonly lower than those of conventionally grown grain crops (Walker and Smith 1992; Entz et al. 2001; Kitchen et al. 2003; Ryan et al. 2004). In one Australian study, organic wheat yields were found to be 21-31% lower than conventional yields (Kitchen et al. 2003). Another study from Australia reported that organic wheat grain yields were less than half of conventional grain yields (Ryan et al. 2004). In Canada, where research relating to organic grain production to date is limited, Entz et al. (2001) found that wheat, oat (*Avena sativa* L.) and barley yields were 23-27% lower on organic farms than conventional farms; however maximum yields were higher on organic farms than long term conventional averages, highlighting the potential for successful organic grain production.

Competition from weeds plays a role in reducing yields, as studies have reported both higher numbers of weeds and greater diversity of weed species in organic cereal crops than in conventional ones (Samuel and Guest 1990). Samuel and Guest (1990) reported that perennial weeds were more problematic in organic fields than annual weeds. On the Canadian Prairies, weed populations appeared to be higher on organic farms, with wild mustard (*Sinapis arvensis* L.) and Canada thistle (*Cirsium arvense* L.) in greater abundance in organic fields than in conventional fields (Entz et al. 2001).

Nutrient deficiency also plays a role in reducing organic crop yields (Barberi 2002). Waldon et al. (1998) reported higher levels of N and P in conventionally managed soils than in organically managed soils in California. In Canada, soil N and K levels in organic fields ranged from deficient to optimal; however P levels were often deficient, especially at the sites managed organically for 70 and 30 years (Entz et al. 2001). Overall, soil nutrient levels were similar to or lower than those of conventionally managed soils (Entz et al. 2001).

Some cultural and climatic factors (e.g., precipitation, temperature) can reduce organic yields as well (French and Schultz 1984; Kitchen et al. 2003). Delayed seeding, in conjunction with tillage, is a cultural practice commonly employed by organic farmers in order to overcome early season weed pressures. Delayed seeding in conventional wheat systems in Australia has been reported to cause grain yield losses of 200-250 kg ha^{-1} week^{-1} (French and Schultz 1984).

Varietal selection may influence the productivity of organic cropping (Poutala et al. 1993); however one study of older and modern Australian spring wheat varieties reported that among the five wheat varieties studied, none were better adapted to organic conditions than conventional conditions, in terms of grain or biomass yield (Kitchen et al. 2003).

An Australian study reported that organic wheat systems in marginal rainfall areas suffered far greater yield losses over conventional systems than did organic systems in moderate rainfall areas (Kitchen et al. 2003). This indicates that organic grain farming may be better suited to moderate rainfall areas (Kitchen et al. 2003). Contrary to those findings, a study of organic and conventional cropping systems in an extreme climate year in the eastern US demonstrated that under drought conditions, maize (*Zea mays* L.) and soybean (*Glycine max* L.) crops were higher yielding under an organic manure-based system than the conventional system (Lotter et al. 2003). Organically managed soils were 100% more effective at retaining rainfall than the conventional soils in that year (Lotter et al. 2003). Similarly, Sahs and Lesoing (1985) reported that maize yields under drought conditions were higher on organic fields than on conventional fields, but the opposite was reported under ideal conditions.

Grain quality is another important consideration in the production of organically grown cereals, especially bread wheats (Stein-Bachinger and Werner 1997). Higher grain quality often translates into higher returns to the producer. In organic hard wheat production it is particularly important that grains be of high quality as most grains produced are used for organic breadmaking rather than for livestock feed (Gooding et al. 1999). In terms of quality, protein content, test weight and Hagberg falling number are some important grain traits. High protein content translates into greater dough strength, while high test weight indicate dense and sound wheat, and low Hagberg falling numbers indicate poor quality dough (Williams 1997; Gooding et al. 1999).

Some researchers have observed that grain protein is higher in conventional systems than in organic systems (Poutala et al. 1993; Starling and Richards 1993). In contrast, Shier et al. (1984) and Ryan et al. (2004) reported no differences in grain protein levels of spring wheat grown in organic and conventional cropping systems, which they attributed to adequate soil nutrient levels in both systems. Soils of organically managed fields often have lower N levels than their conventional counterparts, which may influence organic grain protein content (Nass et al. 2003). The reduction in protein levels in organically grown wheat could also be related to the timing of N availability, since soluble N cannot be added in the later stages of crop growth in organic systems (Starling and Richards 1993). Overall breadmaking quality can be influenced by various soil nutrient deficiencies. Bonfil et al. (1997) reported differences in the protein composition of wheat in N, P, K, S, or Mg deficient soils. Wooding et al. (2000) reported that S deficiencies led to increased levels of high molecular weight glutenins relative to other proteins, thereby increasing dough strength and detrimentally affecting overall baking quality. A study of spring wheat in New Brunswick found that some organically grown varieties did not achieve as high grain protein levels as when grown conventionally, particularly when soil moisture was limiting and cool spring temperatures existed (Nass et al. 2003). Nass et al. (2003) speculated that these factors contributed to reduced mineralization of compost and manure, thereby reducing nutrients supplied to the crop.

1.3 Wheat and Wheat Production

1.3.1 Wheat Origin and Global Production

Wheat (*Triticum aestivum* L.) is the one of the most globally important cereal crops, alongside maize and rice. It is the world's most widely grown crop, cultivated in over 115 nations (Food and Agriculture Organization of the United Nations 2004). In 2004, world production exceeded 560 million t harvested from an area of over 215 million ha (Food and Agriculture Organization of the United Nations 2004).

Wheat is a member of the grass family, Gramineae (=Poaceae), and the genus *Triticum,* which includes several wild and cultivated species and subspecies of wheat. It is thought that wheat originated over 13 000 years ago in the Fertile Crescent, which now encompasses parts of Iran, Iraq, Syria, Jordan and Israel (Feldman 2001). The two most commonly produced wheat species are bread (or common) wheat (*T. aestivum* L.), representing 92% of world production in 1998/99, and durum wheat (*T. turgidum* L.) with 7% of world production in the same year (Pingali 1999). There are both spring and winter types of bread wheat, accounting for 66% and 26% of world wheat production in 1998/99, respectively (Pingali 1999).

Spring wheat (*T. aestivum* L.) is an allohexaploid (2n=6x=42) originating from the hybridization of the tetraploid species *T. turgidum* L. (AABB) with the diploid species *Aegilops tauschii* Coss. (DD) (Poehlman and Sleper 1995; Feldman 2001). Spring wheat is self-pollinating with an annual life cycle and a determinate growth pattern (Stoskopf 1985). The crop exhibits a C3 photosynthetic pathway and can withstand a range of growing temperatures, from ~3°C to ~32°C, with an optimal growing temperature of ~25°C (Stoskopf 1985). Annual precipitation requirements range from 250-1000 mm, but the distribution of the rainfall over the growing season is most important (Stoskopf 1985).

1.3.2 Canadian Wheat Production

Wheat is Canada's most widely grown crop, currently representing ~36% of the area used for crop production (Statistics Canada 2004a). Short-term average (1995-1997) Canadian wheat yields are near 2.3 t ha^{-1}, which is below the world average of 2.5 t ha^{-1}, in part owing to a focus on breeding for disease resistance and high quality in Canadian breeding programs (Pingali 1999) and also due to the semi-arid climate of the Canadian Prairies. Spring wheat is the most widely grown type of wheat in Canada, representing 76% of the national wheat acreage in 2001. Durum wheat accounted for about 20% and winter wheat for the remaining 3% (Statistics Canada 2001). Close to 97% of Canada's wheat is grown in the Prairie provinces, with Saskatchewan being the biggest wheat producer, followed by Alberta and Manitoba, respectively (Statistics Canada 2001).

Canada is the sixth largest producer of wheat in the world after China, the European Union, India, the United States and the Russian Federation, respectively (Canadian Wheat Board 2003). Canada is the world's second largest exporter of wheat, after the United States, with ~70% of its production exported annually (Canadian Wheat Board 2003). To facilitate the Canadian wheat trade, a low-cost method of ensuring grain quality was developed. The system, based on kernel visual distinguishability (KVD) allows for the visual identification and classification of wheat. Canadian wheat varieties are organized into six classes based on a variety of characteristics such as kernel shape and colour, embryo size and shape, and baking characteristics (Table 1-1). Varieties of the Canada Western Red Spring (CWRS) class are the most widely grown in western Canada; comprising about 83% of the hexaploid wheat area in Western Canada in 1998 (Canadian Wheat Board 2001).

1.3.3 Alberta Wheat Production

In Alberta, wheat is the most widely grown crop, representing in terms of area about 30% of all crop production in the province (Alberta Agriculture Food and Rural Development 2001). Of the 2.7 million ha seeded to wheat in Alberta in 2001, almost 85% of it was spring wheat (Statistics Canada 2001). Annual precipitation in Alberta can range from 350-600 mm, with 50-60% occurring in the growing season from May through August (Alberta Agriculture Food and Rural Development 2003a). Temperatures can be variable, but average daily temperatures in July lie between 13 and 18°C and in January between -10 and -24°C (Alberta Agriculture Food and Rural Development 2003a). The agricultural regions of Alberta are considered to be semiarid, averaging less rainfall than the provincial average (Alberta Agriculture Food and Rural Development 2003a).

1.4 Wheat Breeding

1.4.1 Wheat Breeding from a Global Perspective

Over the past 100 years, wheat yields in both developed and developing nations have increased due to a combination of improved varietal performance and an increased use of inputs such as chemical fertilizers, herbicides and pesticides (Ceccarelli 1996). Global wheat breeding efforts over the past 50 years have largely focused on improving both the yield potential and quality of wheat varieties. While these have been two major goals of breeding programs, other areas of focus have included: 1) increasing disease and lodging resistance, 2) improving the response of wheat varieties to chemical fertilizers, and 3) the development of varieties with broad adaptation to various agronomic environments (McCaig and DePauw 1995; Rajaram 2001).

Probably the most significant advance in modern wheat breeding was the introduction of height-reducing (*Rht*) genes and the subsequent development of semidwarf varieties with a higher yielding ability under optimal conditions (Worland and Snape 2001). Semidwarf varieties are much shorter, have greater tillering capacity, higher grain yield per spike and are more responsive to inputs than traditional wheat varieties (Sinha et al. 1981). The wide-scale adoption of these new wheat varieties has resulted in higher yield potential, coupled with an increase in the use of inputs (Bramel-Cox et al. 1991).

1.4.2 History of Canada Western Red Spring (CWRS) Breeding

In Canada, wheat breeding programs geared towards creating disease resistant wheat varieties have been very important, particularly for the CWRS class. One of the most important influences on CWRS wheat variety development was the release of Marquis in 1910 (DePauw and Hunt 2001). In relation to existing varieties at the time (e.g., Red Fife, Hard Red Calcutta), Marquis was a high yielding, high quality, early maturing variety that was widely adapted to different environments, but highly susceptible to stem and leaf rust (vanBeuningen and Busch 1997). Breeding efforts thereafter concentrated on improved disease resistance, resulting in the 1935 release of Thatcher (descendant of Marquis), a variety resistant to rust race 56 and high in quality (Walton 1968). Neepawa (derived from a Thatcher backcross), released in 1969, had increased disease resistance, broad adaptation and high protein content. This set the current standard of quality within the CWRS wheat class (McCaig and DePauw 1995). Concurrently, efforts to increase yield potential continued throughout the century, with grain yield potential in the CWRS class increasing 6-9 kg ha^{-1} yr^{-1} from 1902-1992 (McCaig and DePauw 1995). When compared with the gains in yield potential made in other major wheat producing nations, CWRS gains are low. Australian and Italian bread wheat yield potential has increased in the last century by 5-15 kg ha^{-1} yr^{-1} and 33.5 kg ha^{-1} yr^{-1}, respectively (Perry and D'Antuono 1989; Guarda et al. 2004; Vandeleur and Gill 2004). Canada's comparatively small increase in CWRS grain yield and harvest index over time is likely due to a number of factors. Such factors include Canadian breeding efforts concentrating on high quality and disease resistance, Canada's strict grain classification standards and the extensive use of semidwarf wheat varieties in most of the world, but not in the CWRS wheat class.

1.4.3 Historical and Modern Wheat

With the increased concern over high herbicide and fertilizer use in agriculture worldwide, alternative farming strategies are emerging. Reduced chemical fertilizer and herbicide use may result in changes to the agronomic environment; from the conventional 'stress free' environment to one of increased crop stress. As a result, researchers have begun to question the value of using crop varieties developed for low stress, high input production in higher stress, low input environments (Laing and Fischer 1977; Ceccarelli 1996). It has been hypothesized that wheat varieties developed before the advent of modern, high-input agriculture may be better suited to lower soil nutrient levels and elevated weed competition (Poutala et al. 1993). This theory has encouraged research that has typically focused on the changes in morphological, physiological and agronomic characteristics of wheat and on the effects of N inputs and weed interference on the performance of historical and modern wheat varieties.

Modern bread wheat varieties are typically higher yielding and are shorter than older varieties, leading to an increase in harvest index (McEwan and Cross 1979; Sinha et al. 1981; Kulshrestha and Jain 1982; Austin et al. 1989; Perry and D'Antuono 1989; Guarda et al. 2004; Vandeleur and Gill 2004). Vandeleur and Gill (Vandeleur and Gill 2004) reported that flag leaf length and leaf area index (LAI) have decreased over time in Australian bread wheat. Perry and D'Antuono (1989) reported that both kernels per spike and number of fertile tillers increased in Australian bread wheat from 1860-1982, with a slight decrease in kernel weight over that time. Modern Italian winter wheat varieties are earlier maturing, have better lodging resistance and lower kernel weight compared to historical varieties (Guarda et al. 2004). Numbers of fertile tillers and kernels per spike have increased over time in United Kingdom bread wheats released from 1830-1986, however no changes have occurred in kernel weight (Austin et al. 1989). In Indian wheats released over an eighty year period, higher yield was reported to be the result of an increased number of kernels per spike, while no changes in fertile tillers or kernel weight were observed (Kulshrestha and Jain 1982). Overall, these results indicate that gains in yield potential in wheat may be more related to an increase in kernel number and less so the number of fertile tillers or increased kernel weight.

Researchers have reported that new crop varieties are high yielding under optimal conditions, yet suffer greater yield losses than ancestral varieties when grown under stress conditions (Laing and Fischer 1977; Ceccarelli 1996). In an experiment comparing new and old barley varieties, Ceccarelli (1996) reported that modern barley cultivars significantly outperform Syrian barley landraces in a stress free environment, but in high stress environments the landraces out-yield modern varieties. In contrast, modern wheats of the UK out-yielded older varieties in both weedy and weed-free environments (Vandeleur and Gill 2004) and in maize, newer hybrids have been found to be more tolerant of stress (i.e., low soil moisture, low soil N, weed interference) than older hybrids (Tollenaar and Wu 1999). Another study reported that modern Italian wheat varieties out-yielded historical varieties under different nitrogen regimes, although nitrogen use efficiency increased with release date in Italian wheat (Guarda et al. 2004). The oldest varieties responded best to no N input and the modern varieties responded best to high N input (Guarda et al. 2004). In terms of Canadian bread wheat, breeding programs have typically focused on improving disease resistance, quality and broad adaptation, rather than for increased tolerance to stress. Therefore, the possibility exists that older Canadian breadmaking varieties may be more suited to low-input environments.

While the widespread acceptance of semidwarf wheat varieties has contributed to increased yields and harvest indices, some scientists speculate that semidwarf varieties are less suited to lower soil fertility and moisture levels and to low-input management systems in general (Laing and Fischer 1977; Austin et al. 1989). Semidwarf varieties containing the gibberellic acid (GA) insensitive *Rht-B1b* and *Rht-D1b* (formerly called *Rht1* and *Rht2*, respectively) dwarfing genes exhibit higher partitioning in favour of grains and are more responsive to N inputs than older varieties (Sinha et al. 1981; Worland and Snape 2001). Research has demonstrated that these semidwarf wheat varieties have reduced cell size, contributing to smaller root systems, shorter coleoptile lengths and/or smaller leaf areas than conventional varieties (Gale and Youssefian 1985; Vandeleur and Gill 2004). Conversely, Entz et al. (1992) reported no differences for rooting depth and distribution in the soil for semidwarf and tall wheat varieties in Canada. This variation may indicate that some undesirable characteristics are not common to all semidwarf varieties and may be controlled by specific genes. This, and the use of a GA sensitive dwarfing gene (*Rht8*) that has minimal pleiotropic effects on other plant characteristics, may create the possibility for the modification of undesirable traits through breeding (Gale and Youssefian 1985; Worland and Snape 2001; Ellis et al. 2004).

1.4.4 Historical and Modern CWRS Wheat in Canada

Many of today's modern Canadian hard red spring wheat lines are descendents of Thatcher (1935), and thus ultimately Marquis (1910). Some agronomic characteristics of CWRS varieties have changed over the past century, while others have not. Hucl and Baker (1987) reported (in their study of modern and ancestral Canadian spring wheat varieties registered between 1882 and 1985) a reduction in plant height, but no significant increase in grain yield or harvest index over time. There was a decrease in the length of the vegetative growth phase in CWRS varieties prior to the release of Thatcher, but little change has been seen in that trait since then. The same study also reported a trend of increased kernel weight over time, though changes in number of kernels per spike and tillering capacity over time were inconsistent (Hucl and Baker 1987). In contrast, McCaig and DePauw (1995) found a significant increase (6-9 kg ha^{-1} yr^{-1}) in the yield potential of CWRS wheats over a 90 year period ending in 1992. This increase was attributed mainly to an increase in number of kernels per unit area, since little increase in kernel weight was observed (McCaig and DePauw 1995). Wang et al. (2002) reported that a group of CWRS varieties released from 1994-1997 had increased kernel weight and kernel number per spike when compared to those of the older varieties Neepawa (1969) and Marquis. Significant increases in grain yield and harvest index were observed between the group of new wheat varieties and Marquis, but not for Neepawa (Wang et al. 2002). The small number of studies carried out, and their variable results, suggest the need for more research in this area.

In terms of the relative performance of historical and modern wheats under high stress conditions, very few studies have been carried out in Canada. Hucl and Baker (1987) found that drought conditions had a greater negative impact on yield of the older Canadian wheat cultivars Red Fife and Marquis than on newer wheat cultivars, possibly due to the timing of drought stress in relation to the rate of plant development.

There are only three semidwarf varieties of CWRS wheat: AC Abbey (2000), Superb (2003) and CDC Go (2004) currently registered in Canada; however all of the Canada Prairie Spring (CPS) and Canada Western Soft White Spring (CWSWS) varieties are semidwarf and contain the *Rht-D1b* gene (DePauw and Hunt 2001). If quality can be maintained, future breeding efforts may try to incorporate *Rht* genes into other CWRS varieties as a means to increase harvest indices by reducing aboveground non-grain biomass (Wang et al. 2002).

1.5 Competitive Ability of Wheat

1.5.1 Competitive Ability in Plants

Competition can be defined as the "active demand by two or more organisms or kinds of organisms for some environmental resource in short supply" (Merriam-Webster, 2004). In an agricultural context such resources include light, water and nutrients. In Canada, competition with weeds has reduced crop yields significantly; with documented losses of up to 46% in peas (*Pisum sativum* L.) (Harker 2001), up to 40% in canola (*Brassica napus* L.), 16-29% in barley

(O'Donovan et al. 2000; Didon and Bostrom 2003), and 8-63% in wheat (Kirkland and Hunter 1991; Hucl 1998). In Alberta, wild buckwheat (*Polygonum convolvulus* L.), wild oats (*Avena fatua* L.) and chickweed (*Stellaria media* L.) are the three most abundant weed species in spring wheat crops, occurring in 54%, 46% and 21% of spring wheat fields surveyed in 2001 (Leeson et al. 2002).

Many options exist for weed control, perhaps the most ubiquitous being the use of agrochemicals. Increased herbicide resistance, rising costs of production and an increased interest in environmental protection through the adoption of sustainable and organic management systems are creating the need for researchers to explore non-chemical methods of weed control (Jordan 1993; Lemerle et al. 1996). Such methods include the use of various tillage regimes (Barberi et al. 2000), crop rotations and intercropping (Hartl 1989), crop seeding density (Korres and Froud-Williams 2002), and the use of competitive varieties (Huel and Hucl 1996; Lemerle et al. 1996).

There are two ways to consider the competitive ability of a crop or a plant variety: (a) the ability of a crop to tolerate weed pressure by maintaining grain yield, and (b) the ability of a crop to suppress weed growth and seed production (Coleman et al. 2001). Both are important since yield stability and the prevention of weed seed production and subsequent seed bank build-up are desirable in crops growing in association with weeds (Jordan 1993). Lemerle et al. (2001a) suggested that weed tolerance and weed suppression be considered separately, as they may or may not occur together.

1.5.2 Competitive Ability in Grain Crops

The competitive ability of grain crops was ranked by Pavlychenko and Harrington (1934) in the following order of decreasing competitive ability: barley, rye (*Secale cereale* L.), wheat, and oats. However, Satorre and Snaydon (1992) reported that both barley and oats were more competitive than wheat. Several other studies have found barley to be more competitive than wheat (O'Donovan et al. 1985; Cousens 1996; Fischer et al. 2000).

Yield loss due to weeds in cereal crops can be explained by variations in the cereal yield components. In wheat, the number of fertile tillers per unit area has been found to decrease with increased weed pressure (Kirkland and Hunter 1991; Satorre and Snaydon 1992; Huel and Hucl 1996; Das and Yaduraju 1999; Welsh et al. 1999). The same relationship has been observed in the number of kernels per spike (Satorre and Snaydon 1992; Das and Yaduraju 1999; Welsh et al. 1999). In many studies, the effect of weed interference on kernel weight in wheat has been non-significant (Satorre and Snaydon 1992; Hucl 1998; Welsh et al. 1999; Das and Yaduraju 1999).

Satorre and Snaydon (1992) reported similar results for the yield components of wheat, oat and barley under competition from *Avena fatua* L.; however O'Donovan et al. (1999) reported that competition from *A. fatua* L. caused marginal decreases in the kernel weight of barley. Satorre and Snaydon (1992) suggested that the lack of change in kernel weight as a result of competition may be related to the timing of weed competition. In their experiment, weed competition from *A. fatua* L. subsided in the later stages of cereal development, possibly having less of an effect on kernel weight.

1.5.3 Genetic Variation for Competitive Ability in Wheat

A number of studies have found differences in the competitive ability of genotypes or varieties of crops such as wheat, barley, pea and rice (Wicks et al. 1986; Huel and Hucl 1996; Lemerle et al. 1996; O'Donovan et al. 2000; Caton et al. 2003; McDonald 2003). For producers, knowledge about the competitive ability of varieties would be useful for choosing varieties suited to their environment (Lemerle et al. 2001b). Yield gains of 7-9% have been identified in 'competitive' wheat varieties when compared to 'non-competitive' varieties (Hucl 1998). Morphological, physiological and biochemical traits are thought to control plant competitiveness (Lemerle et al. 2001a). There have been many studies carried out to determine which characters confer competitive ability in wheat. Belowground competition, involving root physiology and morphology, is considered an integral part of weed-crop competition. Satorre and Snaydon (1992) reported that competition between wheat and *A. fatua* L. for soil resources was greater than competition for aboveground resources. Stone et al. (1998) found similar results where aboveground competition from weeds did not affect wheat, while belowground competition reduced wheat height, leaf number, tillering and several other traits. However, studies looking at aboveground morphology and physiology are most common, likely due to the ease associated with the selection for competitiveness based on visual characteristics. As well, many aboveground traits may be related to belowground traits (Singh and Ram 1978; Fageria 2004). Lemerle et al. (1996) found that wheat yield loss and weed dry matter accumulation were correlated with plant morphology and physiology.

Many researchers have determined that plant height plays a role in the competitive ability of wheat (Wicks et al. 1986; Huel and Hucl 1996; Lemerle et al. 1996; Cosser et al. 1997; Champion et al. 1998; Hucl 1998; Korres and Froud-Williams 2002). In a study of Canadian spring wheat varieties, crop height appeared to have the greatest impact on competitive ability, with the shortest wheat varieties experiencing the largest yield reductions and allowing the greatest weed growth (Huel and Hucl 1996). Wicks et al. (1986) suggested however, that height alone does not explain competitive ability, since some shorter varieties have been found to be good competitors. In barley, taller plants were found to be more competitive, but lower yielding than shorter plants, possibly due to resource partitioning in favour of vegetative plant parts over grain yield (O'Donovan et al. 2000). In a comparison of tall and short winter wheat varieties, the taller variety intercepted more photosynthetically active radiation (PAR), accumulated more early dry matter, and accumulated the most nitrogen early in the season. However the taller variety was variable in its ability to suppress weeds and was lower yielding than the shorter varieties (Cosser et al. 1997). The association of plant height with other "competitive" traits further implies that height is not the only factor responsible for competitive ability in wheat.

Canopy structure may have an influence on competitive ability. Champion et al. (1998) found that a tall variety that intercepted a greater percentage of PAR was more effective at suppressing weed growth than a short cultivar with low light interception capabilities (Champion et al. 1998). Interception of PAR at early stem elongation was found to be strongly negatively correlated with yield loss and weed dry matter yield (Lemerle et al. 1996). Grain yields of winter wheat varieties from the United Kingdom were found to be positively correlated with late season light interception (Wicks et al. 1986).

Leaf area index (LAI) may influence competitive ability, as Huel and Hucl (1996) found LAI to be negatively correlated with weed seed yield in their competition study. LAI was not, however, associated with wheat yield reduction resulting from competition with weeds (Huel and Hucl 1996). Flag leaf characteristics have also been found to influence the ability of a variety to suppress weeds and maintain yields. The length of the flag leaf was found to be strongly negatively correlated with wheat yield loss (Huel and Hucl 1996; Lemerle et al. 1996) and weed dry matter yield (Lemerle et al. 1996). Flag leaf angle was also found to be positively correlated with wheat yield reduction (Huel and Hucl 1996). Evidence that early season ground cover also reduces subsequent weed biomass has been reported by Richards and Whytock (1993) and Huel and Hucl (1996). In the Lemerle et al. (1996) study, elevated PAR interception, resulting in high early biomass accumulation, was found in the most competitive wheat genotypes.

In addition to height and canopy structure, tillering capacity (measured as the number of fertile tillers per unit area) has often been reported to confer greater competitive ability in wheat (Lemerle et al. 1996; Hucl 1998; Korres and Froud-Williams 2002). Among other traits, high tiller numbers were found in the most competitive genotypes in a study of wheat genotypes (mainly Australian) from around the world (Lemerle et al. 1996). On the other hand, tiller number has been found to be weakly correlated with weed suppression and grain yield in other studies (Wicks et al. 1986; Champion et al. 1998).

Various other characteristics have been found to contribute to competitiveness, though they are not as commonly reported. In a study of Canadian spring wheat, time of spike emergence was positively correlated with wheat yield reduction and early maturity was associated with competitiveness (Huel and Hucl 1996). In a later study, however, Hucl (1998) found no association between maturity and competitiveness.

It is likely that the association of many traits working together allows a given variety to be more competitive than another (Lemerle et al. 1996). Greater tiller numbers, taller plants, elevated PAR interception and greater early biomass accumulation were all found in the most competitive genotypes in a study of wheat genotypes (mainly Australian) from around the world (Lemerle et al. 1996). Crop height, crop biomass, ground cover and flag leaf length of wheat were found to be negatively correlated with wheat yield reduction in Canadian wheat varieties (Huel and Hucl 1996). Hucl (1998) found that competitive wheat genotypes were taller and had high tiller numbers compared with non-competitive varieties.

The body of literature pertaining to root competition in wheat cropping systems is less extensive than for aboveground traits; however roots play an important role in nutrient and water uptake of plants, as well as in their physical support (Nelson et al. 1984). The structure and functions of roots may be even more important in low-input cropping systems, where nutrient deficiencies and competition from weeds are more common. Relative to many weed species common in cropping systems of the Canadian Prairies, wheat is less effective at both N and P uptake, which may affect weed-crop competition (Blackshaw et al. 2003; Blackshaw et al. 2004)

Pavlychenko and Harrington (1934) suggested that root competitive ability in spring cereals was related to both the extent of the root system and the distribution of the roots in the soil. Some of the aboveground traits thought to be associated with competitive ability are influenced by root traits. Tillering capacity is known to be associated with root number and morphology (Wang and Below 1992). Wang and Below (1992) reported that increased tillering of wheat as a result of mixed N fertilization was associated with increases in root number, branching and enhanced N uptake. Singh and Ram (1978) reported that both tillering and plant height in some wheat varieties were positively associated with the cation exchange capacity of their roots.

There is evidence that genotypic differences exist in root characters of spring wheat varieties. O'Brien (1979) reported that Canadian and Australian wheat varieties exhibited different seminal and lateral rooting depths, lengths and angles. Perhaps more pertinent is that Marquis and Thatcher (a descendent of Marquis) differed in several root characters as well. Satorre and Snaydon (1992) reported that despite a higher level of competition for soil resources than for aerial resources between cereal species (wheat, barley and oats) and *A. fatua* L., the cereals only differed slightly in their root competitive ability against weeds, while there was considerable variation in their shoot competitive ability. They suggest that this is because breeding programs have largely ignored the belowground attributes of wheat and other cereal species. With increased knowledge of genotypic differences in root morphology and physiology of Canadian bread wheat varieties, there may be potential for increasing competitive ability of wheat species by selecting for increased root competitive ability over weeds.

The large volume of research conducted on the subject of crop competition has resulted in numerous suggestions for the direction of future research. Huel and Hucl (1996) tested a number of wheat genotypes for competitive ability against plants of differing growth habits, namely oats and mustard (*Brassica juncea* L.), and found that certain genotypes were effective in suppressing both species. This could mean that the competitive ability of wheat is not weed-specific, or it could simply be that oat and mustard are not strong competitors against wheat. More research is needed to test for weed-specific competitive ability.

Much of the Canadian wheat competition research has involved the use of cultivated crop plants like *Avena sativa*, *Brassica juncea*, *Brassica napus*, etc. (Huel and Hucl 1996; Weiner et al. 2001) or sown densities of wild oat, *Avena fatua* (Kirkland and Hunter 1991). While stressing the need for repeatable trials, Huel and Hucl (1996) suggested that more research is needed to investigate the effect of natural weed populations on the ranking of varieties found to be competitive when tested in controlled environments.

1.5.4 Breeding for competitive ability

Significant differences in the competitive ability of different wheat genotypes have been observed (Wicks et al. 1986; Huel and Hucl 1996; Lemerle et al. 1996), yet the mechanisms by which a crop variety becomes "competitive" are not fully understood. A better understanding of such mechanisms, morphological and physiological, would not only serve to assist plant breeders in developing competitive varieties more quickly and effectively, but would also justify the use of plant breeding to increase crop competitive ability (Lemerle et al. 2001b).

While it is possible that characters that influence the ability of a genotype to withstand yield losses may not be the same as those which allow a genotype to suppress weeds, wheat yield loss and weed dry matter production have been found to be highly positively correlated in wheat (Wicks et al. 1986; Huel and Hucl 1996; Lemerle et al. 1996) and barley (O'Donovan et al. 2000). However, Didon and Bostrom (2003) reported no clear relationship between grain yield loss and weed suppression ability in Swedish barley varieties.

Previous studies have shown that there is much variability in the competitive ability of varieties due to genotype x environment interaction, which is why it is important to test varieties over a wide range of environments and agronomic conditions (Cousens and Mokhtari 1998; Lemerle et al. 2001b; Didon and Bostrom 2003). Varietal performance has to be consistent over years, soil types, and environments in order to make predictions about the competitive ability of a variety (Lemerle et al. 1996). Lemerle et al. (1996) and Cousens and Mokhtari (1998) found more consistency in varietal weed suppression ability over years and sites than varietal tolerances of weeds as measured by grain yield, suggesting that genotype x environment interaction may have a greater influence on grain yield than on weed suppression (Lemerle et al. 2001b).

Environmental conditions that create crop stress and possibly affect competitive ability, such as low soil moisture or fertility, need to be further studied. Pavlychenko and Harrington (1934) considered, to a degree, the relationship between competitive ability and soil moisture deficit in their study of competition in Canadian cereal varieties in the 1930's. Under low soil moisture in early growth stages, cereals had an advantage over weed species; however weeds eventually out-competed the wheat (Pavlychenko and Harrington 1934). As well, work by Richards (1983) suggested that a high leaf area index had undesirable effects on grain yield under drought conditions. Soil fertility can have a pronounced effect on weed and wheat development. In one study, wheat varieties were better able to effectively compete with weeds under high N conditions compared to low soil N conditions (Das and Yaduraju 1999).

Increases in seeding density have resulted in higher levels of weed suppression and increased yields in wheat (Lemerle et al. 1996; Champion et al. 1998; Weiner et al. 2001) and barley (O'Donovan et al. 1999). Champion et al. (1998) found that in wheat, this was true up to a certain density, after which no yield increases were seen. Higher seeding rates increased the number of fertile tillers, but resulted in significant decreases in kernels per spike and grain weight; suggesting interspecific and intraspecific competition effects in wheat (Champion et al. 1998). Korres and Froud-Williams (2002) found that the effect of altering seeding rate was cultivar dependent, with some cultivars showing more weed suppression with increased seeding rates while other varieties showed no significant change in the ability to suppress weeds. Korres and Froud-Williams (2002) concluded that crop density is more reliable than cultivar selection for reducing weed-crop competition.

Lemerle et al. (2001b) suggested that both breeding and agronomy are viable options for increasing competitive ability in wheat. They further suggested that combining the short term use of agronomic tools and the long term goals of plant breeding would be the most favorable option.

1.6 Conclusion

Despite the importance of spring wheat to Canadian agriculture, relatively little research has been conducted with respect to organic wheat production. Varietal selection may alter the productivity of organically managed farming systems. Further, there may be a need for wheat breeding specifically for organic environments, which differ from their conventionally managed counterparts. Historically, Canadian wheat breeding has focused on increasing quality and disease resistance. The CWRS class of wheat has seen a decrease in plant height and a relatively small increase in grain yield potential over the past 100 years. Changes in yield components of CWRS wheat over time have been variable, suggesting the need for more research in this area. Competitive ability can be characterized as the ability of a variety to withstand weed pressure through the maintenance of yield and its ability to suppress weeds. Research suggests that a competitive wheat variety exhibits a suite of 'competitive' traits, such as tallness, superior early season growth, increased leaf area and high tillering capacity, and more research is needed to determine the role of root systems on competitive ability. Possibilities exist for the use of plant breeding and agronomy to increase crop competitive ability in both organic and conventional environments.

1.7 Objectives

The organic sector is the fastest growing food sector in Canada, and demand for organic grain products is increasing at a rapid rate. Over 325 000 ha on the Canadian Prairies were dedicated to organic grain production in 2003, however the current Canadian body of knowledge pertaining to organic grain production is relatively slight. Information about the performance of wheat cultivars in organic compared to conventional management systems is needed in order to determine whether breeding specifically for organically managed or low-input environments is necessary. Historical and modern wheat cultivars may perform differently in organic and conventional systems; yet Canadian research pertaining to the performance of historical and modern wheat cultivars has thus far dealt with a relatively small number of genotypes and has been conducted only on conventionally managed land. Because the intensity of weed-crop competition is often greater under organic management, identification of plant traits that confer competitive ability in wheat cultivars would assist plant breeders in the development of competitive grain cultivars. The identification of 1) competitive grain cultivars and 2) agronomic practices that increase crop competitive ability could help local wheat producers overcome some of the production constraints that accompany increased weed competition.

The objectives of the present thesis research were to:

1. Investigate whether spring wheat cultivars exhibit different agronomic capabilities when grown under organic and conventional management systems.
2. Evaluate the breadmaking quality of organically and conventionally grown Canadian bread wheat cultivars.
3. Determine the effect of tame oat competition, cultivar and seeding rate on the competitive ability and agronomic performance of Canadian spring wheat and barley in organic management systems.
4. Establish plant traits, such as height and tillering capacity, which affect the competitive ability of Canadian spring wheat cultivars grown in conventional and organic systems.
5. Identify differences among cultivar stability in and adaptation to environments differing in yield potential and weed competition.

The underlying null hypotheses tested were:

1. Spring wheat cultivars do not exhibit different agronomic capabilities when grown under organic and conventional management systems.
2. Organically and conventionally grown bread wheat cultivars do not differ in their breadmaking quality.
3. Tame oat competition, cultivar and seeding rate have no effect on the competitive ability and agronomic performance of spring wheat grown under organic management systems.
4. Plant traits, such as height and tillering capacity, have no effect on the competitive ability of spring wheat in organic and conventional systems.
5. Cultivars do not differ in their stability in and adaptation to environments differing in yield potential and weed competition.

1.8 Tables

Table 1-1. Descriptions of Canadian Spring Wheat Classes.[†]

Class	Description
Canada Western Red Spring (CWRS)	Also known as Hard Red Spring Wheat (HRSW). A hard wheat with superior milling and baking properties due to its high water absorption and strong gluten. Mean grain protein content of 13.6%.
Canada Western Amber Durum (CWAD)	Excellent pasta-making quality due to a high yield of semolina. Protein content of less than 13.5%.
Canada Prairie Spring Red (CPSR)	A medium-strength wheat with a reddish coloured kernel used in the making flat breads, hearth breads, noodles and associated products. CPSR varieties are 25-30% higher yielding than CWRS cultivars and contain 1 to 2% less protein.
Canada Prairie Spring White (CPSW)	A medium-strength wheat with white kernels used for producing flat breads, noodles, chapattis and related goods.
Canada Western Extra Strong (CWES)	A hard red wheat with extra-strong gluten suitable for blending with weaker flours, use in frozen dough, and for making special breads. Protein content is slightly lower than varieties of CWRS class.
Canada Western Soft White Spring (CWSWS)	A soft-textured white wheat suitable for the production of cakes, cookies and pastry as well as flat breads, noodle and the like. Protein content is generally under 10.5%.

[†](DePauw and Hunt 2001; Preston et al. 2003).

1.9 Literature Cited

Agriculture and Agri-Food Canada. 2000. Organic Grains and Oilseeds. Bi-Weekly Bulletin. [Online] Available: http://www.agr.gc.ca/mad-dam/e/bulletine/v13e/v13n05e.pdf [6 February 2003].

Alberta Agriculture Food and Rural Development. 2001. 2001 Census of Agriculture for Alberta - Provincial Highlights. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd5728/$file/2001census-brochure.pdf?OpenElement [12 October 2006].

Alberta Agriculture Food and Rural Development. 2003a. Agroclimatic Atlas of Alberta. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6278?opendocument [12 October 2006].

Alberta Agriculture Food and Rural Development. 2003b. Using 1,000 kernel weight for calculating seeding rates and harvest losses. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex81/$file/100_22-1.pdf?OpenElement [14 July 2006].

Alberta Agriculture Food and Rural Development. 2004. Soil Group Map of Alberta. [Online] Available: http://www1.agric.gov.ab.ca/soils/soils.nsf/soilgroupmap?readform [31 August 2006].

Alberta Agriculture Food and Rural Development. 2006. Herbicide Selector. [Online] Available: http://www.agric.gov.ab.ca/app23/herbsel [29 September 2006].

Ames, N. P., Clarke, J. M., Dexter, J. E., Woods, S. M., Selles, F. and Marchylo, B. 2003. Effects of nitrogen fertilizer on protein quantity and gluten strength parameters in durum wheat (*Triticum turgidum* L. var. *durum*) cultivars of variable gluten strength. Cereal Chem. **80**:203-211.

Anonymous. 2004. Official Grain Grading Guide, revised August 1, 2004. Canadian Grain Commission, Winnipeg, Canada. pp.

Austin, R. B., Ford, M. A. and Morgan, C. L. 1989. Genetic improvement in the yield of winter wheat - a further evaluation. J. Agric. Sci. **112**:295-301.

Barberi, P. 2002. Weed management in organic agriculture: are we addressing the right issues? Weed Res. **42**:177-193.

Barberi, P., Silvestri, N., Peruzzi, A. and Raffaelli, M. 2000. Finger-harrowing of durum wheat under different tillage systems. Biol. Agric. Hortic. **17**:285-303.

Bavec, M., Bavec, F., Varga, B. and Kovacevic, V. 2002. Relationships among yield, its quality and yield components, in winter wheat (*Triticum aestivum* L.) cultivars affected by seeding rates. Bodenkultur **53**:143-151.

Bertholdsson, N.-O. 2005. Early vigour and allelopathy- two useful traits for enhanced barley and wheat competitiveness against weeds. Weed Res. **45**:94-102.

Bhatty, R. S., MacGregor, A. W. and Bhatty, R. S. 1993. Nonmalting Uses of Barley Barley Chemistry and Technology. American Association of Cereal Chemists, Inc., St. Paul, MN.

Blackshaw, R. E., Brandt, R. N., Janzen, H. H. and Entz, T. 2004. Weed species response to phosphorus fertilization. Weed Sci. **52**:406-412.

Blackshaw, R. E., Brandt, R. N., Janzen, H. H., Entz, T., Grant, C. A. and Derksen, D. A. 2003. Differential response of weed species to added nitrogen. Weed Sci. **51**:532-539.

Bonfil, D. J., Czosnek, H. and Kafkafi, U. 1997. Changes in wheat seed storage protein fingerprint due to soil mineral content. Euphytica **95**:209-219.

Bramel-Cox, P. J., Barker, T. C., Avala-Garcia, F. and Astin, J. D. 1991. Selection and Testing Environments for Improved Performance under Reduced-Input Conditions, p. 29-56, *In* D. A. Sleper, et al., eds. Plant Breeding and Sustainable Agriculture: Considerations for Objectives and Methods. CSSA Special Publication 18.

Bruinsma, J. 2003. World Agriculture : Towards 2015/2030 : An FAO Perspective. 12th ed. Earthscan, London. 432 pp.

Burger, M. and Jackson, L. E. 2003. Microbial immobilization of ammonium and nitrate in relation to ammonification and nitrification rates in organic and conventional cropping systems. Soil Biol. Biochem. **35**:29-36.

Canadian Grain Commission. 2006. Crop quality data, highlights and reports: Canadian western wheat. [Online] Available: http://www.grainscanada.gc.ca/Quality/Wheat/cdnwhtmenu-e.htm [2006.

Canadian Wheat Board. 2001. Grain Matters: Wheat report for the 1999-2000 crop year. [Online] Available: http://www.cwb.ca/en/publications/farmers/jan-feb-2001/02-12-00-6.jsp [8 November 2003].

Canadian Wheat Board. 2003. 2002-2003 Statistical Tables. [Online] Available: http://www.cwb.ca/en/publications/students_researchers/pdf/2002-03_full_english_statistics.pdf [12 October 2006].

Canadian Wheat Board. 2005. Canada Western Red Spring wheat- CWRS. [Online] Available: http://www.cwb.ca/en/buying/high_quality/2005/no1cwrs [13 July 2005].

Carpenter-Boggs, L., Kennedy, A. C. and Reganold, J. P. 2000. Organic and biodynamic management: Effects on soil biology. Soil Sci. Soc. Am. J. **64**:1651-1659.

Caton, B. P., Cope, A. E. and Mortimer, M. 2003. Growth traits of diverse rice cultivars under severe competition: implications for screening for competitiveness. Field Crops Res. **83**:157-172.

Cauvain, S. P. 2003. Wheat and its Special Properties, p. 2-3, *In* X. P. Cauvain, ed. Bread Making: Improving Quality. Woodhead Publishing Ltd., Cambridge, England.

Ceccarelli, S. 1996. Adaptation to low high input cultivation. Euphytica **92**:203-214.

Champion, G. T., Froud-Williams, R. J. and Holland, J. M. 1998. Interactions between wheat (*Triticum aestivum* L.) cultivar, row spacing and density and the effect on weed suppression and crop yield. Ann. Appl. Biol. **133**:443-453.

Chemists, A. A. o. C., (ed.) 2000. Approved Methods of the AACC. The Association, St. Paul, MN.

Clark, S., Klonsky, K., Livingston, P. and Temple, S. 1999. Crop-yield and economic comparisons of organic, low-input, and conventional farming systems in California's Sacramento Valley. Am. J. Altern. Agric. **14**:109-121.

Coleman, R. D., Gill, G. S. and Rebetzke, G. J. 2001. Identification of quantitative trait loci for traits conferring weed competitiveness in wheat (*Triticum aestivum* L.). Aust. J. Agric. Res. **52**:1235-1246.

Cosser, N. D., Gooding, M. J., Thompson, A. J. and Froud-Williams, R. J. 1997. Competitive ability and tolerance of organically grown wheat cultivars to natural weed infestations. Ann. Appl. Biol. **130**:523-535.

Cousens, R. D. 1996. Comparative growth of wheat, barley, and annual ryegrass (*Lolium rigidum*) in monoculture and mixture. Aust. J. Agric. Res. **47**:449-464.

Cousens, R. D., Barnett, A. G. and Barry, G. C. 2003. Dynamics of competition between wheat and oat: I. Effects of changing the timing of phenological events. Agron. J. **95**:1295-1304.

Cousens, R. D. and Mokhtari, S. 1998. Seasonal and site variability in the tolerance of wheat cultivars to interference from *Lolium rigidum*. Weed Res. **38**:301-307.

Das, T. K. and Yaduraju, N. T. 1999. Effect of weed competition on growth, nutrient uptake and yield of wheat as affected by irrigation and fertilizers. J. Agric. Sci. **133**:45-51.

DePauw, R. and Hunt, T. 2001. Canadian Wheat Pool, p. 479-515, *In* A. P. Bonjean and W. J. Angus, eds. The World Wheat Book: A History of Wheat Breeding. Lavoisier Publishing, Paris, France.

Dexter, J. E., Crowle, W. L., Matsuo, R. R. and Kosmolak, F. G. 1982. Effect of nitrogen-fertilization on the quality characteristics of 5 North-American amber durum-wheat cultivars. Can. J. Plant Sci. **62**:901-912.

Didon, U. M. E. and Bostrom, U. 2003. Growth and development of six barley (*Hordeum vulgare* ssp. *vulgare* L.) cultivars in response to a model weed (*Sinapis alba* L.). J. Agron. Crop Sci. **189**:409-417.

Ellis, M. H., Rebetzke, G. J., Chandler, P., Bonnett, D., Spielmeyer, W. and Richards, R. A. 2004. The effect of different height reducing genes on the early growth of wheat. Funct. Plant Biol. **31**:583-589.

Emmerling, C., Udelhoven, T. and Schroder, D. 2001. Response of soil microbial biomass and activity to agricultural de-intensification over a 10 year period. Soil Biol. Biochem. **33**:2105-2114.

Entz, M. H., Gross, K. G. and Fowler, D. B. 1992. Root growth and soil-water extraction by winter and spring wheat. Can. J. Plant Sci. **72**:1109-1120.

Entz, M. H., Guilford, R. and Gulden, R. 2001. Crop yield and soil nutrient status on 14 organic farms in the eastern portion of the northern Great Plains. Can. J. Plant Sci. **81**:351-354.

Environment Canada. 2004a. Canadian Climate Normals 1971-2000. Edmonton City Centre. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html [31 August 2006].

Environment Canada. 2004b. Canadian Climate Normals 1971-2000. Camrose. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html [31 August 2006].

Environment Canada. 2004c. Canadian Climate Normals 1971-2000. Lacombe. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html [31 August 2006].

Environment Canada. 2004d. Monthly data report for 2003/2004. Camrose. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/climateData/monthlydata_e.html [31 August 2006].

Environment Canada. 2004e. Monthly data report for 2003/2004. Lacombe. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/climateData/monthlydata_e.html [31 August 2006].

Fageria, N. K. 2004. Influence of dry matter and length of roots on growth of five field crops at varying soil zinc and copper levels. J. Plant Nutr. **27**:1517-1523.

Feldman, M. 2001. Origin of Cultivated Wheat, p. 4-56, *In* A. P. Bonjean and W. J. Angus, eds. The World Wheat Book: A History of Wheat Breeding. Lavoisier Publishing, Paris, France.

Fischer, A. J., Messersmith, C. G., Nalewaja, J. D. and Duysen, M. E. 2000. Interference between spring cereals and *Kochia scoparia* related to environment and photosynthetic pathways. Agron. J. **92**:173-181.

Food and Agriculture Organization of the United Nations. 2004. FAOSTAT Classic-Production- Crops Primary. [Online] Available: http://faostat.fao.org/site/408/default.aspx [12 October 2006].

Fowler, D. B. and De la Roche, I. A. 1975. Wheat quality evaluation. 3. Influence of genotype and environment. Can. J. Plant Sci. **55**:263-269.

Fowler, D. B. and Kovacs, M. I. P. 2004. Influence of protein concentration on farinograph absorption, mixing requirements and mixing tolerance. Can. J. Plant Sci. **84**:765-772.

French, R. J. and Schultz, J. E. 1984. Water-use efficiency of wheat in a Mediterranean-type environment. 1. The relation between yield, water-use and climate. Aust. J. Agric. Res. **35**:743-764.

Frick, B. 1993. Weed Communities in Organic and "Conventional" Wheat Fields, p. 164-169 Soil and Crops Workshop, University of Saskatchewan, Saskatoon.

Gale, M. D. and Youssefian, S. 1985. Dwarfing Genes in Wheat, p. 1-35, *In* G. E. Russell, ed. Progress in Plant Breeding. Butterworths, London, UK.

Geleta, B., Atak, M., Baenziger, P. S., Nelson, L. A., Baltenesperger, D. D., Eskridge, K. M., Shipman, M. J. and Shelton, D. R. 2002. Seeding rate and genotype effect on agronomic performance and end-use quality of winter wheat. Crop Sci. **42**:827-832.

Goldberg, D. E. and Landa, K. 1991. Competitive effect and response: Hierarchies and correlated traits in the early stages of competition. J. Ecol. **79**:1013-1030.

Gomez, K. A. and Gomez, A. A. 1984. Statistical Procedures for Agricultural Research. 2nd ed. John Wiley and Sons, Inc., New York, NY. 680 pp.

Gooding, M. J., Cannon, N. D., Thompson, A. J. and Davies, W. P. 1999. Quality and value of organic grain from contrasting breadmaking wheat varieties and near isogenic lines differing in dwarfing genes. Biol. Agric. Hortic. **16**:335-350.

Gooding, M. J., Davies, W. P., Thompson, A. J. and Smith, S. P. 1993a. The challenge of achieving breadmaking quality in organic and low input wheat in the UK- a review. Aspects Appl. Biol. **36**:189-198.

Gooding, M. J., Pinyosinwat, A. and Ellis, R. H. 2002. Responses of wheat grain yield and quality to seed rate. J. Agric. Sci. **138**:317-331.

Gooding, M. J., Thompson, A. J. and Davies, W. P. 1993b. Interception of photosynthetically active radiation, competitive ability and yield of organically grown wheat varieties. Aspects Appl. Biol. **34**:355-362.

Granstedt, A. and Kjellenberg, L. 1997. Long-term field experiments in Sweden: Effects of organic and inorganic fertilizers on soil fertility and crop quality. [Online] Available: http://www.jdb.se/sbfi/publ/boston/boston7.htmL [29 September 2006].

Guarda, G., Padovan, S. and Delogu, G. 2004. Grain yield, nitrogen-use efficiency and baking quality of old and modern Italian bread-wheat cultivars grown at different nitrogen levels. Eur. J. Agron. **21**:181-192.

Guttieri, M. J., Ahmad, R., Stark, J. C. and Souza, E. 2000. End-use quality of six hard red spring wheat cultivars at different irrigation levels. Crop Sci. **40**:631-635.

Hameed, E., Shah, W. A., Shad, A. A., Bakht, J. and Muhammad, T. 2003. Effect of different planting dates, seed rate and nitrogen levels on wheat. Asian J. Plant Sci. **2**:467-474.

Harker, K. N. 2001. Survey of yield losses due to weeds in central Alberta. Can. J. Plant Sci. **81**:339-342.

Hartl, W. 1989. Influence of undersown clovers on weeds and on the yield of winter-wheat in organic farming. Agric. Ecosyst. Environ. **27**:389-396.

Hawkins, H. J., Johansen, A. and George, E. 2000. Uptake and transport of organic and inorganic nitrogen by arbuscular mycorrhizal fungi. Plant Soil **226**:275-285.

Hucl, P. 1998. Response to weed control by four spring wheat genotypes differing in competitive ability. Can. J. Plant Sci. **78**:171-173.

Hucl, P. and Baker, R. J. 1987. A study of ancestral and modern Canadian spring wheats. Can. J. Plant Sci. **67**:87-97.

Huel, D. G. and Hucl, P. 1996. Genotypic variation for competitive ability in spring wheat. Plant Breed. **115**:325-329.

Jenner, C. F., Ugalde, T. D. and Aspinall, D. 1991. The physiology of starch and protein deposition in the endosperm of wheat. Aust. J. Plant Physiol. **18**:211-226.

Johansson, E., Prieto-Linde, M. L., Svensson, G. and Jonsson, J. O. 2003. Influences of cultivar, cultivation year and fertilizer rate on amount of protein groups and amount and size distribution of mono- and polymeric proteins in wheat. J. Agric. Sci. **140**:275-284.

Jordan, N. 1993. Prospects for weed-control through crop interference. Ecol. Appl. **3**:84-91.

Kaur, K., Lukow, O. M., Preston, K. R. and Malcolmson, L. J. 2004. How well do early-generation quality tests predict flour performance? Can. J. Plant Sci. **84**:71-78.

Khatkar, B. S., Bell, A. E. and Schofield, J. D. 1996. A comparative study of the inter-relationships between Mixograph parameters and bread-making qualities of wheat flours and glutens. J. Sci. Food Agric. **72**:71-85.

Kimball, B. A., Morris, C. F., Pinter, P. J., Wall, G. W., Hunsaker, D. J., Adamsen, F. J., LaMorte, R. L., Leavitt, S. W., Thompson, T. L., Matthias, A. D. and Brooks, T. J. 2001. Elevated CO_2, drought and soil nitrogen effects on wheat grain quality. New Phytol. **150**:295-303.

Kirkland, K. J. and Hunter, J. H. 1991. Competitiveness of Canada Prairie Spring wheats with wild oat (*Avena fatua* L.). Can. J. Plant Sci. **71**:1089-1092.

Kitchen, J. L., McDonald, G. K., Shepherd, K. W., Lorimer, M. F. and Graham, R. D. 2003. Comparing wheat grown in South Australian organic and conventional farming systems. 1. Growth and grain yield. Aust. J. Agric. Res. **54**:889-901.

Korres, N. E. and Froud-Williams, R. J. 2002. Effects of winter wheat cultivars and seed rate on the biological characteristics of naturally occurring weed flora. Weed Res. **42**:417-428.

Kulshrestha, V. P. and Jain, H. K. 1982. 80 years of wheat breeding in India - past selection pressures and future-prospects. Z. Pflanzenzucht. **89**:19-30.

L-Baeckstrom, G., Hanell, U. and Svensson, G. 2004. Baking quality of winter wheat grown in different cultivating systems, 1992-2001: A holistic approach. J. Sustain. Agric. **24**:53-79.

Laing, D. R. and Fischer, R. A. 1977. Adaptation of semidwarf wheat cultivars to rainfed conditions. Euphytica **26**:129-139.

Leeson, J. Y., Sheard, J. W. and Thomas, G. A. 2000. Weed communities associated with arable Saskatchewan farm management systems. Can. J. Plant Sci. **80**:177-185.

Leeson, J. Y., Thomas, A. G. and Hall, L. M. 2002. Alberta Weed Survey of Cereal, Oilseed and Pulse Crops in 2001. Agriculture and Agri-Food Canada, Saskatoon, SK.

Lemerle, D., Gill, G. S., Murphy, C. E., Walker, S. R., Cousens, R. D., Mokhtari, S., Peltzer, S. J., Coleman, R. and Luckett, D. J. 2001a. Genetic improvement and agronomy for enhanced wheat competitiveness with weeds. Aust. J. Agric. Res. **52**:527-548.

Lemerle, D., Verbeek, B., Cousens, R. D. and Coombes, N. E. 1996. The potential for selecting wheat varieties strongly competitive against weeds. Weed Res. **36**:505-513.

Lemerle, D., Verbeek, B. and Orchard, B. 2001b. Ranking the ability of wheat varieties to compete with *Lolium rigidum*. Weed Res. **41**:197-209.

Lerner, S. E., Seghezzo, M. L., Molfese, E. R., Ponzio, N. R., Cogliatti, M. and Rogers, W. J. 2006. N- and S-fertiliser effects on grain composition, industrial quality and end-use in durum wheat. J. Cereal Sci. **44**:2-11.

Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D. and Shabenberger, O., (eds.) 2006. SAS for Mixed Models. SAS Institute Inc., Cary, NC.

Lloveras, J., Lopez, A., Ferran, J., Espachs, S. and Solsona, J. 2001. Bread-making wheat and soil nitrate as affected by nitrogen fertilization in irrigated Mediterranean conditions. Agron. J. **93**:1183-1190.

Lotter, D. W., Seidel, R. and Liebhardt, W. 2003. The performance of organic and conventional cropping systems in an extreme climate year. Am. J. Altern. Agric. **18**:146-154.

Mader, P., Edenhofer, S., Boller, T., Wiemken, A. and Niggli, U. 2000. Arbuscular mycorrhizae in a long-term field trial comparing low-input (organic, biological) and high-input (conventional) farming systems in a crop rotation. Biol. Fertil. Soils **31**:150-156.

Mason, M. G. and Madin, R. W. 1996. Effect of weeds and nitrogen fertiliser on yield and grain protein concentration of wheat. Aust. J. Exp. Agric. **36**:443-450.

McCaig, T. N. and DePauw, R. M. 1995. Breeding hard red spring wheat in western Canada - historical trends in yield and related variables. Can. J. Plant Sci. **75**:387-393.

McDonald, G. K. 2003. Competitiveness against grass weeds in field pea genotypes. Weed Res. **43**:48-58.

McEwan, J. M. and Cross, R. J. 1979. Evolutionary changes in New Zealand wheat cultivars, pp. 193-203, *In* S. Ramanujam, (ed.) Proc. Fifth International Wheat Genetics Symposium. Volume 1. Session II Conservation, classification and cataloguing of genetic resources. Indian Society of Genetics and Plant Breeding, New Delhi, India.

Merriam-Webster. 2004. Merriam-Webster Online Dictionary. [Online] Available: http://www.m-w.com [12 October 2006].

Nass, H. G., Ivany, J. A. and MacLeod, J. A. 2003. Agronomic performance and quality of spring wheat and soybean cultivars under organic culture. Am. J. Altern. Agric. **18**:164-170.

Nelson, C. J., Larson, K. L. and Tesar, M. B. 1984. Seedling Growth, p. 93-129 Physiological Basis of Crop Growth and Development. American Society of Agronomy, Inc., Crop Science Society of America, Inc., Madison,WI.

Ngouajio, M. and McGiffen, M. E. 2002. Going organic changes weed population dynamics. HortTechnol. **12**:590-596.

Norwest Labs. 2003. Agricultural Schedule of Services. [Online] Available: http://www.norwestlabs.com/what_we_do/agrisos20032004noprices.pdf [29 September 2006].

O'Brien, L. 1979. Genetic-variability of root-growth in wheat (*Triticum aestivum* L.). Aust. J. Agric. Res. **30**:587-595.

O'Donovan, J. T., Destremy, E. A., O'Sullivan, P. A., Dew, D. A. and Sharma, A. K. 1985. Influence of the relative-time of emergence of wild oat (*Avena fatua*) on yield loss of barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*). Weed Sci. **33**:498-503.

O'Donovan, J. T., Harker, K. N., Clayton, G. W. and Hall, L. M. 2000. Wild oat (*Avena fatua*) interference in barley (*Hordeum vulgare*) is influenced by barley variety and seeding rate. Weed Technol. **14**:624-629.

O'Donovan, J. T., Harker, K. N., Clayton, G. W., Newman, J. C., Robinson, D. and Hall, L. M. 2001. Barley seeding rate influences the effects of variable herbicide rates on wild oat. Weed Sci. **49**:746-754.

O'Donovan, J. T., Newman, J. C., Harker, K. N., Blackshaw, R. E. and McAndrew, D. W. 1999. Effect of barley plant density on wild oat interference, shoot biomass and seed yield under zero tillage. Can. J. Plant Sci. **79**:655-662.

Ohm, J. B. and Chung, O. K. 1999. Gluten, pasting, and mixograph parameters of hard winter wheat flours in relation to breadmaking. Cereal Chem. **76**:606-613.

Organic Agriculture Centre of Canada. 2006. Summary Table of Alberta Purchase Prices for Organic Crops - January 2005. [Online] Available: http://www.oacc.info/DOCs/AB%20Summary%20Tbl.pdf#search=%22oacc%20alberta%20crop%20price%22 [31 August 2006].

Organic Crop Improvement Association. 2000. International Certification Standards As Revised: March 2000. OCIA International, Inc., Lincoln, NE.

Pavlychenko, T. K. and Harrington, J. B. 1934. Competitive efficiency of weeds and cereal crops. Can. J. Res. **10**:77-94.

Perry, M. W. and D'Antuono, M. F. 1989. Yield improvement and associated characteristics of some Australian spring wheat cultivars introduced between 1860 and 1982. Aust. J. Agric. Res. **40**:457-472.

Peterson, C. J., Graybosch, R. A., Shelton, D. R. and Baenziger, P. S. 1998. Baking quality of hard winter wheat: Response of cultivars to environment in the great plains (Reprinted from Wheat: Prospects for global improvement, 1998). Euphytica **100**:157-162.

Pingali, P. L. 1999. CIMMYT 1998-1999 World Wheat Facts and Trends. Global Wheat Research in a Changing World: Challenges and Achievements. CIMMYT, Mexico, D.F.

Poehlman, J. M. and Sleper, D. A. 1995. Breeding Field Crops. 4th ed. Iowa State University Press, Iowa, USA. 494 pp.

Pon, C. R., Lukow, O. M. and Buckley, D. J. 1989. A multichannel, computer-based system for analyzing dough rheology. J. Texture Stud. **19**:343-360.

Poutala, R. T., Korva, J. and Varis, E. 1993. Spring wheat cultivar performance in ecological and conventional cropping systems. J. Sustain. Agric. **3**:63-84.

Preston, K. R., Hatcher, D. W., Stevenson, S. G. and Marchylo, B. A. 2003. Quality of western Canadian wheat [Online] Available: http://www.grainscanada.gc.ca/Quality/Wheat/2003/cdnwht-2003-e.pdf [12 October 2006].

Preston, K. R., Hucl, P., Townley-Smith, T. F., Dexter, J. E., Williams, P. C. and Stevenson, S. G. 2001. Effects of cultivar and environment on farinograph and Canadian short process mixing properties of Canada western red spring wheat. Can. J. Plant Sci. **81**:391-398.

Rajaram, S. 2001. Prospects and promise of wheat breeding in the 21st century. Euphytica **119**:3-15.

Randall, P. J., Freney, J. R., Smith, C. J., Moss, H. J., Wrigley, C. W. and Galbally, I. E. 1990. Effect of additions of nitrogen and sulfur to irrigated wheat at heading on grain-yield, composition and milling and baking quality. Aust. J. Exp. Agric. **30**:95-101.

Revilla, P., Butron, A., Malvar, R. A. and Ordas, A. 1999. Relationships among kernel weight, early vigour and growth in maize. Crop Sci. **39**:654-658.

Rharrabti, Y., Royo, C., Villegas, D., Aparicio, N. and del Moral, L. F. G. 2003. Durum wheat quality in Mediterranean environments I. Quality expression under different zones, latitudes and water regimes across Spain. Field Crops Res. **80**:123-131.

Richards, M. C. and Whytock, G. P. 1993. Varietal competitiveness with weeds. Aspects Appl. Biol. **34**:345-354.

Richards, R. A. 1983. Manipulation of leaf-area and its effect on grain-yield in droughted wheat. Aust. J. Agric. Res. **34**:23-31.

Ryan, M. H., Derrick, J. W. and Dann, P. R. 2004. Grain mineral concentrations and yield of wheat grown under organic and conventional management. J. Sci. Food Agric. **84**:207-216.

Sahota, A. 2004. Overview of the Global Market for Organic Food and Drink, 6th ed. International Federation of Organic Agriculture Movements, Tholey-Theley, Germany.

Sahs, W. W. and Lesoing, G. 1985. Crop rotations and manure versus agricultural chemicals in dryland grain production. J. Soil Water Conserv. **40**:511-516.

Samuel, A. M. and Guest, S. J. 1990. Weed studies in organic and conventional cereals. British Crop Proteciton Council, Farnham, Surrey, UK.

SAS Institute. 1999. Release 8.2. SAS Institute, Cary, NC.

SAS Institute. 2003. Release 9.1. SAS Institute, Cary, NC.

Satorre, E. H. and Snaydon, R. W. 1992. A comparison of root and shoot competition between spring cereals and *Avena fatua*. Weed Res. **32**:45-55.

Scursoni, J. A. and Satorre, E. H. 2005. Barley (*Hordeum vulgare*) and wild oat (*Avena fatua*) competition is affected by crop and weed density. Weed Technol. **19**:790-795.

Shier, N. W., Kelman, J. and Dunson, J. W. 1984. A comparison of crude protein, moisture, ash and crop yield between organic and conventionally grown wheat. Nutr. Rep. Int. **30**:71-76.

Singh, S. and Kapoor, K. K. 1999. Inoculation with phosphate-solubilizing microorganisms and a vesicular arbuscular mycorrhizal fungus improves dry matter yield and nutrient uptake by wheat grown in a sandy soil. Biol. Fertil. Soils **28**:139-144.

Singh, S. and Ram, L. C. 1978. Studies of relationships between cation-exchange capacity of plant roots and tillering and plant-growth of different varieties of paddy and wheat crops. Plant Soil **49**:661-665.

Sinha, S. K., Aggarwal, P. K., Chaturvedi, G. S., Koundal, K. R. and Khannachopra, R. 1981. A comparison of physiological and yield characters in old and new wheat-varieties. J. Agric. Sci. **97**:233-236.

Souza, E. J., Martin, J. M., Guttieri, M. J., O'Brien, K. M., Habernicht, D. K., Lanning, S. P., McLean, R., Carlson, G. R. and Talbert, L. E. 2003. Influence of genotype, environment, and nitrogen management on spring wheat quality. Crop Sci. **44**:425-432.

Starling, W. and Richards, M. C. 1993. Quality of commercial samples of organically grown wheat. Aspects Appl. Biol. **36**:205-209.

Statistics Canada. 2001. Wheat, by provinces (1981-2001 Censuses of Agriculture). [Online] Available: http://www.statcan.ca/english/Pgdb/agrc26a.htm [12 October 2006].

Statistics Canada. 2004a. Canadian Statistics-Field and Specialty Crops, by Province. [Online] Available: http://www.statcan.ca/english/Pgdb/agricul.htm#crops [6 February 2004].

Statistics Canada. 2004b. Certified organic farming, by provinces (2001 Census of Agriculture) [Online] Available: http://www.statcan.ca/english/Pgdb/agricul.htm#farms [12 January 2005].

Steel, R. G. D., Torrie, J. H. and Dickey, D. A. 1996. Principles and Procedures of Statistics: A Biometrical Approach. 3rd ed. McGraw-Hill, New York, NY. 666 pp.

Stein-Bachinger, K. and Werner, W. 1997. Effect of manure on crop yield and quality in an organic agricultural system. Biol. Agric. Hortic. **14**:221-235.

Stone, M. J., Cralle, H. T., Chandler, J. M., Bovey, R. W. and Carson, K. H. 1998. Above- and belowground interference of wheat (*Triticum aestivum*) by Italian ryegrass (*Lolium multiflorum*). Weed Sci. **46**:438-441.

Stopes, C. and Millington, S. 1991. Weed control in organic farming systems, pp. 185-192 Brighton Crop Protection Conference-Weeds, Brighton, UK.

Storey, T., Hogan, R. and Humphreys, J. 1993. The growth, yield and quality of winter wheat and winter oats grown under an organic conversion regime. Aspects Appl. Biol. **36**:199-204.

Stoskopf, N. C. 1985. Cereal Grain Crops. Reston Publishing Co., Inc, Reston, Virginia. pp.

Thompson, G. B. and Woodward, F. I. 1994. Some influences of CO_2 enrichment, nitrogen nutrition and competition on grain-yield and quality in spring wheat and barley. J. Exp. Bot. **45**:937-942.

Tollenaar, M. and Wu, J. 1999. Yield improvement in temperate maize is attributable to greater stress tolerance. Crop Sci. **39**:1597-1604.

vanBeuningen, L. T. and Busch, R. H. 1997. Genetic diversity among North American spring wheat cultivars. 1. Analysis of the coefficient of parentage matrix. Crop Sci. **37**:570-579.

Vandeleur, R. K. and Gill, G. S. 2004. The impact of plant breeding on the grain yield and competitive ability of wheat in Australia. Aust. J. Agric. Res. **55**:855-861.

Waldon, H., Gliessman, S. and Buchanan, M. 1998. Agroecosystem responses to organic and conventional management practices. Agric. Syst. **57**:65-75.

Walker, D. and Smith, A. 1992. Evaluation of spring wheat, oat and hulless oat and barley cultivars under an organic production protocol. Adapt. Res. Rep. **14**:257-260.

Wallace, J., (ed.) 2001. Organic Field Crop Handbook. Canadian Organic Growers, Ottawa, ON.

Walton, P. D. 1968. Spring wheat variety trials in the Prairie provinces. Can. J. Plant Sci. **48**:601-609.

Wang, H., McCaig, T. N., Depauw, R. M., Clarke, F. R. and Clarke, J. M. 2002. Physiological characteristics of recent Canada Western Red Spring wheat cultivars: Yield components and dry matter production. Can. J. Plant Sci. **82**:299-306.

Wang, X. T. and Below, F. E. 1992. Root-growth, nitrogen uptake, and tillering of wheat induced by mixed-nitrogen source. Crop Sci. **32**:997-1002.

Weiner, J., Griepentrog, H. W. and Kristensen, L. 2001. Suppression of weeds by spring wheat *Triticum aestivum* increases with crop density and spatial uniformity. J. Appl. Ecol. **38**:784-790.

Welsh, J. P., Bulson, H. A. J., Stopes, C. E., Froud-Williams, R. J. and Murdoch, A. J. 1999. The critical weed-free period in organically-grown winter wheat. Ann. Appl. Biol. **134**:315-320.

Wicks, G. A., Ramsel, R. E., Nordquist, P. T., Schmidt, J. W. and Challaiah. 1986. Impact of wheat cultivars on establishment and suppression of summer annual weeds. Agron. J. **78**:59-62.

Willer, H. and Yussefi, M. 2000. Organic Agriculture Worldwide Statistics and Future Prospects. [Online] Available: http://www.soel.de/inhalte/publikationen/s/s_74_02.pdf [29 June 2004].

Williams, P. 1997. Cultivar development and quality control of wheat in Canada. Paper presented at the International Japanese Conference on Near-Infrared Reflectance. [Online] Available: http://collection.nlc-bnc.ca/100/200/301/cgc-ccg/cultivar_development-e/cultivar4-e.htm [24 July 2003].

Wooding, A. R., Kavale, S., Wilson, A. J. and Stoddard, E. L. 2000. Effects of nitrogen and sulfur fertilization on commercial-scale wheat quality and mixing requirements. Cereal Chem. **77**:791-797.

Worland, T. and Snape, J. W. 2001. Genetic Basis of Worldwide Wheat Varietal Improvement, p. 59-100, *In* A. P. Bonjean and W. J. Angus, eds. The World Wheat Book: A History of Wheat Breeding. Lavoisier, Paris, France.

Xu, Z.-Z. and Yu, Z.-W. 2006. Nitrogen metabolism in flag leaf and grain of wheat in response to irrigation regimes. Journal of Plant Nutrition and Soil Science **169**:118-126.

Yussefi, M. 2004. Development and State of Organic Agriculture Worldwide [Online] Available: http://www.soel.de/inhalte/publikationen/s/s_74.pdf [12 October 2006].

Zadoks, J. C., Chang, T. T. and Konzak, C. F. 1974. A decimal code for the growth stages of cereals. Weed Res. **14**:415-421.

2.0 The weed-competitive ability of Canada Western Red Spring wheat cultivars grown under organic management[2]

2.1 Introduction

Alternative farming strategies are emerging because of increased concern over high herbicide and fertilizer use in agriculture systems worldwide. One such strategy is organic farming, a system of production that prohibits, among other things, the use of mineral fertilizers, synthetic pesticides and genetically modified organisms (GMOs) (Bruinsma 2003). In organic management systems, grain yields are commonly less than their conventionally managed counterparts (Walker and Smith 1992; Entz et al. 2001; Kitchen et al. 2003; Ryan et al. 2004). In Canada, where research relating to organic grain production is limited to date, Entz et al. (2001) reported that wheat (*Triticum aestivum* L.), oat (*Avena sativa* L.) and barley (*Hordeum vulgare* L.) yields were 23-27% less on organic farms than on conventional farms.

Competition from weeds plays a role in reducing crop yields on organic farms. Studies in Canada and elsewhere have reported both greater numbers of weeds and greater diversity of weed species in organic cereal crops than in conventional ones (Samuel and Guest 1990; Leeson et al. 2000; Entz et al. 2001). Nutrient limitation also serves to reduce organic crop yields (Barberi 2002). On the Canadian Prairies, soil nutrient levels on organically managed soils were reported to be similar to or less than those of conventionally managed soils (Entz et al. 2001). In an attempt to overcome these production constraints, producers make use of farming practices such as crop rotations, changes to planting dates and density, intercropping, the use of animal and green manures, and varietal selection (Stopes and Millington 1991; Barberi 2002).

Breeding efforts in the Canada Western Red Spring (CWRS) class of wheat have focused mainly on developing high protein, disease-resistant cultivars with broad adaptation. Other agronomic characteristics, such as the ability to compete against weeds (measured as weed suppression and/or weed tolerance), have been largely unaddressed in CWRS breeding, likely in part due to the availability of effective herbicides over the past 50 years.

A number of studies have found differential competitive ability of genotypes or cultivars of wheat (Wicks et al. 1986; Huel and Hucl 1996; Lemerle et al. 1996). Yield gains of 7-9% have been reported for 'competitive' wheat cultivars when compared to 'non-competitive' cultivars (Hucl 1998). Morphological, physiological and biochemical traits are thought to control plant competitiveness (Baghestani et al. 1999; Iqbal and Wright 1999; Lemerle et al. 2001a). Many studies have been conducted to determine which characters confer competitive ability in wheat.

---

[2] *This chapter has been accepted for publication in Crop Science.*

Studies examining above-ground morphology and physiology are most common, likely due to the ease associated with the selection for competitiveness based on visual characteristics. Greater tiller numbers, taller plants, elevated photosynthetically active radiation interception and greater early season biomass accumulation were all found in the most competitive genotypes in a study of wheat genotypes (mainly Australian) from around the world (Lemerle et al. 1996). Crop height, crop biomass, ground cover and flag leaf length of wheat were found to be negatively correlated with grain yield reduction in Canadian wheat cultivars (Huel and Hucl 1996). Hucl (1998) found that competitive wheat genotypes were taller and had greater tiller numbers compared with non-competitive cultivars. For producers, knowledge about the competitive ability of cultivars would be useful for choosing cultivars suited to their environment (Lemerle et al. 2001b).

Some researchers question the value of using crop cultivars developed for low stress, high-input production in higher stress, low-input environments, such as organic systems (Laing and Fischer 1977; Ceccarelli 1996). It has been hypothesized that wheat cultivars developed before the advent of modern, high-input agriculture may be better suited to lower soil nutrient levels and elevated weed competition (Poutala et al. 1993). Researchers have reported that modern crop cultivars are better yielding under optimal conditions, yet suffer greater yield losses than ancestral cultivars when grown under stress conditions (Laing and Fischer 1977; Ceccarelli 1996; Guarda et al. 2004). In contrast, modern wheats of the UK out-yielded older cultivars in both weedy and weed-free environments (Vandeleur and Gill 2004). In terms of the relative performance of historical and modern wheats subjected to stress, very few studies have been conducted in Canada. Hucl and Baker (1987) found that drought conditions had a greater negative impact on yield of the older Canadian wheat cultivars Red Fife and Marquis than on newer wheat cultivars, possibly due to the timing of drought stress in relation to the rate of plant development.

Much of the Canadian wheat competition research has involved the use of cultivated crop plants like *Avena sativa* L., *Brassica juncea* L. and *Brassica napus* L. (Huel and Hucl 1996; Weiner et al. 2001) or sown densities of wild oat, *Avena fatua* L. (Kirkland and Hunter 1991) as weed analogs. While stressing the need for repeatable trials, Huel and Hucl (1996) suggested that more research was needed to investigate the effect of natural weed populations on the ranking of cultivars found to be competitive when tested in controlled environments. In addition, there has been virtually no attempt by Canadian researchers to investigate wheat competition with weeds on organic farms or to compare the varietal performance of wheat under conventional and organic management systems.

The objectives of the present study were to determine whether spring bread wheat cultivars exhibit different capabilities when grown under organic and conventional management, and to establish which, if any, agronomic traits affect the competitive ability of Canadian spring wheat cultivars in the two systems. Through this research, we sought to describe a competitive spring bread wheat ideotype for northern organic wheat production systems on the Canadian Prairies.

2.2 Materials and Methods

Twenty seven Canadian spring wheat cultivars (Table 2-1) representing 114 years of Canadian wheat breeding were grown under both conventional and organic management systems. Field trials were conducted at two locations in 2002, and at four locations in each of 2003 and 2004. In all three years, the trial was conducted at the Edmonton Research Station (ERS), Edmonton, Alberta (53° 34'N, 113° 31'W) on paired sites, one organically managed and one conventionally managed, located approximately 1 km apart. In 2003 and 2004, the trial was also conducted in conventionally managed fields at the Alberta Agriculture, Food and Rural Development Field Crop Development Centre Research Farm in Lacombe, Alberta (52° 28'N, 113° 44'W), as well as at a certified organic farm near New Norway, Alberta (52° 52'N, 112° 56'W). Soils at New Norway sites were Eluviated Black Chernozems (Albic Argicryolls), while soils at Edmonton and Lacombe sites were classified as Orthic Black Chernozems (Typic Haplustolls), typical of central Alberta (Alberta Agriculture Food and Rural Development 2004).

Each of the seven trials were designed as randomized compete blocks with four replications. All plots were seeded at a rate of 300 viable seeds m^{-2}. At the ERS in 2002 and at the ERS and the certified organic farm in 2003, plot dimensions were 6 m x 0.9 m and consisted of four rows spaced approximately 23 cm apart. Plots were seeded using a four row, double disk drill (Fabro Enterprises Ltd., Swift Current, SK, Canada). In 2004, plot dimensions at ERS and the certified organic farm were 4 m x 1.38 m, consisting of 6 rows spaced approximately 23 cm apart. Plots were seeded using a six row, no-till double disk drill (Fabro Enterprises Ltd., Swift Current, SK, Canada). At Lacombe in 2003 and 2004, plot dimensions were 4.5 m x 1.12 m, consisting of 8 rows spaced approximately 14 cm apart. Seed used each year was increased the previous year at the ERS. The trials were not irrigated. All trials were planted in mid- to late May and harvested in early to mid-September. Precipitation and temperature data for each year and location are presented in Table 2-2. Climate data for the certified organic farm at New Norway was taken from the nearest provincial weather station, located approximately 20 km away, at Camrose, Alberta.

Conventional sites were managed according to local recommendations (Alberta Agriculture Food and Rural Development 2003b; 2006). Mineral fertilizers were applied following soil fertility testing in early spring. At the 2003 ERS-Conventional site, fertilizer (90 kg ha^{-1} N as 46-0-0 and 28 kg ha^{-1} P as 8-24-24) was broadcast after seeding. At the 2004 ERS-Conventional site, fertilizer (39 kg ha^{-1} N as 46-0-0) was banded at a depth of 8.5 cm into the soil in the fall of 2003 and again in spring 2004 (11 kg ha^{-1} N as 46-0-0 and 6 kg ha^{-1} P as 8-24-24) prior to seeding. Soil tests were conducted after seeding each year at each site (Table 2-3). All ERS-Conventional fields were cultivated and harrowed prior to planting in spring, and received late spring applications of MCPA Amine 500 at a rate of 1.5 L ha^{-1} to control broadleaf weeds (Alberta Agriculture Food and Rural Development 2006). In both years, the Lacombe sites received applications of seed banded 6-25-30 at 112 kg ha^{-1} and late spring applications of Refine/CurtailM at 19 g ha^{-1} & 1.5 L ha^{-1} to control broadleaf weeds. Soil testing was not performed at Lacombe in either year.

Organically managed sites did not receive any applications of chemical fertilizers and herbicides, and were managed according to Organic Crop Improvement Association International Certification Standards (Organic Crop Improvement Association 2000). Soil tests were conducted after seeding each year at each organic site (Table 2-3). The ERS-Organic sites were designated to be organically managed in the spring of 2001, but were not certified. The 2003 ERS-Organic site was planted to fall rye (*Secale cereale* L.) in the fall of 2001, which was mowed throughout the summer of 2002. The vegetative fall rye was disked under in the fall of 2002, just prior to an application of composted dairy manure at a rate of 60 t ha^{-1}. In the spring of 2003, the land was cultivated and harrowed just prior to seeding of the 2003 trial. The 2004 site was left to triticale stubble in the fall of 2001 and was seeded with berseem clover (*Trifolium alexandrinum* L.) in the spring of 2002. Extreme drought across the Canadian Prairies in the 2002 growing season caused the clover crop to fail and the land was seeded to fall rye in late summer of 2002. In the summer of 2003, the fall rye was harvested, and the soil was disked and treated with an application of composted dairy manure at a rate of 60 t ha^{-1}. In the spring of 2004, the land was cultivated and harrowed prior to planting. Composted dairy manure was estimated to be at ~50% dry matter content, with 1.3% total N.

At the certified organic farm, experimental trials followed cereal-legume plowdowns without crop removal in the year prior to planting. The 2003 trial was planted at a site that received a green manure plowdown in 2002 and 2001, and was seeded to barley in 2000 and oats in 1999. The 2004 site received a green manure plowdown in 2003 and was seeded to a pea/barley intercrop in 2002. The 2003 certified organic farm trial was lost to cow grazing in late

June, allowing only a modest amount of data to be collected; the 2003 certified organic farm data is therefore not included in the subsequent analyses and discussion.

Disease assessments were conducted at all site-years, and very mild and sporadic incidences of powdery mildew (*Erysiphe graminis)* and stripe rust (*Puccinia striiformis*) were observed, with no apparent differences between sites or years. Because of the low and infrequent disease incidence, it was determined that no control measures were necessary.

2.2.1 Data Collection

Emerged seedlings were counted in one 1 m row per plot at the 1-3 leaf stage (Zadoks growth stage (ZGS) 11-13) (Zadoks et al. 1974). Early season vigour was rated at the 3-4 leaf stage (ZGS 13-14). Early season vigour was based on plant leaf size, number and overall form on a scale of 1-5, with 1 being the least vigourous and 5 the most (Revilla et al. 1999).

Spike emergence (heading) was recorded as the day when 75% of the emerged spikes in the plot had visible peduncles. After stem elongation was complete, plant height (representing the distance from the soil surface to the tip of the spike, excluding awns in awned cultivars) was recorded on a per plot basis. At early dough development (ZGS 80), incidence of both powdery mildew (*Erysiphe graminis*; rating from a 1-5) and leaf spot diseases (mainly *Septoria tritici*; 1= no disease incidence to 9= highest incidence of disease) was recorded. Maturity was recorded as the day when 75% of the spikes and peduncles in the plot were brown, which was estimated to be approximately 30% seed moisture content. At maturity, all spikes in a 1 m row section of each plot were counted and used to calculate spikes m^{-2}.

In 2002, weed presence at the time of grain harvest was negligible, due to existing drought conditions in that year. In 2003 at the ERS, weed biomass m^{-2} in each plot was determined by separating and weighing the aboveground portion of the weeds from a harvested 1 m x 0.23 m row of wheat at maturity. In 2004 at the ERS and the certified organic farm, weed biomass m^{-2} in each plot was determined by collecting the aboveground portion of weeds from within a randomly placed 0.0625 m^2 quadrat at harvest maturity. Weeds present in both 2003 and 2004 at the Edmonton Research Station included stinkweed (*Thlaspi arvense* L.), lamb's quarters (*Chenopodium album* L.), wild buckwheat (*Polygonum convolvulus* L.), shepherd's purse (*Capsella bursa-pastoris* L.) and Canada thistle (*Cirsium arvense* L.) while weeds in both years at the New Norway site were mainly wild oats (*Avena fatua* L.) and lamb's quarters.

Plots were harvested using a Wintersteiger plot combine following maturity. Grain yield was recorded on a dry weight basis. Harvested grain samples were dried at 60°C for ~24 hours and weed seeds were removed using a 2 mm mesh sieve (Canadian Standard Sieve Series No.10).

At the COF in 2004, there was a substantial wild oat presence, requiring that plot harvests be cleaned using a Vac-A-Way Seed Cleaner with a No.12 screen (Hance Corp., Westerville, OH, USA). Plot grain yield at that site was then determined by weighing the cleaned sample. Hectolitre weight was determined from a 1 pint (473 mL) subsample of plot yield, except in 2002 when drought conditions reduced yields, allowing only a 60 mL subsample to be used.

2.2.2 Data Analysis

All data were subjected to analysis of variance (Steel et al. 1996). For each location-year (environment), analysis of variance was performed using the PROC GLM procedure of SAS (SAS Institute, 1999). For each management system, an analysis of variance using PROC GLM (fixed effects) was used in order to obtain the percent sums of squares breakdown, providing information about relative sources of variation.

A combined analysis of all data was performed using the PROC MIXED procedure of SAS in order to determine differences between management systems (SAS Institute 1999). Management system, cultivar and the management system x cultivar interaction were considered fixed effects, while environment within management system, replication within environment, and associated interactions were considered random. Subsequently, analyses of variance within each management system (i.e., conventional, organic) were performed using the PROC MIXED procedures of SAS, where location-years (environments), replications within environment and the environment x cultivar interaction were considered random. Cultivar was considered as a fixed effect because cultivars were selected so as to adequately represent 114 years of CWRS wheat breeding. In addition to including some of the most important CWRS wheats released in Canadian history (e.g., Red Fife, Marquis, Thatcher), the selected collection of cultivars contain representatives from each decade from the 1880's through 1990's, with the exception of the 1950's. Pearson's coefficients of correlation were computed within each management system using the least squares means from each of the environments (location-years) with the PROC CORR procedure of SAS.

2.3 Results

In 2002, a province-wide drought reduced grain yield, with average yields of 0.8 t ha^{-1} at ERS-Conventional and 1.2 t ha^{-1} at ERS-Organic. At the conventional site, grain yield ranged from 0.4 to 1.2 t ha^{-1} and at the organic site, grain yield ranged from 0.8 to 1.5 t ha^{-1}. Overall yields in that year were reduced by a factor of ~4 in conventional plots and by a factor of ~2 in organic plots compared to the overall average (averaged over years) for each system (data not shown). Cultivars did not differ for yield ($P \approx 0.30$) under conventional management; however under organic management, cultivars did differ for grain yield ($P < 0.01$). Due to the high variability of the 2002 season, we have removed the 2002 data from the overall analyses, and they are not included in the subsequent analyses and discussion. The grain yields achieved in 2002 were well below the long term average and would be considered crop failures.

In 2003, grain yield averaged 3.7 t ha^{-1} at Lacombe, 4.3 t ha^{-1} at ERS-Conventional, and 3.7 t ha^{-1} at ERS-Organic. In 2004, grain yield averaged 5.6 t ha^{-1} at Lacombe, 3.5 t ha^{-1} at ERS-Conventional, 1.2 t ha^{-1} at the certified organic farm, and 2.9 t ha^{-1} at ERS-Organic. Percent sum of squares breakdown indicated that environment was the largest source of variation for most traits, particularly grain yield and days to maturity (Appendix 7-1). When analyzed in fixed effects models within each management system, environment x cultivar effects were significant for most traits, however the percentage of variation attributed to that interaction was small (≤16%) for all traits (Appendix 7-2). Thus environmental effects were a large source of variation but environment x cultivar interactions were not. Disease incidence was low, and preliminary analyses showed no significant differences in disease incidence among environments or cultivars, thus disease data is not included in the subsequent results and discussion.

Differences were observed in the performance of CWRS wheat in conventional and organic management systems (Appendix 7-3). Grain yield (P=0.07) and weed biomass (P=0.06) differed significantly between management systems, with conventional yields 63% greater than organic yields and an average weed biomass of 134 g m^{-2} under organic management and 1.4 g m^{-2} under conventional management (Tables 2-4 and 2-5). Plant emergence, early season vigour, time to heading and maturity, plant height, and spikes m^{-2}, were not significantly different between the two systems. A significant (P<0.01) management x cultivar interaction for weed biomass was detected. In order to further investigate each management system more thoroughly, separate analyses for each management system were carried out. Data are presented by management system (i.e., organic, conventional).

For conventional management, the best yielding eight cultivars out of 27 were not found to be significantly different for grain yield based on the Fisher-protected LSD, while 21 of the 27 cultivars under organic management were found in the first LSD grouping for that trait (Tables 2-4 and 2-5). Cultivars found to be among the top five yielding cultivars in their respective management systems were ranked among the top 10 yielding cultivars in the opposing management system, with the exception of Garnet. Garnet was the fifth highest yielding cultivar under organic management and the second lowest yielding cultivar under conventional management.

2.3.1 Correlations of Competitive Traits in Conventional and Organic Management Systems

Early season vigour and time to heading and maturity were similarly associated with yield in the two management systems, though the association between yield and time to maturity was somewhat stronger under organic management than under conventional management (Table 2-6). Spikes m^{-2} and yield were strongly positively correlated at organic and negatively correlated at conventionally managed sites. Height and yield were found to be correlated at conventional and organic sites. Yield and weed biomass were strongly negatively correlated in organic fields.

Because of herbicide use in the conventional system, weed biomass under conventional management was not found to be significantly correlated with any of the competitive plant traits. However, under organic management, weed biomass was negatively correlated with height, maturity, and spikes per m^{-2} (Table 2-6).

Time to heading and number of spikes m^{-2} were found to be negatively correlated in organic, but not in conventional systems (Table 2-6). Maturity and spikes m^{-2} were positively correlated under conventional and were negatively correlated under organic management. Spikes m^{-2} and height were strongly negatively correlated under conventional management and were not correlated under organic management.

Early season vigour and spikes m^{-2} were positively correlated in organic fields, but were not correlated in conventional fields. Early season vigour and maturity were more strongly negatively correlated in organic fields than in conventional fields. Time to heading and maturity were strongly positively correlated under conventional management but were not associated under organic management (Table 2-6).

2.4 Discussion

Following the 2002 drought and resulting crop failure, precipitation levels in the north central Alberta region increased in the subsequent two growing seasons, almost reaching the thirty year average in Camrose and Lacombe in 2004 and surpassing it in Edmonton in the same year. Regardless, average grain yields were notably low at the certified organic farm and at ERS-Organic site in 2004, likely a result of a combination of intense weed competition and lower soil nutrient levels (Table 2-3), particularly at the certified organic farm.

Similar to other reports (Walker and Smith 1992; Entz et al. 2001; Kitchen et al. 2003; Ryan et al. 2004), the mean yield of cultivars grown under conventional management was greater than that of cultivars grown under organic management. This may be due to increased stress under organic management caused by nutrient limitation and more importantly, weed competition. While the soil nutrient and moisture status at the various organic sites was variable (Tables 2-2 and 2-3), overall mean weed biomass at organic sites (134 g m^{-2}) was much greater than at conventionally managed sites (1.4 g m^{-2}).

According to LSD groupings, cultivars yielded more similarly under organic management than under conventional management. This may be due to the increase in crop stress associated with organic crop management, likely resulting from reduced nutrient availability (Table 2-3) and elevated weed competition. Another study similarly reported no significant varietal differences in grain yield of spring wheat in an ecological cropping system whereas significant differences were detected between the same cultivars grown in a conventional system (Poutala et al. 1993). The lower yield potential of organic systems highlights the need for the development of cultivars with increased performance within such systems.

With most of the cultivars, there were no clear indications that some were more suitable for organic management systems than others (Tables 2-4 and 2-5). Some cultivars (e.g., AC Intrepid, Sinton) performed well in both systems, while others (e.g., Red Fife, Chester) performed relatively poorly in both systems. The cultivar Garnet was an exception, yielding comparatively greater in the organic system and less in the conventional system. Similarly, an eastern Canadian study reported that while AC Walton typically out-yielded AC Barrie in conventional cultivar trials, AC Barrie out-yielded AC Walton under organic management (Nass et al. 2003). Collectively, these results indicate that there may be some cultivars more suited for production in organic compared to conventional management systems.

The negative relationship between yield and time to maturity observed in both systems indicates that early maturing cultivars are appropriate for use in northern wheat cropping systems, both conventional and organic. Because delayed seeding is a common practice among organic wheat producers as a means of weed control, early maturing cultivars would be particularly desirable in northern regions. Poutala et al. (1993) reported that an early maturing cultivar (Satu) performed well in an ecological cropping system, contrary to suggestions that early maturing cultivars are not well suited to northern ecological systems due to climate. Early maturing cultivars, which develop more quickly than later maturing cultivars (Karimi and Siddique 1991), may have greater nutrient demands early in the season than their late maturing counterparts. Cooler spring temperatures associated with northern climates may reduce and/or delay the release of plant available nitrogen (Agehara and Warncke 2005).

Number of fertile tillers may be an indicator of competitive ability in organic systems, as spikes m^{-2} and yield were positively correlated in organic management and were negatively correlated in conventional management. Tillering capacity and spikes m^{-2} have been previously reported to be associated with competitive ability, although in experiments conducted in conventionally managed fields (Hucl 1998).

The stronger association between height and yield at the conventional sites compared to the organic sites suggests that height alone may not be a good indicator of competitive ability in organic systems. Since overall average plant height remained similar between the two management systems, the negative correlation between weed biomass and plant height in organic fields implies that weed biomass decreased as height increased, suggesting that height does help to suppress weeds. In previous studies, plant height was associated with competitive ability in both conventional (Huel and Hucl 1996; Lemerle et al. 1996; Hucl 1998), and organic systems (Gooding et al. 1993b).

The strong negative correlation between yield and weed biomass observed here in organic fields has been reported in many studies in both organic (Ryan et al. 2004) and conventional fields (Lemerle et al. 1996; Hucl 1998). The often studied association between increased weed biomass and reduced yield can be explained by competition for growth limiting resources (i.e., light, water, nutrients) between weeds and crop plants.

The positive correlation between weed biomass and time to maturity of cultivars in organic fields indicates that weed growth was higher in cultivars with increased time to maturity. Thus, it may be desirable for organic wheat producers to use early maturing cultivars in order to reduce weed biomass in the field. A competition experiment in Sweden using wheat breeding lines from an organic breeding program reported no significant correlation between weed biomass and wheat maturity (Bertholdsson 2005).

The negative correlation between weed biomass and spikes m^{-2} under organic management may indicate that weed growth was suppressed by cultivars with high fertile tiller number. That the overall average number of spikes m^{-2} in organic fields was 8% less than in conventional fields suggests that competition with weeds reduced the number of spikes m^{-2}, which is again supported by the findings of various studies (Kirkland and Hunter 1991; Lemerle et al. 1996; Hucl 1998).

The negative correlation between spikes m^{-2} and height at conventional sites that was not seen at organic sites may reflect the trend toward reduced height and greater kernels per unit area in Canadian CWRS breeding (McCaig and DePauw 1995). High weed populations present at the organic sites may have altered this relationship. In the current experiment, negative associations were observed between spikes m^{-2} and both time to heading and maturity at organic sites. Spikes m^{-2} and time to heading were not associated under conventional management, while spikes m^{-2} and time to maturity were positively correlated under conventional management. The combination of high tiller numbers and weed competition in organic fields may have increased rate of development of certain cultivars. Increasing plant densities have increased the rate of maturation in winter wheat (Gooding et al. 2002), and although Hameed et al. (2003) reported no significant effect of seeding rate on time to heading or maturity, they did observe significant decreases in time to heading and maturity in plots receiving no N fertilizer. We observed that time to heading and maturity were strongly correlated under conventional management, and were not correlated under organic management. The dynamics of weed development, timing of competitive stress in terms of crop development and resource limitation likely weaken the relationship between heading and maturity in organic fields.

Early season vigor and yield were positively correlated in both management systems, however early season vigor was positively correlated with spikes m^{-2} and negatively correlated with weed biomass in organic fields, but not in conventional fields. Further, there was a stronger correlation between early season vigour and maturity in organic fields than in conventional fields. Early season vigor may be more important in organic fields than in conventional fields, allowing a plant to develop more tillers and reach maturity faster, thereby reducing the effects of weed competition and enabling a plant to maintain yield in weedy conditions. In support of these findings, another study reported that early vigour, as measured by early wheat biomass, was negatively associated with weed biomass (Bertholdsson 2005). Regression models used in that study predict that a 20% increase in early biomass would reduce weed biomass in wheat by 15 to 39% (Bertholdsson 2005).

2.5 Conclusions

Organic and conventional management systems differed greatly in terms of weed biomass, which in turn decreased overall wheat grain yield. From observations made at the experimental sites and from the results of soil testing, it is likely that moisture and nutrient availability in some organic location-years were somewhat limiting as well. Spring wheat cultivars performed differently in the two management systems. Differences among cultivars were more pronounced in the conventional system, probably because genetic differences were expressed to a greater extent in the absence of stresses associated with weeds and low soil nutrient status of the organic systems. Modern cultivars, typically selected in high yielding environments, may be more responsive to inputs than older cultivars, and may or may not perform poorly in low yielding environments (Calderini and Slafer 1999). When grown in low yielding environments, barley cultivars selected at high yielding sites yielded up to 49% less than barley cultivars selected at low yielding sites (Ceccarelli et al. 1992).

This study identified traits that have the potential to improve wheat competition with weeds and result in better grain yields in organic production systems in northern regions. Earlier heading and maturity were found to be more important for achieving improved grain yield in organic fields than in conventional fields. Greater numbers of spikes m^{-2} were also found to be associated with increased grain yield in organic fields. Increased plant height and faster time to maturity were found to be associated with reduced weed biomass. Vigourous early season growth was related to increased yield, increased spikes m^{-2} and reduced weed biomass in organic fields. Based on these findings, a suitable spring wheat ideotype for organic management may be a taller cultivar with fast early season growth, early maturity, with a greater number of fertile tillers.

2.6 Tables

Table 2-1. Description of Canada Western Red Spring cultivars included in trials conducted in 2002, 2003 and 2004 at four sites in north central Alberta, Canada.

Cultivar	Year of Release	Origin
Red Fife	1885	Peterborough, ON from Danzig, Poland
Hard Red Calcutta	1890	India
Preston	1895	Agriculture Canada, Ottawa, ON
Marquis	1910	Agriculture Canada, Ottawa, ON
Ruby	1920	Agriculture Canada, Ottawa, ON
Garnet	1925	Agriculture Canada, Ottawa, ON
Red Bobs 222	1926	University of Alberta
Reward	1928	Agriculture Canada, Ottawa, ON
Early Red Fife	1932	Agriculture Canada, Ottawa, ON
Canus	1935	University of Alberta
Thatcher	1935	University of Minnesota
Saunders	1947	Agriculture Canada, Ottawa, ON
Cypress	1962	Agriculture Canada, Lethbridge, AB
Park	1963	Agriculture Canada, Lacombe, AB
Manitou	1965	Agriculture Canada, Winnipeg, MB
Neepawa	1969	Agriculture Canada, Winnipeg, MB
Sinton	1975	Agriculture Canada, Regina and Swift Current, SK
Chester	1976	Agriculture Canada, Lethbridge, AB
Columbus	1980	Agriculture Canada, Winnipeg, MB
Katepwa	1981	Agriculture Canada, Winnipeg, MB
Roblin	1986	Agriculture Canada, Winnipeg, MB
CDC Teal	1991	Crop Development Center, Saskatoon, SK
AC Barrie	1994	Agriculture Canada, Swift Current, SK
AC Splendor	1996	Agriculture Canada, Winnipeg, MB
AC Intrepid	1997	Agriculture Canada, Swift Current, SK
McKenzie	1997	Saskatchewan Wheat Pool
5600 HR	1999	UGG Research Farm

Table 2-2. Mean monthly precipitation and temperature data for the 2002-2004 growing seasons at Edmonton, Camrose and Lacombe, Alberta, Canada.

		Precipitation (mm)					
Location	Year	May	June	July	August	Sept.	Total
Edmonton Research Station	2002[†]	17	22	35	52	10	136
	2003[†]	35	42	61	47	-	185
	2004[†]	44	22	225	36	40	367
	Normal[‡]	49	87	92	69	44	341
Camrose	2003[§]	50[§§]	53[§§]	35	45	25[§§]	80
	2004[§]	27	24	118	70	42	281
	Normal[¶]	47	87	88	62	42	326
Lacombe	2003[#]	46[§§]	45	16[§§]	20	34	161
	2004[#]	70	50	69	73	22	284
	Normal[††]	56	76	89	71	47	339

		Temperature (°C)				
Location	Year	May	June	July	August	September
Edmonton Research Station	2002[†]	-	19	21	15	10
	2003[†]	10	15	19	18	-
	2004[†]	9	15	17	15	10
	Normal[‡]	12	16	18	17	11
Camrose	2003[§]	10[§§]	14	17[§§]	17[§§]	10
	2004[§]	8	13	16	14	9
	Normal[¶]	11	15	17	16	10
Lacombe	2003[#]	9	14	17	17	10
	2004[#]	8	13	16	14	9
	Normal[††]	10	14	15	15	10

[†] Data collected by the University of Alberta, Edmonton Research Station.

[‡] Data from Environment Canada (2004a).

[§] Data from Environment Canada (2004d).

[¶] Data from Environment Canada (2004b).

[#] Data from Environment Canada (2004e).

[††] Data from Environment Canada (2004c).

[§§] denotes estimated value.

Table 2-3. Soil properties of 0-15cm depth soil samples taken at experimental sites at the Edmonton Research Station, Edmonton, AB and the certified organic farm at New Norway, AB in the 2003 and 2004 growing seasons directly after seeding.[†,‡]

	ERS-Conventional			ERS-Organic			Certified Organic Farm		
Soil Property[a,b]	2003	2004	Average	2003	2004	Average	2003	2004	Average
N (kg ha^{-1})	156	65	111	74	74	74	27	65	46
P (kg ha^{-1})	89	37	63	>130	56	>93	18	47	56
K (kg ha^{-1})	>1300	473	>887	918	551	735	184	728	456
pH	6.8	5.9	6.4	6.6	6.3	6.5	7.7	6.5	7.1
Organic Matter (%)	10.1	11.2	10.7	9.9	10.3	10.1	5.5	5.4	5.5
Textural Class	Clay	Clay		Clay	Clay		Sandy Loam	Clay Loam	

[†] Available N determined using $CaCl_2$ extraction (Norwest Labs 2003).

[‡] Available P and K determined using a modified Kelowna extract (Norwest Labs 2003).

Table 2-4. Conventional management overall least squares means for grain yield, days to heading, days to maturity, plant height, spikes per m^{-2} and weed biomass of cultivars grown in 2003 and 2004, at four site-years in north central Alberta, Canada, and arranged in descending order of grain yield.[†]

Cultivar	Year of Release	Grain Yield (t ha^{-1})	Early Season Vigour (1-5)	Days to Heading	Days to Maturity	Plant Height (cm)	Spikes m^{-2}	Weed Biomass (g m^{-2})
Sinton	1975	4.84	3	58	99	102	485	4.2
CDC Teal	1991	4.63	4	59	99	96	560	5.4
AC Intrepid	1997	4.60	4	57	97	97	505	0.0
Canus	1935	4.56	4	63	107	109	470	0.0
Roblin	1986	4.44	4	57	99	96	550	4.6
5600HR	1999	4.42	4	59	100	102	575	0.0
Red Bobs	1926	4.37	4	58	98	105	515	1.4
Park	1963	4.36	4	54	98	99	585	0.0
Saunders	1947	4.31	4	56	97	92	560	5.9
Katepwa	1981	4.25	5	57	98	97	610	1.4
Columbus	1980	4.20	4	60	102	105	530	0.0
Cypress	1962	4.16	4	60	101	106	490	3.0
AC Barrie	1994	4.14	4	59	101	91	555	4.8
Thatcher	1935	4.13	5	58	99	102	570	0.0
Manitou	1965	4.08	4	58	99	98	615	0.0
Marquis	1910	4.07	4	61	103	113	560	3.3
McKenzie	1997	4.06	4	57	100	94	685	0.0
Hard Red Calcutta	1890	4.05	3	60	99	111	520	0.0
AC Splendor	1996	4.04	4	57	97	96	545	0.2
Preston	1895	4.01	4	65	105	111	490	0.0
Early Red Fife	1932	3.95	4	62	105	112	470	3.2
Reward	1928	3.91	4	62	101	104	505	0.8
Chester	1976	3.90	5	59	102	96	520	0.0
Neepawa	1969	3.89	5	58	99	98	625	0.0
Red Fife	1885	3.87	4	63	109	114	435	0.0
Garnet	1925	3.75	4	55	95	104	515	0.0
Ruby	1920	3.63	3	57	97	107	540	0.0
Overall mean		4.17	4	59	100	102	540	1.41
F test$_{cultivar}$		0.0014	0.0784	<.0001	<.0001	<.0001	0.0034	0.6618
Fisher-protected LSD		0.52	0.8	2	3	5	100	2.6

[†] Cultivars did not differ significantly for emergence and data are not presented.

Table 2-5. Organic management overall least squares means for grain yield, days to heading, days to maturity, plant height, spikes per m^{-2} and weed biomass of cultivars grown under in 2003 and 2004, at three site-years in north central Alberta, Canada, and arranged in descending order of grain yield.[†]

Cultivar	Year of Release	Grain Yield (t ha^{-1})	Early Season Vigour (1-5)	Days to Heading	Days to Maturity	Plant Height (cm)	Spikes m^{-2}	Weed Biomass (g m^{-2})
Park	1963	2.96	4	54	95	100	520	198
Red Bobs	1926	2.92	4	56	96	109	460	126
Sinton	1975	2.91	3	57	98	103	430	157
AC Intrepid	1997	2.91	3	56	95	98	525	174
Garnet	1925	2.83	3	54	93	105	480	181
Canus	1935	2.74	3	61	104	109	475	122
AC Barrie	1994	2.74	3	58	100	96	515	145
5600HR	1999	2.73	3	59	98	105	440	208
Early Red Fife	1932	2.72	3	61	103	111	450	52
CDC Teal	1991	2.70	3	57	97	97	500	140
Roblin	1986	2.69	3	56	97	99	510	133
Katepwa	1981	2.66	3	57	99	100	555	126
Manitou	1965	2.65	3	57	97	101	560	171
Thatcher	1935	2.61	3	57	97	102	580	177
Neepawa	1969	2.60	3	59	97	101	545	194
McKenzie	1997	2.60	3	56	96	97	630	107
AC Splendor	1996	2.55	3	56	97	96	485	114
Hard Red Calcutta	1890	2.54	3	58	97	108	490	119
Columbus	1980	2.54	3	61	102	104	455	220
Ruby	1920	2.52	4	56	95	106	535	57
Saunders	1947	2.50	3	56	95	93	470	174
Marquis	1910	2.42	3	60	100	109	485	71
Preston	1895	2.22	4	61	103	111	450	29
Reward	1928	2.11	3	62	104	111	470	70
Chester	1976	1.94	3	58	101	97	465	189
Red Fife	1885	1.92	3	62	105	111	465	60
Cypress	1962	1.91	3	61	101	100	470	98
Overall mean		2.56	3	58	99	103	495	133.8
F test $_{\text{cultivar}}$		0.0002	0.0454	<.0001	<.0001	<.0001	0.0009	0.0062
Fisher-protected LSD		0.48	0.7	2	4	6	87	9.9

[†] Cultivars did not differ significantly for emergence and data are not presented.

Table 2-6. Least squares mean (based on environment within management system) genotypic correlations of eight agronomic traits for 27 wheat cultivars grown at four conventionally (n=108) and 3 organically (n=81) managed sites during 2003 and 2004 in north central Alberta, Canada.[†,‡]

	Emergence	Early Season Vigour	Days to Heading	Days to Maturity	Plant Height	Spikes m^{-2}	Weed Biomass	Grain Yield
Emergence		-	-	-	-	-	-	-
Early Season Vigour	-		-	-0.30*	-	-	-	0.34**
Days to Heading	-	-		0.83**	-	-	-	-0.35**
Days to Maturity	0.36**	-0.72**	-		-0.39**	0.49**	-	-0.55**
Plant Height	-0.31*	-	-	-		-0.82**	-	0.61**
Spikes m^{-2}	0.43*	0.47**	-0.40*	-0.44*	-		-	-0.85**
Weed Biomass	0.35**	-0.23*	-	0.59**	-0.48**	-0.53**		-
Grain Yield	-0.42**	0.23*	-0.40*	-0.63**	0.36**	0.61**	-0.73**	

[†] Values above diagonal represent conventional management; values below represent organic management.

[‡] r values significant at *$P < 0.05$, ** $P < 0.01$; - indicates no significant correlation ($P \geq 0.05$).

2.7 Literature Cited

Agehara, S. and Warncke, D. D. 2005. Soil moisture and temperature effects on nitrogen release from organic nitrogen sources. Soil Sci. Soc. Am. J. **69**:1844-1855.

Alberta Agriculture Food and Rural Development. 2003. Using 1,000 kernel weight for calculating seeding rates and harvest losses. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex81/$file/100_22-1.pdf?OpenElement [14 July 2006].

Alberta Agriculture Food and Rural Development. 2004. Soil Group Map of Alberta. [Online] Available: http://www1.agric.gov.ab.ca/soils/soils.nsf/soilgroupmap?readform [31 August 2006].

Alberta Agriculture Food and Rural Development. 2006. Herbicide Selector. [Online] Available: http://www.agric.gov.ab.ca/app23/herbsel [29 September 2006].

Baghestani, A., Lemieux, C., Leroux, G. D., Baziramakenga, R. and Simard, R. R. 1999. Determination of allelochemicals in spring cereal cultivars of different competitiveness. Weed Sci. **47**:498-504.

Barberi, P. 2002. Weed management in organic agriculture: are we addressing the right issues? Weed Res. **42**:177-193.

Bertholdsson, N.-O. 2005. Early vigour and allelopathy- two useful traits for enhanced barley and wheat competitiveness against weeds. Weed Res. **45**:94-102.

Bruinsma, J. 2003. World Agriculture : Towards 2015/2030 : An FAO Perspective. 12th ed. Earthscan, London. 432 pp.

Calderini, D. F. and Slafer, G. A. 1999. Has yield stability changed with genetic improvement of wheat yield? Euphytica **107**:51-59.

Ceccarelli, S. 1996. Adaptation to low/high input cultivation. Euphytica **92**:203-214.

Ceccarelli, S., Grando, S. and Hamblin, J. 1992. Relationship between barley grain yield measured in low- and high-yielding environments. Euphytica **64**:49-58.

Entz, M. H., Guilford, R. and Gulden, R. 2001. Crop yield and soil nutrient status on 14 organic farms in the eastern portion of the northern Great Plains. Can. J. Plant Sci. **81**:351-354.

Environment Canada. 2004a. Canadian Climate Normals 1971-2000. Edmonton City Centre. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html [31 August 2006].

Environment Canada. 2004b. Canadian Climate Normals 1971-2000. Camrose. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html [31 August 2006].

Environment Canada. 2004c. Canadian Climate Normals 1971-2000. Lacombe. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html [31 August 2006].

Environment Canada. 2004d. Monthly data report for 2003/2004. Camrose. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/climateData/monthlydata_e.html [31 August 2006].

Environment Canada. 2004e. Monthly data report for 2003/2004. Lacombe. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/climateData/monthlydata_e.html [31 August 2006].

Gooding, M. J., Pinyosinwat, A. and Ellis, R. H. 2002. Responses of wheat grain yield and quality to seed rate. J. Agric. Sci. **138**:317-331.

Gooding, M. J., Thompson, A. J. and Davies, W. P. 1993. Interception of photosynthetically active radiation, competitive ability and yield of organically grown wheat varieties. Aspects Appl. Biol. **34**:355-362.

Guarda, G., Padovan, S. and Delogu, G. 2004. Grain yield, nitrogen-use efficiency and baking quality of old and modern Italian bread-wheat cultivars grown at different nitrogen levels. Eur. J. Agron. **21**:181-192.

Hameed, E., Shah, W. A., Shad, A. A., Bakht, J. and Muhammad, T. 2003. Effect of different planting dates, seed rate and nitrogen levels on wheat. Asian J. Plant Sci. **2**:467-474.

Hucl, P. 1998. Response to weed control by four spring wheat genotypes differing in competitive ability. Can. J. Plant Sci. **78**:171-173.

Hucl, P. and Baker, R. J. 1987. A study of ancestral and modern Canadian spring wheats. Can. J. Plant Sci. **67**:87-97.

Huel, D. G. and Hucl, P. 1996. Genotypic variation for competitive ability in spring wheat. Plant Breed. **115**:325-329.

Iqbal, J. and Wright, D. 1999. Effects of weed competition on flag leaf photosynthesis and grain yield of spring wheat. J. Agric. Sci. **132**:23-30.

Karimi, M. M. and Siddique, K. H. M. 1991. Crop growth and relative growth rates of old and modern wheat cultivars. Aust. J. Agric. Res. **42**:13-20.

Kirkland, K. J. and Hunter, J. H. 1991. Competitiveness of Canada Prairie Spring wheats with wild oat (*Avena fatua* L.). Can. J. Plant Sci. **71**:1089-1092.

Kitchen, J. L., McDonald, G. K., Shepherd, K. W., Lorimer, M. F. and Graham, R. D. 2003. Comparing wheat grown in South Australian organic and conventional farming systems. 1. Growth and grain yield. Aust. J. Agric. Res. **54**:889-901.

Laing, D. R. and Fischer, R. A. 1977. Adaptation of semidwarf wheat cultivars to rainfed conditions. Euphytica **26**:129-139.

Leeson, J. Y., Sheard, J. W. and Thomas, G. A. 2000. Weed communities associated with arable Saskatchewan farm management systems. Can. J. Plant Sci. **80**:177-185.

Lemerle, D., Gill, G. S., Murphy, C. E., Walker, S. R., Cousens, R. D., Mokhtari, S., Peltzer, S. J., Coleman, R. and Luckett, D. J. 2001a. Genetic improvement and agronomy for enhanced wheat competitiveness with weeds. Aust. J. Agric. Res. **52**:527-548.

Lemerle, D., Verbeek, B., Cousens, R. D. and Coombes, N. E. 1996. The potential for selecting wheat varieties strongly competitive against weeds. Weed Res. **36**:505-513.

Lemerle, D., Verbeek, B. and Orchard, B. 2001b. Ranking the ability of wheat varieties to compete with *Lolium rigidum*. Weed Res. **41**:197-209.

McCaig, T. N. and DePauw, R. M. 1995. Breeding hard red spring wheat in western Canada - historical trends in yield and related variables. Can. J. Plant Sci. **75**:387-393.

Nass, H. G., Ivany, J. A. and MacLeod, J. A. 2003. Agronomic performance and quality of spring wheat and soybean cultivars under organic culture. Am. J. Alt. Agric. **18**:164-170.

Norwest Labs. 2003. Agricultural Schedule of Services. [Online] Available: http://www.norwestlabs.com/what_we_do/agrisos20032004noprices.pdf [29 September 2006].

Organic Crop Improvement Association. 2000. International Certification Standards As Revised: March 2000. OCIA International, Inc., Lincoln, NE.

Poutala, R. T., Korva, J. and Varis, E. 1993. Spring wheat cultivar performance in ecological and conventional cropping systems. J. Sustain. Agric. **3**:63-84.

Revilla, P., Butron, A., Malvar, R. A. and Ordas, A. 1999. Relationships among kernel weight, early vigour and growth in maize. Crop Sci. **39**:654-658.

Ryan, M. H., Derrick, J. W. and Dann, P. R. 2004. Grain mineral concentrations and yield of wheat grown under organic and conventional management. J. Sci. Food Agric. **84**:207-216.

Samuel, A. M. and Guest, S. J. 1990. Weed studies in organic and conventional cereals. British Crop Proteciton Council, Farnham, Surrey, UK.

SAS Institute. 1999. Release 8.2. SAS Institute, Cary, NC.

Steel, R. G. D., Torrie, J. H. and Dickey, D. A. 1996. Principles and Procedures of Statistics: A Biometrical Approach. 3rd ed. McGraw-Hill, New York, NY. 666 pp.

Stopes, C. and Millington, S. 1991. Weed control in organic farming systems, pp. 185-192 Brighton Crop Protection Conference-Weeds, Brighton, UK.

Vandeleur, R. K. and Gill, G. S. 2004. The impact of plant breeding on the grain yield and competitive ability of wheat in Australia. Aust. J. Agric. Res. **55**:855-861.

Walker, D. and Smith, A. 1992. Evaluation of spring wheat, oat and hulless oat and barley cultivars under an organic production protocol. Adapt. Res. Rep. **14**:257-260.

Weiner, J., Griepentrog, H. W. and Kristensen, L. 2001. Suppression of weeds by spring wheat *Triticum aestivum* increases with crop density and spatial uniformity. J. Appl. Ecol. **38**:784-790.

Wicks, G. A., Ramsel, R. E., Nordquist, P. T., Schmidt, J. W. and Challaiah. 1986. Impact of wheat cultivars on establishment and suppression of summer annual weeds. Agron. J. **78**:59-62.

Zadoks, J. C., Chang, T. T. and Konzak, C. F. 1974. A decimal code for the growth stages of cereals. Weed Res. **14**:415-421.

3.0 Does growing Canadian hard red spring wheat under organic management alter its breadmaking quality?[3]

3.1 Introduction

There are a number of factors used to evaluate bread quality, such as flavour, nutritional value, texture and colour (Cauvain 2003). In combination with industrial processes (e.g., milling, baking), wheat flour properties, dough mixing abilities and loaf characteristics are determinants of bread quality (Cauvain 2003). These determinants can be further broken down into categories and are often evaluated in terms of breadmaking potential using a variety of tests (Figure 1).

Cultivars of the Canada Western Hard Red Spring (CWRS) class of wheat are the most widely grown in western Canada; comprising about 83% of the hexaploid wheat area in the region, and generating $3 billion in gross revenue in 1998) (Canadian Wheat Board 2001). Canada Western Red Spring wheat is recognized as premium quality wheat, ideal for breadmaking due to its superior milling qualities, baking characteristics and protein content (Canadian Wheat Board 2005). It is ideal for use in the production of high-volume pan breads, and it is commonly utilized, either alone or in mixture with weaker wheats, in the production of hearth breads, noodles, flat breads and steam breads (Canadian Wheat Board 2005). A number of analytical procedures are used in the evaluation of each new CWRS cultivar in order to ensure conformity with Canadian industrial quality standards. The Canadian Grain Commission divides these tests into two main categories, 1) wheat tests, including protein content, test weight, flour yield, kernel hardness, falling number, and sodium dodecyl sulphate (SDS) sedimentation, and 2) flour tests, including ash content, gluten index, extensigraph, amylograph, farinograph and mixograph tests (Williams 1997).

Grain protein content is one of the main factors influencing wheat quality and is a valuable predictor of overall breadmaking quality (Ohm and Chung 1999; Souza et al. 2003). It is the protein portion that gives the strength to the dough, allowing it to trap CO_2 gases produced during fermentation (Gooding et al. 1999). For breadmaking, protein contents ranging from 10.5-13.5% are most desirable (Williams 1997). Wheats with lower than 10% protein are often used for making cakes, cookies and crackers, or are blended with grain containing higher than 14% protein. Test weight is used to indicate the density and soundness of the wheat, and generally, high test weights (>75 kg hL^{-1}) are desirable. Flour yield is another important consideration and a

---

[3] *This chapter has been published in:* Mason, H., Navabi, A., Frick, B., O'Donovan, J., Niziol, D. and Spaner, D. 2007. Renew. Agric. Food Syst. (in press).

simple measure of milling quality. A high flour yield is ~78%. Kernel hardness is usually expressed in terms of Particle Size Index (PSI). Canada Western Red Spring cultivars usually fall between 50-55 PSI. Harder kernels require more energy to break down into flour thereby increasing the amount of damaged starch granules in the flour, influencing gas production and flour water absorption. Falling number is an indicator of the sprouting resistance of the wheat. Sprouting can cause the release of large amounts of normally absent α-amylase into the kernel, ultimately altering its water holding properties. A falling number above 400 is indicative of a sound starch with little or no α-amylase present (Williams 1997).

The SDS sedimentation test is used to distinguish wheat genotypes with superior gluten strength and is commonly referred to as an indicator of protein quality and overall end-use potential (Gooding et al. 1993a; Peterson et al. 1998). Sodium dodecyl sulphate sedimentation tests give a measure of high molecular weight proteins, mainly glutenins, present in wheat flour (Gooding et al. 1999). Sedimentation volumes range from 15 mL in wheat with weak gluten to 80 mL in wheats with strong gluten; CWRS wheats typically fall between 55 and 60 mL. The mixograph is one of many physical dough testing instruments available in order to predict the behavior of dough mixing properties of wheat cultivars (Khatkar et al. 1996). The mixograph tests the physicochemical properties of dough, which are strongly related to gluten properties (Williams 1997).

Grain protein content is the most commonly studied parameter of wheat quality. Both grain protein content and overall bread quality are affected by genotype and environment (e.g., year, temperature, rainfall, soil nutrient management) (Johansson et al. 2003; Rharrabti et al. 2003; Souza et al. 2003; Fowler and Kovacs 2004; Lerner et al. 2006) (Figure 3-1). Fowler and De la Roche (1975) reported significant differences among Canadian spring wheat cultivars for test weight, protein content, flour yield and for some mixograph parameters. Preston et al. (2001) found genotypic differences in kernel hardness, protein content, and physical flour properties of CWRS wheats, but that environment had the largest effect on protein content. Similarly, Fowler and De la Roche (1975) reported that the effect of environment was the main contributor to variation in yield and protein content in Canadian spring wheat. Variation among environments can be due to climatic and/or management factors. The most important management and climatic effects on protein content are nitrogen fertilizers and soil moisture (Fowler and De la Roche 1975; Shier et al. 1984; Randall et al. 1990). Grain protein content of wheat is commonly reported to increase with applications of N fertilizer (Randall et al. 1990; Gooding et al. 1993a; Lloveras et al. 2001), and is lower in nitrogen deficient soils. In addition to protein quantity, gluten strength (as measured by SDSS) has been positively influenced by increased N (Gooding et al. 1993a;

Lloveras et al. 2001; Lerner et al. 2006) and S (Lerner et al. 2006) application. Several studies have reported that N fertilizer regimes that increased protein quantity also increased gluten strength (Dexter et al. 1982; Ames et al. 2003; Johansson et al. 2003). Under moderate drought stress, grain protein concentrations have reportedly increased (Guttieri et al. 2000; Kimball et al. 2001; Rharrabti et al. 2003), yet tend to decrease under more extreme moisture conditions (Xu and Yu 2006). This increased protein under limited moisture is thought to be a result of altered starch and protein deposition in the grain leading to an increase in the ratio of protein to starch (Jenner et al. 1991). Researchers in Spain reported that, in addition to protein content, test weight and gluten strength were higher under rainfed conditions compared to irrigated conditions (Rharrabti et al. 2003). Another climatic factor, heat stress, appears to be more variable in its effect on grain protein quantity, although it has been reported to have detrimental effects on protein and baking quality (Peterson et al. 1998).

Organic cropping systems differ primarily from conventional systems because the use of mineral fertilizers and synthetic chemical pesticides are prohibited. Organic wheat production is becoming more prevalent in Canada, due to an increased consumer demand for organic wheat products. Differences may exist in the baking and milling quality of wheat grown under conventional and organic management, a result of the dissimilarity between organic and conventional soil and crop management practices. Soils of organically managed fields often have lower N levels than their conventional counterparts, which may influence organic grain protein content (Nass et al. 2003). Aside from differences in soil N, organic and conventional systems often differ in terms of weed prevalence and diversity, and soil biology, which could influence competition for soil resources (i.e., nutrients, moisture) and stress tolerance. Mason and Madin (1996) reported variable effects of weed competition on the grain protein content of wheat, while others have reported both improvements and declines in various wheat quality measures with changes in seeding rate (Bavec et al. 2002; Geleta et al. 2002; Gooding et al. 2002). This suggests that both inter- and intra-specific competition effects have the potential to affect wheat quality and should be further studied. The various inputs associated with organic management (e.g., crop residues, animal manure) can greatly increase the biological activity of a soil which can alter nutrient availability (Carpenter-Boggs et al. 2000; Emmerling et al. 2001; Burger and Jackson 2003). Burger and Jackson (2003) reported that organic soils receiving inputs of composted manure and harvest residues had a higher N supplying capacity than conventionally managed soils receiving mineral fertilizers and harvest residues. They also suggested that the supply of N in organic soils extended later in to the growing season than in the conventionally managed soil. In addition, mycorrhizal colonization of wheat has been found to be greater in soils under organic management when compared to conventionally managed soils, and has also been found to moderate yield losses commonly experienced by organic producers (Mader et al. 2000). While mycorrhizae are known largely for their ability to assist in phosphorus uptake, there is evidence that mycorrhizal associations assist in the uptake of N in wheat (Singh and Kapoor 1999; Hawkins et al. 2000).

Research investigating quality differences between organically and conventionally grown wheat has been conducted in some European nations, however there is no evidence of any research of this kind in Canada to date. Some researchers have observed that grain protein is higher in conventional systems than in organic (Poutala et al. 1993; Starling and Richards 1993; L-Baeckstrom et al. 2004) and biodynamic management systems (Granstedt and Kjellenberg 1997), where no chemical fertilizers or pesticides were used. In contrast, Shier et al. (1984) reported no differences in grain protein levels of spring wheat grown in organic and conventional cropping systems, which they attributed to adequate soil nutrient levels in both systems. Similarly, Ryan et al. (2004) found no difference in grain nitrogen concentration between organic and conventional sites. Other studies, though not directly comparing organic and conventionally grown grain, have reported grain protein levels in organic systems to be lower than is required for breadmaking (Storey et al. 1993; Gooding et al. 1999; Nass et al. 2003).

The effect of organic management systems on other wheat quality parameters such as test weight, falling number and flour yield has been less frequently studied. Gooding et al. (1999) reported that the test weights of several cultivars grown under organic management were adequate for breadmaking (>75 kg hL^{-1}), thus test weight was not a significant constraint to marketing organic bread wheat. Storey et al. (1993) also found test weights of organic wheat to be above 75 kg hL^{-1}. L-Baeckstrom et al. (2004) and Poutala et al. (1993) similarly reported that test weights were similar between organic and conventional cropping systems. Storey et al. (1993) reported low Hagberg falling numbers for organically produced winter wheat, while Gooding et al. (1999) found falling number values of organically grown UK wheat cultivars to be lower than required for breadmaking in many instances. L-Baeckstrom et al. (2004) reported that Swedish winter wheat cultivars grown under conventional and organic management had similar falling number values. Conversely, Granstedt and Kjellenberg (1997) reported higher falling number values for wheat grown in biodynamic systems and Poutala et al. (1993) found that falling number values were generally higher under organic cropping systems. L-Baeckstrom et al. (2004) reported that although conventional values for flour yield were slightly higher in conventional systems, differences were not significant.

The objective of this experiment was to determine if quality differences exist between organically and conventionally grown CWRS cultivars, in order to establish whether high quality CWRS wheat can be produced on organically managed land. We also wished to determine if any wheat cultivars exhibited different and potentially superior breadmaking potential in organically managed systems, as this would suggest the potential for breeding wheat cultivars especially suited to high quality organic wheat production.

3.2 Materials and Methods

Twenty-seven Canada Western Red Spring (CWRS) wheat cultivars representing 114 years of CWRS wheat breeding were grown under both conventional and organic management systems. Field trials were conducted in 2003 and 2004 at the Edmonton Research Station (ERS), Edmonton, Alberta (53° 34'N, 113° 31'W) on one organically managed field and one conventionally managed field, located less than 1 km apart. Soils were classified as Orthic Black Chernozemics, typical of central Alberta (Alberta Agriculture Food and Rural Development 2004).

The experiment was designed as a randomized compete block with four replicates. All plots were seeded at a rate of 300 viable seeds m^{-2}, according to local recommended seeding rates (Alberta Agriculture Food and Rural Development 2003b). In 2003, plot dimensions were 6 m x 0.9 m and consisted of four rows spaced approximately 23 cm apart. Plots were seeded using a four row, double disk drill (Fabro Enterprises Ltd., Swift Current, SK, Canada). In 2004, plot dimensions at ERS were 4 m x 1.38 m, consisting of 6 rows spaced approximately 23 cm apart. Plots were seeded using a six row, no-till double disk drill (Fabro Enterprises Ltd., Swift Current, SK, Canada). Seed used each year was increased the previous year at the ERS on conventionally managed land. Seeds were free of disease and therefore did not receive chemical seed treatment prior to seeding. The trials were not irrigated. All trials were planted in May and harvested in early to mid-September.

Conventional sites were managed according to local recommendations (Alberta Agriculture Food and Rural Development 2003b; 2006). Fertilizers were applied following soil fertility testing in early spring. At the 2003 site, fertilizer (90 kg ha^{-1} N as 46-0-0 and 28 kg ha^{-1} P as 8-24-24) was broadcast after seeding. At the 2004 site, fertilizer (39 kg ha^{-1} N as 46-0-0) was banded at a depth of 8.5 cm into the soil in the fall of 2003 and again in spring 2004 (11 kg ha^{-1} N as 46-0-0 and 6 kg ha^{-1} P as 8-24-24) prior to seeding. Soil tests were conducted after seeding each year at each site (Table 3-1). All conventional fields were cultivated and harrowed prior to planting in spring and received recommended rates (Alberta Agriculture Food and Rural Development 2006) of MCPA Amine 500 to control broadleaf weeds.

Organically managed sites did not receive any applications of chemical fertilizers or herbicides, and were managed in accordance with the guidelines of the Organic Crop Improvement Association International Certification Standards (Organic Crop Improvement Association 2000). The organic sites were situated on a section of land at the ERS that was first designated to be organically managed (no chemical fertilizers or synthetic pesticides) in the spring of 2001. This land received its last application of chemical fertilizer (67 kg ha^{-1} N as 46-0-0 and 22 kg ha^{-1} P as 8-24-24) in the fall of 2000. The land was subsequently seeded to winter triticale (*Triticale hexaploide* Lart.) which was harvested in fall 2001; triticale stubble was left on the field. Prior to the planting of experiments, the organic land was divided into sections which were subsequently managed with different crop rotations.

The 2003 organic site was planted to fall rye in the fall of 2001, which was mowed throughout the summer of 2002. The vegetative fall rye was disked under in the fall of 2002, just prior to an application of composted dairy manure at a rate of 60 t ha^{-1}. In the spring of 2003, the land was cultivated and harrowed just prior to seeding of the 2003 trial. The 2004 organic site was left to triticale stubble in the fall of 2001 and was seeded with berseem clover (*Trifolium alexandrinum* L.) in the spring of 2002. Extreme drought across the Canadian Prairies in the 2002 growing season caused the clover crop to fail and the land was seeded to fall rye in late summer of 2002. In the summer of 2003, the fall rye was harvested, and the soil was disked and treated with an application of composted dairy manure at a rate of 60 t ha^{-1}. In the spring of 2004, the land was cultivated and harrowed prior to planting. Weeds at both organic sites were manually removed at the 5-6 leaf crop stage in each year, and were subsequently left untouched. Despite the absence of leguminous crops in the rotation, the chernozemic soils typical of north central Alberta have developed under prairie grassland and are thereby relatively high in fertility and organic matter.

Disease assessments were conducted at all site-years, and very mild and sporadic incidences of powdery mildew (*Erysiphe graminis)* and stripe rust (*Puccinia striiformis*) were observed, with no apparent differences between sites or years. Because of the low and infrequent disease incidence, it was determined that no control measures were necessary.

Plots were harvested using a Wintersteiger plot combine following maturity. Grain yield was recorded on a dry weight basis. Harvested grain samples were dried at 60°C for ~24 hours and weed seeds were removed using a 2 mm mesh sieve (Canadian Standard Sieve Series No.10).

Hectolitre weight (i.e., test weight) was determined from a 1 pint (473 mL) subsample of plot yield.

Five of the 27 cultivars were chosen for quality analysis, where quality parameters (including test weight) were selected based on their importance in meeting breadmaking quality objectives and their use in the Canadian wheat grading system (Anonymous 2004; Canadian Grain Commission 2006). The cultivars [Red Fife (released 1885), Marquis (released 1910), Thatcher (released 1935), Park (released 1963) and McKenzie (released 1997)] were chosen as representatives of some of the most important wheat cultivars in the history of CWRS wheat breeding. Grain samples from each replication of the 2003 and 2004 sites were analyzed for breadmaking quality traits at the Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg. Grain samples (~20 g) used to determine wholemeal protein (PRO), particle size index (PSI) and wholemeal SDS sedimentation volume (SDS) were ground using a UDY Cyclone Sample Mill (UDY Corporation, Fort Collins, CO, USA) using a 1.0 mm screen. Wholemeal protein (N x 5.7) and PSI were then determined using a 3 g flour sample in a Instalab 600 Series Near-Infrared Reflectance Analyzer (DICKEY-john Corporation, Auburn, IL, USA). Sodium dodecyl sulphate sedimentation tests were conducted in accordance with Approved Method 56-61A (American Association of Cereal Chemists 2000). Flour Yield (FLY) was determined using a Brabender Quadrumat Junior Mill (C.W. Brabender Instruments, South Hackensack, NJ, USA) according to the Approved Method 26-50 (American Association of Cereal Chemists 2000). Falling number (FN) tests were conducted according to Approved Method 56-81B (American Association of Cereal Chemists 2000). All flour tests were expressed on a 14% moisture basis.

Mixograph parameters were determined using a 10 g fixed bowl mixograph (K&S Tool and Die Ltd., Winnipeg, MB) at 60% water absorption. Automated data collection and analysis were performed as described by Pon et al. (1989). Measurements included mixing development time (MDT), peak height, total energy under the graph, energy to peak (ETP), peak bandwidth (PBW), and bandwidth energy.

Analyses of data were performed using the PROC MIXED procedure of SAS (SAS Institute 1999). The experiment was analysed as a split plot with management system as the main plot and cultivar as the sub plot. Years were treated as blocks and were considered as a random effect in both combined analysis and analysis by management system. Cultivar and management system (where applicable) were considered as fixed effects. Effects were considered significant at $P \leq 0.10$, an appropriate level for an experiment of small size (Steel et al. 1996). Data were also analysed using a fixed effects model, with the PROC GLM procedure of SAS, for the purpose of exploring the percent variation attributable to year, cultivar, management and their interactions.

Single degree of freedom contrasts were employed to identify differences in the breadmaking quality of cultivars in conventional vs. organic systems. Pearson's coefficients of correlation were computed using genotypic least squares means within each management system (organic and conventional) within the PROC CORR procedure of SAS. Three of the six mixograph parameters; peak height, total energy under the graph, and bandwidth energy were found to be non-significant for all effects and are therefore hereafter not discussed.

3.3 Results and Discussion

The organic and conventional sites were less than 1 km apart, with similar growing temperatures and precipitation levels within years (Table 3-2), thus differences between the two systems are likely due to the different management strategies and the resulting differences in nutrient levels (Table 3-1) and weed pressure. Weed biomass was significantly higher at the organic sites, with an average biomass of 54 g m^{-2} under organic management and 1.4 g m^{-2} under conventional management. The main effect of management was significant for grain yield, test weight, SDSS volume, and mixograph peak bandwidth (Table 3-3). Management x cultivar interactions were significant for the mixograph parameter mixing development time, while cultivar main effects were significant for several traits, including grain protein, flour yield, particle size index, mixing development time and energy to peak (Table 3-3).

Grain yield was greater under conventional management, with average grain yields of 3.7 t ha^{-1} compared with 3.2 t ha^{-1} under organic management (Table 3-3). Test weight was lower on organic land (77 kg hL^{-1}) compared to conventional (78 kg hL^{-1}). It is likely that the elevated competition with weeds for moisture and nutrients on organic land contributed to lower grain yields and test weights. Many studies conducted on conventional land have reported similar results, where grain yields were reduced by the presence of weeds in the crop (Thompson and Woodward 1994; Mason and Madin 1996; Das and Yaduraju 1999); however the effect of weeds and the resulting competition for resources on test weight is less clearly defined. Das and Yaduraju (1999) reported test weight of wheat was not significantly affected by weed growth and that frequent irrigation increased test weight. They also reported that the effect of chemical N, P and K fertilizers on test weight was significant yet erratic. While test weights in the present study did differ between the two systems, averages for each management system were above the minimum 75 kg hL^{-1} for a No.1 CWRS grading. In terms of cultivar averages, only Red Fife under organic management was below the desired level, with an average test weight of 73 kg hL^{-1}, meaning, all other factors remaining equal, that it would receive a No.2 CWRS grading (Anonymous 2004).

Mean wholemeal protein content did not differ between conventional and organic management systems (Table 3-3). This is supported by Shier et al. (1984) and Ryan et al. (2004) and, who reported no significant difference between grain protein content of organically and conventionally grown wheat, which Shier et al. (1984) attributed to adequate soil N levels in both systems. Conversely, L-Baeckstrom et al. (2004) and Poutala et al. (1993) reported higher grain protein concentrations under conventional management than in organic cropping systems. Overall, protein contents were high under both conventional and organic management, at 14.9% and 14.7%, respectively. This level of protein content surpasses the minimum standard of 13.5% protein for CWRS wheat (Table 3-3), indicating the potential for growing high quality bread wheat under either management system in north central Alberta. While varietal differences in protein were significant (Table 3-3), average protein content for all cultivars again exceeded 13.5% protein (data not shown). Marquis achieved the highest protein level, while Red Fife achieved the lowest.

Post-seeding soil tests in the current study indicated that in 2003, the conventional site had greater N levels than the organic site, while in 2004, the organic and conventional sites had similar N content (Table 3-1). Averaged across years, N content was 75 kg ha^{-1} in the organic system and 111 kg ha^{-1} in the conventional system. There are several possible explanations for the relatively high protein levels of the organically grown wheat in the current study, despite comparatively low soil N concentrations. Crop residues and animal manure can increase soil biological activity, altering the extent and timing of nutrient availability (Carpenter-Boggs et al. 2000; Emmerling et al. 2001; Burger and Jackson 2003). This could be related to mycorrhizal colonization, which has been found to be greater in organic soils than in conventional soils (Mader et al. 2000). Though these effects were not measured in the present study, the organically managed land did receive applications of composted manure and greater crop residues than the conventionally manages sites.

Crop stress (e.g. limited moisture), has been found to shorten the duration of starch deposition into the wheat kernels, thereby increasing the ratio of protein to starch, ultimately increasing protein percentage (Jenner et al. 1991). In the present experiment, it may be that crop weeds created some moisture stress and, despite lower N availability, helped to increase the ratio of protein to starch. Mason and Madin (1996) reported that the effect of weeds on the protein content of wheat was variable across sites and suggested that the impact of weeds on wheat protein was likely dependent on late season competition between crop and weeds for nitrogen and water, and on the interaction between those factors. Another possible explanation for the relatively high protein content of organic wheat is that the soil analyses may not have adequately described the potential of the soil to supply nitrogen to the crop. Our soil analyses measured nitrate-nitrogen (NO_3), which varies with changes in soil temperature, moisture and biological activity (Wallace 2001). Wallace (2001) suggested that analyses of nitrate-nitrogen give an idea of the current, rather than long-term, N status of the soil.

Higher gluten strength, as measured by SDS sedimentation, occurred under conventional (43 mL) as opposed to organic (41 mL) management (Table 3-3). While no studies comparing the quality of organically and conventionally grown wheat have considered SDS sedimentation, Gooding et al. (1993a), Lloveras et al. (2001) and Ames et al. (2003) reported increases in SDSS volumes with nitrogen fertilization in UK bread wheat, Spanish bread wheat and Canadian durum wheat, respectively. Thus, higher SDSS volumes under conventional management in the current study could be due to higher N availability at conventional sites. Dexter et al. (1982) suggested that increases in SDSS volumes from increases in N fertilizer were related to overall increases in protein. Ames et al. (2003) reported a trend in durum wheat towards higher SDSS volumes with increasing protein. In the current study, SDSS volumes were not related to protein content on conventional land, but were positively associated with protein content on organic land (Table 3-4). These discrepancies suggest that a difference may exist in the partitioning of high and low molecular weight proteins between organically and conventionally grown wheat, which may be related to the stresses associated with organic production.

Average mixograph values for each management system revealed trends toward higher dough strength under organic management (Table 3-3). The main effect of management on peak bandwidth (PBW) was significant, as was the management x cultivar interaction for mixing development time (MDT). Peak bandwidth was higher on organic land than conventional, measuring 19% and 17.6% torque min^{-1}, respectively, reflective of stronger glutenic bonds that may be more tolerant to mixing. Examination of the management x cultivar interaction for MDT reveals that organically grown Red Fife performed poorly relative to all other cultivars in either management system, with a MDT of 1.7 minutes, indicating low dough strength. Conventional Red Fife, with a MDT of 2.1 minutes, performed equally or better than all but the organic Park and McKenzie, both at 2.4 minutes. This interaction suggests that it may be possible to select for high quality wheat cultivars specific to organic environments.

In order to assess the effects of genotypic and environmental factors, we consider year management system and their interaction as environmental effects, and as expected, cultivar effects in our model are discussed as genotypic effects. Environmental effects (year, management, year x management) accounted for over 35% of the variation in grain yield, test weight, wholemeal protein, and PBW (Table 3-5). Fowler and De la Roche (1975) reported that yield, test weight and protein exhibited the largest response to environment, while Preston et al. (2001) similarly suggested that flour protein was most influenced by environment. The effect of year was more prominent than the effect of management system, which contributed less than 10% of the variation in all traits except for yield (14%) and SDSS volume (16%) (Table 3-5). Fowler and De la Roche (1975) reported that SDSS volume was influenced equally by genotype and environment, and our results indicate a similar outcome for both SDSS and falling number. Of the three mixograph parameters measured, mixing development time and energy to peak were more influenced by genotype than by environment, representing the possibility for achieving high breadmaking quality on organic land (Table 3-5). Fowler and De la Roche (1975) reported that MDT showed a high degree of heritability compared to the influence of environment, although the effects of genotype and environment on other mixograph parameters in that study were less clearly defined. Mixing development time has been reported to be strongly associated with farinograph dough development time and stability (Kaur et al. 2004), and a study of CWRS wheat by Preston et al. (2001) suggested that farinograph dough development time and stability were mainly influenced by genotype. Cultivar main effects accounted for less than 25% of the variation in four of the six remaining breadmaking quality traits; however cultivar effects were considerable for particle size index (kernel hardness) and flour yield (Table 3-5). Fowler and De la Roche (1975) reported a larger genetic influence than environmental for kernel hardness and flour yield, and Preston et al. (2001) reported genotype to be the main contributor to kernel hardness, although they reported the effect of environment to be significant as well.

Grain yield was positively associated with test weight, SDSS volume, MDT, and ETP under organic management, but not under conventional management, suggesting that cultivars that yield well on organic land also possess higher breadmaking quality (Table 3-4). This may be related to varietal ability to withstand stresses associated with organic management, since the same relationships were not observed in the relatively low-stress conventional system. Test weight was found to be negatively associated with flour yield, falling number, MDT, ETP, and PBW on conventional land, while it was positively related to SDSS volume, MDT and ETP on organic land. If varieties that are capable of attaining high grain yield and test weight under organic management are consistently found to have high breadmaking quality, selection of high quality wheat for organic production could be simplified.

Within the conventional management system, the main effect of cultivar was significant for wholemeal protein, flour yield, and PSI (kernel hardness), with Red Fife among the lowest in protein and flour yield, with the softest kernels (Table 3-3). Under organic management, cultivars differed for grain yield, PSI, mixing development time and energy to peak, again with Red Fife having the lowest grain yield, MDT, ETP, and the softest kernels (Table 3-3). In both systems, Park and McKenzie were the superior cultivars, while Red Fife appeared to be the least suitable cultivar for breadmaking of the five cultivars tested, suggesting that older CWRS cultivars may not be suitable for breadmaking by today's conventional breadmaking standards. However Marquis and Thatcher, released in 1910 and 1935, respectively, had some of the highest protein contents under conventional management, while McKenzie, released in 1997, was among the lowest (yet adequate) in protein content. Further, Park was released in 1963 and could hardly be considered a 'modern' wheat cultivar. In a study of 14 CWRS cultivars released from 1981-1995, Preston et al. (2001) reported no trends in quality parameters, including protein content, between registration date and cultivar. A study by Wang et al. (2002) on the semi-arid Prairies indicated that Marquis had significantly lower protein content than newer cultivars released 1996-1999, primarily due to more efficient utilization of plant N, rather than increased N uptake by the newer cultivars. However, it is possible that this relationship may be altered by increased soil moisture levels.

There were few differences in the performance of individual cultivars in the two systems, excepting Red Fife. Red Fife was the oldest cultivar (released 1885), and it exhibited higher test weight, SDS sedimentation, mixing development time and energy to peak under conventional when compared to organic management (Table 3-3). The peak bandwidth of Red Fife was higher under organic management. In general, our results suggest that protein quality of Red Fife was higher under conventional management. Marquis (released 1910) had lower mixing development time under conventional management versus organic, reflecting higher breadmaking quality under organic management. The cultivar Thatcher (released 1935) did not perform differently between the two management systems. Park (released 1963) exhibited significantly higher SDS sedimentation volume under organic management, indicating higher breadmaking quality. McKenzie (released 1997) produced higher flour yield under conventional management. The variability of the performance of these cultivars within the two systems allows us to conclude that older cultivars do not necessarily perform better on organic land in terms of breadmaking quality.

3.4 Conclusions

Grain yield and test weight were higher on conventional land when compared to organic, however protein content did not differ between the two systems, despite the probability that overall N availability was higher at the conventional sites. Despite existing differences between management systems and cultivars, test weight and protein content were sufficiently high in both management systems to meet the grading requirements for CWRS wheat. Gluten strength, as measured by SDSS volume, was improved under conventional management, possibly as a result of higher overall N availability. The trend toward enhanced dough strength of organically grown cultivars, as determined through the use of the mixograph, requires further examination. Overall, the results of this study suggest that organically managed CWRS wheat varieties are capable of achieving good breadmaking quality. The significant management x cultivar interaction for mixing development time indicates that some cultivars may be able to achieve higher breadmaking quality when grown on organic land than if grown on conventional land, and implies that breeding specifically for high quality organic wheat production may be possible. Grain yield, test weight and protein content were largely determined by environment, while flour yield, kernel hardness, mixing development time and energy to peak were more influenced by genotypic factors. Falling number and SDSS volume were similarly influenced by genotype and environment. The cultivar Red Fife, released in 1885, had the poorest breadmaking quality of the five cultivars studied, while the most modern cultivars, Park and McKenzie, had the highest quality. This suggests that the oldest CWRS cultivars may not be suitable for breadmaking, despite management system. The variable performance of old and new cultivars under different management regimes indicated that older cultivars, while selected prior to the widespread use of pesticides and fertilizers in breeding programs, may not be better suited to organic production.

3.5 Tables and Figures

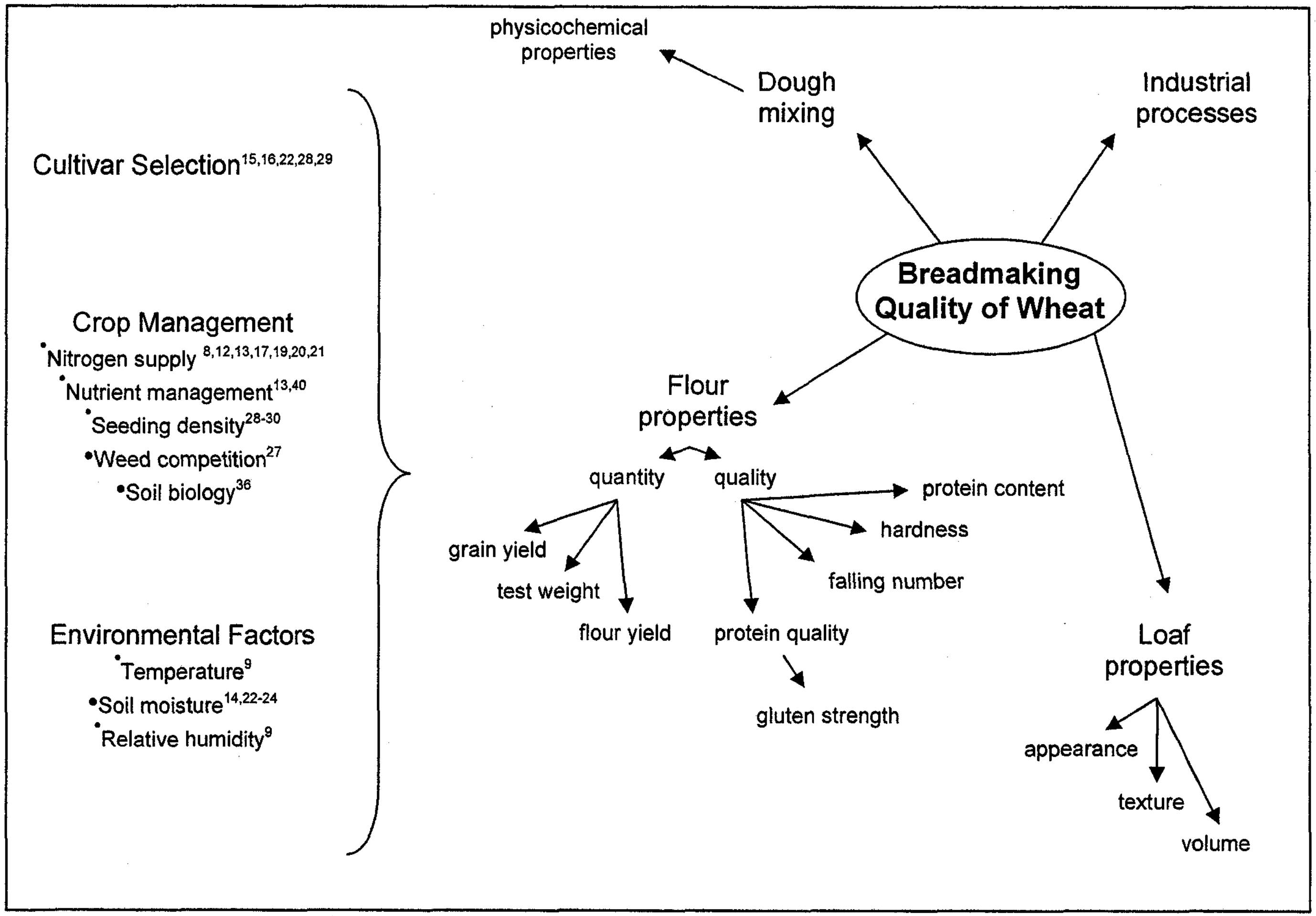

Figure 3-1. Flow chart describing components that determine breadmaking quality and mediating influences of cultivar selection, crop management and environmental factors.[†]

[†] Numbers correspond with parenthesized numbers located at the end of selected citations found in the Literature Cited section of this chapter.

Table 3-1. Soil properties of 0-10cm depth soil samples taken at experimental sites at Edmonton Research Station, Edmonton, AB in the 2003 and 2004 growing seasons directly after seeding.[†,‡]

	ERS-Conventional			**ERS-Organic**		
Soil Property[a,b]	**2003**	**2004**	**System Average**	**2003**	**2004**	**System Average**
N (kg ha^{-1})	156	65	111	74	76	75
P (kg ha^{-1})	89	37	63	>130	58	>94
K (kg ha^{-1})	>1300	473	>887	410	570	490
pH	6.8	5.9	6.4	6.6	6.3	6.5
Organic Matter (%)	10.1	11.2	10.7	9.9	10.3	10.1
Textural Class	Clay	Clay		Clay	Clay	

[†]Available N determined using CaCl2 extraction (Norwest Labs 2003).

[‡]Available P and K determined using a modified Kelowna extract (Norwest Labs 2003).

Table 3-2. Precipitation and mean temperature data for the 2003 and 2004 growing seasons at Edmonton Research Station, Edmonton, AB.[†,‡]

	Precipitation (mm)						**Mean Temperature (°C)**				
Year	**May**	**June**	**July**	**Aug.**	**Sept.**	**Total**	**May**	**June**	**July**	**Aug.**	**Sept.**
2003	35	42	61	47	-	185	10	15	19	18	-
2004	44	22	225	36	40	367	9	15	17	15	10
Normal[b]	49	87	92	69	44	341	12	16	18	17	11

[†]Data collected by the University of Alberta, Edmonton Research Station.

[†]Data from Environment Canada (Environment Canada 2004a).

-Data not available.

Table 3-3. Least squares means and analyses of variance of grain yield, test weight, grain protein, wholemeal protein, flour yield (FLY), falling number (FN), particle size index (PSI), SDS sedimentation (SDSS), mixing development time (MDT), energy to peak (ETP), and peak bandwidth (PBW) for CWRS cultivars grown under conventional and organic management in Edmonton, AB in 2003 and 2004.†

Cultivar	YOR‡	Yield (t ha^{-1})	Test Weight (kg hL^{-1})	Grain Protein (%)	FLY (%)	FN	PSI (%)	SDSS (mL)	MDT (min.)	ETP (%)	PBW (% torque min.$^{-1}$)
		Conventional									
Red Fife	1885	3.5	79	14.2	67	434	61	42.9	2.1	26	16
Marquis	1910	3.8	79	15.5	69	435	56	45.3	2.0	26	18
Thatcher	1935	3.7	78	15.3	70	500	56	43.9	2.2	33	18
Park	1963	4.0	78	14.9	70	500	55	42.3	2.3	37	18
McKenzie	1997	3.6	78	14.4	72	500	54	41.1	2.3	39	18
Conventional Mean		3.7	78	14.9	70	474	56	43.1	2.2	32	17.6
F test$_{cultivar}$		ns	ns	**	**	ns	***	ns	ns	ns	ns
SE$_{cultivar}$		0.83	0.5	0.30	0.8	46.9	0.6	1.90	0.14	6.1	1.3
		Organic									
Red Fife	1885	2.5	73	14.1	67	471	60	37.6	1.7	19	19
Marquis	1910	3.0	77	15.1	69	464	55	41.0	2.2	33	19
Thatcher	1935	3.3	77	14.4	72	492	55	39.8	2.1	30	19
Park	1963	3.7	78	15.1	69	489	57	43.9	2.4	45	18
McKenzie	1997	3.3	78	14.6	69	495	54	41.5	2.4	46	19
Organic Mean		3.2	77	14.7	69	482	56	40.8	2.2	35	19
F test$_{cultivar}$		*	ns	ns	ns	ns	*	ns	**	***	ns
SE$_{cultivar}$		0.30	3.1	0.69	1.9	19.4	1.4	2.19	0.14	5.1	1.1
		Combined ANOVA									
F test$_{mgmt}$		*	*	ns	ns	ns	ns	**	ns	ns	**
SE$_{mgmt}$		0.27	1.0	0.23	0.6	8.4	0.5	0.75	0.09	7.4	0.5
F test$_{cultivar}$		ns	ns	*	*	ns	***	ns	**	**	ns
SE$_{cultivar}$		0.43	1.5	0.37	1.0	33.1	0.8	1.74	0.10	4.2	0.8
F test$_{mgmt*cultivar}$		ns	ns	ns	ns	ns	ns	ns	**	ns	ns

†F values significant at the following levels: *** 0.01, ** 0.05, * 0.1, ns denotes non-significance.
‡YOR indicates Year of Release.

Table 3-4. Genotypic correlations of yield, test weight, protein, particle size index (PSI), flour yield, falling number (FN), sodium dodecyl sulphate sedimentation volume (SDSS) and mixograph parameters of 5 CWRS cultivars, released 1885-1997, grown at conventionally and organically managed sites in 2003 and 2004 at Edmonton Research Station, Edmonton, AB.[†,‡,§]

	Yield	**Test Weight**	**Protein**	**PSI**	**Flour Yield**	**FN**	**SDSS**	**MDT**	**ETP**	**PBW**
Yield		-	-	-	-	-	-	-	-	-
Test Weight	0.90**		-	-	-0.80*	-0.99***	-	-0.91**	-0.92**	-0.80*
Protein	-	-		-	-	-	-	-	-	-
PSI	-	-0.83*	-		-0.93**		-	-	-	-0.96**
Flour Yield	-	-	-	-		0.81**	-	-	0.88**	0.91**
FN	-	-	-	-	-		-	0.91**	0.93**	0.81*
SDSS	0.90**	0.86*	0.85*	-	-	-		-0.84*	-	-
MDT	0.88**	0.97***	-	-	-	-	0.92**		0.95**	-
ETP	0.87*	0.90**	-	-	-	-	0.92**	0.97***		-
PBW	-	-	-0.81*	-	-	-	-	-	-	

[†] Mixograph parameters include mixing development time (MDT), energy to peak (ETP), peak bandwidth (PBW).

[‡] r values significant at the following levels: *** 0.01, ** 0.05, * 0.1, - denotes non-significance.

[§] Correlations above the diagonal represent conventional management, while those on the bottom represent organic management.

Table 3-5. Percent sums of squares within fixed effects analyses of variance for the grain parameters yield, test weight, wholemeal protein, flour yield, falling number, particle size index (PSI) and SDS sedimentation (SDSS), and for the mixograph parameters mixing development time, energy to peak and peak bandwidth.[†]

Effect	**df**	**Grain Parameters**							**Mixograph Parameters**		
		Yield	Test Weight	Wholemeal Protein	Flour Yield	Falling Number	PSI	SDSS	Mixing Development Time	Energy to Peak	Peak Bandwidth
		(% Total Sum of Squares)									
Year	1	21	40	46	0	20	0	2	4	12	46
Management (Mgmt)	1	14	8	1	2	1	0	16	0	1	5
Year*Mgmt	1	2	1	1	0	0	1	1	2	7	0
Cultivar	4	12	8	21	40	22	70	14	26	28	3
Year*Cultivar	4	8	8	6	13	20	2	15	4	4	4
Mgmt*Cultivar	4	3	9	6	15	5	3	22	10	5	4
Year*Mgmt*Cultivar	4	20	12	10	12	4	6	7	3	3	5
Error	60	19	15	9	18	29	18	23	50	42	33
Corrected Total	79	100	100	100	100	100	100	100	100	100	100

[†] Corrected totals may not sum to 100% due to rounding.

3.6 Literature Cited

Alberta Agriculture Food and Rural Development. 2003. Using 1,000 kernel weight for calculating seeding rates and harvest losses. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex81/$file/100_22-1.pdf?OpenElement [14 July 2006].

Alberta Agriculture Food and Rural Development. 2004. Soil Group Map of Alberta. [Online] Available: http://www1.agric.gov.ab.ca/soils/soils.nsf/soilgroupmap?readform [31 August 2006].

Alberta Agriculture Food and Rural Development. 2006. Herbicide Selector. [Online] Available: http://www.agric.gov.ab.ca/app23/herbsel [29 September 2006].

American Association of Cereal Chemists, (ed.) 2000. Approved Methods of the AACC. The Association, St. Paul, MN.

Ames, N. P., Clarke, J. M., Dexter, J. E., Woods, S. M., Selles, F. and Marchylo, B. 2003. Effects of nitrogen fertilizer on protein quantity and gluten strength parameters in durum wheat (*Triticum turgidum* L. var. *durum*) cultivars of variable gluten strength. Cereal Chem. **80**:203-211. (20)

Anonymous. 2004. Official Grain Grading Guide, revised August 1, 2004. Canadian Grain Commission, Winnipeg, Canada.

Bavec, M., Bavec, F., Varga, B. and Kovacevic, V. 2002. Relationships among yield, its quality and yield components, in winter wheat (*Triticum aestivum* L.) cultivars affected by seeding rates. Bodenkultur **53**:143-151. (28)

Burger, M. and Jackson, L. E. 2003. Microbial immobilization of ammonium and nitrate in relation to ammonification and nitrification rates in organic and conventional cropping systems. Soil Biol. Biochem. **35**:29-36.

Canadian Grain Commission. 2006. Crop quality data, highlights and reports: Canadian western wheat. [Online] Available: http://www.grainscanada.gc.ca/Quality/Wheat/cdnwhtmenu-e.htm [2006.

Canadian Wheat Board. 2001. Grain Matters: Wheat report for the 1999-2000 crop year. [Online] Available: http://www.cwb.ca/en/publications/farmers/jan-feb-2001/02-12-00-6.jsp [8 November 2003].

Canadian Wheat Board. 2005. Canada Western Red Spring wheat- CWRS. [Online] Available: http://www.cwb.ca/en/buying/high_quality/2005/no1cwrs [13 July 2005].

Carpenter-Boggs, L., Kennedy, A. C. and Reganold, J. P. 2000. Organic and biodynamic management: Effects on soil biology. Soil Sci. Soc. Am. J. **64**:1651-1659.

Cauvain, S. P. 2003. Wheat and its Special Properties, p. 2-3, *In* X. P. Cauvain, ed. Bread Making: Improving Quality. Woodhead Publishing Ltd., Cambridge, England.

Das, T. K. and Yaduraju, N. T. 1999. Effect of weed competition on growth, nutrient uptake and yield of wheat as affected by irrigation and fertilizers. J. Agric. Sci. **133**:45-51.

Dexter, J. E., Crowle, W. L., Matsuo, R. R. and Kosmolak, F. G. 1982. Effect of nitrogen-fertilization on the quality characteristics of 5 North-American amber durum-wheat cultivars. Can. J. Plant Sci. **62**:901-912. (21)

Emmerling, C., Udelhoven, T. and Schroder, D. 2001. Response of soil microbial biomass and activity to agricultural de-intensification over a 10 year period. Soil Biol. Biochem. **33**:2105-2114.

Environment Canada. 2004. Canadian Climate Normals 1971-2000. Edmonton City Centre. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html [31 August 2006].

Fowler, D. B. and De la Roche, I. A. 1975. Wheat quality evaluation. 3. Influence of genotype and environment. Can. J. Plant Sci. **55**:263-269. (15)

Fowler, D. B. and Kovacs, M. I. P. 2004. Influence of protein concentration on farinograph absorption, mixing requirements and mixing tolerance. Can. J. Plant Sci. **84**:765-772.

Geleta, B., Atak, M., Baenziger, P. S., Nelson, L. A., Baltenesperger, D. D., Eskridge, K. M., Shipman, M. J. and Shelton, D. R. 2002. Seeding rate and genotype effect on agronomic performance and end-use quality of winter wheat. Crop Sci. **42**:827-832. (29)

Gooding, M. J., Cannon, N. D., Thompson, A. J. and Davies, W. P. 1999. Quality and value of organic grain from contrasting breadmaking wheat varieties and near isogenic lines differing in dwarfing genes. Biol. Agric. Hortic. **16**:335-350.

Gooding, M. J., Davies, W. P., Thompson, A. J. and Smith, S. P. 1993. The challenge of achieving breadmaking quality in organic and low input wheat in the UK- a review. Aspects Appl. Biol. **36**:189-198. (8)

Gooding, M. J., Pinyosinwat, A. and Ellis, R. H. 2002. Responses of wheat grain yield and quality to seed rate. J. Agric. Sci. **138**:317-331. (30)

Granstedt, A. and Kjellenberg, L. 1997. Long-term field experiments in Sweden: Effects of organic and inorganic fertilizers on soil fertility and crop quality. [Online] Available: http://www.jdb.se/sbfi/publ/boston/boston7.htmL [29 September 2006]. (40)

Guttieri, M. J., Ahmad, R., Stark, J. C. and Souza, E. 2000. End-use quality of six hard red spring wheat cultivars at different irrigation levels. Crop Sci. **40**:631-635. (22)

Hawkins, H. J., Johansen, A. and George, E. 2000. Uptake and transport of organic and inorganic nitrogen by arbuscular mycorrhizal fungi. Plant Soil **226**:275-285.

Jenner, C. F., Ugalde, T. D. and Aspinall, D. 1991. The physiology of starch and protein deposition in the endosperm of wheat. Aust. J. Plant Physiol. **18**:211-226.

Johansson, E., Prieto-Linde, M. L., Svensson, G. and Jonsson, J. O. 2003. Influences of cultivar, cultivation year and fertilizer rate on amount of protein groups and amount and size distribution of mono- and polymeric proteins in wheat. J. Agric. Sci. **140**:275-284. (12)

Kaur, K., Lukow, O. M., Preston, K. R. and Malcolmson, L. J. 2004. How well do early-generation quality tests predict flour performance? Can. J. Plant Sci. **84**:71-78.

Khatkar, B. S., Bell, A. E. and Schofield, J. D. 1996. A comparative study of the inter-relationships between Mixograph parameters and bread-making qualities of wheat flours and glutens. J. Sci. Food Agric. **72**:71-85.

Kimball, B. A., Morris, C. F., Pinter, P. J., Wall, G. W., Hunsaker, D. J., Adamsen, F. J., LaMorte, R. L., Leavitt, S. W., Thompson, T. L., Matthias, A. D. and Brooks, T. J. 2001.

Elevated CO_2, drought and soil nitrogen effects on wheat grain quality. New Phytol. **150**:295-303. (23)

L-Baeckstrom, G., Hanell, U. and Svensson, G. 2004. Baking quality of winter wheat grown in different cultivating systems, 1992-2001: A holistic approach. J. Sustain. Agric. **24**:53-79.

Lerner, S. E., Seghezzo, M. L., Molfese, E. R., Ponzio, N. R., Cogliatti, M. and Rogers, W. J. 2006. N- and S-fertiliser effects on grain composition, industrial quality and end-use in durum wheat. J. Cereal Sci. **44**:2-11. (13)

Lloveras, J., Lopez, A., Ferran, J., Espachs, S. and Solsona, J. 2001. Bread-making wheat and soil nitrate as affected by nitrogen fertilization in irrigated Mediterranean conditions. Agron. J. **93**:1183-1190. (19)

Mader, P., Edenhofer, S., Boller, T., Wiemken, A. and Niggli, U. 2000. Arbuscular mycorrhizae in a long-term field trial comparing low-input (organic, biological) and high-input (conventional) farming systems in a crop rotation. Biol. Fertil. Soils **31**:150-156.

Mason, M. G. and Madin, R. W. 1996. Effect of weeds and nitrogen fertiliser on yield and grain protein concentration of wheat. Aust. J. Exp. Agric. **36**:443-450. (27)

Nass, H. G., Ivany, J. A. and MacLeod, J. A. 2003. Agronomic performance and quality of spring wheat and soybean cultivars under organic culture. Am. J. Altern. Agric. **18**:164-170.

Norwest Labs. 2003. Agricultural Schedule of Services. [Online] Available: http://www.norwestlabs.com/what_we_do/agrisos20032004noprices.pdf [29 September 2006].

Ohm, J. B. and Chung, O. K. 1999. Gluten, pasting, and mixograph parameters of hard winter wheat flours in relation to breadmaking. Cereal Chem. **76**:606-613.

Organic Crop Improvement Association. 2000. International Certification Standards As Revised: March 2000. OCIA International, Inc., Lincoln, NE.

Peterson, C. J., Graybosch, R. A., Shelton, D. R. and Baenziger, P. S. 1998. Baking quality of hard winter wheat: Response of cultivars to environment in the great plains (Reprinted from Wheat: Prospects for global improvement, 1998). Euphytica **100**:157-162. (9)

Pon, C. R., Lukow, O. M. and Buckley, D. J. 1989. A multichannel, computer-based system for analyzing dough rheology. J. Texture Stud. **19**:343-360.

Poutala, R. T., Korva, J. and Varis, E. 1993. Spring wheat cultivar performance in ecological and conventional cropping systems. J. Sustain. Agric. **3**:63-84.

Preston, K. R., Hucl, P., Townley-Smith, T. F., Dexter, J. E., Williams, P. C. and Stevenson, S. G. 2001. Effects of cultivar and environment on farinograph and Canadian short process mixing properties of Canada western red spring wheat. Can. J. Plant Sci. **81**:391-398. (16)

Randall, P. J., Freney, J. R., Smith, C. J., Moss, H. J., Wrigley, C. W. and Galbally, I. E. 1990. Effect of additions of nitrogen and sulfur to irrigated wheat at heading on grain-yield, composition and milling and baking quality. Aust. J. Exp. Agric. **30**:95-101. (17)

Rharrabti, Y., Royo, C., Villegas, D., Aparicio, N. and del Moral, L. F. G. 2003. Durum wheat quality in Mediterranean environments I. Quality expression under different zones, latitudes and water regimes across Spain. Field Crops Res. **80**:123-131. (14)

Ryan, M. H., Derrick, J. W. and Dann, P. R. 2004. Grain mineral concentrations and yield of wheat grown under organic and conventional management. J. Sci. Food Agric. **84**:207-216.

SAS Institute. 1999. Release 8.2. SAS Institute, Cary, NC.

Shier, N. W., Kelman, J. and Dunson, J. W. 1984. A comparison of crude protein, moisture, ash and crop yield between organic and conventionally grown wheat. Nutr. Rep. Int. **30**:71-76.

Singh, S. and Kapoor, K. K. 1999. Inoculation with phosphate-solubilizing microorganisms and a vesicular arbuscular mycorrhizal fungus improves dry matter yield and nutrient uptake by wheat grown in a sandy soil. Biol. Fertil. Soils **28**:139-144. (36)

Souza, E. J., Martin, J. M., Guttieri, M. J., O'Brien, K. M., Habernicht, D. K., Lanning, S. P., McLean, R., Carlson, G. R. and Talbert, L. E. 2003. Influence of genotype, environment, and nitrogen management on spring wheat quality. Crop Sci. **44**:425-432.

Starling, W. and Richards, M. C. 1993. Quality of commercial samples of organically grown wheat. Aspects Appl. Biol. **36**:205-209.

Steel, R. G. D., Torrie, J. H. and Dickey, D. A. 1996. Principles and Procedures of Statistics: A Biometrical Approach. 3rd ed. McGraw-Hill, New York, NY. 666 pp.

Storey, T., Hogan, R. and Humphreys, J. 1993. The growth, yield and quality of winter wheat and winter oats grown under an organic conversion regime. Aspects Appl. Biol. **36**:199-204.

Thompson, G. B. and Woodward, F. I. 1994. Some influences of CO_2 enrichment, nitrogen nutrition and competition on grain-yield and quality in spring wheat and barley. J. Exp. Bot. **45**:937-942.

Wallace, J., (ed.) 2001. Organic Field Crop Handbook. Canadian Organic Growers, Ottawa, ON.

Wang, H., McCaig, T. N., Depauw, R. M., Clarke, F. R. and Clarke, J. M. 2002. Physiological characteristics of recent Canada Western Red Spring wheat cultivars: Yield components and dry matter production. Can. J. Plant Sci. **82**:299-306.

Williams, P. 1997. Cultivar development and quality control of wheat in Canada. Paper presented at the International Japanese Conference on Near-Infrared Reflectance. [Online] Available: http://collection.nlc-bnc.ca/100/200/301/cgc-ccg/cultivar_development-e/cultivar4-e.htm [24 July 2003].

Xu, Z.-Z. and Yu, Z.-W. 2006. Nitrogen metabolism in flag leaf and grain of wheat in response to irrigation regimes. Journal of Plant Nutrition and Soil Science **169**:118-126. (24)

4.0 Cultivar and seeding rate effects on the competitive ability of spring cereals grown under organic production in northern Canada[4]

4.1 Introduction

Organic management is a holistic system of production that uses natural long term strategies (i.e., rotation) for soil building and pest management. It prohibits the use of mineral fertilizers, synthetic pesticides and genetically modified organisms (GMOs) (Bruinsma 2003). Producers have made the transition from conventional to organic production for a number of reasons, including concerns about environmental stewardship, pesticide resistance, grower independence, high input costs, increasing human health concerns, and rising consumer demand (Entz et al. 2001; Ngouajio and McGiffen 2002). Production constraints associated with organic agriculture are similar to those faced in conventional production. Nevertheless, increased weed pressure and soil nutrient deficiencies, particularly nitrogen and phosphorus, are more common in organic management systems, which may lead to crop yield reductions (Waldon et al. 1998; Clark et al. 1999; Ryan et al. 2004).

In Canada, competition with weeds on conventional land has reduced crop yields significantly; with documented losses from 16-29% in barley (Harker 2001; Didon and Bostrom 2003; Scursoni and Satorre 2005), and 8-63% in wheat (Kirkland and Hunter 1991; Hucl 1998). The three most abundant weed species in conventional spring wheat production fields in Alberta are wild buckwheat (*Polygonum convolvulus* L.), wild oats (*Avena fatua* L.) and chickweed (*Stellaria media* L.) (Leeson et al. 2002). In organic cereal production fields, greater weed species diversity and higher weed populations have been reported (Samuel and Guest 1990; Leeson et al. 2000), with wild mustard (*Sinapis arvensis* L.) and Canada thistle (*Cirsium arvense* L.) the most problematic weed species (Entz et al. 2001).

Organic production systems must have reliable non-chemical weed control methods to maximize returns (Jordan 1993; Lemerle et al. 1996). Weed control may be accomplished by using various tillage regimes (Barberi et al. 2000), crop rotations and intercrops (Hartl 1989), changes to crop seeding density (Korres and Froud-Williams 2002), and the use of competitive cultivars (Huel and Hucl 1996; Lemerle et al. 1996).

Generally, barley has been found to be more competitive than wheat (Pavlychenko and Harrington 1934; O'Donovan et al. 1985; Cousens 1996; Fischer et al. 2000). In addition, there are differences in the competitive ability of genotypes or cultivars of both wheat and barley crops (Wicks et al. 1986; Huel and Hucl 1996; Lemerle et al. 1996; O'Donovan et al. 2000). The

---

[4] *This chapter has been accepted for publication in Agronomy Journal.*

competitive ability of a crop or a plant cultivar may be due to (1) tolerance to weed pressure by maintaining grain yield (crop competitive response), and/or (2) the ability to suppress weed growth (crop competitive effect) (Goldberg and Landa 1991; Coleman et al. 2001). Both are important since yield stability and the prevention of weed seed production (and subsequent seed bank build-up) are desirable in crops growing in association with weeds (Jordan 1993). When considering crop competitive ability, weed tolerance and weed suppression need to be considered separately, as they may or may not occur together (Jordan 1993).

Morphological, physiological and biochemical traits are thought to control plant competitiveness (Lemerle et al. 2001a). Plant height, tillering capacity, canopy structure, light interception, early biomass accumulation, ground cover, flag leaf length, and timing of spike emergence have been found to contribute to competitiveness (Wicks et al. 1986; Huel and Hucl 1996; Lemerle et al. 1996; Champion et al. 1998; Hucl 1998; Korres and Froud-Williams 2002). From an agronomic perspective, increases in seeding density have resulted in higher levels of weed suppression and increased yields in wheat (Lemerle et al. 1996; Champion et al. 1998; Weiner et al. 2001) and barley (O'Donovan et al. 1999). Korres and Froud-Williams (2002) concluded that altering crop density was a more reliable tool than cultivar selection to reduce weed-crop competition.

The identification of plant traits that improve competitive ability may help crop breeders develop competitive crop cultivars. Choosing cultivars and management techniques that increase competitive ability will help growers to maximize production. The objectives of the present study were to determine the effect of cultivar and seeding rate on the competitive ability and agronomic performance of Canadian spring wheat and barley cultivars grown under organic management.

4.2 Materials and Methods

Nine hard spring wheat and two spring barley cultivars were chosen for this experiment on the basis of height, tillering potential and maturity characters (Table 4-1). These 11 cultivars were grown under organic management at single (300 seeds m^{-2}) and doubled seeding rates, with single seeding rate based on the upper end of the recommended hard red wheat and 2 and 6 row barley seeding range for the growing region (Alberta Agriculture Food and Rural Development 2003b). Field trials were conducted at two locations in both 2003 and 2004; the Edmonton Research Station (ERS), Edmonton, Alberta (53° 34'N, 113° 31'W) in an organically managed field and on a certified organic farm near New Norway, Alberta (52° 52'N, 112° 56'W). Soils at New Norway sites were Eluviated Black Chernozemics, while soils at Edmonton sites were

Orthic Black Chernozemics, typical of central Alberta (Alberta Agriculture Food and Rural Development 2004). Tillering potential of cultivars was determined from data generated in trials conducted at the ERS on conventional land in 1999 through 2002.

The experiment was designed as a strip-plot with three replicates, where the horizontal-strip plot factor was simulated weed competition with tame oat (cv. Grizzly), and the vertical-strip plot factor included the 22 cultivar x seeding rate combinations. In 2003, plot dimensions were 4.5 m x 0.9 m consisting of 4 rows spaced approximately 23 cm apart. Plots were seeded using a four row, double disk drill (Fabro Enterprises Ltd., Swift Current, SK, Canada). In 2004, plot dimensions were 4 m x 1.38 m consisting of 6 rows spaced approximately 23 cm apart. Plots were seeded using a six row, no-till double disk drill (Fabro Enterprises Ltd., Swift Current, SK, Canada). In both years, plots receiving the simulated weed treatment were cross-seeded with tame oats immediately after crop seeding at a rate of 60 tame oat seeds m^{-2}. Seed used in the 2003 trial was either certified seed or was grown in increase plots at the ERS in 2002, and seed used in the 2004 trials was grown on organically managed increase plots at ERS in 2003. The trials were not irrigated. Rainfall for the 2003 growing season (May-September) was below the regional thirty year average of ~330 mm, with 185 mm of precipitation at ERS and 80 mm at New Norway. Rainfall over the 2004 growing season totaled 367 mm at ERS and 281 mm at New Norway. All trials were planted in late May and harvested in early to mid-September.

Trials did not receive any applications of chemical fertilizer or herbicide, and were managed in accordance with the Organic Crop Improvement Association International Certification Standards (Organic Crop Improvement Association 2000). Edmonton sites were situated on a section of land at the ERS that was first designated to be organically managed in the spring of 2001. The 2003 organically managed trial followed a cereal plowdown and an application of composted dairy manure at a rate of 60 t ha^{-1}. The 2004 organically managed trial followed a cereal-legume rotation and an application of composted dairy manure at a rate of 60 t ha^{-1}. Composted dairy manure was estimated to be ~50% dry matter content, with 1.3% total N. At the certified organic farm, experimental trials followed cereal-legume plowdowns without crop removal in the year prior to planting.

4.2.1 Data Collection

In both years, early season vigour was rated at the 3-4 leaf stage (Zadoks growth stage (ZGS) 13-14) (Zadoks et al. 1974), and was based on plant leaf size, number and overall form on a scale of 1 (least vigourous) to 5 (most vigourous) (Revilla et al. 1999). After stem elongation was complete, plant height (representing the distance from the soil surface to the tip of the spike, excluding awns in awned cultivars) was recorded on a per plot basis. Maturity was recorded as the day when 75% of the spikes and peduncles in the plot were tan brown, estimated to be approximately 30% seed moisture content. At maturity, all spikes in either a 1 m^2 (2003) or 1 m row (2004) section of each plot were counted and used to calculate spikes m^{-2}.

In 2003, dry weed biomass in each plot was determined from the aboveground portion of weeds from the harvested 1 m^2. In 2004, dry weed biomass in each plot was determined by harvesting the aboveground portion of weeds from within two randomly placed 0.0625 m^2 quadrats (25 cm x 25 cm) at crop maturity. In both years, samples were dried at 60°C for ~24 hours and then weighed. Weeds present in both 2003 and 2004 at the ERS included field pennycress (*Thlaspi arvense* L.), common lambsquarters (*Chenopodium album* L.), wild buckwheat (*Polygonum convolvulus* L.) , shepherd's-purse (*Capsella bursa-pastoris* L.) and Canada thistle (*Cirsium arvense* L.) while weeds in both years at the New Norway site were mainly wild oats and lambsquarters.

In both years, tame oat samples were harvested from plots just prior to crop harvest. Tame oats were harvested from a 1 m^2 area in 2003 and from within two randomly placed 0.0625 m^2 quadrats in 2004. The samples were dried at 60°C for ~24 hours and weighed to obtain oat biomass and threshed to calculate grain weight.

Prior to harvest, ten randomly chosen wheat/barley spikes in each plot were collected and used to determine kernels spike^{-1} and thousand kernel weight. At crop maturity, grain was harvested from the entire plot using a Wintersteiger plot combine. Grain yield was recorded on a dry weight basis. Harvested grain samples were dried at 60°C for ~24 hours and weed seeds were removed using a 2 mm mesh sieve (Canadian Standard Sieve Series No.10). The weed seed-free grain samples were weighed and plot yields were recorded for those plots without tame oats. For plots with tame oats, the weed seed-free grain sample was weighed, a 100 g sample of grain was removed, and tame oats and wheat were separated and weighed. Grain yields for plots with tame oats were based on multiplication of the weed seed-free plot grain yield by the ratio of grain:oats from the 100 g sample. For the sake of varietal comparison, grain yield and kernel weight of the hulled cultivar Seebe were adjusted downward by 15% to account for the weight of the hull (Bhatty et al. 1993). Percent yield loss was calculated as the difference between grain yield in plots without and with tame oats, divided by the grain yield in plots without.

4.2.2 Data Analysis

A variance-stabilizing square root transformation ($(Y+0.5)^{1/2}$) was used for all natural weed, tame oat and total weed biomass measures (Gomez and Gomez 1984). A preliminary analysis of variance was performed to detect significant location x treatment differences using the MIXED procedure of SAS (SAS Institute, 2003), where location was considered to be a fixed effect while year was considered random. The effects of seeding rate, location and cultivar were most important, respectively, while few significant location x treatment interactions occurred (Table 4-2). Seven of a possible fifty-one location by treatment interactions were significant ($P<0.10$), and of those only 4 were significant at $P<0.05$ (Table 4-2). Subsequent analyses of variance were therefore performed using data combined across environments (year x location), again using the MIXED procedure of SAS (Littell et al. 2006). Environment (year x location) was considered to be a random effect, while competition from tame oats, cultivar and seeding rate were considered fixed effects. Preliminary analysis of variance showed a high degree of variation existed in the naturally occurring weed biomass, thus an analysis of covariance was attempted in order to control error, and increase the precision of treatment effect estimation (Steel et al. 1996). Analysis of covariance was conducted (where appropriate) using the previous model with natural weed biomass as a covariate. Due to the conservative nature of probability estimation in the horizontal- and vertical-strip plot factors of the strip plot design (Gomez and Gomez 1984), effects were considered significant at $P<0.10$. Single degree of freedom contrasts were performed to detect significant differences in weed and oat biomass between Seebe, a competitive barley cultivar (O'Donovan et al. 2000), and the other ten cultivars tested.

A simple economic analysis was conducted to determine the net return associated with doubling the seeding rate, based on the seeding rates used, and yield gains and kernel weights observed in this trial. Crop prices were obtained from documents detailing Alberta purchase prices for organically grown crops in 2005 (Organic Agriculture Centre of Canada, 2006). Seed costs were calculated as the crop price per bushel plus an additional \$0.65 per bushel to account for seed cleaning and transportation (Bernie Ehnes, Ehnes Organic Seed Cleaning, personal communication). The net return was calculated as:

$$N = (YP)-C*S$$

where N is the net return in \$CAD ha^{-1}, Y is crop yield (t ha^{-1}), P is crop price in t ha^{-1}, C is the cost of seed and S is the seeding rate (300 or 600 seeds m^{-2}, converted to t ha^{-1}). This equation was adapted from O'Donovan et al. (2001).

4.3 Results and Discussion

Through analysis of covariance, weed biomass was found to have an effect on grain yield ($P<0.01$), plant height and tame oat biomass ($P<0.10$) (Tables 4-3 and 4-4). Grain yield was most affected by weed biomass, and although overall significance of effects did not change, the magnitude of competition x cultivar interaction effects did. Fewer cultivars differed in grain yield between competition and non-competition treatments than with the traditional analysis of variance approach, suggesting that analysis of covariance is an appropriate method for handling the variation associated with weedy systems. Though least squares means were adjusted through analysis of covariance, the treatment effects on plant height and tame oat biomass were consistent with those from analysis of variance.

4.3.1 Simulated Weed Competition from Tame Oats

Actual tame oat density was lower than targeted, averaging 20 plants m^{-2}, rather than 60 plants m^{-2} (data not shown). Despite this shortfall, competition from tame oats reduced overall grain yield, spikes m^{-2}, number of kernels $spike^{-1}$ and kernel weight (Table 4-3). Average overall grain yield for wheat and barley combined was reduced by 27% due to competition from tame oats. Seebe barley averaged a 14% loss in yield, while the semidwarf cultivar Peregrine suffered a 26% yield loss (Figure 4-1C). Wheat yield losses from tame oat competition ranged from 23-34%. In terms of crop tolerance (i.e., maintaining yield under weed pressure), barley (averaging 20% yield loss) was generally more competitive than wheat (averaging 29% yield loss). As only two barley cultivars were used, this conclusion should be taken with caution; however it is supported by numerous prior studies (Pavlychenko and Harrington 1934; O'Donovan et al. 1985; Satorre and Snaydon 1992; Cousens 1996; Fischer et al. 2000).

Yield loss due to weeds in cereal crops can be explained by variations in the cereal yield components. Spikes m^{-2} exhibited the greatest reduction as a result of competition with tame oats (13%), followed by kernels $spike^{-1}$ and kernel weight. Based on these and previous findings (Satorre and Snaydon 1992; O'Donovan et al. 1999; Welsh et al. 1999), kernel number (spikes m^{-2} x kernels $spike^{-1}$) can be identified as the grain yield component primarily affected by competition from weeds. Kernel weight appears to be less affected. This suggests that grain crop yield under weed competition is sink (i.e., kernel number), rather than source, limited (Shanahan et al. 1984). Timing of weed competition may play a role in this, as kernel number is determined earlier in cereal development than kernel weight. Satorre and Snaydon (1992) suggested that weed competition may subside in the later stages of cereal development, possibly having less of an effect on kernel weight. Competition from tame oats reduced early season vigour in the present experiment (Table 4-3), possibly contributing to reduced sink strength at the time of grain filling, and thereby diminished grain yield.

Tame oat grain weight and tame oat total plant biomass (dry weight) were correlated ($r=0.95$, $P<0.01$), and were similarly reduced by cultivar and seeding rate (data not shown).

These data suggest that any decreases observed in overall oat biomass would result in decreased oat grain production, ultimately leading to a reduced soil weed seed bank.

4.3.2 Effect of Cultivar on Agronomic Performance and Competitive Ability

Cultivars differed for all measured traits (Tables 4-3 and 4-4). Seebe barley and the semidwarf wheat CDC Go yielded more grain than all other cultivars, averaging 3.46 t ha^{-1} and 3.27 t ha^{-1}, respectively (Table 4-3). Marquis wheat was among the lowest yielding cultivars, at 2.24 t ha^{-1}.

Average natural weed biomass was highest in plots with Kohika, Peregrine and CDC Go (Table 4-3). Seebe barley was identified in a previous trial as a weed suppressive cultivar, capable of consistently reducing wild oat seed production (O'Donovan et al. 2000). Similarly, Seebe barley was the most weed suppressive cultivar in the current study. Single degree of freedom contrasts between Seebe and other cultivars highlight some of the major trends among cultivars (Table 4-4). Without competition from tame oats, total weed biomass accumulation in plots with Seebe was lower than for all other cultivars except Hard Red Calcutta, Marquis and McKenzie. With competition from tame oats, total weed biomass in Seebe plots was lower than all cultivars except for Hard Red Calcutta, Katepwa, Marquis and McKenzie (Table 4-4).

Competition x cultivar interaction effects were detected for early season vigour, kernels $spike^{-1}$ and grain yield (Table 4-3; Figure 4-1A-C). Wheat cultivars Marquis and Park experienced reduced early season vigour under competitive stress, while the breeding line 9207-DB3*D demonstrated the opposite response (Figure 4-1A). Five of the eleven cultivars experienced reduced kernels $spike^{-1}$ as a result of tame oat competition (Figure 4-1B). While oat competition decreased grain yield for all cultivars, the magnitude of the losses differed, where only the wheat cultivars CDC Go and Sapphire experienced statistically significant yield losses (Figure 4-1C). These results are indicative of genotypic differences in the response of wheat and barley cultivars to competition from weeds on organically managed land, as other studies done on conventionally managed land have suggested (Wicks et al. 1986; Huel and Hucl 1996; Lemerle et al. 1996; O'Donovan et al. 2000).

4.3.3 Competitive Traits- Height, Tillering Capacity, Early Season Vigour and Maturity

Previous research has determined that height plays a role in competitive ability (Wicks et al. 1986; Huel and Hucl 1996; Lemerle et al. 1996; Cosser et al. 1997; Champion et al. 1998; Hucl 1998; Korres and Froud-Williams 2002). While two of the three semidwarf cultivars (CDC Go and Sapphire) in the current study incurred significant yield reductions as a result of weed competition, the other cultivars did not (Figure 4-1C). Percent yield loss was weakly correlated with height at (r=-0.12, P<0.05). Overall, height and natural weed biomass were correlated (r=-0.34, P<0.01), with some of the tallest cultivars (i.e., Hard Red Calcutta, Marquis) suppressing the most natural weeds (Table 4-3). Similar trends were observed for weed biomass in plots without tame oat competition and for natural weed, tame oat and total weed biomass in plots with tame oat competition (Table 4-4). Total weed biomass was found to be correlated with height in both tame oat (r=-0.32, P<0.01) and non-tame oat plots (r=-0.34, P<0.01). While there appears to be a relationship between height and weed suppression, other plant traits, in association with height, likely contribute to the ability of a cultivar to suppress and/or tolerate weeds.

Tillering capacity (i.e., spikes m^{-2}) may affect competitive ability, but weed competition is known to affect tillering capacity. The absence of weed-free controls in the present report complicates analysis of tillering effects on competitive ability. Tillering capacity alone does not appear to be a consistent predictor of crop response to weeds, as the least weed tolerant cultivars (CDC Go and Sapphire) differed in their tillering ability (Table 4-4). The relationship between crop competitive effect and tillering is similarly unclear. Overall, natural weed biomass and tame oats were highest in plots with two of the lower tillering cultivars (Kohika and Peregrine), but those cultivars were also the shortest cultivars in the trial. Further, relatively high total weed biomass accumulation was observed in plots of the high tillering CDC Go. Champion et al. (1998) similarly reported a high degree of variability in the potential for high tillering wheat cultivars to suppress weeds.

Early season vigour (ESV), also thought of as early biomass accumulation, may improve crop competitive response and/or effect by allowing the plant to overcome weed competition early in its growth, allowing it to better compete for above- and below-ground resources. Percent yield loss was found to be negatively associated with early season vigour (r=-0.37, P<0.01), suggesting an association between ESV and crop competitive response. Greater early season vigour may increase crop tolerance to weed competition through increased sink strength (i.e., higher kernel number). Overall natural weed biomass, as well as total weed biomass in plots without tame oat competition were positively associated (r=0.27, P<0.01 and r=0.19, P<0.05) respectively) with ESV, while tame oat biomass and total weed biomass in plots with tame oats were negatively associated with ESV (r=-0.42, P<0.01 and r=-0.21, P<0.01, respectively). Since the tame oats in the current study were planted at the same time as the crop and emerged slightly earlier than the natural weed flora, the higher association values for tame oat suggest that ESV may play a role in crop competitive effect, assisting in the suppression of early emerging weeds. In keeping with the trends observed for height and tillering capacity, the cultivars at the extreme low end of early season vigour were among those with the lowest grain yield and highest weed biomass, but the relationship between ESV and competitive effect or response was not consistent for all cultivars.

While time to maturity as a competitive trait has been less studied, the relationship between the timing of phenological events and competitive ability has been investigated, with results linking early biomass accumulation to increased competitive ability in wheat (Lemerle et al. 1996; Cousens et al. 2003a). Cultivars with differing growth rates may respond differently to environmental stresses (e.g., moisture, light), and those that develop quickly could avoid some of those stresses. Yield loss was positively correlated ($r=0.75$, $P<0.01$) with days to maturity. This was most apparent with the cultivar Sapphire, which was very late maturing and incurred the highest yield loss. Marquis, however, was also late maturing and did not incur yield loss from competition with tame oats. Furthermore, CDC Go was relatively early maturing. These data suggest that time to maturity alone is not a reliable predictor of crop tolerance to weeds.

Overall natural weed biomass and total weed biomass in plots without tame oat competition were positively associated ($r=0.40$, $P<0.01$ and $r=0.42$, $P<0.01$, respectively) with days to maturity, as were tame oat biomass and total weed biomass in plots with tame oat competition ($r=0.47$, $P<0.01$ and $r=0.50$, $P<0.01$, respectively). The positive associations between all measures of weed biomass and days to maturity suggests that early maturing cultivars allow less weed growth than later maturing cultivars. As with the other competitive traits in this study, these associations are somewhat inconsistent, yet it remains that time to maturity may play a role in the ability of wheat and barley cultivars to tolerate competition from weeds and to suppress their growth.

4.3.4 Grain Yield and Weed Suppressive Nature of Cultivars

Many studies (Wicks et al. 1986; Huel and Hucl 1996; Lemerle et al. 1996) have focused on competitive effect (i.e., weed suppression) and response (i.e., yield loss) of cultivars. For the organic producer, more important measures may be overall grain yielding ability under competition combined with weed suppressive ability. In the present study, cultivars differed in their ability to achieve high grain yield and suppress weeds (Figures 4-2A and B). A cluster of wheat cultivars, including Park, 9207-DB3*D and Katepwa were found to be relatively high yielding and good at suppressing weeds, a desirable combination for organic grain production. Despite their favorable performance, these wheat cultivars exhibited varying levels of each of the four 'competitive traits' discussed in this paper, again suggesting that competitive ability in general can not be controlled by one trait alone and that it results from a number of traits working together.

The weed biomass of cultivars varied more without competition from tame oats (Figure 4-2A) than when faced with tame oat competition (Figure 4-2B), likely the result of the uncontrolled and patchy (i.e., non-uniform) nature of the natural weed populations in the non-tame oat plots. While the two figures are similar, Figure 4-2B, depicting grain yield and weed biomass of cultivars under competition from tame oat and naturally occurring weeds, more clearly suggests that the semidwarf varieties (Kohika, Peregrine, Sapphire, CDC Go) are not as effective at weed suppression when compared to the taller varieties (Seebe, Marquis, Hard Red Calcutta).

4.3.5 Competitive Effect and Response

Some cultivars maintain yield primarily by suppressing weeds (competitive effect) while others maintain yield without suppressing weeds, i.e., by tolerating weeds (competitive response). Some studies have demonstrated a positive association between competitive response and effect (Goldberg and Fleetwood 1987), but others have reported no relationship between the two (Goldberg and Landa 1991; Keddy et al. 1994). Goldberg and Fleetwood (1987) suggest that the association may depend on the nature of competition (i.e., size symmetry) and/or plant traits that are important for competitive ability in a particular system (i.e., growth rate).

Huel and Hucl (1996) and Lemerle et al. (1996) reported correlations between percent yield loss and weed suppression in wheat, suggesting that competitive response and effect in wheat cropping systems may be related. In the current study, tame oat biomass and total weed biomass were correlated with percent yield loss ($r=0.41$, $P<0.01$ and $r=0.38$, $P<0.01$, respectively). Despite this association between weed biomass and yield loss, the cultivars tested appear to differ in their ability to both suppress weeds and maintain yields (Table 4-3). These results seem to support the theory that the competitive effect and response of cultivars should be considered separately when trying to identify cultivars with superior competitive ability. The use of weed suppressive cultivars, for example, could supply organic crop producers with an approach for managing weeds that could be combined with other management tools (e.g., seeding density) to both increase yield and suppress weeds.

4.3.6 The Effect of Doubling the Seeding Rate

On average, doubling the seeding rate increased grain yield by 10%, from 2.62 t ha^{-1} at the single seeding rate to 2.85 t ha^{-1} at the double seeding rate (Table 4-3). Similar results have been reported for wheat (Champion et al. 1998; Weiner et al. 2001) and barley (O'Donovan et al.

2000; Scursoni and Satorre 2005) grown in the presence of weeds. In terms of yield components, average number of spikes m^{-2} increased by almost 19% at the higher seeding rate, while kernels $spike^{-1}$ did not change. Champion et al. (1998) reported increases in spikes m^{-2} and decreases in kernels $spike^{-1}$ and kernel weight with increased seeding rate, a reflection of increased intraspecific competition. For kernel weight, a cultivar x seeding rate interaction was detected, where Marquis and Sapphire wheat were the only cultivars to exhibit kernel weight reductions in response to increased seeding rates (data not shown), indicating the potential for cultivars to respond differently to higher seeding rates. No cultivar x seeding rate interaction effects were detected for grain yield (Figure 4-3), suggesting that both barley and wheat cultivar grain yield is similarly affected by a doubling of the seeding rate.

Overall natural weed biomass m^{-2} decreased from 98 g m^{-2} to 71 g m^{-2} at the higher seeding rate, a reduction of 28% (Table 4-3). A competition x seeding rate interaction was detected for natural weed biomass, where doubling the seeding rate more greatly reduced natural weed biomass in plots without competition from tame oats than in plots with competition from tame oats (Figure 4-4). In plots without tame oats, total weed biomass decreased by 33% at the doubled seeding rate. Plots with tame oats experienced a total weed biomass reduction of 27%, with a 16% decrease in natural weed biomass and a 33% reduction in tame oat biomass at the higher seeding rate. It may be that the tame oats acted along with the crop to intercept light and nutrients, so effectively suppressing the natural weed population at the single seeding rate that the double seeding rate appears less effective at suppressing the natural weeds. However, when we look at the total weed biomass including oats, and consider the tame oats to be a weed analog, doubling the seeding rate remains an effective strategy in reducing weeds. Moreover, the mixture of tame oats (a grassy weed) and natural weed populations (mostly broadleaf) in this study reflects the more diverse population of weeds common to organic wheat cropping systems when to compared to conventional systems (Frick 1993; Leeson et al. 2000). Previous researchers have reported that weed suppression increases with increased seeding density (Lemerle et al. 1996; Champion et al. 1998; Weiner et al. 2001), although Korres and Froud-Williams (2002) reported it to be cultivar specific in a test using a number of different seeding densities and winter wheat cultivars. The lack of cultivar x seeding rate interactions for any of the weed-related parameters in this trial suggest that the relationship between weed suppression and seeding density in spring wheat and barley is not cultivar specific. Additionally, the presence of only one significant cultivar x seeding rate interaction (kernel weight) in this study substantiates the idea that the relationship between competitive response and seeding rate is not cultivar specific (Table 4-3).

4.3.7 Economic Analysis- Net Return Associated with Doubling the Seeding Rate

Increasing the seeding rate may increase overall wheat and barley yields, however net returns may not be high enough to justify such a practice. An economic analysis was conducted to determine the net return associated with the extra yield. Typical organic management practices were considered, factoring in the cost of seed, obtained on farm, but cleaned off farm.

Based on the average yield of Canadian Western Red Spring wheat seeded at single and doubled rates in the current study (2.55 t ha^{-1} and 2.81 t ha^{-1}, respectively), net economic gains associated with doubling the seeding rate ranged from \$34.62 ha^{-1} to \$53.72 ha^{-1}, depending on grade. Seebe and Peregrine barley yield differed enough to warrant separate analyses. Based on 2006 organic feed barley prices, Peregrine barley produced an additional net return of \$15.74 ha^{-1} when seeded at the doubled rate. Net returns for Seebe barley seeded at the doubled rate were negative, however, with a net loss of \$7.99 ha^{-1}. This was likely due to the comparatively smaller increase in grain yield of Seebe as a result of doubling the seeding rate.

Although a number of factors were not considered in this analysis (e.g., extra labour and fuel costs, yield and market fluctuations, climatic factors) it appears to be generally advantageous for producers to consider an increased seeding rate to improve weed suppression and grain yield. Net returns could increase further if the value of weed suppression to the farmer was factored in to the analysis. Reduced weed seed bank build-up has many potential benefits in an organic production system, including less fuel and labour costs, a possibility to diversify crop rotations, reduced yield loss, and more yield stability over time.

4.4 Conclusions

Crop types and cultivars differed in their competitive abilities, measured as the ability to suppress weeds and/or maintain grain yield under weed competition. Although height appears to have an association with both measures of competitive ability, particularly weed suppression, its variable role in both cultivar competitive effect and response suggests that other plant traits must play a role. Reduced time to maturity and high early season vigour also appear to be related to both minimizing the effect of weeds and improving crop response to weeds, which may relate to the timing of weed competition and sink size at the time of grain fill. The role of tillering capacity in competitive ability of cultivars in this trial was not consistent, likely owing to the effect of weed competition on tiller production, thus further investigation is required. The unpredictable associations between height, tillering, maturity, and early season vigour with competitive ability in general suggest that traits other than these have a role in conferring a competitive advantage.

Although the competitive effect and response of cultivars were correlated, not all wheat cultivars that accumulated high weed biomass experienced the same degree of yield loss as a result of weed competition. That the traits that control these two measures of competitive ability may differ suggests that wheat cultivars could be bred specifically for yield maintenance and/or weed suppression. This may be especially significant when considering breeding for organic wheat production, where increased weed populations may render weed suppression more important than yield maintenance.

Choice of cultivar can have an impact on the ability of the crop to achieve high grain yield and suppress weeds, which could be a potential benefit for organic wheat producers, giving them another tool for overcoming weed problems. Doubling the seeding rate was effective for suppressing weeds and increasing grain yield under our organic growing conditions, however these results may not hold true in different soil types, or under different weed pressure or moisture regimes. In areas of low rainfall, for example, the practice of doubling the crop seeding rate may present a greater risk to crop quality than weed competition. McKenzie et al. (2005) reported reduced benefits of doubling the barley seeding rate under low moisture conditions (<300 mm per season) compared to irrigated conditions. Increases in grain yield were less prominent, while reductions in kernel number and weight were more pronounced under low soil moisture.

Because the overall benefits of doubling the seeding rate do not appear to be cultivar specific, increasing the seeding rate may be a more viable management option for organic producers who are aiming to ameliorate problems associated with weed competition. Increasing seeding rates may currently be less complex and more effective than choosing a cultivar that is both weed suppressive and high yielding under elevated weed conditions.

The presence of naturally occurring weeds, which can be non-uniform in distribution, is one of the problems associated with conducting field trial on organically managed land, and one that we attempted to address by using covariate analysis. Though the increased variation in the data can pose certain analytical difficulties, studies conducted on organically managed land aim to better represent the realities of such production systems.

4.5 Tables and Figures

Table 4-1. Cultivar descriptions for spring wheat and barley cultivars included in trials conducted in 2003 and 2004 in Edmonton, AB and New Norway, AB.

Crop	Cultivar	Description	Year of Release	Country of Origin	Height	Tillering potential	Maturity
Wheat	Kohika	Bread	1997	New Zealand	semidwarf	high	medium
	Sapphire	Bread	1995	New Zealand	semidwarf	low	late
	CDC Go	CWRS[†]	2003	Canada	semidwarf	high[‡]	medium[‡]
	Katepwa	CWRS	1981	Canada	medium	high	medium
	Park	CWRS	1963	Canada	medium	high	early
	McKenzie	CWRS	1997	Canada	medium	high	medium
	9207-DB3*D	CWRS	unreleased	Canada	medium	low	medium-late
	Hard Red Calcutta	CWRS	1890	India	tall	low	medium
	Marquis	CWRS	1910	Canada	tall	high	late
Barley	Peregrine	6-row hulless	1999	Canada	semidwarf	low	early-medium
	Seebe	2-row feed	1992	Canada	tall	high	medium-late

[†] CWRS-Canada Western Red Spring.

[‡] denotes characteristic determined from current experimental data; unknown prior to start of experiment.

Table 4-2. F values associated with preliminary ANOVA (using location as a fixed effect) for trials conducted at four organic locations in 2003 and 2004 at Edmonton, AB and New Norway, AB.

Source of Variation	df	Grain Yield	Spikes m^{-2}	Kernel weight	Kernels $spike^{-1}$	Early season vigour	Natural weed biomass	Tame oat biomass	Total weed biomass	
									no oats	with oats
Location (L)	1	2	6**	4*	7**	315***	0	22***	0	0
Competition (C)	1	6	10	4	4	3	2	-	-	-
L*C	1	1	3	0	0	0	3	-	-	-
Cultivar (V)	10	8***	5**	29***	19***	5***	1	2	2	2
L*V	10	2	2	3**	1	2**	1	1	0	1
Seeding Rate (SR)	1	27***	16	2	17***	275***	20***	21***	22***	31***
L*SR	1	1	4*	0	3	14***	1	2	2	1
V*SR	10	1	0	2**	1	1	1	0	1	1
L*V*SR	10	1	1	1	2*	2*	1	1	1	1
C*V	10	3***	1	1	2**	2*	1	-	-	-
L*C*V	10	2	1	0	0	1	1	-	-	-
C*SR	1	0	1	3	0	0	9***	-	-	-
L*C*SR	1	6**	0	2	1	0	2	-	-	-
C*V*SR	10	1	1	1	1	1	1	-	-	-
L*C*V*SR	10	2	0	1	1	1	1	-	-	-

*,**,*** Effects are significant at $P< 0.1$, $P< 0.05$ and $P< 0.01$, respectively.

Table 4-3. The effect of competition with tame oats, cultivar and seeding rate on grain yield, spikes m^{-2}, kernel weight, kernels spike^{-1}, early season vigour, plant height and natural weed biomass of wheat and barley grown at four organically managed sites in 2003 and 2004 at Edmonton, AB and New Norway, AB.

Treatment	Parameter							
	Grain yield (t ha^{-1})	Spikes m^{-2}	Kernel weight (g)	Kernels spike^{-1}	Maturity	Early season vigour (1-5)	Plant height (cm)	Natural weed biomass (g m^{-2})
Competition (C)								
Without oats	3.17	545	32	31	98	3.0	86	102
With oats	2.30	475	31	29	98	2.9	86	67
F test competition	*	**	*	**	*ns*	**	*ns*	*ns*
SE[†]	0.327	15.8	0.4	0.5	0.7	0.05	0.4	8.9
Cultivar (V)								
Wheat								
9207-DB3*D	2.75	500	35	26	100	2.8	84	80
CDC Go	3.27	540	37	25	98	3.4	84	111
Hard Red Calcutta	2.65	510	25	33	98	2.7	106	75
Katepwa	2.74	580	31	26	98	3.0	95	85
Kohika	2.67	455	29	33	98	2.4	72	121
Marquis	2.24	520	32	26	102	3.0	101	66
McKenzie	2.43	580	30	26	97	3.0	93	70
Park	2.77	555	30	28	95	3.3	95	80
Sapphire	2.62	405	31	38	108	3.0	75	81
Barley								
Peregrine	2.49	375	27	40	91	2.7	59	112
Seebe	3.46	595	39	25	94	3.1	83	51
F test cultivar	***	***	***	***	***	*	***	**
SE[†]	0.185	39.3	1.2	1.6	1.8	0.25	2.4	10.3
LSD 0.05	0.38	82	2	3	4	0.6	5	21
Seeding Rate (SR)								
single	2.62	465	32	30	99	2.4	87	98
double	2.85	555	31	29	97	3.5	85	71
F test seeding rate	***	*	*	*ns*	**	*ns*	*ns*	***
SE[†]	0.06	23.0	0.3	0.4	0.9	0.25	0.8	3.6
V*SR	*ns*	*ns*	**	*ns*	*ns*	*ns*	*ns*	*ns*
C*V	**	*ns*	*ns*	**	*ns*	**	*ns*	*ns*
C*SR	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	***
C*V*SR	*ns*	*ns*	*ns*	*ns*	*	*ns*	*ns*	*ns*
Natural weed biomass as a covariate[‡]	***	*ns*	*ns*	*ns*	*ns*	*ns*	*	n/a

*,**,*** Effects are significant at $P < 0.1$, $P < 0.05$, $P < 0.01$, respectively; *ns* denotes non-significant effects.

[†] Standard error of the difference of two least-squares means. Standard errors of natural weed biomass have been backtransformed.

[‡] Least-squares means and F test results of covariate analysis presented only where covariate was significant at $P<0.10$.

Table 4-4. The effect of cultivar and seeding rate on total weed biomass† on plots grown without tame oat competition and on natural weed, tame oat, total weed biomass in plots grown with tame oat competition at four organically managed sites in 2003 and 2004 at Edmonton, AB and New Norway, AB.

	Without tame oat competition		With tame oat competition				
	Total weed biomass† (g m^{-2})	Total weed biomass-contrast with Seebe	Natural weed biomass (g m^{-2})	Tame oat biomass (g m^{-2})	Tame oat biomass (g m^{-2}) with covariate	Total weed biomass (g m^{-2})	Total weed biomass-contrast with Seebe
Cultivar (V)							
Wheat							
9207-DB3*D	84	*	77	116	117	193	*
CDC Go	135	***	86	139	142	226	*
Hard Red Calcutta	97	ns	53	103	102	158	ns
Katepwa	109	**	61	120	119	181	ns
Kohika	145	***	96	227	231	323	***
Marquis	79	ns	53	97	95	150	ns
McKenzie	72	ns	67	122	122	188	ns
Park	104	**	56	140	139	196	*
Sapphire	102	**	60	166	165	226	**
Barley							
Peregrine	142	***	81	164	166	245	***
Seebe	55	-	47	76	73	123	-
F test cultivar	***		*	*	*	*	
SE‡	13.44		10.11	17.3	17.95	24.15	
LSD 0.05	27		21	35	37	49	
Seeding Rate (SR)							
single	122		73	160	161	233	
double	82		61	108	107	169	
F test seeding rate	***		**	***	***	***	
SE‡	5.7		3.2	6.0	6.1	6.8	
VxSR	*ns*		*ns*	*ns*	*ns*	*ns*	
Natural weed biomass as a covariate§	n/a		n/a	n/a	*	n/a	

---

*,**,*** Effects are significant at $P< 0.1$, $P< 0.05$, $P< 0.01$, respectively; *ns* denotes non-significant effects.

† Total weed biomass in plots without tame oat competition is equal to the natural weed biomass.

‡ Standard error of the difference of two least-square means. Standard errors of natural weed biomass have been backtransformed.

§ Least-squares means and F test results of covariate analysis presented only where covariate was significant at $P<0.10$.

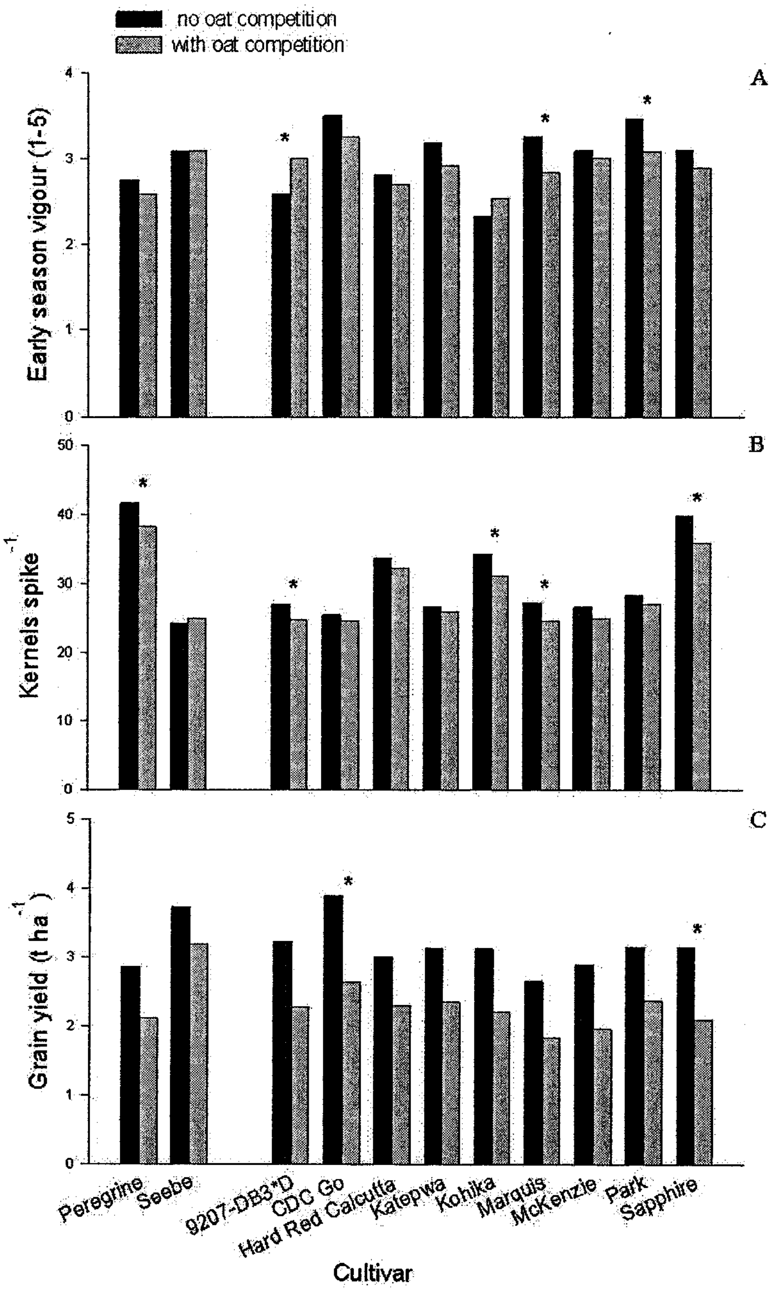

Figure 4-1. Interaction between competition from oats and crop cultivar on early season vigour (A), kernels per spike (B), spikes per m^{-2} (C) and grain yield (D) of wheat and barley cultivars[†] grown at four locations in 2003 and 2004 at Edmonton, AB and New Norway, AB[‡].

[†] Peregrine and Seebe are barley cultivars, others are wheat.

[‡] Within each cultivar and trait, bars with * differ significantly at $P<0.05$ according to the LSD.

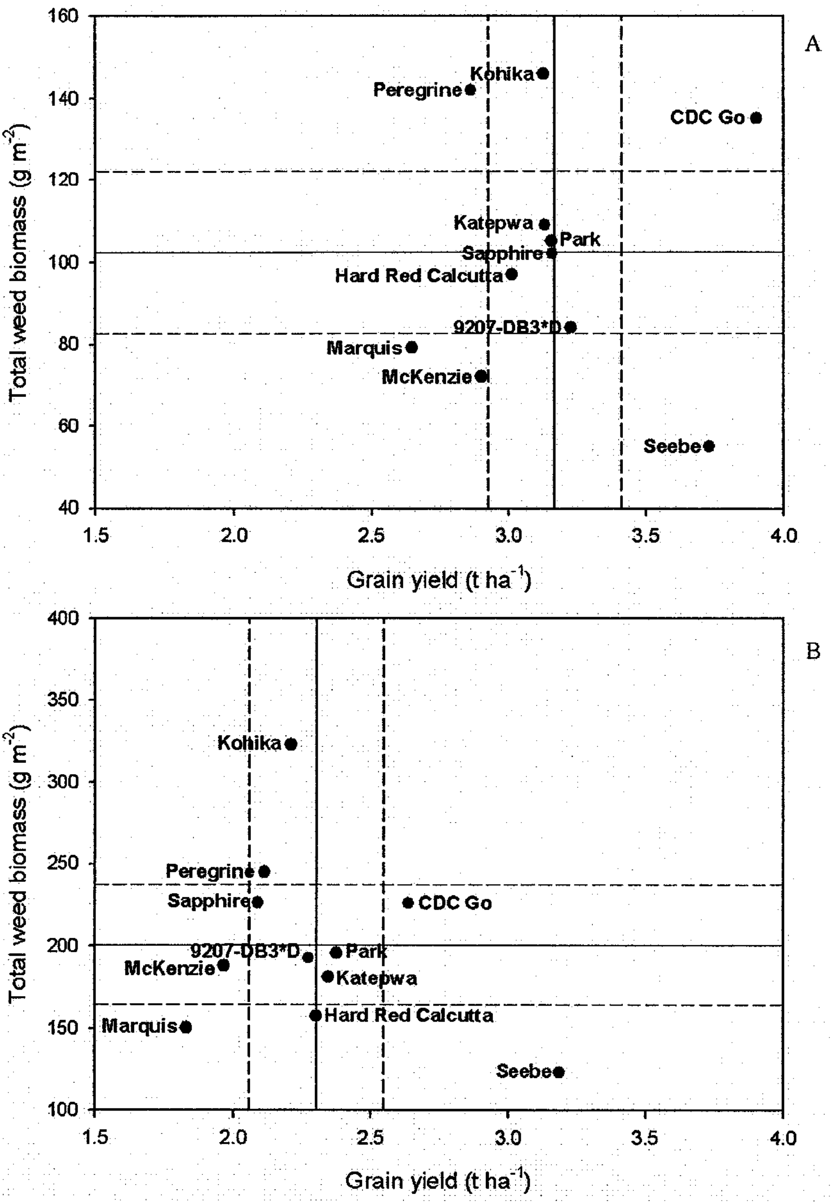

Figure 4-2. Relationship between grain yield and total weed biomass without additional competition from tame oats (A) and total weed biomass with tame oat competition (B) of wheat and barley cultivars[†] grown at four locations in 2003 and 2004 at Edmonton, AB and New Norway, AB[‡].

[†] Peregrine and Seebe are barley cultivars, others are wheat.

[‡] Solid lines represent means and dotted lines represent upper and lower 95% confidence limits.

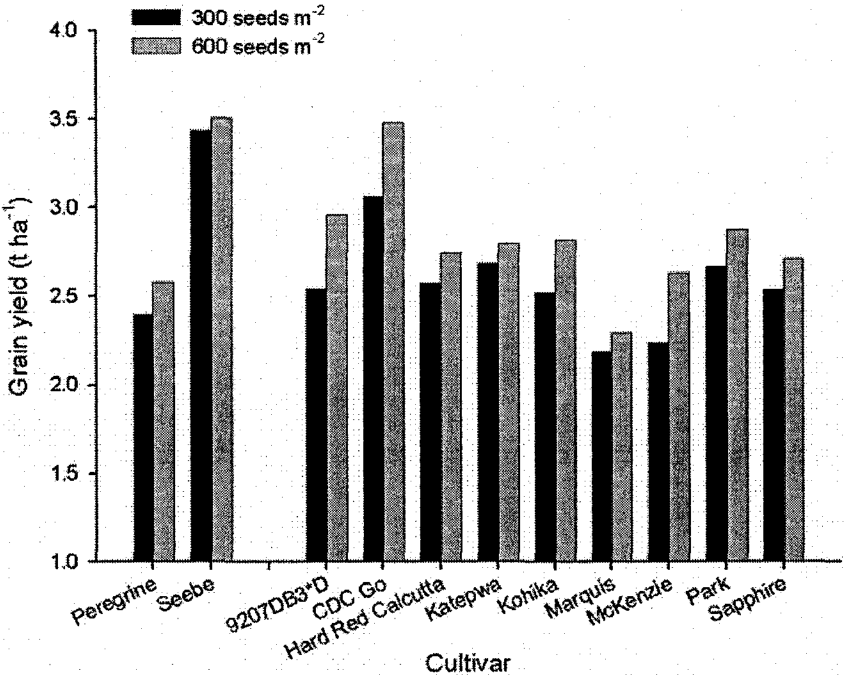

Figure 4-3. Interaction between seeding rate and crop cultivar on grain yield of wheat and barley cultivars† grown at four locations in 2003 and 2004 at Edmonton, AB and New Norway, AB.
†Peregrine and Seebe are barley cultivars, others are wheat.

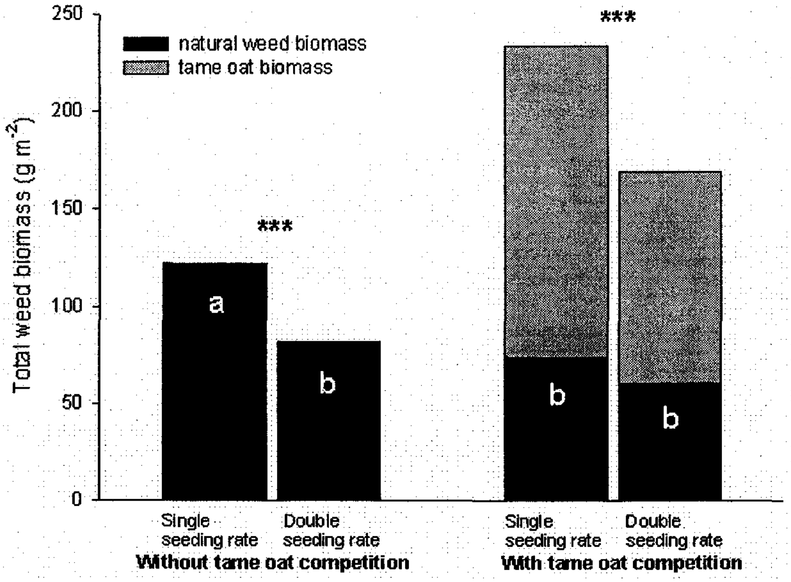

Figure 4-4. Interaction between competition with tame oats and seeding rate on natural (■) and total weed biomass of wheat and barley cultivars grown at four locations in 2003 and 2004 at Edmonton, AB and New Norway, AB†.

† within natural weed biomass, bars with different letters are significantly different at P<0.10 according to the LSD.

*** within tame oat competition treatments, single and double seeding rates differ for total weed biomass at P<0.01.

4.6 Literature Cited

Alberta Agriculture Food and Rural Development. 2003. Using 1,000 kernel weight for calculating seeding rates and harvest losses. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex81/$file/100_22-1.pdf?OpenElement [14 July 2006].

Alberta Agriculture Food and Rural Development. 2004. Soil Group Map of Alberta. [Online] Available: http://www1.agric.gov.ab.ca/soils/soils.nsf/soilgroupmap?readform [31 August 2006].

Barberi, P., Silvestri, N., Peruzzi, A. and Raffaelli, M. 2000. Finger-harrowing of durum wheat under different tillage systems. Biol. Agric. Hortic. **17**:285-303.

Bhatty, R. S., MacGregor, A. W. and Bhatty, R. S. 1993. Nonmalting Uses of Barley Barley Chemistry and Technology. American Association of Cereal Chemists, Inc., St. Paul, MN.

Bruinsma, J. 2003. World Agriculture : Towards 2015/2030 : An FAO Perspective. 12th ed. Earthscan, London. 432 pp.

Champion, G. T., Froud-Williams, R. J. and Holland, J. M. 1998. Interactions between wheat (*Triticum aestivum* L.) cultivar, row spacing and density and the effect on weed suppression and crop yield. Ann. Appl. Biol. **133**:443-453.

Clark, S., Klonsky, K., Livingston, P. and Temple, S. 1999. Crop-yield and economic comparisons of organic, low-input, and conventional farming systems in California's Sacramento Valley. Am. J. Altern. Agric. **14**:109-121.

Coleman, R. D., Gill, G. S. and Rebetzke, G. J. 2001. Identification of quantitative trait loci for traits conferring weed competitiveness in wheat (*Triticum aestivum* L.). Aust. J. Agric. Res. **52**:1235-1246.

Cosser, N. D., Gooding, M. J., Thompson, A. J. and Froud-Williams, R. J. 1997. Competitive ability and tolerance of organically grown wheat cultivars to natural weed infestations. Ann. Appl. Biol. **130**:523-535.

Cousens, R. D. 1996. Comparative growth of wheat, barley, and annual ryegrass (*Lolium rigidum*) in monoculture and mixture. Aust. J. Agric. Res. **47**:449-464.

Cousens, R. D., Barnett, A. G. and Barry, G. C. 2003. Dynamics of competition between wheat and oat: I. Effects of changing the timing of phenological events. Agron. J. **95**:1295-1304.

Didon, U. M. E. and Bostrom, U. 2003. Growth and development of six barley (*Hordeum vulgare* ssp. *vulgare* L.) cultivars in response to a model weed (*Sinapis alba* L.). J. Agron. Crop Sci. **189**:409-417.

Entz, M. H., Guilford, R. and Gulden, R. 2001. Crop yield and soil nutrient status on 14 organic farms in the eastern portion of the northern Great Plains. Can. J. Plant Sci. **81**:351-354.

Fischer, A. J., Messersmith, C. G., Nalewaja, J. D. and Duysen, M. E. 2000. Interference between spring cereals and *Kochia scoparia* related to environment and photosynthetic pathways. Agron. J. **92**:173-181.

Frick, B. 1993. Weed Communities in Organic and "Conventional" Wheat Fields, p. 164-169 Soil and Crops Workshop, University of Saskatchewan, Saskatoon.

Goldberg, D. E. and Fleetwood, L. 1987. Competitive effect and response in four annual plants. J. Ecol. **75**:1131-1143.

Goldberg, D. E. and Landa, K. 1991. Competitive effect and response: Hierarchies and correlated traits in the early stages of competition. J. Ecol. **79**:1013-1030.

Gomez, K. A. and Gomez, A. A. 1984. Statistical Procedures for Agricultural Research. 2nd ed. John Wiley and Sons, Inc., New York, NY. 680 pp.

Harker, K. N. 2001. Survey of yield losses due to weeds in central Alberta. Can. J. Plant Sci. **81**:339-342.

Hartl, W. 1989. Influence of undersown clovers on weeds and on the yield of winter-wheat in organic farming. Agric. Ecosyst. Environ. **27**:389-396.

Hucl, P. 1998. Response to weed control by four spring wheat genotypes differing in competitive ability. Can. J. Plant Sci. **78**:171-173.

Huel, D. G. and Hucl, P. 1996. Genotypic variation for competitive ability in spring wheat. Plant Breed. **115**:325-329.

Jordan, N. 1993. Prospects for weed-control through crop interference. Ecol. Appl. **3**:84-91.

Keddy, P. A., Twolan-Strutt, L. and Wisheu, I. C. 1994. Competitive effect and response rankings in 20 wetland plants: are they consistent across three environments? J. Ecol. **82**:635-643.

Kirkland, K. J. and Hunter, J. H. 1991. Competitiveness of Canada Prairie Spring wheats with wild oat (*Avena fatua* L.). Can. J. Plant Sci. **71**:1089-1092.

Korres, N. E. and Froud-Williams, R. J. 2002. Effects of winter wheat cultivars and seed rate on the biological characteristics of naturally occurring weed flora. Weed Res. **42**:417-428.

Leeson, J. Y., Sheard, J. W. and Thomas, G. A. 2000. Weed communities associated with arable Saskatchewan farm management systems. Can. J. Plant Sci. **80**:177-185.

Leeson, J. Y., Thomas, A. G. and Hall, L. M. 2002. Alberta Weed Survey of Cereal, Oilseed and Pulse Crops in 2001. Agriculture and Agri-Food Canada, Saskatoon, SK.

Lemerle, D., Gill, G. S., Murphy, C. E., Walker, S. R., Cousens, R. D., Mokhtari, S., Peltzer, S. J., Coleman, R. and Luckett, D. J. 2001. Genetic improvement and agronomy for enhanced wheat competitiveness with weeds. Aust. J. Agric. Res. **52**:527-548.

Lemerle, D., Verbeek, B., Cousens, R. D. and Coombes, N. E. 1996. The potential for selecting wheat varieties strongly competitive against weeds. Weed Res. **36**:505-513.

Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D. and Shabenberger, O., (eds.) 2006. SAS for Mixed Models. SAS Institute Inc., Cary, NC.

McKenzie, R. H., Middleton, A. B. and Bremer, E. 2005. Fertilization, seeding date, and seeding rate for malting barley yield and quality in southern Alberta. Can. J. Plant Sci. **85**:603-614.

Ngouajio, M. and McGiffen, M. E. 2002. Going organic changes weed population dynamics. HortTechnol. **12**:590-596.

O'Donovan, J. T., Destremy, E. A., O'Sullivan, P. A., Dew, D. A. and Sharma, A. K. 1985. Influence of the relative-time of emergence of wild oat (*Avena fatua*) on yield loss of barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*). Weed Sci. **33**:498-503.

O'Donovan, J. T., Harker, K. N., Clayton, G. W. and Hall, L. M. 2000. Wild oat (*Avena fatua*) interference in barley (*Hordeum vulgare*) is influenced by barley variety and seeding rate. Weed Technol. **14**:624-629.

O'Donovan, J. T., Harker, K. N., Clayton, G. W., Newman, J. C., Robinson, D. and Hall, L. M. 2001. Barley seeding rate influences the effects of variable herbicide rates on wild oat. Weed Sci. **49**:746-754.

O'Donovan, J. T., Newman, J. C., Harker, K. N., Blackshaw, R. E. and McAndrew, D. W. 1999. Effect of barley plant density on wild oat interference, shoot biomass and seed yield under zero tillage. Can. J. Plant Sci. **79**:655-662.

Organic Agriculture Centre of Canada. 2006. Summary Table of Alberta Purchase Prices for Organic Crops - January 2005. [Online] Available: http://www.oacc.info/DOCs/AB%20Summary%20Tbl.pdf#search=%22oacc%20alberta%20crop%20price%22 [31 August 2006].

Organic Crop Improvement Association. 2000. International Certification Standards As Revised: March 2000. OCIA International, Inc., Lincoln, NE.

Pavlychenko, T. K. and Harrington, J. B. 1934. Competitive efficiency of weeds and cereal crops. Can. J. Res. **10**:77-94.

Revilla, P., Butron, A., Malvar, R. A. and Ordas, A. 1999. Relationships among kernel weight, early vigour and growth in maize. Crop Sci. **39**:654-658.

Ryan, M. H., Derrick, J. W. and Dann, P. R. 2004. Grain mineral concentrations and yield of wheat grown under organic and conventional management. J. Sci. Food Agric. **84**:207-216.

Samuel, A. M. and Guest, S. J. 1990. Weed studies in organic and conventional cereals. British Crop Proteciton Council, Farnham, Surrey, UK.

SAS Institute. 2003. Release 9.1. SAS Institute, Cary, NC.

Satorre, E. H. and Snaydon, R. W. 1992. A comparison of root and shoot competition between spring cereals and *Avena fatua*. Weed Res. **32**:45-55.

Scursoni, J. A. and Satorre, E. H. 2005. Barley (*Hordeum vulgare*) and wild oat (*Avena fatua*) competition is affected by crop and weed density. Weed Technol. **19**:790-795.

Shanahan, J. F., Smith, D. H. and Welsh, J. R. 1984. An analysis of post-anthesis sink-limited winter wheat grain yields under various environments. Agron. J. **76**:611-615.

Steel, R. G. D., Torrie, J. H. and Dickey, D. A. 1996. Principles and Procedures of Statistics: A Biometrical Approach. 3rd ed. McGraw-Hill, New York, NY. 666 pp.

Waldon, H., Gliessman, S. and Buchanan, M. 1998. Agroecosystem responses to organic and conventional management practices. Agric. Syst. **57**:65-75.

Weiner, J., Griepentrog, H. W. and Kristensen, L. 2001. Suppression of weeds by spring wheat *Triticum aestivum* increases with crop density and spatial uniformity. J. Appl. Ecol. **38**:784-790.

Welsh, J. P., Bulson, H. A. J., Stopes, C. E., Froud-Williams, R. J. and Murdoch, A. J. 1999. The critical weed-free period in organically-grown winter wheat. Ann. Appl. Biol. **134**:315-320.

Wicks, G. A., Ramsel, R. E., Nordquist, P. T., Schmidt, J. W. and Challaiah. 1986. Impact of wheat cultivars on establishment and suppression of summer annual weeds. Agron. J. **78**:59-62.

Zadoks, J. C., Chang, T. T. and Konzak, C. F. 1974. A decimal code for the growth stages of cereals. Weed Res. **14**:415-421.

5.0 Competitive traits and the stability of wheat cultivars in differing natural weed environments on the northern Canadian Prairies[5]

5.1 Introduction

Weed competition has been reported to reduce cereal crop yields in Canada; with documented losses of up to 29% in barley (O'Donovan et al. 2000), and up to 63% in wheat (Kirkland and Hunter 1991; Hucl 1998). Many options exist for weed control, perhaps the most common being the use of agrochemicals. Increased herbicide resistance, rising costs of production and an increased interest in environmental protection (through the adoption of sustainable and organic management systems) are creating the need for researchers to explore non-chemical methods of weed control (Jordan 1993; Lemerle et al. 1996). Such methods include the use of various tillage regimes (Barberi et al. 2000), crop rotations and intercropping (Hartl 1989), crop seeding density (Korres and Froud-Williams 2002), and the use of competitive cultivars (Huel and Hucl 1996; Lemerle et al. 1996).

There are two ways to consider the competitive ability of a crop or a plant cultivar: (a) the ability of a crop to tolerate weed pressure by maintaining grain yield, and (b) the ability of a crop to suppress weed growth and seed production (Coleman et al. 2001). Both are important since yield stability and the prevention of weed seed production, and subsequent seed bank build-up, are desirable in crops growing in association with weeds (Jordan 1993). Lemerle et al. (2001a) suggested that weed tolerance and weed suppression be considered separately, as they may or may not occur together.

Morphological, physiological and biochemical traits are thought to control plant competitiveness (Lemerle et al. 2001a), and many studies have been conducted to determine which characters confer competitive ability in wheat. Plant height plays a role in the competitive ability of wheat (Wicks et al. 1986; Huel and Hucl 1996; Lemerle et al. 1996; Cosser et al. 1997; Champion et al. 1998; Hucl 1998; Korres and Froud-Williams 2002). In a study of Canadian spring wheat cultivars, crop height appeared to have the greatest impact on competitive ability, with the shortest wheat cultivars experiencing the largest yield reductions and allowing the greatest weed growth (Huel and Hucl 1996). Wicks et al. (1986) suggested however, that height alone does not explain competitive ability, since some shorter cultivars have been found to be good competitors. In a comparison of tall and short winter wheat cultivars, the taller cultivar intercepted more photosynthetically active radiation (PAR), accumulated more early dry matter,

---

[5] *This chapter has been submitted (November 10, 2006) to Crop Science.*

and accumulated the most nitrogen early in the season. However, the taller cultivar was variable in its ability to suppress weeds and was lower yielding than the shorter cultivars (Cosser et al. 1997). The association of plant height with other competitive traits further implies that height is not the only factor responsible for competitive ability in wheat.

Canopy structure may have an influence on competitive ability. Champion et al. (1998) found that a tall cultivar that intercepted a greater percentage of PAR was more effective at suppressing weed growth than a short cultivar with low light interception capabilities (Champion et al. 1998). Interception of PAR at both early (Lemerle et al. 1996) and late (Wicks et al. 1986) growth stages was associated with wheat grain yield maintenance under competition from weeds. Huel and Hucl (1996) found leaf area index to be negatively correlated with weed seed yield. Leaf area index was not, however, associated with wheat yield reduction resulting from competition with weeds (Huel and Hucl 1996). Flag leaf length was strongly negatively correlated with wheat yield loss (Huel and Hucl 1996; Lemerle et al. 1996) and weed dry matter yield (Lemerle et al. 1996), while flag leaf angle was positively correlated with wheat yield reduction (Huel and Hucl 1996). Evidence that early season ground cover also reduces subsequent weed biomass has been reported by Richards and Whytock (1993) and Huel and Hucl (1996). In the Lemerle et al. (1996) study, elevated PAR interception, resulting in high early biomass accumulation, was found in the most competitive wheat genotypes.

In addition to height and canopy structure, tillering capacity (measured as the number of fertile tillers per unit area) has often been reported to confer greater competitive ability in wheat (Lemerle et al. 1996; Hucl 1998; Korres and Froud-Williams 2002). Among other traits, high tiller numbers were found in the most competitive wheat (mainly Australian) from around the world (Lemerle et al. 1996). On the other hand, tiller number has been found to be weakly correlated with weed suppression and grain yield in other studies (Wicks et al. 1986; Champion et al. 1998). Various other characters have been found to contribute to competitiveness, though they are not as commonly reported. In a study of Canadian spring wheat, time of spike emergence was positively correlated with wheat yield reduction and early maturity was associated with competitiveness (Huel and Hucl 1996). In a later study, however, Hucl (1998) found no association between maturity and competitiveness.

A better understanding of the mechanisms by which a crop cultivar becomes competitive would not only serve to assist plant breeders in developing competitive cultivars more quickly and effectively, but would also justify the use of plant breeding to increase crop competitive ability (Lemerle et al. 2001b). For producers, knowledge about the competitive ability of cultivars would be useful for choosing cultivars suited to their environment (Lemerle et al.

2001b). Yield gains of 7-9% have been identified in ‘competitive’ wheat cultivars when compared to ‘non-competitive’ cultivars (Hucl 1998).

The objectives of this study were to identify competitive traits in wheat cultivars grown in differing levels of natural weed environments, and to determine whether traits associated with competitive ability differ under increasing weed pressure. Additionally, we wished to identify differences among cultivar stability in and adaptation to environments differing in yield potential and weed competition.

5.2 Materials and Methods

Nine spring wheat cultivars were chosen for this experiment on the basis of height, tillering potential and maturity characters (Table 5-1). The cultivars were planted at 300 seeds m^{-2}, the upper end of the recommended hard red wheat seeding range for the growing region (Alberta Agriculture Food and Rural Development 2003b). Field trials were conducted at one conventional and two organic locations in both 2003 and 2004. The conventionally managed site and one of the organically managed sites were located at the Edmonton Research Station (ERS), Edmonton, Alberta (53° 34’N, 113° 31’W), approximately 1 km apart, with the other organic site located at a certified organic farm near New Norway, Alberta (52° 52’N, 112° 56’W). Soils at New Norway sites were Eluviated Black Chernozemics, while soils at Edmonton sites were classified as Orthic Black Chernozemics, typical of central Alberta (Alberta Agriculture Food and Rural Development 2004). Tillering potential of cultivars was determined from data generated in various trials conducted at the Edmonton Research Station on conventional land between 1999 and 2002. Precipitation and temperature data for each year and location are presented in Table 2-2.

The experiment was designed as a strip-plot with three replicates, where the horizontal factor was competition with tame oats (*Avena sativa* L.) and the vertical factor was cultivar. There were thus 9 wheat cultivars x 3 replicates x 2 tame oat competition levels (54 plots) per trial. In 2003, plot dimensions were 4.5 m x 0.9 m consisting of 4 rows spaced approximately 23 cm apart. Plots were seeded using a four row, double disk drill (Fabro Enterprises Ltd., Swift Current, SK, Canada). In 2004, plot dimensions were 4 m x 1.38 m consisting of 6 rows spaced 23 cm apart. Plots were seeded using a six row, no-till double disk drill (Fabro Enterprises Ltd., Swift Current, SK, Canada). In both years, plots receiving the tame oat treatment were cross-seeded immediately after crop seeding at a rate of 60 tame oat seeds m^{-2}. Seed used in the 2003 trial was either certified seed or was increased at the ERS in 2002, and seed used in the 2004 trials was increased on an organically managed site at ERS in 2003. The trials were not irrigated.

All trials were planted in mid to late May and harvested in early to mid-September. Soil tests were conducted after seeding in each year at each site (Table 2-3).

Conventionally managed sites received mineral fertilizer applications according to soil test recommendations and also received recommended rates of MCPA Amine 500 to control broadleaf weeds (Alberta Agriculture Food and Rural Development 2006). Organically managed sites were managed according to Organic Crop Improvement Association recommendations (Organic Crop Improvement Association 2000), and did not receive any applications of chemical fertilizers and herbicides. At ERS-Organic, composted dairy manure at $\approx$ 60 t ha^{-1} was applied annually. At the certified organic farm, experimental trials followed cereal-legume plowdowns without crop removal in the year prior to planting. Land management at each of these sites is described in greater detail in Appendix 7-4.

5.2.1 Data Collection

Spike emergence (heading) was recorded as the day when 75% of the spikes in the plot emerged with visible peduncles. After stem elongation was complete, plant height (representing the distance from the soil surface to the tip of the spike, excluding awns in awned cultivars) was recorded on a per plot basis. Maturity was recorded as the day when 75% of the spikes and peduncles in the plot were tan brown in colour; approximately 30% seed moisture content. Plot lodging was rated on a scale from 1= no lodging to 9= highest degree of lodging. Lodging ratings were conducted at various sites after specific lodging events (heavy rains, snowfall) and at all sites just prior to harvest. At maturity, all spikes in either a 1m^2 (2003) or 1m row (2004) section of each plot were counted and used to calculate spikes m^{-2}.

In 2003, weed biomass m^{-2} in each plot was determined by weighing the above ground portion of the weeds from the harvested 1 m^2. In 2004, weed biomass m^{-2} in each plot was determined by harvesting the above ground portion of weeds from within two randomly placed 0.0625 m^2 quadrats (25cm x 25cm) at plot maturity. Weeds present in both 2003 and 2004 at the Edmonton Research Station included stinkweed (*Thlaspi arvense* L.), lamb's quarters (*Chenopodium album* L.), wild buckwheat (*Polygonum convolvulus* L.), shepherd's purse (*Capsella bursa-pastoris* L.) and Canada thistle (*Cirsium arvense* L.), while weeds in both years at the New Norway site were mainly wild oats (*Avena fatua* L.) and lamb's quarters.

In both years, tame oats were harvested from plots just prior to crop harvest. In 2003, tame oats were harvested from a 1 m^2 area and were counted, dried, weighed to obtain oat biomass and threshed to calculate grain weight. In 2004, tame oats were harvested from within two randomly placed 0.0625 m^2 quadrats and were dried, weighed for oat biomass and threshed to calculate grain weight.

Prior to harvest, ten randomly chosen spikes in each plot were collected and used to determine kernels $spike^{-1}$ and thousand kernel weight. Plots were harvested using a Wintersteiger plot combine following maturity. Grain yield was recorded on a dry weight basis. Harvested grain samples were dried at 60°C for ~24 hours and weed seeds were removed using a 2 mm mesh sieve (Canadian Standard Sieve Series No.10). The weed-seed free grain samples were weighed and plot yields were recorded for those plots without tame oats. For plots with tame oats, the weed-seed free grain sample was weighed and then a 100 g sample of grain was removed and tame oats and wheat were separated and weighed. Grain yields for plots with tame oats were based on multiplication of the weed-seed free plot grain yield by the ratio of grain:oats from the 100 g sample.

5.2.2 Data Analysis

5.2.2.1 Weed pressure levels

For all analyses using high, medium and low weed pressure levels (i.e., analysis of variance, correlation, principal component analysis and multiple regression), data from the certified organic farm were not used, due to missing values for days to heading and maturity. These observations were not recorded at the certified organic farm because it was far away from the Edmonton Research Station. Data from the two years of trials on conventional and organic land at the Edmonton Research Station were divided into eight groups, based on year, location-management and tame oat competition. These eight environments were grouped in to low, medium and high weed pressure levels based on the average total weed biomass (tame oats plus natural weeds) of each environment (Table 5-2). An analysis of variance was performed using the PROC MIXED procedure of SAS (SAS Institute 2003), where weed pressure level, cultivar and weed pressure level x cultivar were considered fixed, while environment within weed pressure level, replication and associated interactions were considered random effects. For all analyses, a variance-stabilizing square root transformation ($(Y+0.5)^{1/2}$) was used for total weed biomass data (Gomez and Gomez 1984).

Raw data were then analyzed by weed pressure level using the PROC CORR and PROC PRINCOMP procedures of SAS (SAS Institute, 2003). Whereas simple linear correlation analysis allows one to measure the degree of linear association between two variables (Gomez and Gomez 1984), principal component (PC) analysis allows one to analyze relationships among a wide range of variables (Timm 2002). The PC analysis removes intercorrelations that may exist between variables by transforming the original variables into smaller, hypothetical components (PCs) (Smith 1991; Timm 2002). The new PCs are orthogonal to one another, so that the data expressed in each PC is uncorrelated with all other PCs (Smith 1991). A total of 9 variables were analyzed: height, days to heading and maturity, lodging, grain yield, spikes m^{-2}, kernel weight, kernels spike^{-1} and total weed biomass. The principal component (PC) analysis was done on the correlation matrix, since original measurements were made in different units (Jolliffe 2002). Interpretation of PCs can be a fairly subjective process, for which there are no general rules (Mallarino et al. 1999). Retention of PCs was based on those PCs with eigenvalues >1 (Jolliffe 2002). In the low and medium weed pressure levels, the first three PCs fit this criteria, and for the high weed pressure level, the first four PCs had eigenvalues >1. For simplicity of interpretation, the first three PCs are presented for all levels. As a starting point, variables with absolute loadings (eigenvalues) greater than the mean of the absolute loading value were selected as variables in the PCs. Subsequently, the criteria used to interpret variables within each PC included both the loading value and its relative difference from the other loading values in that PC. Loading plots for PC1 versus PC2 were constructed for each weed pressure level in order to visually evaluate variables that tend to be associated with one another, since two factors with high loadings in the same PC tend to vary together within a particular environment (Mallarino et al. 1999). Values for the loading plots were determined by multiplying the loading value for each variable by the square root of the eigenvalue for the respective PC, which also shows the correlation between the variables and PCs (Smith 1991). The length of a vector (the line from the origin to the point) shows the strength of the correlation of a variable with PC1 or PC2. For example, a long vector (approaching a length of 1) in the direction of PC1 indicates a strong relationship between that variable and PC1, while a short vector indicates that the variable has little to do with PC1 or PC2 (Smith 1991).

5.2.2.2 Stability Analysis

The two growing years, three locations (ERS-Conventional, ERS-Organic and the certified organic farm) and two competition levels (with or without tame oats) used in the study produced 12 different environments in which wheat cultivars were grown. Cultivar (genotypic) response to the 12 environments (also referred to as "sites") were described using an adaptation of the Finlay-Wilkinson analysis (Finlay and Wilkinson 1963). In the Finlay-Wilkinson analysis, site mean yield is used to describe each environment (e.g., low or high yielding) and a linear regression of individual cultivar yield on site mean yield for each site is calculated. The regression coefficient (*b*) of each cultivar describes its stability across sites, which is used to characterize its adaptability to specific environments. A visual representation of cultivar adaptation is achieved by plotting the regression coefficient of each cultivar against the cultivar mean yield across all environments. In the current study, both grain yield and total weed biomass, considered here to be indicators of competitive ability, were used to describe environments.

Regression analyses were conducted using the PROC REG procedure of SAS (SAS Institute 2003). Grain yield and total weed biomass data were log transformed prior to analysis (Finlay and Wilkinson 1963). Ten environments were used for the total weed biomass analysis due to the absence of weeds at two of the twelve sites.

5.3 Results

5.3.1 Weed pressure levels

The three natural weed pressure levels differed ($P<0.01$) for total weed biomass, with 15, 168 and 433 g m^{-2} under low, medium and high weed biomass, respectively (Table 5-3). Grain yield differed among weed pressure levels ($P<0.06$), with yield reductions of 37% and 31% under high weeds compared to the low and medium weed pressure environments, respectively (Table 5-3). Grain yield did not differ between low and medium weed pressure levels. Mean values for the three weed pressure levels did not differ for the remaining 7 traits ($P>0.10$). Wheat cultivars differed ($P<0.01$) for all traits with the exception of lodging, which exhibited a high degree of variability (Table 3).

The fewest significant correlations occurred at high weed pressure, where grain yield was positively correlated with height and negatively correlated with days to heading and maturity (Table 5-4). Weed biomass and spikes m^{-2} were negatively correlated (Table 5-4). Under medium weed pressure, grain yield was positively correlated with days to maturity, lodging, spikes m^{-2} and kernel weight, and was negatively correlated with kernels spike^{-1} and weed biomass (Table 5-4). Weed biomass was negatively associated with height and positively associated with heading time. Under low weed pressure, grain yield was negatively associated with time to heading and was positively associated with spikes m^{-2} and kernel weight (Table 5-4). Days to maturity, lodging, yield, and spikes m^{-2} were negatively correlated with weed biomass. In all three weed pressure levels, days to heading and maturity were positively correlated, which was expected, as the two variables are measures of development rate (Table 5-4).

Under high weed biomass, the first three components of the principal component (PC) analysis described 26.0%, 22.3% and 14.5% of the variation, respectively (Table 5-5). PC1 had equally high absolute loadings for days to heading and maturity, lodging, weed biomass, grain yield and height. PC2 had the highest loadings for the yield components kernels per spike and spikes m^{-2}. PC3 exhibited high loadings for height, and days to heading and maturity. The loading plot of PC's 1 and 2 for the high weed pressure level reveal that height and yield are positively related and that there is a positive association between weed biomass, days to heading and maturity, and lodging (Figure 5-1A). Under medium weed pressure, the first three PC's accounted for 36.6%, 20.4% and 16.0% of the variation, respectively (Table 5-5). Days to maturity, lodging, grain yield and spikes m^{-2} had relatively high positive loadings in PC1. PC2 had the highest positive loadings for days to heading and weed biomass. In PC3, kernel weight had the highest loading values, followed by height and weed biomass. The loading plot shows that spikes per m^{-2} and grain yield are most closely associated at this weed level (Figure 5-1B). At the low weed level, PC's 1, 2 and 3 accounted for 30.0%, 23.2% and 16.4% of the variation, respectively (Table 5-7). PC1 had equally high positive loadings for days to maturity, lodging and spikes m^{-2}. PC2 had high loadings for days to heading and kernels per spike, and to a lesser extent, grain yield and kernel weight. PC3 had high loadings for height and kernel weight. The loading plot of PCs 1 and 2 for the low weed pressure level shows comparatively less association between plant traits than the two weedy environments, with the exception of maturity, lodging and spikes m^{-2} (Figure 5-1C).

Multiple regression analyses were carried out on the raw data to determine which of the traits most determined yield and weed biomass (Table 5-6). Although all models were statistically significant, R^2 values ranged from 0.23 to 0.51, suggesting that factors not considered here may be responsible for variation in grain yield and weed biomass among wheat cultivars. Nonetheless, some trends were identified. Under high weed pressure, tall plants, early heading, high kernel weight and high kernels spike^{-1} determined grain yield, while shorter plants and reduced spikes m^{-2} led to increased weed biomass. Under medium weed pressure, shorter plants, high spikes m^{-2}, high thousand kernel weight and low weed biomass increased yield while shorter height, later time to heading, reduced yield and high kernel weights led to increased weed biomass. Under low weeds, early heading and low weeds contributed most to high grain yield, while longer times to heading, shorter times to maturity and reduced yield contributed to increased weed biomass.

5.3.2 Stability analysis

The regression lines of the five cultivars with the highest and lowest yield stability are presented in Figure 2A. Cultivars exhibited differences in their response to variation in environmental yield potential. Park (*b*=0.84), a cultivar released in 1963, demonstrated above average stability, with small yield changes despite large changes in the yield potential of the environment. Park produced above average yields in low yielding environments and below average yields in high yielding environments. Sapphire (*b*=0.91) was relatively stable, but below average yielding in all environments. Katepwa, CDC Go and McKenzie were characterized by regression coefficients ≥ 1.07 (Figure 5-2A).

Park (*b*=0.69) and McKenzie (*b*=0.83) exhibited the least sensitivity to changes in weed pressure (Figure 5-2B). Kohika (*b*=1.14), CDC Go (*b*=1.17) and Sapphire (*b*=1.21, not shown) became increasingly less competitive against weeds as weed pressure increased. Hard Red Calcutta (*b*=1.07) demonstrated average weed stability as weed pressure increased, yet consistently allowed below average weed growth at all sites.

5.4 Discussion

5.4.1 Weed pressure levels

Our correlation and principal components analyses grouped traits associated with grain yield in the three weed biomass environments similarly. Both analyses indicated that tallness, and early heading and maturity were related to grain yield in the high weed pressure environment. Height and time to maturity have been previously identified as competitive traits in wheat (Huel and Hucl 1996; Lemerle et al. 1996). In terms of maintaining grain yield, tallness allows the crop to intercept more solar radiation, while early heading and maturity may allow the crop to escape increasingly heavy competition for soil moisture and nutrients. Time to heading has been less studied, although other measures of early plant development, such as rapid ground cover and early biomass accumulation, have been identified as competitive traits (Richards and Whytock 1993; Mason et al., unpublished work). Spikes m^{-2} was associated with grain yield under medium weed pressure, and to a lesser extent under low weed biomass, indicating that tillering capacity influences yielding ability in weedy environments. Other researchers have similarly reported tillering capacity to be associated with competitive ability (Lemerle et al. 1996; Hucl 1998).

In contrast with high weed biomass, grain yield under medium weed pressure was positively correlated with days to maturity. This would be expected under ideal growing conditions since later maturing cultivars often exhibit higher grain yield as a result of increased growing period (Baker and Townley-Smith 1986). Under medium and low weed pressure, associations among yield and yield components demonstrated the typical compensatory mechanisms that exist among spike m^{-2}, kernel spike^{-1} and kernel weight, and their influence on grain yield. When one of these factors increases, a decrease in another factor usually follows (Baker and Townley-Smith 1986). Although the yield components exhibited this same compensatory relationship under high weed biomass, none of the yield components were associated with yield itself, reflecting the complexity and variability of associations among plant traits in high weed environments.

The different associations between grain yield and competitive traits under high, medium and low weed biomass suggests that the level of weediness alters the importance of certain competitive traits. The absence of associations between height and grain yield in the low and medium weed biomass environments, along with the absence of a correlation between yield and spikes m^{-2} at the high weed level suggests that height and rapid early growth (as measured by heading and maturity) are stronger determinants of grain yield in extremely weedy environments.

Correlation analyses indicated that only spikes m^{-2} was associated with weed biomass under high weed pressure, but PC analyses suggested that reduced height and greater days to heading and maturity were also related to increased weed biomass. Taller plants that develop more quickly may be able to preempt weeds from capturing above- and below-ground resources, allowing more tiller initiation and survival, promoting further weed suppression. Our PC and correlation analyses show that tallness and early heading were associated with reduced weed biomass in medium weed pressure environments. Tallness is reported to be associated with weed suppression (Wicks et al. 1986; Gooding et al. 1993b; Cosser et al. 1997; Korres and Froud-Williams 2002) as is early growth (Richards and Whytock 1993; Lemerle et al. 1996; Champion et al. 1998), and though these traits are common to both weed environments here, the roles of maturity and spikes m^{-2} in weed suppression are most apparent at the high weed pressure level. Our results show negative correlations between weed biomass and both maturity and spikes m^{-2} at the low weed biomass level, but the PC analysis showed that weed biomass was not strongly associated with any of the variables studied, which may be due to the very low weed presence in that environment overall.

That the degree of weed pressure affects competitive traits differently may help to explain some of the discrepancies commonly found in this research area. Studies have reported, for example, tillering ability to be an important competitive trait (Lemerle et al. 1996; Hucl 1998), while others have reported tillering as less important (Wicks et al. 1986; Huel and Hucl 1996; Champion et al. 1998). Levels of weed pressure, competing weed species and cultivars tested may all have an impact on which traits emerge as competitive, as do the varying criteria for measuring competitive ability.

Our results suggest that although plant height was important for grain yield under high weed pressure, it may play a more general and consistent role in weed suppression, especially over a range of environments. Although time to heading was related to both yield and weed suppression, its function was not consistent across weed pressure levels. As with other studies, the results of these analyses suggest that spikes m^{-2} influence competitive ability, however their exact role in grain yield and weed suppression is unpredictable, and may be influenced by others traits such as height (Champion et al. 1998). While time to maturity did not figure prominently in the regression analyses, the PC analysis suggests that it may influence grain yield and weed biomass in high weed environments. These results suggest that a combination of competitive traits results in cultivars with differing weed-competitive abilities, as has been previously proposed (Lemerle et al. 1996; Champion et al. 1998).

5.4.2 Stability analysis

With its above average stability and high yields in low yielding environments, Park (released in 1963) is relatively well adapted to lower yielding environments, compared to the more modern and least yield stable ($b \geq 1.07$) cultivars Katepwa, CDC Go and McKenzie (Figure 5-2A). Katepwa exhibited below average yields in low yielding environments, and above average yields in high yielding environments, thus is best adapted to high yielding environments. CDC Go displayed above average yield in all environments, which increased with environmental yield potential, suggesting that it is well adapted to all environments included in the present study. In contrast, McKenzie yielded below average at all sites, indicating that it is poorly adapted to all sites.

Yield stability across environments did not appear to be conclusively associated with any of the plants traits measured in this study. For example, the most stable cultivars differed in height, heading, maturity and tillering habit; Park was of medium height, high tillering and early heading and maturing, while Hard Red Calcutta was tall, low tillering and of medium heading and maturity. Three of the four most stable cultivars were developed between 1890 and 1963, while the least stable cultivars were released between 1981 and 2003, suggesting that older cultivars may exhibit greater yield stability across a wide range of productivity. Modern cultivars (typically described as those developed after the mid-1900's) are commonly reported to have decreased stability when compared to older cultivars, meaning that they are highly responsive to improved growing environments, which is often the result of increased inputs (Hucl and Baker 1987; Calderini and Slafer 1999; Fufa et al. 2005). It has been proposed that stable cultivars may be desirable for low-input systems, while others argue that modern cultivars may still out-yield older ones in relatively poor environments despite their reduced stability (Calderini and Slafer 1999). In the current study, the semidwarf CDC Go (released 2003) achieved above average grain yield at all sites, but was out-yielded by Park in the very lowest yielding environments, lending credence to the idea of cultivar yield stability as a desirable quality for low-input agriculture. The New Zealand cultivars Sapphire and Kohika differed in their stability; however both were relatively poor yielding overall, indicating that these cultivars are poorly adapted to northern Canadian growing environments. Overall yielding ability is similarly not explained by any of the competitive traits studied here. For example, the semidwarf CDC Go is of medium tillering, heading and maturity, Katepwa is medium height, medium heading, early maturing and high tillering, and McKenzie is of average height, early heading and maturity and high tillering ability.

Cultivars with high weed stability (or low sensitivity to weed pressure), Park and McKenzie, demonstrate superior weed suppressive abilities as weed competition increases, and are therefore notable competitors. Hard Red Calcutta, although not the most weed stable cultivar, similarly demonstrated high weed competitive ability by consistently allowing below average weed growth at all sites (Figure 5-2B). Weed stability was not consistently explained by plant height, tillering or heading and maturity, although the three least weed stable cultivars were semidwarf in habit, suggesting that short stature or other semidwarf qualities may lead to diminishing competitive ability in increasingly weed environments. Weed suppression appeared to be influenced by height, as the tallest cultivars accumulated less weed biomass while the shorter cultivars allowed the most weed growth. Cousens et al. (2003b) reported greater yield loss due to weed competition and less weed suppression in semidwarf lines compared to conventional height isolines. Dwarfing genes may have pleiotropic effects on growth, resulting in semidwarf wheat cultivars with reduced cell size, contributing to smaller root systems, shorter coleoptile lengths and/or smaller leaf areas than conventional cultivars (Gale and Youssefian 1985; Vandeleur and Gill 2004). This may affect future wheat production in Canada and the rest of the world, where the use of semidwarf wheat cultivars is increasing; in western Canada, the semidwarf Superb (released in 2003) was the most widely grown cultivar, representing 18% of the Prairie wheat acreage only three years after its release (Canadian Wheat Board 2006a).

5.5 Conclusions

Cultivars differed in their competitive ability; therefore selection for competitive cultivars is realistic. The high yielding ability of the cultivar Park, combined with its yield and weed stability indicates that cultivars can both achieve high yield and be competitive against weeds. Park was characterized as well adapted to low yielding or high weed environments. Identifying traits that consistently increase competitive ability is difficult. Plant height appears to be the trait most strongly associated with competitiveness in the wheat cultivars studied; though tillering and time to maturity are also related. Time to heading, which may be related to early growth/biomass accumulation, is also a competitive trait for wheat cultivars in Canada. Future studies should consider time to heading as a possible competitive indicator as it be may an easily identifiable character for plant breeders. Despite the identification of competitive traits, cultivars differing in their competitive ability could not be classified according to those traits, suggesting that cultivar competitive ability results from an interaction of those traits and/or traits not investigated here.

5.6 Tables and Figures

Table 5-1. Cultivar descriptions for spring wheat cultivars and breeding lines grown in trials conducted in 2003 and 2004 in Edmonton, AB and New Norway, AB.

Cultivar	Description	Year of Release	Country of Origin	Height	Tillering potential	Maturity
Kohika	Bread	1997	New Zealand	semi-dwarf	high	medium
Sapphire	Bread	1995	New Zealand	semi-dwarf	low	late
CDC Go	CWRS[†]	2003	Canada	semi-dwarf	‡	‡
Katepwa	CWRS	1981	Canada	medium	high	medium
Park	CWRS	1963	Canada	medium	high	early
McKenzie	CWRS	1997	Canada	medium	high	medium
9207-DB3*D[§]	CWRS	breeding line	Canada	medium	low	medium-late
Hard Red Calcutta	CWRS	1890	India	tall	low	medium
Marquis	CWRS	1910	Canada	tall	high	late

[†] CWRS-Canadian Western Red Spring.

[‡] denotes unknown character prior to start of experiment.

[§] The authors gratefully acknowledge Dr. R. DePauw for allowing us to use this line for experimental purposes.

Table 5-2. Growing year, location, management, tame oat competition and total weed biomass data for weed pressure levels of four experimental sites in 2003 and 2004.

Year	Location-Management	Tame oats	Total weed biomass (g m^{-2})	Weed pressure level
2003	ERS[†]-Conventional	no	0	low
	ERS-Conventional	yes	195	medium
	ERS-Organic	no	46	low
	ERS-Organic	yes	141	medium
2004	ERS-Conventional	no	0	low
	ERS-Conventional	yes	465	high
	ERS-Organic	no	168	medium
	ERS-Organic	yes	401	high

[†] ERS-Edmonton Research Station.

Table 5-3. Analysis of variance and least squares means for the effects of weed pressure, wheat cultivar and their interaction on weed biomass, plant height, days to heading and maturity, lodging, grain yield and the yield components from 8 environments at Edmonton, AB in 2003 and 2004.

	Total weed biomass (g m^{-2})	Plant height (cm)	Days to heading	Days to maturity	Lodging (0-9)	Grain yield (t ha^{-1})	Spikes m^{-2}	Kernels spike^{-1}	1,000 Kernel weight (g)
Weed pressure									
Low	15	96	56	98	2.8	3.5	508	38	34
Medium	168	95	57	98	3.1	3.2	480	34	33
High	433	93	58	107	6.0	2.2	537	29	30
F test	0.001	0.687	0.534	0.362	0.306	0.064	0.926	0.213	0.258
SE_{diff}†	26.7	2.9	1.4	5.8	1.87	0.40	143.8	4.1	1.9
Cultivar									
9207-DB3*D	228	88	59	101	3.9	3.0	485	31	36
CDC Go	222	88	54	100	3.9	3.6	528	29	38
Hard Red Calcutta	145	112	58	100	4.9	3.0	518	39	26
Katepwa	227	99	56	99	3.4	3.1	553	31	33
Kohika	334	77	58	101	4.6	2.9	441	37	30
Marquis	143	111	60	103	3.7	2.9	534	31	35
McKenzie	128	97	54	99	3.7	2.9	574	30	31
Park	153	99	52	98	3.9	3.0	539	31	33
Sapphire	269	80	62	109	4.0	2.5	403	43	31
F test	<.0001	<.0001	<.0001	<.0001	0.154	0.005	<.0001	<.0001	<.0001
SE_{diff}†	19.1	1.7	0.7	0.8	0.50	0.21	29.1	1.4	1.0
Weed pressure x *Cultivar*									
F test	0.002	0.145	0.901	0.807	0.948	0.350	0.910	0.292	0.949

†Standard error of the difference (SE_{diff}) for total weed biomass has been backtransformed.

Table 5-4. Correlations among plant height, time to heading and maturity, lodging, grain yield, and yield components under high, medium and low weed pressure for wheat cultivars grown in 8 environments at Edmonton, AB in 2003 and 2004.[†,‡]

Weed pressure		HT	HDG	MAT	LDG	YLD	SM2	KPS	TKW
High	HDG	*ns*							
n=54	MAT	*ns*	0.55						
	LDG	-0.31	*ns*	*ns*					
	YLD	0.44	-0.36	-0.33	*ns*				
	SM2	*ns*	*ns*	*ns*	*ns*	*ns*			
	KPS	*ns*	*ns*	*ns*	*ns*	*ns*	-0.43		
	TKW	-0.40	*ns*	*ns*	*ns*	*ns*	*ns*	-0.42	
	WBS	*ns*	*ns*	*ns*	*ns*	*ns*	-0.38	*ns*	*ns*
Medium	HDG	*ns*							
n=81	MAT	-0.29	0.49						
	LDG	*ns*	0.40	0.70					
	YLD	*ns*	*ns*	0.37	0.43				
	SM2	*ns*	*ns*	0.62	0.77	0.59			
	KPS	*ns*	*ns*	-0.38	-0.46	-0.38	0.60		
	TKW	*ns*	-0.28	*ns*	-0.28	0.22	*ns*	*ns*	
	WBS	-0.26	0.25	*ns*	*ns*	-0.23	*ns*	*ns*	*ns*
Low	HDG	*ns*							
n=81	MAT	*ns*	0.51						
	LDG	*ns*	0.23	0.60					
	YLD	*ns*	-0.27	*ns*	*ns*				
	SM2	*ns*	*ns*	0.51	0.70	0.26			
	KPS	-0.29	0.49	*ns*	-0.27	*ns*	-0.44		
	TKW	-0.25	-0.31	*ns*	-0.32	0.25	*ns*	*ns*	
	WBS	*ns*	*ns*	-0.41	-0.32	-0.41	-0.39	*ns*	*ns*

[†] HT, height; HDG, days to heading; MAT, days to maturity; LDG, lodging; YLD, grain yield; SM2, spikes per m^2; KPS, kernels per spike; TKW, kernel weight.

[‡] r values below 0.36 were significant at $P<0.05$ and those above were significant at $P<0.01$. Exceptions were correlations between MAT and HT under medium weed biomass, and KPS and HT, TKW and HDG, TKW and LDG, and WBS and LDG under low weed biomass, due to missing values for one of the variables.

Table 5-5. Factor loadings, eigenvalues, and percentages of total and cumulative variance for the first three principal components in each level of weed pressure for wheat cultivars grown in 8 environments at Edmonton, AB in 2003 and 2004.[†,‡]

	Weed pressure level								
	High			Medium			Low		
Variables	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3
HT	**-0.43**	0.10	**0.47**	-0.07	-0.30	**-0.54**	0.02	-0.13	**-0.58**
HDG	**0.40**	0.04	**0.54**	0.19	**0.55**	-0.10	0.20	**0.55**	0.05
MAT	**0.39**	-0.19	**0.45**	**0.45**	0.25	0.14	**0.48**	0.22	0.27
LDG	**0.36**	0.03	-0.20	**0.49**	0.10	-0.15	**0.53**	0.02	-0.17
YLD	**-0.44**	0.29	-0.03	**0.35**	-0.30	0.24	0.13	-0.40	0.30
SM2	-0.15	**-0.53**	0.13	**0.50**	-0.10	-0.13	**0.52**	-0.18	-0.16
KPS	-0.05	**0.60**	0.23	**-0.37**	0.35	-0.12	-0.10	**0.49**	0.36
TKW	-0.13	-0.33	-0.24	-0.07	-0.32	**0.64**	-0.16	-0.37	**0.46**
WBS	**0.38**	0.34	-0.35	-0.07	**0.45**	**0.41**	-0.35	0.24	-0.33
Mean of absolute loading value	0.30	0.27	0.29	0.28	0.30	0.27	0.28	0.29	0.30
Eigenvalue	2.34	2.01	1.30	3.30	1.83	1.44	2.70	2.09	1.47
Proportion of total variance (%)	26.0	22.3	14.5	36.6	20.4	16.0	30.0	23.2	16.4
Cumulative proportion of total variance (%)	26.0	48.3	62.8	36.6	57.0	73.0	30.0	53.2	69.6

[†] HT, height; HDG, days to heading; MAT, days to maturity; LDG, lodging; YLD, grain yield; SM2, spikes per m^2; KPS, kernels per spike; TKW, kernel weight.

[‡] Bold font indicates variables selected to create each principal component, based on both absolute loading values greater than the mean absolute loading value and relative loading values within each component.

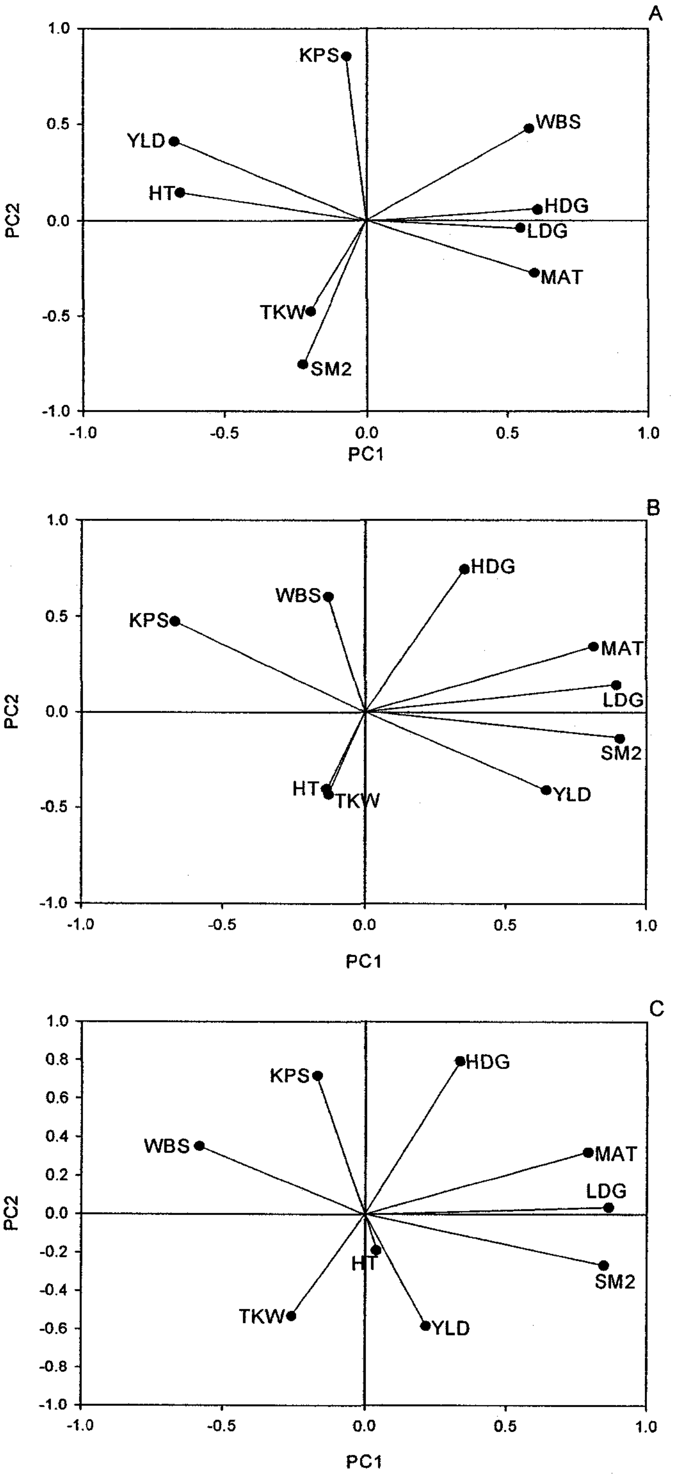

Figure 5-1. Loading plot describing the relationship among HT, height; HDG, days to heading; MAT, days to maturity; LDG, lodging; YLD, grain yield; SM2, spikes m^{-2}; KPS, kernels spike^{-1} and TKW, kernel weight in high (A), medium (B) and low (C) weed pressure levels, using PCs 1 and 2, for wheat cultivars grown in 8 environments at Edmonton, AB in 2003 and 2004.

Table 5-6. Multiple regression statistics and equations relating grain yield and weed biomass in high, medium and low weed pressure levels with the variables height, days to heading and maturity, lodging, grain yield, spikes m^{-2}, kernel $spike^{-1}$, kernel weight and weed biomass for wheat cultivars grown in 8 environments at Edmonton, AB in 2003 and 2004.

Parameter	Weed pressure level	Regression equation	R^2	$P > F$
Grain Yield (y)	High	y=0.85 + 0.02 plant height – 0.07 days to heading + 0.06 kernel weight + 0.05 kernels $spike^{-1}$	0.45	0.01
	Medium	y=1.05 – 0.01 plant height + 0.003 spikes m^{-2} + 0.06 kernel weight – 0.03 weed biomass	0.51	0.01
	Low	y=6.48 – 0.05 days to heading – 0.10 weed biomass	0.23	0.01
Weed Biomass (w)	High	w=48.6 – 0.20 plant height – 0.02 spikes m^{-2}	0.34	0.01
	Medium	w=-1.11 – 0.09 plant height + 0.35 days to heading – 1.74 grain yield + 0.23 kernel weight	0.24	0.01
	Low	w=21.4 + 0.23 days to heading – 0.27 days to maturity – 1.45 grain yield	0.39	0.01

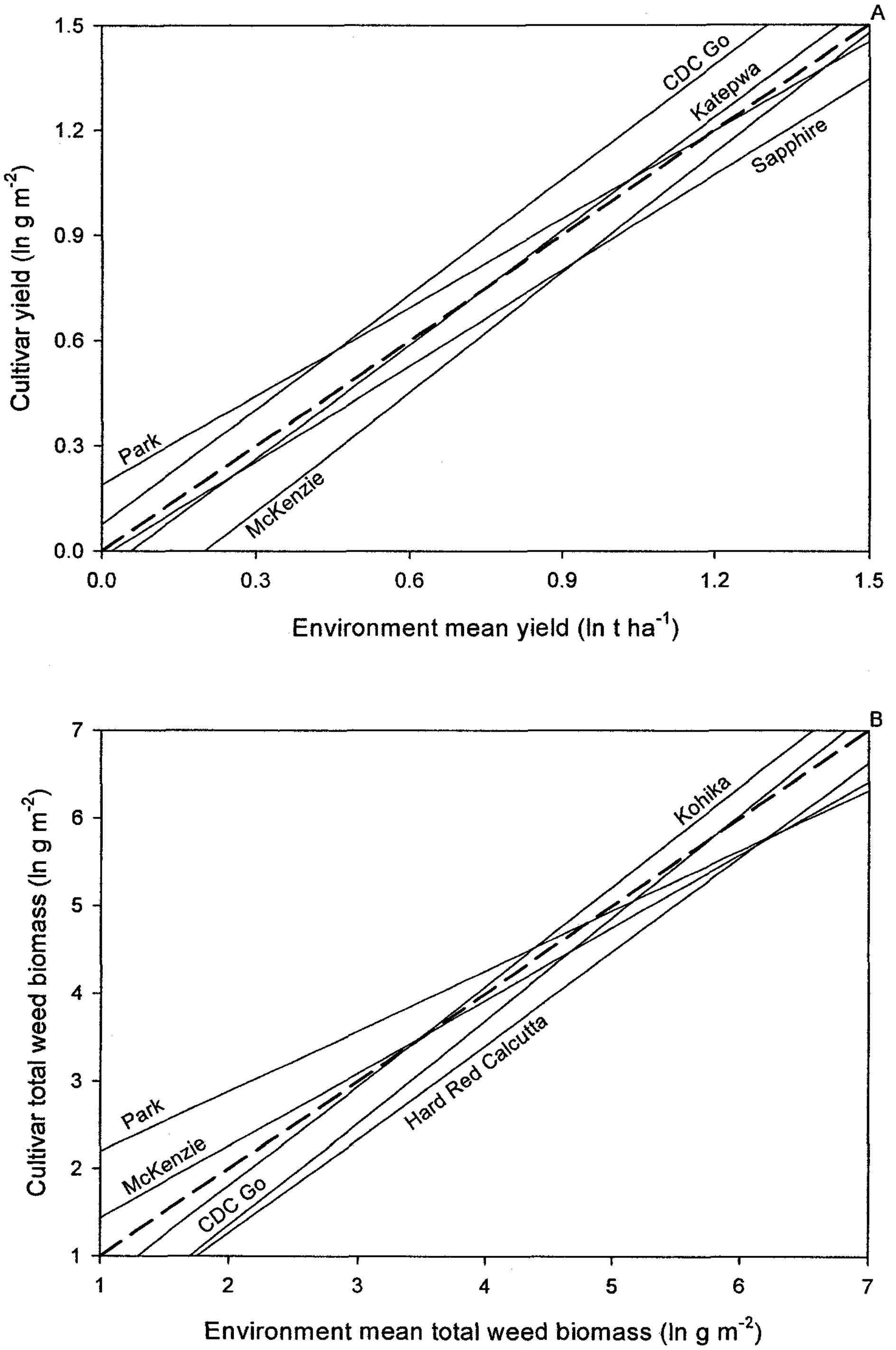

Figure 5-2. Regression lines, showing the relationship between individual cultivar yield and environment mean yield (A) and between individual cultivar total weed biomass and environment mean total weed biomass (B) of wheat cultivars grown in 12 different environments at Edmonton, AB and New Norway, AB in 2003 and 2004.

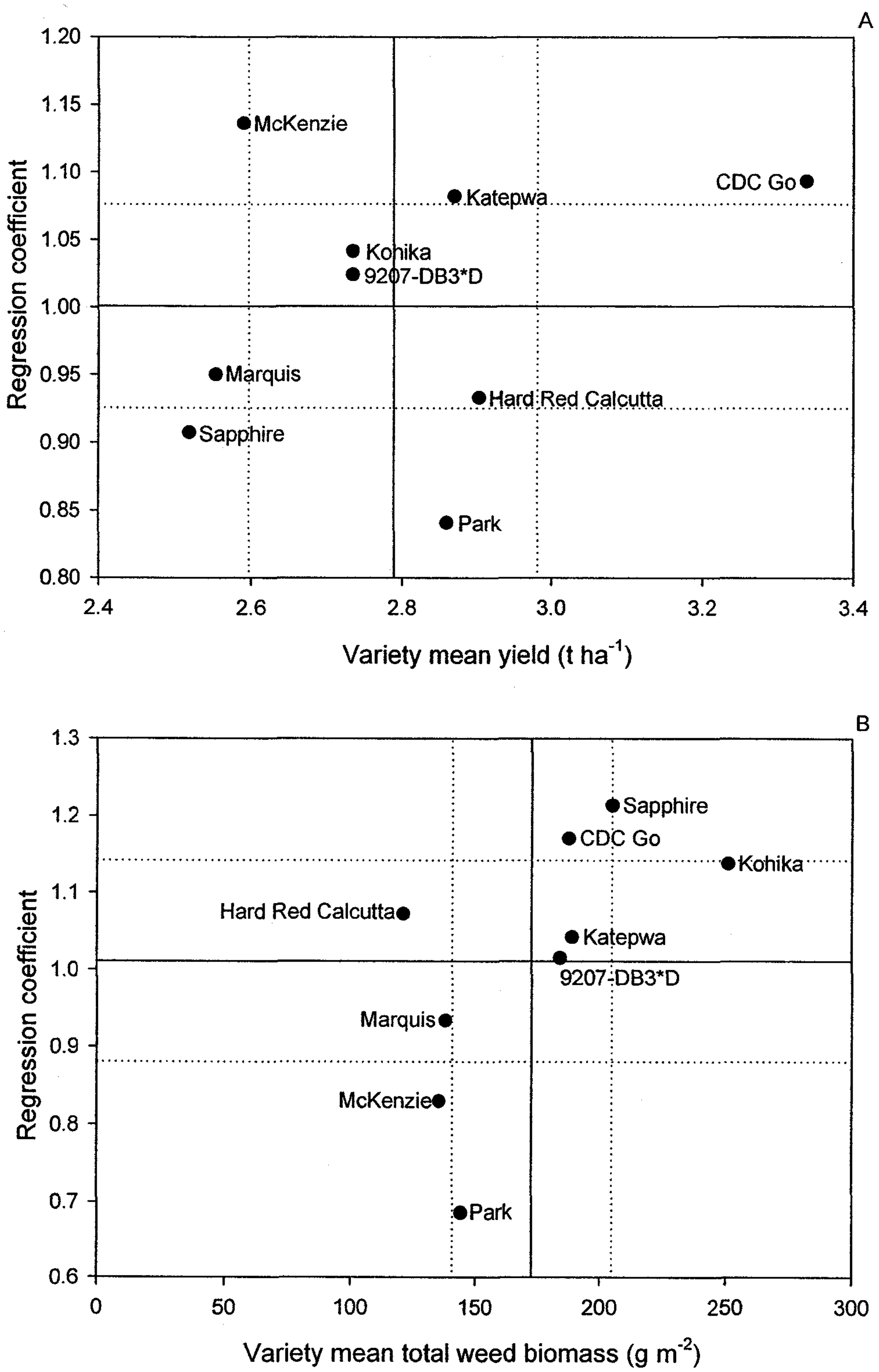

Figure 5-3. The relationship between cultivar adaptation and cultivar mean yield for 9 wheat cultivars grown in 12 environments (A), and between cultivar adaptation and cultivar mean total weed biomass for 9 wheat cultivars grown in 10 different environments (B).[†]

[†]Solid lines indicate the mean values and dotted lines represent the 95% confidence limits.

5.7 Literature Cited

Alberta Agriculture Food and Rural Development. 2003. Using 1,000 kernel weight for calculating seeding rates and harvest losses. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex81/$file/100_22-1.pdf?OpenElement [14 July 2006].

Alberta Agriculture Food and Rural Development. 2004. Soil Group Map of Alberta. [Online] Available: http://www1.agric.gov.ab.ca/soils/soils.nsf/soilgroupmap?readform [31 August 2006].

Alberta Agriculture Food and Rural Development. 2006. Herbicide Selector. [Online] Available: http://www.agric.gov.ab.ca/app23/herbsel [29 September 2006].

Baker, R. J. and Townley-Smith, T. F. 1986. Breeding Wheat for Yield, p. 443-452, *In* A. E. Slinkard and D. B. Fowler, eds. Wheat Production in Canada- A Review. Proc. Can. Wheat Production Symp. Division of Extension and Community Relations, University of Saskatchewan, Saskatoon, SK.

Barberi, P., Silvestri, N., Peruzzi, A. and Raffaelli, M. 2000. Finger-harrowing of durum wheat under different tillage systems. Biol. Agric. Hortic. **17**:285-303.

Calderini, D. F. and Slafer, G. A. 1999. Has yield stability changed with genetic improvement of wheat yield? Euphytica **107**:51-59.

Canadian Wheat Board. 2006. 2006 CWB news releases. [Online] Available: http://www.cwb.ca/public/en/news/releases/2006/101906.jsp [29 October 2006].

Champion, G. T., Froud-Williams, R. J. and Holland, J. M. 1998. Interactions between wheat (*Triticum aestivum* L.) cultivar, row spacing and density and the effect on weed suppression and crop yield. Ann. Appl. Biol. **133**:443-453.

Coleman, R. D., Gill, G. S. and Rebetzke, G. J. 2001. Identification of quantitative trait loci for traits conferring weed competitiveness in wheat (*Triticum aestivum* L.). Aust. J. Agric. Res. **52**:1235-1246.

Cosser, N. D., Gooding, M. J., Thompson, A. J. and Froud-Williams, R. J. 1997. Competitive ability and tolerance of organically grown wheat cultivars to natural weed infestations. Ann. Appl. Biol. **130**:523-535.

Cousens, R. D., Rebetzke, G. J. and Barnett, A. G. 2003. Dynamics of competition between wheat and oat: II. Effects of dwarfing genes. Agron. J. **95**:1305-1313.

Finlay, K. W. and Wilkinson, G. N. 1963. The analysis of adaptation in a plant-breeding programme. Aust. J. Agric. Res. **14**:742-754.

Fufa, H., Baenziger, P. S., Beecher, B. S., Graybosch, R. A., Eskridge, K. M. and Nelson, L. A. 2005. Genetic improvement trends in agronomic performances and end-use quality characteristics among hard red winter wheat cultivars in Nebraska. Euphytica **144**:187-198.

Gale, M. D. and Youssefian, S. 1985. Dwarfing Genes in Wheat, p. 1-35, *In* G. E. Russell, ed. Progress in Plant Breeding. Butterworths, London, UK.

Gomez, K. A. and Gomez, A. A. 1984. Statistical Procedures for Agricultural Research. 2nd ed. John Wiley and Sons, Inc., New York, NY. 680 pp.

Gooding, M. J., Thompson, A. J. and Davies, W. P. 1993. Interception of photosynthetically active radiation, competitive ability and yield of organically grown wheat varieties. Aspects Appl. Biol. **34**:355-362.

Hartl, W. 1989. Influence of undersown clovers on weeds and on the yield of winter-wheat in organic farming. Agric. Ecosyst. Environ. **27**:389-396.

Hucl, P. 1998. Response to weed control by four spring wheat genotypes differing in competitive ability. Can. J. Plant Sci. **78**:171-173.

Hucl, P. and Baker, R. J. 1987. A study of ancestral and modern Canadian spring wheats. Can. J. Plant Sci. **67**:87-97.

Huel, D. G. and Hucl, P. 1996. Genotypic variation for competitive ability in spring wheat. Plant Breed. **115**:325-329.

Jolliffe, I. T. 2002. Principal Component Analysis. Springer-Verlag New York, Inc., Secaucus, NJ. 487 pp.

Jordan, N. 1993. Prospects for weed-control through crop interference. Ecol. Appl. **3**:84-91.

Kirkland, K. J. and Hunter, J. H. 1991. Competitiveness of Canada Prairie Spring wheats with wild oat (*Avena fatua* L.). Can. J. Plant Sci. **71**:1089-1092.

Korres, N. E. and Froud-Williams, R. J. 2002. Effects of winter wheat cultivars and seed rate on the biological characteristics of naturally occurring weed flora. Weed Res. **42**:417-428.

Lemerle, D., Gill, G. S., Murphy, C. E., Walker, S. R., Cousens, R. D., Mokhtari, S., Peltzer, S. J., Coleman, R. and Luckett, D. J. 2001a. Genetic improvement and agronomy for enhanced wheat competitiveness with weeds. Aust. J. Agric. Res. **52**:527-548.

Lemerle, D., Verbeek, B., Cousens, R. D. and Coombes, N. E. 1996. The potential for selecting wheat varieties strongly competitive against weeds. Weed Res. **36**:505-513.

Lemerle, D., Verbeek, B. and Orchard, B. 2001b. Ranking the ability of wheat varieties to compete with *Lolium rigidum.* Weed Res. **41**:197-209.

Mallarino, A. P., Oyarzabal, E. S. and Hinz, P. N. 1999. Interpreting within-field relationships between crop yields and soil and plant variables using factor analysis Precision Agriculture **1**:15-25.

O'Donovan, J. T., Harker, K. N., Clayton, G. W. and Hall, L. M. 2000. Wild oat (*Avena fatua*) interference in barley (*Hordeum vulgare*) is influenced by barley variety and seeding rate. Weed Technol. **14**:624-629.

Organic Crop Improvement Association. 2000. International Certification Standards As Revised: March 2000. OCIA International, Inc., Lincoln, NE.

Richards, M. C. and Whytock, G. P. 1993. Varietal competitiveness with weeds. Aspects Appl. Biol. **34**:345-354.

SAS Institute. 2003. Release 9.1. SAS Institute, Cary, NC.

Smith, G. L. 1991. Principal component analysis: an introduction. Analytical Proceedings **28**:150-151.

Timm, N. H. 2002. Applied Multivariate Analysis. Springer-Verlag New York, Inc., Secaucus, NJ. 693 pp.

Vandeleur, R. K. and Gill, G. S. 2004. The impact of plant breeding on the grain yield and competitive ability of wheat in Australia. Aust. J. Agric. Res. **55**:855-861.

Wicks, G. A., Ramsel, R. E., Nordquist, P. T., Schmidt, J. W. and Challaiah. 1986. Impact of wheat cultivars on establishment and suppression of summer annual weeds. Agron. J. **78**:59-62.

6.0 General Discussion and Conclusions

6.1 Introduction

"Organics" is the most rapidly growing division of the Canadian food sector, and the demand for organic bread and pasta products is increasing rapidly (Canadian Wheat Board 2006b). Over 325 000 ha on the Canadian Prairies were dedicated to organic grain production in 2003 (Canadian Wheat Board 2006b). Organic agriculture takes a holistic approach to farming and makes use of natural long-term management strategies, prohibiting the use of chemical fertilizers and synthetic pesticides. Competition from weeds plays a role in reducing crop yields on organic farms. Studies in Canada and elsewhere have reported both higher numbers of weeds and greater diversity of weed species in organic cereal crops than in conventionally grown ones (Samuel and Guest 1990; Leeson et al. 2000). Relatively little research pertaining to grain production in Canadian organic systems has been conducted thus far.

In an effort to overcome weed competition, producers may make use of farming practices such as crop rotations, changes to seeding dates and rates, intercropping and cultivar selection (Stopes and Millington 1991; Barberi 2002). Increases in seeding density have resulted in higher levels of weed suppression and increased yields in wheat (Lemerle et al. 1996; Champion et al. 1998; Weiner et al. 2001) and barley (O'Donovan et al. 1999) under weed competition, while yield gains of 7-9% have been identified in 'competitive' wheat cultivars when compared to 'non-competitive' cultivars (Hucl 1998).

A number of studies have found differences in the weed-competitive ability of cultivars of grain crops such as wheat and barley (Wicks et al. 1986; Huel and Hucl 1996; O'Donovan et al. 2000). For producers, knowledge about the competitive ability of cultivars would be useful for choosing cultivars suited to their environment (Lemerle et al. 2001b). Yield gains of 7-9% have been identified in 'competitive' wheat cultivars when compared to 'non-competitive' cultivars (Hucl 1998). Presently, research pertaining to the Canadian wheat cultivars suitable for organic production is limited. Some researchers question the value of using crop cultivars developed for low-stress, high-input production in higher stress, low-input environments, such as organic systems (Laing and Fischer 1977; Ceccarelli 1996). It has been hypothesized that wheat cultivars developed before the advent of modern, high-input agriculture may be better suited to lower soil nutrient levels and elevated weed competition (Poutala et al. 1993).

Morphological, physiological and biochemical traits are thought to control plant competitiveness (Lemerle et al. 2001a). Many researchers have determined that plant height and/or tillering capacity play a role in the competitive ability of wheat (Lemerle et al. 1996; Hucl 1998; Korres and Froud-Williams 2002). Various other characteristics, such as canopy structure, light interception, early biomass accumulation, ground cover, flag leaf length, and timing of spike emergence have been found to contribute to competitiveness (Wicks et al. 1986; Huel and Hucl 1996; Lemerle et al. 1996; Champion et al. 1998). The identification of competitive traits could help plant breeders develop cultivars with improved weed-competitive ability.

The goal of this thesis was to increase our understanding of cultivar performance and weed-crop competition in organic and conventional spring wheat production systems. The specific objectives were 1) to investigate whether spring wheat cultivars exhibit different agronomic capabilities when grown under organic and conventional management systems, 2) to evaluate the breadmaking quality of organically and conventionally grown Canadian bread wheat cultivars, 3) to determine the effect of tame oat competition, cultivar and seeding rate on the competitive ability and agronomic performance of Canadian spring wheat and barley in organic management systems, 4) to establish plant traits, such as height and tillering capacity, which affect the competitive ability of Canadian spring wheat cultivars grown in conventional and organic systems, and 5) to identify differences among cultivar stability in and adaptation to environments differing in yield potential and weed competition.

6.2 The weed-competitive ability of Canada Western Red Spring wheat cultivars grown under organic management

Twenty seven CWRS wheat cultivars representing 114 years of Canadian wheat breeding were grown under both conventional and organic management systems at twelve locations in 2003 and 2004 (Chapter 3.0). Mean yield of cultivars grown under conventional management was greater than that of cultivars grown under organic management. This may be due to increased stress under organic management caused by nutrient limitation and more importantly, weed competition. Overall mean weed biomass at organic sites was 95 times greater than at conventionally managed sites.

Cultivars performed differently in the two management systems, but differences among cultivars were more pronounced in the conventional system. This is probably because genetic differences were expressed to a greater extent in the absence of stresses associated with weeds and low soil nutrient status of the organic systems. Modern cultivars, typically selected in high yielding environments, may be more responsive to inputs than older cultivars, and may or may not perform poorly in low yielding environments (Calderini and Slafer 1999). If the yielding ability of the modern cultivars was somewhat diminished in the organic system, cultivar performance in that system would then be more similar. The lower yield potential of organic systems highlights the need for the development of cultivars with increased performance within such systems.

Cultivars more suited to organic management systems than conventional systems were not obvious. Some cultivars (e.g., AC Intrepid, Sinton) performed well in both systems; while others (e.g., Red Fife, Chester) performed relatively poorly in both systems. The top yielding cultivars in their respective management system were among the top 10 yielding cultivars in the opposing system, with one exception. Garnet was the fifth highest yielding cultivar under organic management and the second lowest yielding cultivar under conventional management, suggesting that there may be some cultivars more suited for production in organic compared to conventional management systems.

6.3 The breadmaking quality of Canada Western Red Spring wheat under organic and conventional management

Five CWRS cultivars grown under conventional and organic management in 2003 and 2004 were selected for quality analysis (Chapter 2.0). Cultivars were chosen as representatives of some of the most important wheat cultivars in the history of CWRS wheat breeding.

Test weight and protein content are two of the most important characteristics in the Canadian wheat quality grading system (Anonymous 2004). While test weights in the present study were slightly higher in conventional systems, averages for each management system were above the minimum 75 kg hL^{-1} for a No.1 CWRS grading. Only Red Fife under organic management was below the desired level, with an average test weight of 73 kg hL^{-1}, meaning, all other factors remaining equal, that it would receive a No.2 CWRS grading (Anonymous 2004). Mean wholemeal protein content did not differ between conventional and organic management systems. Protein contents were high under both conventional and organic management, surpassing the minimum standard of 13.5% protein for CWRS wheat. These results suggest that there is the potential for growing high quality bread wheat under organic management systems in north central Alberta, and that organic systems have the potential to supply adequate nitrogen to wheat crops.

Gluten strength, as measured by SDS sedimentation, was higher under conventional than under organic management, which may be related to higher N availability at conventional sites (Gooding et al. 1993a; Lloveras et al. 2001; Ames et al. 2003). Average mixograph values for each management system revealed trends toward higher dough strength under organic management. Overall, the results of this study suggest that organically managed CWRS wheat varieties are capable of achieving good breadmaking quality. The significant management x cultivar interaction for mixing development time indicates that some cultivars may be able to achieve higher breadmaking quality when grown on organic land than if grown on conventional land, and implies that breeding specifically for high quality organic wheat production may be feasible.

Our analyses suggest that cultivars that yield well on organic land also possess higher breadmaking quality. This may be related to varietal ability to withstand stresses associated with organic management, since the same relationships were not observed in the relatively low-stress conventional system. Similar relationships were observed with test weight and some quality parameters. Grain yield, test weight and protein content were found to be largely determined by environment, as opposed to genotype. If cultivars that are capable of attaining high grain yield and test weight under organic management are consistently found to have high breadmaking quality, selection of high quality wheat for organic production could be simplified.

The cultivar Red Fife, released in 1885, had the poorest breadmaking quality of the five cultivars studied, while the most modern cultivars, Park and McKenzie, had the highest quality. This suggests that older CWRS cultivars may not be suitable for breadmaking, despite management system. Red Fife and McKenzie (released 1997) were of higher quality under conventional management, while Marquis (released 1910) and Park (released 1963) exhibited higher breadmaking quality under organic management. The cultivar Thatcher (released 1935) did not perform differently between the two management systems. The variability of the performance of these cultivars within the two systems indicates that older cultivars do not necessarily perform better on organic land in terms of breadmaking quality.

6.4 Tame oat competition, cultivar and seeding rate effects on Canadian spring wheat and barley in organic management systems

Nine spring wheat and two spring barley cultivars were chosen on the basis of height, tillering potential and maturity characters. These 11 cultivars were grown under organic management with and without additional competition from tame oat, and at single (300 seeds m^{-2}) and doubled seeding rates at two locations in each of the 2003 and 2004 growing seasons (Chapter 4.0).

Competition from tame oats reduced early season vigour, overall grain yield and the yield components spikes m^{-2}, number of kernels $spike^{-1}$ and kernel weight in organic fields. Average overall grain yield for wheat and barley combined was reduced by 27% due to competition from tame oats. Barley averaged 20% yield loss while wheat averaged 29% yield loss; suggesting that, in terms of maintaining yield under weed pressure, barley is more competitive than wheat. Spikes m^{-2} and the number of kernels $spike^{-1}$ were the yield components in wheat and barley that were primarily affected by competition from weeds, where kernel weight was less affected. Timing of weed competition may play a role in this, as spike and kernel numbers are determined earlier in cereal development than kernel weight. These results indicate that wheat grain yield under competition is sink-limited, thus efforts to decrease yield loss due to weed competition should focus on increasing the overall sink size.

Cultivars differed in terms of their yield loss from tame oat competition, with the semidwarf wheat cultivars CDC Go and Sapphire suffering the highest losses. Thus, genotypic differences exist in the response of wheat and barley cultivars to competition from weeds on organic land, indicating that the selection of cultivars more suited to organic production is possible. Cultivars performed differently for all measured traits, with Seebe barley and CDC Go wheat yielding the highest and Marquis the lowest. In general, weed biomass was lowest in Seebe barley and Marquis, Hard Red Calcutta and McKenzie wheat, and highest in the semidwarf wheat cultivars Kohika, Sapphire and CDC Go and the semidwarf barley cultivar Peregrine.

For the organic producer, more important measures may be overall grain yielding ability under competition combined with weed suppressive ability. Wheat and barley cultivars differed in their ability to achieve high grain yield and suppress weeds (Chapter 4). Park, 9207-DB3*D and Katepwa were found to be relatively high yielding and good at suppressing weeds on organic land, the most desirable combination for organic grain production.

Despite the presence of an overall correlation between weed biomass and yield loss, the cultivars tested appear to differ in their ability to both suppress weeds and maintain yields. CDC Go and Sapphire experienced high yield losses and relatively high weed biomass accumulation, while Kohika did not experience a significant yield loss, but had the highest weed biomass accumulation of all the varieties. The mechanisms that control crop response and effect may differ, and our results seem to support the theory that the competitive effect and response of cultivars should be considered separately when trying to identify cultivars with superior competitive ability.

Doubling the seeding rate increased average grain yield by 10%. Both barley and wheat cultivars were similarly affected by a doubling of the seeding rate. Doubling the seeding rate is an effective strategy in reducing weeds under organic management. The relationship between weed suppression and grain yield with seeding density in spring wheat and barley was not cultivar specific, indicating that it may be a suitable strategy for overcoming weed competition in organic grain production.

6.5 Traits that confer competitive ability in organic and conventional management systems

Early season vigour, time to heading and maturity, plant height and tillering capacity were considered as competitive traits in these experiments. Our results concerning each of them are detailed below:

6.5.1 Early Season Vigour

Early season vigour (ESV), also thought of as early biomass accumulation, may confer competitive ability by allowing the plant to overcome weed competition early in its life cycle, allowing it to better compete for above- and below-ground resources. Early season vigour and yield were positively correlated in both management systems (Chapter 2.0). Increased ESV was associated with reduced yield loss in organic fields (Chapter 4.0). Early season vigor may be more important in organic fields than in conventional fields, allowing a plant to develop faster, thereby reducing the effects of weed competition and enabling a plant to maintain yield in weedy conditions.

Early season vigour was negatively correlated with weed biomass in wheat on organic land (Chapter 2.0). Between 11 wheat and barley cultivars, those with low ESV were among those with the lowest grain yield and highest weed biomass, but the relationship between ESV and competitive ability was not consistent for all cultivars (Chapter 4.0).

6.5.2 Time to Heading and Maturity

While times to heading and maturity as competitive traits have not been widely studied, they are related to the rate of plant development, which is more commonly considered. Cultivars with differing growth rates are likely to respond differently to environmental stresses (e.g., moisture, light), and those that develop more quickly could avoid some of those stresses.

A negative relationship between yield and time to maturity was observed in both organic and conventional management system, indicating that early maturing cultivars are appropriate for use in northern wheat cropping systems, both conventional and organic (Chapter 2.0). Because delayed seeding is a common practice among organic wheat producers as a means of weed control, early maturing cultivars would be particularly desirable in northern regions. Later maturing wheat cultivars experienced a higher degree of yield loss as a result of tame oat competition; however the trend was not consistent (Chapter 4.0). Early heading and maturity were related to high grain yield in high weed environments (Chapter 5.0).

The positive correlations between weed biomass and days to maturity of cultivars in organic fields suggests that early maturing cultivars allow less weed growth overall than later maturing cultivars (Chapters 2.0 and 4.0). Early maturity was also related to weed suppression in weedy environments, while later heading was related to increased weed biomass in high and medium weed environments (Chapter 5.0). Time to maturity appears to play a role in the ability of wheat cultivars to withstand competition from weeds and to suppress their growth.

6.5.3 Plant Height

Research has determined that height plays a role in competitive ability. The stronger association between height and yield at the conventional sites compared to the organic sites suggests that height alone may not be a good indicator of competitive ability in organic systems (Chapter 2.0). However, plant height was important for grain yield in extremely weedy environments (Chapter 5.0).

Height appears to be more strongly and consistently related to weed suppression than to grain yield maintenance in weedy environments. Plant height was negatively correlated with weed biomass in organic fields (Chapters 2.0 and 4.0). Semidwarf cultivars (Kohika, Peregrine, Sapphire, CDC Go) were not as effective at weed suppression than taller cultivars (Seebe, Marquis, Hard Red Calcutta) (Chapter 4.0). In high and medium weed pressure environments, tallness was associated with weed suppression.

6.5.4 Tillering Capacity

Tillering capacity (i.e., spikes m^{-2}) is also thought to have an effect on competitive ability, but weed competition is known to affect tillering capacity as well. Comparing organic and conventional systems (Chapter 2.0), the average number of spikes m^{-2} in organic fields was 8% less than in conventional fields, in organic systems only, competition from tame oats significantly reduced spikes m^{-2} (Chapter 4.0). The number of spikes m^{-2} did not differ among low, medium and high weed environments, however.

Spikes m^{-2} and yield were positively correlated in organic management and were negatively correlated in conventional management (Chapter 2.0). Cultivars with high tiller numbers were among the highest yielding and those with low tiller numbers were among the lowest yielding in organic systems; however this may be related to cultivar differences in height, etc. (Chapter 4.0). Spikes m^{-2} were not associated with grain yield under high weed pressure, but were in the medium and low weed environments (Chapter 5.0).

The negative correlation between weed biomass and spikes m^{-2} under organic management may indicate that weed growth was suppressed by cultivars with high fertile tiller number (Chapter 2.0). At high weed pressure levels, spikes m^{-2} was negatively associated with weed biomass (Chapter 5.0). The results of these analyses suggest that spikes m^{-2} influence competitive ability, however their exact role in grain yield and weed suppression is unpredictable.

6.5.5 Competitive traits at different weed pressure levels

The different associations between grain yield and competitive traits under high, medium and low weed biomass suggest that the level of weediness alters the importance of certain competitive traits (Chapter 5.0). Therefore, competitive crop ideotypes could be developed for specific levels or ranges of weed pressure. The absence of associations between height and grain yield in the low and medium weed biomass environments, indicates that height and rapid early growth (as measured by heading and maturity) are stronger determinants of grain yield in extremely weedy environments. Associations between grain yield and spikes m^{-2} only observed at the medium and low weed biomass level affect the importance of sink size on wheat grain yield moderate weed competition.

That the degree of weed pressure affects competitive traits differently may help to explain some of the discrepancies commonly found in this research area. Levels of weed pressure, competing weed species and cultivars tested may all have an impact on which traits emerge as competitive, as do the varying criteria for measuring competitive ability.

6.6 Cultivar stability and adaptation in differing natural weed environments

Nine spring wheat cultivars were chosen for this experiment on the basis of height, tillering potential and maturity characters. The cultivars were planted at 300 seeds m^{-2} and grown under 12 different environments differing in their yield potential and weed biomass (Chapter 5).

Cultivars differed in their yielding ability and yield stability, which did not appear to be conclusively associated with any of the "competitive" plants traits measured in this study. Older cultivars exhibited greater yield stability across a wide range of productivity. Modern cultivars are often highly responsive to improved growing environments (i.e., less stable), possibly as a result of selection from high input environments (Calderini and Slafer 1999; Fufa et al. 2005). Stable cultivars may be desirable for low-input systems, while others argue that modern cultivars may still out-yield older ones in relatively poor environments despite their reduced stability (Calderini and Slafer 1999). In the current study, the semidwarf CDC Go (released 2003) achieved above average grain yield at all sites, but was out-yielded by Park in the very lowest yielding environments, supporting the concept of cultivar yield stability as a desirable quality for organic and/or low-input agriculture.

Cultivars with high weed stability are less sensitive to weed pressure. Weed stability was not consistently explained by plant height, tillering or heading and maturity, although the three least weed stable cultivars were semidwarf in habit, suggesting that short stature or other semidwarf qualities may lead to diminishing competitive ability in increasingly weedy environments. Weed suppression appeared to be influenced by height, as the tallest cultivars accumulated less weed biomass while the shorter cultivars allowed the most weed growth.

6.7 General Discussion

Improvement of organic grain production on the Canadian Prairies requires that we have a better understanding of cultivar performance under organic management. This begins with research conducted on organically managed land, as it may better reflect the complexities of organic production than do results extrapolated from trials conducted at conventional sites.

Spring wheat cultivars exhibited different capabilities when grown in organic and conventional production systems. Differences in breadmaking quality, agronomic traits and competitive ability among cultivars grown in the two management systems have been identified in this thesis.

High quality organic bread wheat production on the northern Canadian Prairies is currently possible. The differential performance of Canadian bread wheat cultivars on organic and conventional land suggests that breeding for improved quality on organic land is reasonable. However, given the stringent quality guidelines for Canada Western Red Spring wheat and the multitude of suitable registered cultivars for organic bread wheat production, breeding solely for improved quality under organic management is somewhat unnecessary.

Research conducted as part of this thesis suggests that grain yields are lower and weed biomass is higher in organic fields when compared to conventional fields. Cultivars performed more similarly in the organic system, which further suggests that the organic systems are of lower yield potential. The theory that older cultivars are better suited to low input environments was not supported by the research conducted herein. Older cultivars were more stable across a range of environments, yet some were lower yielding than more modern and less stable cultivars when grown in low yielding environments. Results indicate that modern semidwarf wheat and barley cultivars are not effective weed suppressors and, despite the high yielding ability of the Canadian semidwarf CDC Go across all sites, may not be best suited to organic or low input wheat production. Cultivars best suited to low input environments were identified as those with high yielding ability, weed suppressive capabilities, and yield and weed stability. The identification of cultivar differences suggests that it may be valuable to breed wheat cultivars specifically suited to low input environments.

Increased understanding of weed-crop competition on organic land is the first step in improving the competitive response of wheat to weed competition and the effects of wheat on weed populations. Cultivars differed in their responses to tame oat competition, with some cultivars suffering greater yield losses and accumulating more weed biomass than others. Weed suppression and yield maintenance were not always associated in cultivars, thus it may be possible to breed for weed suppression without focusing on yield loss. The use of weed suppressive cultivars, for example, in combination with other management tools (e.g., seeding density), could supply organic crop producers with a wider variety of management strategies.

Knowledge about which wheat plant traits are important for improving weed competition on organic land may contribute to the development of competitive cultivars for organic farming. Early season vigour, early heading and maturity, tallness and elevated tillering capacity were identified as competitive traits. Plant height was the most important trait, particularly in terms of weed suppression. Early season vigour, early heading and early maturity may all relate to plant developmental rate, suggesting that faster growing plants may preempt limited resources from competing weeds, thereby gaining the ability to maintain yields under weed pressure and suppress weeds. The relatively faster development of barley when compared to wheat may help explain why barley is generally more competitive than wheat. In this research, tillering capacity was variable in its role as a competitive trait. In general, the results of this thesis suggest that the competitive ability of wheat is determined through the interaction of a number of plant traits, and that those interactions are complex. That competitive traits differ depending on the level of weed pressure further complicates our understanding of weed-crop competition. Traits that confer competitive ability under organic management may differ solely as a result of increased weed pressure in organic environments, but may also be related to the potentially different soil processes involved. Further research is required to investigate the belowground traits of wheat grown in conventional and organic management systems, and how they relate to biological soil processes.

Aside from cultivar selection, increasing seeding density is a relatively simple and effective management tool that organic wheat and barley producers can use to increase grain yield, reduce weed biomass and weed seed-bank build up, and increase economic returns. The practice was not cultivar specific here, thus is a widely applicable strategy, providing that soil moisture and nutrients are adequate, and biotic stresses are not a complicating factor.

Throughout the course of this thesis work, experimental difficulties associated with conducting research on organic land and in comparing organic and conventional systems were identified. Principally, the high degree of variability that exists on organically managed land requires many replications to be included in the experimental design, increasing the experimental size and workload. Secondly, because it is not possible to have weed-free controls under organic management, some form of simulated weed competition may be required. Simulated weed competition in experimental plots allows for a direct evaluation of crop competitive response and can help reduce experimental error, though determining species and optimum seeding rates may be difficult. Covariate analysis may be used to reduce variation caused by uneven weed growth, thus measures (i.e., counts) of weeds should be conducted early on. Finally, due to inherent management differences, the comparison of organic and conventional systems cannot be conducted on the same land which complicates statistical analyses. Statistical analyses conducted in this thesis effectively employed mixed model methodology in order to deal with these complexities.

6.8 Conclusions

The following provides a summary of conclusions drawn from this thesis:

- Spring wheat and spring barley cultivars exhibit somewhat different capabilities when grown in organic and conventional production systems, thus breeding cultivars specifically for organic grain production may be desirable.
- Barley cultivars are generally more competitive than wheat cultivars.
- Organically managed Canadian bread wheat cultivars are capable of achieving good breadmaking quality.
- Wheat cultivars differ in their competitive ability in organic systems, with some Canadian wheat cultivars better suited to organic production than others.
- Older wheat cultivars are not necessarily better suited to organic production, although some may be more yield stable than modern cultivars over a wide range of environments.
- Modern semidwarf wheat and barley cultivars are not effective weed suppressors, and therefore may not be well suited to organic production.
- Weed suppression and yield maintenance are not always associated, thus it may be possible to breed specifically for one or the other.
- Breeding specifically for weed suppression may be desirable in organic systems, in order to reduce problems associated with weed biomass and subsequent weed seed build up.
- Tallness, early season vigour, early heading and maturity and elevated tillering potential are plant traits that contribute to the competitive ability of wheat cultivars.

- Cultivar competitive ability appears to result from the complex interaction of a number of "competitive" traits, making it difficult to select competitive cultivars based on one particular trait.
- The importance of competitive traits may be altered by changes in weed pressure.
- A competitive crop ideotype for organic grain production would be a tall plant, with strong early vigour and early heading and maturity.
- The use of competitive cultivars can be a useful strategy for reducing problems associated with weed competition in organic systems.
- Doubling the seeding rate has the potential to be effective for suppressing weeds and increasing grain yield and economic returns under organic growing conditions.
- The overall benefits of doubling the seeding rate under organic conditions do not appear to be cultivar specific.

6.9 Original contributions to knowledge

Mechanisms of weed-crop competition are poorly understood in general, and research relating the problem to organic production systems in Canada is relatively scant. The original contributions to the knowledge of competition in spring wheat under organic and conventional management are discussed in the following paragraphs:

The subject of crop competitive ability is further complicated when alternative management systems are considered. Chapter 1.0 of the thesis is a review of the literature pertaining to the competitive ability of spring wheat in organic and conventional management systems and is, to the best of my knowledge, the first literature review to integrate the competitive ability of wheat with organic management systems in Canada. The review consolidates and summarizes what is known about the specific research areas, and will be a frame of reference for future researchers who wish to examine related topics.

Chapter 2.0 of the thesis investigates a wide range of CWRS wheat genotypes released over a 114 year period of time, and compares cultivar performance in organic and conventional systems. Other Canadian research has compared cultivar performance in organic and conventional fields (Walker and Smith 1992), but it is my understanding that this is the widest array of genotypes evaluated in the two systems to date. The study is the first in Canada to establish that Canadian bread wheat cultivars perform differently in the two management systems, and that it may be desirable to breed specifically for organic management systems. My results suggest that older Canadian bread wheat cultivars are not better suited to organic systems than conventional systems. With abundant speculation regarding the suitability of historical versus modern cultivars for organic/low input wheat production (Laing and Fischer 1977; Ceccarelli 1996), this research adds to the knowledge of the subject and may be useful in low-input and organic wheat breeding programs. The experiment identifies differences in the agronomic performance and aboveground competitive traits of wheat cultivars in the two systems, thereby increasing our understanding of how plant traits affect crop performance under different management regimes on the Canadian Prairies.

The experiment in Chapter 3.0 investigated the potential for production of high quality organic Canadian bread wheat and again compares conventionally and organically grown CWRS cultivars. Research has been presented on the quality of CWRS spring wheat (Fowler and De la Roche 1975; Preston et al. 2001), as well as on the possibility of growing organic spring wheat in eastern Canada (Nass et al. 2003), however this is the first research, to the best of my knowledge, that investigates differences among western Canadian bread wheat cultivars grown in the two management systems. The study established that the production of high quality organic bread wheat on the Canadian Prairies is possible. It is the first in Canada to identify differences in the breadmaking quality of organic and conventionally grown wheat, indicating that breeding specifically for high quality organic bread wheat is feasible. The research contributes to the knowledge of high quality organic grain production in western Canada and may help plant breeders and agronomists to increase Canadian food quality by helping them understand how wheat quality is affected by management system.

The experiment in Chapter 4.0 was designed to examine the effect of weed competition, seeding rate and cultivar on the performance of wheat and barley in organic systems. The study is the first of its kind in Canada to directly compare the effects of competition on cultivars exclusively in an organic management system. It identifies plant traits, such as early heading and maturity, which confer competitive ability in organic management systems, and may contribute to plant breeding programs with a focus on developing competitive cultivars for organic production. It establishes that the use of competitive cultivars and increased seeding density can be used by producers on the northern Canadian Prairies to ameliorate the effects of weed competition in organic wheat and barley production.

Chapter 5.0 investigates "competitive" plant traits under differing natural weed biomass environments, and considers the yield and weed stability of wheat cultivars under environments differing in yielding ability and weediness. To my knowledge, this is the first Canadian study that discusses cultivar weed stability in organic systems. The adaptation of the Finlay-Wilkinson model is a novel approach to evaluation of cultivar weed stability. The study established that competitive traits may change under different levels of weediness, and suggests that the description of crop ideotypes that reflect those differences may be useful. Differences in wheat cultivar stability across environments and some of the factors that may be responsible for those differences were identified. Older cultivars are more yield stable than modern cultivars, while semidwarf cultivars are the least weed stable, indicating that semidwarf cultivars are less suitable for organic production. This increases the knowledge about competition in spring wheat across environments varying in weed biomass and yield potential.

This thesis, as a whole, constitutes an "advancement of knowledge in the domains in which the research was conducted". Possibilities and limitations of organic spring wheat production on the northern Canadian Prairies were discussed, and plant traits conferring competitive ability in spring wheat under organic management were established. Differences in cultivar performance between organic and conventional management systems were identified.

6.10 Literature Cited

Ames, N. P., Clarke, J. M., Dexter, J. E., Woods, S. M., Selles, F. and Marchylo, B. 2003. Effects of nitrogen fertilizer on protein quantity and gluten strength parameters in durum wheat (*Triticum turgidum* L. var. *durum*) cultivars of variable gluten strength. Cereal Chem. **80**:203-211.

Anonymous. 2004. Official Grain Grading Guide, revised August 1, 2004. Canadian Grain Commission, Winnipeg, Canada. pp.

Barberi, P. 2002. Weed management in organic agriculture: are we addressing the right issues? Weed Res. **42**:177-193.

Calderini, D. F. and Slafer, G. A. 1999. Has yield stability changed with genetic improvement of wheat yield? Euphytica **107**:51-59.

Canadian Wheat Board. 2006. Meeting the need for organic grain through the Canadian Wheat Board. [Online] Available: http://www.cwb.ca/en/buying/high_quality/organic_customer.jsp [2 November 2006].

Ceccarelli, S. 1996. Adaptation to low/high input cultivation. Euphytica **92**:203-214.

Champion, G. T., Froud-Williams, R. J. and Holland, J. M. 1998. Interactions between wheat (*Triticum aestivum* L.) cultivar, row spacing and density and the effect on weed suppression and crop yield. Ann. Appl. Biol. **133**:443-453.

Fowler, D. B. and De la Roche, I. A. 1975. Wheat quality evaluation. 3. Influence of genotype and environment. Can. J. Plant Sci. **55**:263-269.

Fufa, H., Baenziger, P. S., Beecher, B. S., Graybosch, R. A., Eskridge, K. M. and Nelson, L. A. 2005. Genetic improvement trends in agronomic performances and end-use quality characteristics among hard red winter wheat cultivars in Nebraska. Euphytica **144**:187-198.

Gooding, M. J., Davies, W. P., Thompson, A. J. and Smith, S. P. 1993. The challenge of achieving breadmaking quality in organic and low input wheat in the UK- a review. Aspects Appl. Biol. **36**:189-198.

Hucl, P. 1998. Response to weed control by four spring wheat genotypes differing in competitive ability. Can. J. Plant Sci. **78**:171-173.

Huel, D. G. and Hucl, P. 1996. Genotypic variation for competitive ability in spring wheat. Plant Breed. **115**:325-329.

Korres, N. E. and Froud-Williams, R. J. 2002. Effects of winter wheat cultivars and seed rate on the biological characteristics of naturally occurring weed flora. Weed Res. **42**:417-428.

Laing, D. R. and Fischer, R. A. 1977. Adaptation of semidwarf wheat cultivars to rainfed conditions. Euphytica **26**:129-139.

Leeson, J. Y., Sheard, J. W. and Thomas, G. A. 2000. Weed communities associated with arable Saskatchewan farm management systems. Can. J. Plant Sci. **80**:177-185.

Lemerle, D., Gill, G. S., Murphy, C. E., Walker, S. R., Cousens, R. D., Mokhtari, S., Peltzer, S. J., Coleman, R. and Luckett, D. J. 2001a. Genetic improvement and agronomy for enhanced wheat competitiveness with weeds. Aust. J. Agric. Res. **52**:527-548.

Lemerle, D., Verbeek, B., Cousens, R. D. and Coombes, N. E. 1996. The potential for selecting wheat varieties strongly competitive against weeds. Weed Res. **36**:505-513.

Lemerle, D., Verbeek, B. and Orchard, B. 2001b. Ranking the ability of wheat varieties to compete with *Lolium rigidum.* Weed Res. **41**:197-209.

Lloveras, J., Lopez, A., Ferran, J., Espachs, S. and Solsona, J. 2001. Bread-making wheat and soil nitrate as affected by nitrogen fertilization in irrigated Mediterranean conditions. Agron. J. **93**:1183-1190.

Nass, H. G., Ivany, J. A. and MacLeod, J. A. 2003. Agronomic performance and quality of spring wheat and soybean cultivars under organic culture. Am. J. Altern. Agric. **18**:164-170.

O'Donovan, J. T., Harker, K. N., Clayton, G. W. and Hall, L. M. 2000. Wild oat (*Avena fatua*) interference in barley (*Hordeum vulgare*) is influenced by barley variety and seeding rate. Weed Technol. **14**:624-629.

O'Donovan, J. T., Newman, J. C., Harker, K. N., Blackshaw, R. E. and McAndrew, D. W. 1999. Effect of barley plant density on wild oat interference, shoot biomass and seed yield under zero tillage. Can. J. Plant Sci. **79**:655-662.

Poutala, R. T., Korva, J. and Varis, E. 1993. Spring wheat cultivar performance in ecological and conventional cropping systems. J. Sustain. Agric. **3**:63-84.

Preston, K. R., Hucl, P., Townley-Smith, T. F., Dexter, J. E., Williams, P. C. and Stevenson, S. G. 2001. Effects of cultivar and environment on farinograph and Canadian short process mixing properties of Canada western red spring wheat. Can. J. Plant Sci. **81**:391-398.

Samuel, A. M. and Guest, S. J. 1990. Weed studies in organic and conventional cereals. British Crop Proteciton Council, Farnham, Surrey, UK.

Stopes, C. and Millington, S. 1991. Weed control in organic farming systems, pp. 185-192 Brighton Crop Protection Conference-Weeds, Brighton, UK.

Walker, D. and Smith, A. 1992. Evaluation of spring wheat, oat and hulless oat and barley cultivars under an organic production protocol. Adapt. Res. Rep. **14**:257-260.

Weiner, J., Griepentrog, H. W. and Kristensen, L. 2001. Suppression of weeds by spring wheat *Triticum aestivum* increases with crop density and spatial uniformity. J. Appl. Ecol. **38**:784-790.

Wicks, G. A., Ramsel, R. E., Nordquist, P. T., Schmidt, J. W. and Challaiah. 1986. Impact of wheat cultivars on establishment and suppression of summer annual weeds. Agron. J. **78**:59-62.

7.0 Appendices

Appendix 7-1. Percent sums of squares within fixed effects analysis of variance for emergence, days to heading and maturity, early season vigour, weed biomass, spikes m^{-2}, plant height and grain yield of 27 CWRS wheat cultivars grown in 2003 and 2004 at seven site-years in north central Alberta, Canada.

Effect	df	Emergence	Days to Heading	Days to Maturity	df	Early Season Vigour	Weed Biomass	Spikes m^{-2}	df	Plant Height	Grain Yield
Environment	**3**	5	17	75	**4**	37	66	68	**6**	40	83
Rep(Environment)	**12**	3	1	1	**15**	7	2	2	**20**	6	2
Cultivar	**26**	8	59	17	**26**	11	3	7	**26**	27	3
Environment*Cultivar	**78**	18	9	3	**104**	14	7	6	**156**	9	6
Error	**311**	66	14	5	**387**	30	21	17	**519**	17	6
Corrected Total	**430**	100	100	100	**536**	100	100	100	**821**	100	100

Appendix 7-2. Percent sums of squares by management system within fixed effects analysis of variance for emergence, days to heading and maturity, early season vigour, weed biomass, spikes m^{-2}, plant height and grain yield of 27 CWRS wheat cultivars grown in 2003 and 2004 at seven site-years in north central Alberta, Canada.

Conventional Management

Effect	df	Emergence	Early Season Vigour	Days to Heading	Days to Maturity	Weed Biomass	df	Spikes m^{-2}	df	Plant Height	Grain Yield
Environment	**1**	0	4	28**	72**	0	**2**	75**	**3**	50**	68**
Rep(Environment)	**6**	3	6**	0	1**	2	**9**	1**	**11**	5**	2**
Cultivar	**26**	21	28	62**	21**	12	**26**	6**	**26**	24**	8**
Environment*Cultivar	**26**	16*	16**	6**	2**	15	**52**	5**	**78**	6**	10**
Error	**156**	60	46	4	3	71	**234**	12	**286**	14	11
Corrected Total	**215**	100	100	100	100	100	**323**	100	**404**	100	100

Organic Management

	df	Emergence	Days to Heading	df	ESV	df	Days to Maturity	df	Plant Height	Grain Yield	Weed Biomass	df	Spikes m^{-2}
Env (E)	**1**	7**	0	**2**	34**	**1**	75**	**2**	10*	76**	51**	**1**	15**
Rep(Env)	**6**	3	2	**9**	10**	**6**	2**	**9**	11**	5**	3**	**6**	4*
Variety (V)	**26**	9	64**	**26**	12*	**26**	16**	**26**	39**	7**	8**	**26**	20**
E*V	**26**	13	8*	**52**	13**	**25**	3**	**52**	13**	4**	7	**26**	7
Error	**155**	69	26	**231**	32	**149**	7	**233**	27	8	31	**153**	53
Corrected Total	**214**	100	100	**320**	100	**207**	100	**322**	100	100	100	**212**	100

*, ** Values are significant at 0.05 and 0.01, respectively

Appendix 7-3. Analysis of variance combined over management systems for grain yield, spikes m^{-2}, plant height, weed biomass, lodging, early season vigour, days to heading and maturity and emergence of 27 CWRS wheat cultivars grown in 2003 and 2004 at seven site-years in north central Alberta, Canada.

Effect	Grain Yield	Spikes m^{-2}	Plant Height	Weed Biomass	Lodging	Early Season Vigour	Effect	Days to Heading	Days to Maturity	Emergence
Management	0.067	0.713	0.989	0.057	0.673	0.593	**Location**	0.686	0.348	0.982
Location(Management)	0.265	0.014	0.647	<.0001	0.001	0.004	**Variety**	<.0001	<.0001	0.543
Cultivar	0.001	0.043	<.0001	0.001	<.0001	0.006	**Location*Cultivar**	0.862	0.749	0.856
Management*Cultivar	0.397	0.999	0.374	0.004	<.0001	0.985				
Location*Cultivar(Management)	0.999	0.132	0.009	0.008	<.0001	0.493				

Appendix 7-4. Detailed Site Management

7.4.1 Edmonton Research Station-Conventional

In each year, mineral fertilizers were applied following soil fertility testing in early spring. In 2002, fertilizer (73 kg ha^{-1} N as 46-0-0) was broadcast and tilled in to the land prior to planting. At the 2003 site, fertilizer (90 kg ha^{-1} N as 46-0-0 and 28 kg ha^{-1} P as 8-24-24) was broadcast after seeding. At the 2004 site, fertilizer (39 kg ha^{-1} N as 46-0-0) was banded at a depth of 8.5 cm into the soil in the fall of 2003 and again in spring 2004 at a rate of 11 kg ha^{-1} N as 46-0-0 and 6 kg ha^{-1} P as 8-24-24 prior to seeding. Soil tests were conducted after seeding in 2003 and 2004 (Table 3). All ERS-Conventional fields were cultivated and harrowed prior to planting in spring, and received late spring applications of MCPA Amine 500 at a rate of 1.5 L ha^{-1} to control broadleaf weeds.

7.4.2 Edmonton Research Station-Organic

A section of land at the ERS became organically managed (no chemical fertilizers or synthetic pesticides) in the spring of 2001. This land received its last application of chemical fertilizer (67 kg ha^{-1} N as 46-0-0 and 22 kg ha^{-1} P as 8-24-24) in the fall of 2000. The land was subsequently seeded to winter triticale (*Triticale hexaploide* Lart.) which was harvested in fall 2001; triticale stubble was left on the field. In the summer of 2001, the organically managed land was divided into three sections; one of each of the three fields was used in each year of this trial. Soil tests were conducted after seeding in 2003 and 2004 (Table 3).

7.4.2.1 2002 Site

After the triticale harvest in the fall of 2001, the 2002 organic site received an application of uncomposted dairy manure at a rate of 60 t ha^{-1}. In spring 2002, the land was cultivated and harrowed just prior to seeding. The trial was not weeded in the early stages of crop growth because weed pressure was limited due to the lack of precipitation in May and June; however, just prior to harvest, weeds taller than the wheat in each plot were cut back below crop height to facilitate combining.

7.4.2.2 2003 Site

The 2003 ERS-Organic site was planted to fall rye (*Secale cereale* L.) in the fall of 2001, which was mowed throughout the summer of 2002. The vegetative fall rye was disked under in the fall of 2002, just prior to an application of composted dairy manure at a rate of 60 t ha^{-1}.

Composted dairy manure was estimated to be at ~50% dry matter content, with 1.3% total N. In the spring of 2003, the land was cultivated and harrowed just prior to seeding of the 2003 trial. Weeds were manually removed at the 5-6 leaf stage.

7.4.2.3 2004 Site

The 2004 site was left to triticale stubble in the fall of 2001 and was seeded with berseem clover (*Trifolium alexandrinum* L.) in the spring of 2002. Extreme drought across the Canadian Prairies in the 2002 growing season caused the clover crop to fail and the land was seeded to fall rye in late summer of 2002. In the summer of 2003, the fall rye was harvested, and the soil was disked and treated with an application of composted dairy manure at a rate of 60 t ha^{-1}. In the spring of 2004, the land was cultivated and harrowed prior to planting. Weeds were removed by hand at the 5-6 leaf stage.

7.4.3 Lacombe Research Station-Lacombe

In both 2003 and 2004, the Lacombe sites received applications of seed-banded fertilizer (6-25-30 at 112 kg ha^{-1}) and late spring applications of Refine/CurtailM at 19 g ha^{-1} & 1.5 L ha^{-1} to control broadleaf weeds. Soil testing was not performed at Lacombe in either year.

7.4.4 Certified Organic Farm-New Norway

In both years, experimental trials followed cereal-legume plow-downs without crop removal in the year prior to planting. The 2003 trial was planted at a site that received a green manure plowdown in 2002 and 2001, and was seeded to barley in 2000 and oats in 1999. The 2004 site received a green manure plowdown in 2003 and was seeded to a pea/barley intercrop in 2002.

Appendix 7-5. Least squares means and analysis of variance of agronomic traits measured on 32 spring wheat cultivars grown on conventionally managed land at the Edmonton Research Station, Edmonton, AB in 2002.

Cultivar	YOR	Emergence (plants m^{-2})	Early Season Vigour (1-5)	Heading (days)	Maturity (days)	Height (cm)	Spikes m^{-2}	Harvest Index (%)	1,000 Kernel wt. (g)	Kernels spike^{-1}	Test wt. (kg hL^{-1})	Grain Yield (t ha^{-1})
Red Fife	1885	142	2	60	104	62	181	45	33	28	77	0.96
Hard Red Calcutta	1890	209	4	54	90	54	262	44	22	34	79	0.97
Preston	1895	186	4	58	94	48	219	40	27	21	78	0.81
Marquis	1910	219	4	57	94	54	248	39	28	22	79	0.87
Ruby	1920	186	4	51	86	49	206	42	24	23	82	0.56
Garnet	1925	189	3	49	85	39	202	39	23	19	78	0.42
Red Bobs	1926	191	4	53	87	51	228	45	26	26	77	0.83
Reward	1928	216	4	56	92	52	196	44	30	23	77	0.83
Early Red Fife	1932	214	4	58	96	59	213	45	31	25	79	0.99
Canus	1935	219	4	59	101	50	197	38	29	21	79	0.82
Thatcher	1935	204	3	53	89	51	267	40	25	26	76	0.94
Saunders	1947	173	3	52	87	47	210	45	27	24	77	0.65
Cypress	1962	204	4	57	92	52	169	44	29	22	77	1.00
Park	1963	195	5	51	86	53	255	44	26	23	76	0.95
Manitou	1965	189	3	54	87	47	244	41	24	22	76	0.64
Neepawa	1969	193	3	53	90	49	193	43	27	26	75	0.91
Sinton	1975	189	3	57	93	52	222	47	29	25	78	0.96
Chester	1976	138	3	56	92	51	204	39	28	23	74	0.88
Columbus	1980	162	3	57	93	55	234	46	28	26	78	1.06
Katepwa	1981	170	3	53	88	44	232	39	27	22	74	0.64

Appendix 7-5. continued

Cultivar	YOR	Emergence (plants m^{-2})	Early Season Vigour (1-5)	Heading (days)	Maturity (days)	Height (cm)	Spikes m^{-2}	Harvest Index (%)	1,000 Kernel wt. (g)	Kernels spike^{-1}	Test wt. (kg hL^{-1})	Grain Yield (t ha^{-1})
Roblin	1986	195	4	50	86	39	284	40	27	24	74	0.71
Cutler	1990	188	3	50	85	40	212	43	32	22	76	0.62
AC Taber	1991	199	3	54	94	45	204	43	37	20	78	0.93
CDC Teal	1991	190	4	54	87	47	229	41	25	25	73	0.95
AC Barrie	1994	190	3	55	90	43	186	37	30	23	76	0.80
AC Foremost	1994	199	3	51	92	38	222	43	37	16	78	0.70
AC Splendor	1996	163	3	50	85	40	196	40	26	20	74	0.53
AC Vista	1996	206	4	54	91	39	232	45	38	19	77	0.80
Laser	1996	203	4	49	85	40	233	34	34	19	75	0.64
AC Intrepid	1997	203	4	50	85	44	258	46	27	24	72	1.02
McKenzie	1997	170	2	53	89	42	181	39	28	20	78	0.41
5600HR	1999	197	4	57	92	54	216	47	27	29	76	1.15
Overall Mean		190	3	54	90	48	220	42	28	23	77	0.81
CV (%)		14	24	2	2	13	19	10	5	21	2	37
F test$_{\text{cultivar}}$		0.0696	0.0134	<.0001	<.0001	0.0003	0.1881	0.0557	<.0001	0.0830	<.0001	0.2877
SE$_{\text{diff}}$		22.5	0.65	1.1	1.7	5.3	34.1	3.5	1.2	4.0	1.5	0.243
LSD		45	1.3	2	3	11	68	7	2	8	3	0.49

Appendix 7-6. Least squares means and analysis of variance of agronomic traits measured on 32 spring wheat cultivars grown on organically managed land at the Edmonton Research Station, Edmonton, AB in 2002.

Cultivar	YOR	Emergence (plants m^{-2})	Early Season Vigour (1-5)	Heading (days)	Maturity (days)	Height (cm)	Spikes m^{-2}	Harvest Index	1,000 Kernel wt. (g)	Kernels $spike^{-1}$	Test wt. (kg hL^{-1})	Grain Yield (t ha^{-1})
Red Fife	1885	116	2	59	102	58	173	52	33	30	80	0.87
Hard Red Calcutta	1890	189	4	56	92	66	244	52	24	40	80	1.45
Preston	1895	199	5	59	92	62	273	42	27	33	79	1.47
Marquis	1910	161	3	58	94	60	281	49	30	29	81	1.18
Ruby	1920	201	4	55	88	58	256	53	26	31	79	1.17
Garnet	1925	201	4	51	85	55	257	54	25	33	78	1.18
Red Bobs	1926	179	3	53	89	55	201	52	30	30	79	1.18
Reward	1928	177	4	57	92	60	272	49	34	29	80	1.10
Early Red Fife	1932	191	3	59	99	64	229	50	35	31	82	1.39
Canus	1935	212	4	59	100	60	296	49	30	29	81	1.50
Thatcher	1935	185	3	56	92	52	239	52	27	28	80	1.03
Saunders	1947	156	4	52	85	55	257	51	26	32	78	0.99
Cypress	1962	174	3	58	94	55	194	53	33	29	80	1.13
Park	1963	149	4	52	85	55	239	55	28	30	78	1.12
Manitou	1965	194	4	54	89	57	271	51	26	29	78	1.20
Neepawa	1969	172	3	55	92	50	206	53	28	28	79	1.01
Sinton	1975	173	2	58	98	58	224	54	32	34	80	1.30
Chester	1976	139	3	56	92	54	206	45	30	27	79	0.82
Columbus	1980	144	2	59	97	58	228	56	31	29	80	1.23
Katepwa	1981	183	3	55	90	50	240	54	29	26	78	1.05

Appendix 7-6. continued

Cultivar	YOR	Emergence (plants m^{-2})	Early Season Vigour (1-5)	Heading (days)	Maturity (days)	Height (cm)	Spikes m^{-2}	Harvest Index	1,000 Kernel wt. (g)	Kernels spike^{-1}	Test wt. (kg hL^{-1})	Grain Yield (t ha^{-1})
Roblin	1986	188	3	52	86	42	210	51	30	28	76	0.95
Cutler	1990	200	3	50	85	43	156	56	34	29	79	0.97
AC Taber	1991	176	3	55	95	48	238	50	42	28	80	1.21
CDC Teal	1991	183	4	53	85	50	246	52	27	31	76	1.16
AC Barrie	1994	143	3	56	94	48	225	55	32	30	81	1.28
AC Foremost	1994	173	4	52	94	40	253	54	42	24	78	1.30
AC Splendor	1996	190	3	52	85	48	259	52	30	30	77	1.03
AC Vista	1996	186	4	54	87	50	287	52	38	27	77	1.27
Laser	1996	174	3	50	86	50	214	43	37	26	76	0.90
AC Intrepid	1997	164	4	53	88	50	219	57	31	32	77	1.31
McKenzie	1997	170	3	53	90	49	197	52	28	27	79	1.12
5600HR	1999	165	3	57	93	57	239	53	30	32	80	1.28
Overall Mean		175	3	55	91	53	235	51	31	30	79	1.16
CV (%)		14	26	2	3	10	21	6	3	10	1	19
F test$_{cultivar}$		<.0001	0.0001	<.0001	<.0001	<.0001	0.0249	<.0001	<.0001	<.0001	<.0001	0.0006
SE$_{diff}$		17.1	0.6	0.7	1.7	3.6	35.2	2.1	0.8	2.0	0.7	0.156
LSD		34	1.2	1	3	7	70	4	1	4	1	0.31

Appendix 7-7. Least squares means and analysis of variance of agronomic traits measured on 32 spring wheat cultivars grown on conventionally managed land at the Lacombe Research Station, Lacombe, AB in 2003.

Cultivar	YOR	Height (cm)	1,000 Kernel wt. (g)	Test wt. (kg hL^{-1})	Grain Yield (t ha^{-1})
Red Fife	1885	98	38	81	3.04
Hard Red Calcutta	1890	110	27	81	3.71
Preston	1895	103	31	80	3.05
Marquis	1910	112	34	82	3.50
Ruby	1920	105	31	81	3.28
Garnet	1925	103	29	81	3.62
Red Bobs	1926	100	34	81	3.63
Reward	1928	98	35	81	3.38
Early Red Fife	1932	103	40	83	3.52
Canus	1935	102	35	82	4.13
Thatcher	1935	95	30	80	3.58
Saunders	1947	93	34	80	3.87
Cypress	1962	100	38	81	4.17
Park	1963	95	35	81	3.75
Manitou	1965	98	31	81	3.42
Neepawa	1969	95	33	81	3.16
Sinton	1975	97	35	79	4.23
Chester	1976	92	36	79	3.26
Columbus	1980	102	36	82	3.71
Katepwa	1981	102	34	81	3.54

Appendix 7-7. continued

Cultivar	YOR	Height (cm)	1,000 Kernel wt. (g)	Test wt. (kg hL^{-1})	Grain Yield (t ha^{-1})
Roblin	1986	95	38	81	3.88
Cutler	1990	75	37	79	4.23
AC Taber	1991	72	44	81	4.10
CDC Teal	1991	95	35	80	3.92
AC Barrie	1994	87	36	81	3.36
AC Foremost	1994	75	45	80	5.00
AC Splendor	1996	88	38	80	3.24
AC Vista	1996	95	40	81	3.99
Laser	1996	90	42	78	3.95
AC Intrepid	1997	92	39	80	4.03
McKenzie	1997	85	34	81	2.96
5600HR	1999	97	34	81	3.82
Overall Mean		95	36	81	3.69
CV (%)		6	4	1	12
F test$_{cultivar}$		<.0001	<.0001	<.0001	<.0001
SE$_{diff}$		4.7	1.1	0.5	0.354
LSD		9	2	1	0.71

Appendix 7-8. Least squares means and analysis of variance of agronomic traits measured on 32 spring wheat cultivars grown on conventionally managed land at the Edmonton Research Station, Edmonton, AB in 2003.[†,‡]

Cultivar	YOR	Emerg. (plants m^{-2})	Early Season Vigour (1-5)	Heading (days)	PM (%)	Leaf Disease (1-9)	Maturity (days)	Height (cm)	Lodging (1-9)	Spikes m^{-2}	Harvest Index (%)	1,000 Kernel wt. (g)	Kernels spike^{-1}	Test wt. (kg hL^{-1})	Grain Protein (%)	Weed Biomass (g m^{-2})	Grain Yield (t ha^{-1})
Red Fife	1885	198	3	62	20	1	102	122	2	432	34	34	34	80	14.9	0.0	3.10
Hard Red Calcutta	1890	299	5	58	30	2	91	112	2	546	37	26	38	81	15.8	0.0	4.20
Preston	1895	222	5	62	20	1	99	117	5	525	33	30	40	79	16.0	0.0	4.39
Marquis	1910	318	5	60	25	2	97	115	2	628	31	33	30	81	16.6	4.9	3.70
Ruby	1920	280	4	55	65	2	92	109	3	613	35	32	34	80	17.3	0.0	3.47
Garnet	1925	293	4	50	40	2	88	107	2	519	38	28	35	81	15.6	0.0	3.90
Red Bobs	1926	254	5	56	35	2	91	110	2	529	38	34	32	82	15.0	0.0	4.33
Reward	1928	274	5	61	45	2	96	111	3	530	35	36	30	79	17.6	0.0	3.64
Early Red Fife	1932	276	4	61	40	3	99	116	2	483	34	37	32	82	14.4	6.5	3.69
Canus	1935	264	5	60	40	1	99	112	2	514	36	31	35	81	14.9	0.0	4.47
Thatcher	1935	260	4	56	55	2	94	103	1	664	40	32	34	80	15.9	0.0	4.26
Saunders	1947	236	4	55	20	2	91	95	1	595	42	34	35	79	15.3	11.3	4.24
Cypress	1962	246	5	59	5	1	95	112	4	489	36	38	32	80	15.6	0.0	3.98
Park	1963	224	5	52	25	1	93	99	2	639	42	34	32	80	16.0	0.0	4.13
Manitou	1965	244	4	57	15	2	94	101	2	693	40	32	34	80	17.1	0.0	4.15
Neepawa	1969	264	4	57	40	2	96	104	2	650	38	33	33	80	15.9	0.0	3.90
Sinton	1975	230	4	57	10	3	95	106	1	468	42	35	37	79	15.8	0.0	5.03
Chester	1976	191	3	58	40	2	97	97	1	527	39	36	35	79	17.5	0.0	3.56
Columbus	1980	229	4	59	30	3	97	109	1	596	36	36	30	81	17.3	0.0	4.11
Katepwa	1981	290	4	56	25	2	93	100	2	644	39	34	31	80	16.5	0.0	4.39

Appendix 7-8. continued

Cultivar	YOR	Emerg. (plants m^{-2})	Early Season Vigour (1-5)	Heading (days)	PM (%)	Leaf Disease (1-9)	Maturity (days)	Height (cm)	Lodging (1-9)	Spikes m^{-2}	Harvest Index (%)	1,000 Kernel wt. (g)	Kernels $spike^{-1}$	Test wt. (kg hL^{-1})	Grain Protein (%)	Weed Biomass (g m^{-2})	Grain Yield (t ha^{-1})
Roblin	1986	269	5	53	20	2	94	94	1	542	40	36	30	79	18.2	7.5	4.53
Cutler	1990	293	4	56	20	3	94	80	1	563	44	39	35	79	15.4	0.0	4.92
AC Taber	1991	196	3	62	20	3	103	85	1	441	47	39	48	80	12.4	0.0	4.80
CDC Teal	1991	252	4	58	0	2	94	100	1	595	41	35	34	80	16.8	0.0	4.73
AC Barrie	1994	246	4	58	55	2	96	96	1	533	40	35	30	81	17.3	9.5	4.25
AC Foremost	1994	254	4	58	15	3	99	78	1	488	47	39	46	79	12.4	0.0	5.10
AC Splendor	1996	260	5	55	25	1	92	99	1	556	41	37	30	79	17.7	0.0	4.28
AC Vista	1996	247	4	58	50	2	97	89	1	471	45	44	41	79	12.7	0.0	5.16
Laser	1996	246	5	55	25	3	95	91	1	472	43	39	35	78	16.3	0.0	5.09
AC Intrepid	1997	267	4	55	10	3	92	101	1	576	41	40	30	81	16.3	0.0	4.96
McKenzie	1997	240	4	56	50	2	95	100	1	660	39	32	35	80	15.2	0.0	4.70
5600HR	1999	295	3	58	45	2	94	105	1	638	40	34	30	81	16.3	0.0	4.20
Overall Mean		255	4	57	30	2	95	102	2	557	39	35	34	80	15.9	1	4.29
CV (%)		17	12	1	49	35	2	3	35	9	5	4	7	1	3	76	9
F $test_{cultivar}$		0.0085	<.0001	<.0001	<.0001	0.0015	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.4284	<.0001
SE_{diff}		31.0	0.4	0.5	10.4	0.5	1.1	2.3	0.4	37.1	1.3	1.0	1.7	0.4	0.50	2.69	0.273
LSD		62	0.7	1	21	1.0	2	5	0.8	74	3	2	3	1	1	5.2	0.54

[†] Weed biomass statistical analysis was conducted on square root ($(x+1)^{0.5}$) transformed data.

[‡] SE_{diff} and LSD have been re-transformed for comparison of actual mean weed biomass.

Appendix 7-9. Least squares means and analysis of variance of agronomic traits measured on 32 spring wheat cultivars grown on organically managed land at the Edmonton Research Station, Edmonton, AB in 2003.[†,‡]

Cultivar	YOR	Emerg. (plants m^{-2})	Early Season Vigour (1-5)	Heading (days)	PM (%)	Leaf Disease (1-9)	Maturity (days)	Height (cm)	Lodging (1-9)	Spikes m^{-2}	Harvest Index (%)	1,000 Kernel wt. (g)	Kernels $spike^{-1}$	Test wt. (kg hL^{-1})	Grain Protein (%)	Weed Biomass (g m^{-2})	Grain Yield (t ha^{-1})
Red Fife	1885	139	3	62	0	2	98	113	3	486	35	34	38	79	15.0	12.2	3.35
Hard Red Calcutta	1890	237	4	58	5	2	90	117	5	513	38	27	39	79	14.3	4.8	3.59
Preston	1895	240	5	62	10	2	95	109	3	489	35	28	37	77	16.7	1.5	3.56
Marquis	1910	250	4	60	10	2	95	111	3	561	38	33	34	79	16.0	7.2	3.43
Ruby	1920	212	5	57	30	1	90	114	4	574	37	33	33	78	15.9	8.0	3.11
Garnet	1925	298	4	55	12	1	87	109	4	502	40	30	36	80	14.9	35.6	3.32
Red Bobs	1926	235	5	57	25	1	90	112	1	498	39	35	33	80	14.3	15.1	3.78
Reward	1928	206	4	60	35	1	93	115	3	520	36	35	32	77	16.1	13.3	3.19
Early Red Fife	1932	246	4	61	25	2	96	115	3	473	37	38	30	81	14.8	4.7	4.01
Canus	1935	273	5	61	35	1	95	108	2	533	39	32	35	81	13.8	4.0	4.22
Thatcher	1935	238	4	57	15	2	91	107	3	623	40	32	35	78	15.4	10.5	3.67
Saunders	1947	203	4	56	10	2	89	96	2	566	39	33	32	75	14.7	40.3	3.10
Cypress	1962	219	3	60	5	2	95	108	5	502	36	34	32	78	15.0	12.9	3.38
Park	1963	256	5	54	12	2	90	104	2	551	42	33	32	79	15.0	11.8	3.98
Manitou	1965	301	4	57	10	2	90	105	3	568	41	33	32	78	16.7	7.3	3.63
Neepawa	1969	273	3	58	15	2	90	106	1	579	39	33	31	78	16.1	27.4	3.57
Sinton	1975	233	4	58	5	2	92	103	2	507	39	33	36	75	15.3	9.8	3.90
Chester	1976	182	3	58	25	3	94	102	3	499	37	32	33	76	15.6	8.4	2.73
Columbus	1980	226	3	59	20	2	94	109	2	494	39	36	29	80	16.6	16.5	3.55
Katepwa	1981	301	4	57	15	2	91	106	2	629	40	35	29	79	15.3	9.4	3.88

Appendix 7-9. continued

Cultivar	YOR	Emerg. (plants m^{-2})	Early Season Vigour (1-5)	Heading (days)	PM (%)	Leaf Disease (1-9)	Maturity (days)	Height (cm)	Lodging (1-9)	Spikes m^{-2}	Harvest Index (%)	1,000 Kernel wt. (g)	Kernels $spike^{-1}$	Test wt. (kg hL^{-1})	Grain Protein (%)	Weed Biomass (g m^{-2})	Grain Yield (t ha^{-1})
Roblin	1986	241	5	55	0	1	91	103	1	499	39	38	30	78	17.9	9.4	4.11
Cutler	1990	248	4	57	12	2	91	86	1	415	41	36	37	75	15.5	34.3	4.10
AC Taber	1991	169	3	62	10	2	98	84	1	335	39	35	45	76	14.8	23.7	3.46
CDC Teal	1991	229	4	58	5	2	90	103	1	545	39	33	34	77	15.6	20.7	3.72
AC Barrie	1994	219	4	58	25	1	91	100	1	549	39	34	30	80	16.1	12.4	3.93
AC Foremost	1994	260	3	58	5	2	96	82	1	448	46	36	41	75	13.9	20.2	3.88
AC Splendor	1996	236	4	56	20	2	89	95	1	513	37	36	30	78	17.7	34.3	3.42
AC Vista	1996	227	4	58	20	2	91	95	1	521	43	41	37	77	13.4	5.4	3.83
Laser	1996	222	4	54	15	2	90	97	1	454	41	39	37	76	15.9	16.3	4.14
AC Intrepid	1997	245	4	56	10	2	90	98	1	576	43	38	31	79	16.3	10.0	4.11
McKenzie	1997	282	4	57	5	2	91	100	2	605	40	32	31	78	14.2	14.1	3.62
5600HR	1999	233	4	59	15	2	93	108	1	542	39	35	31	79	14.8	6.6	3.76
Overall Mean		237	4	58	14	2	92	104	2	521	39	34	34	78	15.4	15	3.66
CV (%)		20	16	1	73	41	2	4	30	13	4	6	7	1	3	42	9
F $test_{cultivar}$		0.0022	<.0001	<.0001	<.0001	0.4692	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0005	<.0001
SE_{diff}		34.0	0.4	0.5	7.6	0.5	1.0	2.9	0.5	47.7	1.0	1.5	1.7	0.6	0.45	4.20	0.243
LSD		68	0.9	1	15	1	2	6	1	96	2	3	3	1	0.9	9.6	0.49

[†] Weed biomass statistical analysis was conducted on square root ($(x+1)^{0.5}$) transformed data.

[‡] SE_{diff} and LSD have been re-transformed for comparison of actual mean weed biomass.

Appendix 7-10. Least squares means and analysis of variance of agronomic traits measured on 32 spring wheat cultivars grown on conventionally managed land at the Lacombe Research Station, Lacombe, AB in 2004.

Cultivar	YOR	Height (cm)	Lodging (1-9)	Spikes m^{-2}	1,000 Kernel wt. (g)	Kernels $spike^{-1}$	Test wt. ($kg\ hL^{-1}$)	Grain Protein (%)	Grain Yield ($t\ ha^{-1}$)
Red Fife	1885	129	3	258	40	35	78	10.4	5.34
Hard Red Calcutta	1890	126	8	258	30	42	81	10.3	5.01
Preston	1895	124	7	341	35	33	79	11.1	4.65
Marquis	1910	126	2	324	38	27	81	11.4	5.26
Ruby	1920	120	5	355	32	38	80	11.4	4.65
Garnet	1925	115	1	325	32	34	81	12.7	4.13
Red Bobs	1926	118	5	282	38	37	81	10.8	5.67
Reward	1928	116	4	311	41	27	81	11.7	5.45
Early Red Fife	1932	126	1	224	44	34	80	9.8	4.69
Canus	1935	119	3	305	38	36	80	10.5	6.05
Thatcher	1935	116	1	322	33	29	80	11.3	5.54
Saunders	1947	106	5	312	37	29	80	11.7	5.67
Cypress	1962	111	8	240	39	29	79	11.7	5.10
Park	1963	110	2	327	36	28	81	11.7	5.61
Manitou	1965	111	2	342	34	27	80	11.8	5.24
Neepawa	1969	111	1	316	37	27	80	11.3	5.36
Sinton	1975	114	1	259	40	27	80	10.7	6.24
Chester	1976	109	2	287	38	28	80	11.4	5.59
Columbus	1980	119	1	239	39	32	82	10.7	5.35
Katepwa	1981	113	1	321	39	30	80	11.7	5.94

Appendix 7-10. continued

Cultivar	YOR	Height (cm)	Lodging (1-9)	Spikes m^{-2}	1,000 Kernel wt. (g)	Kernels $spike^{-1}$	Test wt. ($kg\ hL^{-1}$)	Grain Protein (%)	Grain Yield ($t\ ha^{-1}$)
Roblin	1986	115	1	335	38	30	80	11.5	5.87
Cutler	1990	94	1	252	45	32	80	10.4	6.36
AC Taber	1991	90	1	215	44	35	80	8.8	6.47
CDC Teal	1991	103	1	320	40	30	80	11.8	6.06
AC Barrie	1994	104	1	302	40	26	81	11.0	5.68
AC Foremost	1994	89	1	231	46	29	80	9.7	6.34
AC Splendor	1996	110	1	275	41	32	80	12.1	5.50
AC Vista	1996	101	1	254	47	34	80	10.1	6.73
Laser	1996	106	1	233	44	38	79	11.2	6.15
AC Intrepid	1997	106	1	265	44	34	79	11.8	6.06
McKenzie	1997	105	1	287	39	29	81	11.7	6.02
5600HR	1999	115	1	286	39	30	81	9.9	6.08
Overall Mean		112	2	288	39	31	80	11.1	5.62
CV (%)		3	58	13	4	9	1	5	7
F $test_{cultivar}$		<.0001	<.0001	<.0001	<.0001	0.0005	<.0001	<.0001	<.0001
SE_{diff}		2.7	1.0	27.3	1.2	2.9	0.5	0.41	0.287
LSD		5	2	54	2	6	1	0.8	0.57

Appendix 7-11. Least squares means and analysis of variance of agronomic traits measured on 32 spring wheat cultivars grown on conventionally managed land at the Edmonton Research Station, Edmonton, AB in 2004.†,‡

Cultivar	YOR	Emerg. (plants m^{-2})	Early Season Vigour (1-5)	Heading (days)	PM (%)	Leaf Disease (1-9)	Maturity (days)	Height (cm)	Lodging (1-9)	Spikes m^{-2}	Harvest Index (%)	1,000 Kernel wt. (g)	Kernels $spike^{-1}$	Test wt. (kg hL^{-1})	Grain Protein (%)	Weed Biomass (g m^{-2})	Leaf Area Index	Grain Yield (t ha^{-1})
Red Fife	1885	244	4	65	8	3	116	107	1	613	32	38	29	77	14.1	0.0	4.36	3.99
Hard Red Calcutta	1890	247	4	61	11	4	107	97	2	749	35	28	39	73	13.0	0.0	3.57	3.28
Preston	1895	288	4	67	1	3	112	98	4	609	36	36	33	78	15.1	0.0	4.88	3.94
Marquis	1910	278	4	62	4	3	108	99	1	724	33	38	30	78	14.8	0.8	3.93	3.84
Ruby	1920	274	5	59	9	4	103	94	1	655	36	33	30	77	16.2	0.0	3.41	3.15
Garnet	1925	241	3	59	9	3	102	90	1	704	34	31	32	78	14.8	0.0	4.23	3.40
Red Bobs	1926	237	4	59	9	3	105	93	1	731	38	38	29	77	13.8	1.4	3.72	3.85
Reward	1928	233	4	63	6	3	107	89	1	667	33	38	27	71	15.7	0.8	3.78	3.19
Early Red Fife	1932	267	4	64	13	3	113	102	1	696	34	39	30	76	13.2	0.0	4.84	3.92
Canus	1935	262	4	66	16	4	115	104	1	590	38	37	30	80	14.2	0.0	4.55	3.60
Thatcher	1935	256	4	59	16	4	105	93	2	721	33	33	27	77	14.6	0.0	3.66	3.13
Saunders	1947	272	4	58	4	3	102	76	1	778	38	32	24	77	14.7	0.2	2.64	3.46
Cypress	1962	229	4	61	6	5	106	100	2	747	33	38	29	72	14.6	3.0	4.53	3.44
Park	1963	236	5	57	5	4	103	91	1	787	37	36	26	76	15.4	0.0	3.83	3.94
Manitou	1965	348	4	59	4	4	104	84	1	812	37	31	31	75	15.4	0.0	3.67	3.53
Neepawa	1969	252	4	60	11	5	103	83	1	916	34	33	31	75	14.7	0.0	3.99	3.13
Sinton	1975	240	4	60	3	3	105	93	1	722	37	38	34	74	14.0	4.2	3.83	3.87
Chester	1976	239	4	61	13	4	107	86	1	750	30	35	26	74	15.4	0.0	3.68	3.19
Columbus	1980	247	4	61	9	4	107	92	1	758	34	39	26	77	15.3	0.0	4.12	3.63
Katepwa	1981	274	3	58	6	4	104	77	1	858	36	31	30	73	14.9	1.4	3.28	3.11

Appendix 7-11. continued

Cultivar	YOR	Emerg. (plants m^{-2})	Early Season Vigour (1-5)	Heading (days)	PM (%)	Leaf Disease (1-9)	Maturity (days)	Height (cm)	Lodging (1-9)	Spikes m^{-2}	Harvest Index (%)	1,000 Kernel wt. (g)	Kernels $spike^{-1}$	Test wt. (kg hL^{-1})	Grain Protein (%)	Weed Biomass ($g\ m^{-2}$)	Leaf Area Index	Grain Yield ($t\ ha^{-1}$)
Roblin	1986	225	4	60	1	4	104	80	1	771	33	33	29	74	14.6	0.8	3.94	3.48
Cutler	1990	263	3	59	4	4	106	63	1	689	40	34	29	75	15.1	1.0	3.31	3.67
AC Taber	1991	261	3	63	0	3	116	75	1	710	37	40	34	73	12.6	0.0	3.58	3.78
CDC Teal	1991	257	4	60	4	4	105	87	1	764	38	37	31	76	14.7	5.4	3.29	3.79
AC Barrie	1994	246	5	61	16	4	106	78	1	827	31	36	23	78	15.2	0.0	3.94	3.27
AC Foremost	1994	260	3	60	5	4	109	73	1	717	41	35	34	73	13.2	11.0	3.52	3.36
AC Splendor	1996	251	5	58	5	4	103	87	1	804	36	36	28	74	15.2	0.2	3.68	3.13
AC Vista	1996	237	4	61	15	4	111	89	1	643	43	39	37	74	13.2	0.0	3.88	4.50
Laser	1996	251	4	58	11	5	102	77	1	710	36	35	37	73	15.1	5.6	3.81	3.20
AC Intrepid	1997	274	4	59	1	4	103	91	1	673	37	40	28	74	14.4	0.0	3.57	3.34
McKenzie	1997	257	4	59	10	3	105	85	1	1105	35	32	28	76	14.3	0.0	3.80	2.51
5600HR	1999	260	3	60	19	4	106	90	1	798	38	37	31	75	14.4	0.0	3.82	3.58
Overall Mean		256	4	60	8	4	106	88	1	744	36	35	30	75	14.6	1	3.83	3.50
CV (%)		14	17	1	63	20	1	10	28	18	7	5	12	2	2	84	16	11
F $test_{cultivar}$		0.0695	0.0212	<.0001	<.0001	0.0002	<.0001	<.0001	<.0001	0.002	<.0001	<.0001	<.0001	<.0001	<.0001	0.3981	0.001	<.0001
SE_{diff}		26.2	0.5	0.5	3.5	0.5	0.9	6.0	0.2	92.8	1.7	1.3	2.6	1.3	0.25	3.30	0.429	0.274
LSD		52	0.9	1	7	1	2	12	0.5	184	4	3	5	3	0.5	6.9	0.85	0.54

[†] Weed biomass statistical analysis was conducted on square root ($(x+1)^{0.5}$) transformed data.

[‡] SE_{diff} and LSD have been re-transformed for comparison of actual mean weed biomass.

Appendix 7-12. Least squares means and analysis of variance of agronomic traits measured on 32 spring wheat cultivars grown on organically managed land at a certified organic farm in New Norway, AB in 2004.†,‡

Cultivar	YOR	Early Season Vigour (1-5)	Leaf Disease (1-9)	Height (cm)	Lodging (1-9)	Spikes m^{-2}	Test wt. (kg hL^{-1})	Grain Protein (%)	Weed Biomass (g m^{-2})	Grain Yield (t ha^{-1})
Red Fife	1885	3	3	118	4	444	65	13.5	82.2	0.63
Hard Red Calcutta	1890	3	4	104	4	467	71	12.5	161.8	1.19
Preston	1895	4	4	115	6	416	67	13.8	37.4	0.85
Marquis	1910	3	3	107	3	412	73	15.2	81.4	1.20
Ruby	1920	4	3	99	6	499	74	15.3	77.4	1.54
Garnet	1925	3	3	101	5	461	77	13.2	185.2	1.58
Red Bobs	1926	4	3	102	3	420	74	13.7	147.8	1.41
Reward	1928	3	3	111	4	412	63	14.5	84.4	0.78
Early Red Fife	1932	4	3	108	3	430	70	13.5	58.6	1.42
Canus	1935	3	4	107	3	418	73	13.8	161.0	1.44
Thatcher	1935	4	3	98	3	534	71	13.7	220.6	1.15
Saunders	1947	3	3	89	4	370	75	13.8	178.8	1.17
Cypress	1962	4	4	96	6	434	66	14.5	103.4	0.62
Park	1963	3	3	94	4	486	73	14.4	245.0	1.37
Manitou	1965	3	3	95	5	555	72	14.4	161.8	1.25
Neepawa	1969	4	3	98	3	511	73	14.4	260.2	1.44
Sinton	1975	3	4	101	3	358	70	13.9	186.0	1.17
Chester	1976	3	3	94	5	428	68	15.2	135.4	0.72
Columbus	1980	3	3	103	3	416	70	14.5	207.0	1.14
Katepwa	1981	4	3	94	4	484	73	15.0	126.8	1.01

Appendix 7-12. continued

Cultivar	YOR	Early Season Vigour (1-5)	Leaf Disease (1-9)	Height (cm)	Lodging (1-9)	Spikes m^{-2}	Test wt. (kg hL^{-1})	Grain Protein (%)	Weed Biomass (g m^{-2})	Grain Yield (t ha^{-1})
Roblin	1986	3	3	93	4	517	74	14.6	150.2	1.08
Cutler	1990	4	3	81	4	332	72	14.9	144.6	1.14
AC Taber	1991	3	3	82	3	317	65	11.6	186.6	0.73
CDC Teal	1991	3	3	88	3	451	72	14.8	152.8	0.96
AC Barrie	1994	3	3	91	3	481	73	14.8	126.4	1.27
AC Foremost	1994	4	3	77	5	219	69	13.4	183.8	0.72
AC Splendor	1996	4	3	92	4	453	72	15.2	107.6	1.10
AC Vista	1996	3	3	83	4	399	69	13.5	262.2	0.95
Laser	1996	4	4	88	3	365	71	15.1	207.6	1.27
AC Intrepid	1997	4	3	97	3	475	73	14.7	130.6	1.36
McKenzie	1997	4	4	93	5	651	74	14.4	102.8	1.15
5600HR	1999	3	3	105	3	339	70	14.2	287.4	1.07
Overall Mean		3	3	97	4	436	71	14.2	154.5	1.12
CV (%)		19	14	7	49	25	4	5	36	33
F $test_{cultivar}$		0.1817	0.0269	<.0001	0.4173	0.0023	<.0001	<.0001	0.1288	0.0040
SE_{diff}		0.4	0.3	4.5	1.3	76.2	2.0	0.55	26.33	0.262
LSD		1	1	9	3	153	4	1.1	84.7	0.52

†Weed biomass statistical analysis was conducted on square root ($(x+1)^{0.5}$) transformed data.

‡SE_{diff} and LSD have been re-transformed for comparison of actual mean weed biomass.

Appendix 7-13. Least squares means and analysis of variance of agronomic traits measured on 32 spring wheat cultivars grown on organically managed land at the Edmonton Research Station, Edmonton, AB in 2004.[†,‡]

Cultivar	YOR	Emergence (plants m^{-2})	Early Season Vigour (1-5)	Heading (days)	PM (%)	Leaf Disease (1-9)	Maturity (days)	Height (cm)	Lodging (1-9)	1,000 Kernel wt. (g)	Kernels $spike^{-1}$	Test wt. (kg hL^{-1})	Grain Protein (%)	Weed Biomass (g m^{-2})	Grain Yield (t ha^{-1})
Red Fife	1885	325	3	63	16	3	113	102	7	33	25	67	13.6	1.2	1.75
Hard Red Calcutta	1890	242	3	58	30	4	104	104	8	26	32	71	12.8	14.8	2.74
Preston	1895	292	3	61	20	3	110	107	7	32	32	70	14.4	15.0	2.22
Marquis	1910	319	3	61	15	3	106	111	6	37	25	76	14.7	21.8	2.60
Ruby	1920	263	3	54	28	3	101	106	7	30	29	77	14.8	4.6	2.89
Garnet	1925	266	2	53	23	2	98	107	6	28	27	79	12.7	69.0	3.51
Red Bobs	1926	229	3	55	13	3	103	115	6	40	28	78	13.7	33.0	3.53
Reward	1928	285	3	65	25	3	114	108	7	38	25	65	14.8	13.4	2.31
Early Red Fife	1932	239	3	60	41	3	-	111	6	38	29	66	12.6	17.6	2.69
Canus	1935	276	3	62	31	3	112	112	7	35	32	76	13.0	53.8	2.52
Thatcher	1935	282	3	56	26	3	104	101	7	33	30	76	13.8	39.6	2.93
Saunders	1947	283	2	57	6	3	102	95	7	33	27	76	13.2	62.0	3.21
Cypress	1962	337	2	61	8	4	107	96	8	27	24	65	14.1	36.6	1.69
Park	1963	253	3	54	10	4	100	103	6	34	25	77	14.2	46.6	3.44
Manitou	1965	287	3	57	6	3	104	103	6	32	26	76	14.0	91.6	3.00
Neepawa	1969	324	3	60	30	4	104	99	6	34	24	74	14.1	17.6	2.72
Sinton	1975	258	3	56	5	4	104	105	5	37	32	75	14.3	44.2	3.60
Chester	1976	309	3	58	14	3	108	96	8	34	22	71	14.5	143.2	2.32
Columbus	1980	288	3	63	19	3	109	99	8	39	24	73	14.6	115.4	2.86
Katepwa	1981	261	3	57	13	4	107	102	5	33	24	74	14.1	58.0	3.03

Appendix 7-13. continued

Cultivar	YOR	Emergence (plants m^{-2})	Early Season Vigour (1-5)	Heading (days)	PM (%)	Leaf Disease (1-9)	Maturity (days)	Height (cm)	Lodging (1-9)	1,000 Kernel wt. (g)	Kernels spike^{-1}	Test wt. (kg hL^{-1})	Grain Protein (%)	Weed Biomass (g m^{-2})	Grain Yield (t ha^{-1})
Roblin	1986	252	3	57	13	4	103	102	6	34	25	76	13.6	44.6	2.85
Cutler	1990	340	2	57	5	4	104	86	6	35	31	76	14.0	16.8	3.55
AC Taber	1991	232	3	64	3	2	111	89	8	27	34	59	11.8	143.6	1.70
CDC Teal	1991	266	2	57	10	4	104	100	5	34	27	77	13.8	47.4	3.38
AC Barrie	1994	217	3	59	21	3	109	99	5	35	27	75	13.7	50.2	2.99
AC Foremost	1994	326	2	59	4	3	111	97	8	29	37	72	12.4	57.4	2.71
AC Splendor	1996	276	3	55	4	4	106	101	5	34	26	74	14.8	46.8	3.07
AC Vista	1996	236	2	58	16	3	114	97	8	35	29	72	13.0	183.2	2.79
Laser	1996	215	3	55	16	4	100	99	3	36	34	76	13.9	76.4	3.85
AC Intrepid	1997	278	3	56	4	3	101	101	6	39	24	75	14.0	125.8	3.23
McKenzie	1997	293	2	55	15	4	101	98	6	30	27	77	13.5	51.0	2.97
5600HR	1999	228	3	59	30	4	104	102	6	33	28	74	13.4	21.0	3.29
Overall Mean		274	3	58	16	3	106	101	6	34	28	73	13.7	55	2.87
CV (%)		31	22	4	55	24	3	5	18	8	12	3	2	80	16
F test$_{cultivar}$		0.8820	0.0374	<.0001	<.0001	0.0034	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.2049	<.0001
SE$_{diff}$		60.3	0.4	1.7	6.3	0.5	2.4	3.6	0.8	2.0	2.4	1.8	0.22	31.37	0.316
LSD		120	1	3	12	1	5	7	1.6	4	5	3	0.4	102.7	0.63

[†] Weed biomass statistical analysis was conducted on square root $((x+1)^{0.5})$ transformed data.

[‡] SE$_{diff}$ and LSD have been re-transformed for comparison of actual mean weed biomass.