University of Alberta

The Effect of Cultivar, Seeding Date, and Seeding Rate on Triticale in the Western Canadian Prairies

by

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Abstract

Triticale (× *Triticosecale* Wittmack) is a minor cereal crop in Alberta that has garnered interest as a biofuel feedstock. Little agronomic information has been reported on triticale cultivars released since 1990. Field experiments were conducted at four sites in Alberta to compare cultivar selection, seeding date and seeding rate on grain yield, grain quality, and other agronomic traits. Six triticale cultivars released between 1996 and 2011, and one Canadian Western Soft White Spring (CWSWS) wheat cultivar were evaluated over two seeding dates and three seeding rates. Triticale cultivars differed in yield and quality in all environments, and yielded more grain than CWSWS wheat in five of seven environments, however CWSWS wheat exhibited greater grain quality. Triticale yield increased linearly with seeding rate in five of seven environments. Any seeding date that allowed the accumulation of 1750 growing degree days (Base = 0^{o}C) is sufficient for triticale to mature in Alberta.

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1.0 Introduction and Literature Review

1.1 Introduction

Triticale (× *Triticosecale Wittmack)* is a cereal crop grown throughout the world. Triticale is a member of the *Poaceae* family (tribe *Triticeae*), and is a man-made intergeneric hybrid between rye (*Secale* ssp.) and wheat (*Triticum* ssp.) (Oettler 2005).

Triticale is a relatively minor cereal crop globally; worldwide production of triticale in 2009 was equal to about two percent of global wheat production in the same year, despite the average grain yield per hectare being greater for triticale than wheat (FAO 2011).

Production of triticale in Canada peaked in 1999 (Figure 1.1) (FAO 2011). Canada is a small producer of triticale accounting for less than one percent of the global triticale grain harvest in 2009 (FAO 2011). A majority of the triticale produced in Canada is grown in Alberta, however 75% of the area seeded to triticale in Alberta is harvested in some manner other than as grain; generally as feed or forage (AARD 2011).

Most new triticale germplasm is produced at CIMMYT in Mexico, where the goal of the program is to generate germplasm that is suited to marginal growing environments globally (Mergoum et al. 1998). Thus, individual national breeding programs often use CIMMYT germplasm, thereafter selecting for characteristics favorable to their specific growing regions. For example, the triticale cultivar 'Pronghorn' developed at the Field Crop Development Centre at Lacombe, Alberta, was the result of an initial cross between 'Wapiti' (a Canadian triticale cultivar), and an F_2 triticale from CIMMYT (Salmon et al. 1997) (Appendix 1).

In comparison to other cereal grains triticale is an evolutionary infant, however, successful breeding programs from the 1950's on have rapidly increased the potential and suitability of triticale as a commercial crop. The average yield increase in triticale under both intensely managed and marginal production conditions in CIMMYT trials has been greater than 1.5% per year (Mergoum et al. 1998). In addition, yield components of triticales bred in the 1990's are far superior to cultivars released just ten to fifteen years earlier. Grain yields for triticale cultivars released in the 1990's averaged 17% higher than cultivars released in the 1980's, harvest index was on average 16% greater, grains m^{-2} averaged 17% greater, while spikes m^{-2} and test weight were 12% greater on average. At the same time average plant height decreased by 11% (Mergoum et al. 1998).

Triticale is a relatively late maturing crop on the Canadian Prairies. In Alberta Pronghorn triticale requires 112 days to mature, while the Canadian Western Red Spring wheat check cultivar 'AC Barrie' requires 109 days. Most Canadian Prairie Spring wheat cultivars mature earlier than triticale by one to ten days (Briggs 2001).

When triticale was first developed the goal was to incorporate the yield and quality of wheat with the stress tolerance characteristics of rye. Current triticale cultivars have greater yield potential than wheat and good stress tolerances, but grain quality continues to be an issue. Nutritionally, modern triticale cultivars compare favourably to wheat and corn, and do not suffer from the palatability issues of older cultivars (Myer and Lozano del Rio 2004; Beltranena et al. 2008). Triticale harvested as grain is used for seed, and also as an important part of animal feed rations. Triticale has been shown to be an appropriate alternative grain for use in non-ruminant diets, most commonly chickens and pigs (Jaikaran et al. 1998; Boros 1999). Hexaploid spring triticale has been determined to be as good as wheat, and better than rye in the diets of broiler chickens (Salmon et al. 2004). Hogs fed diets consisting mainly of triticale performed as well or better than hogs fed diets of mainly corn or hulless barley (Jaikaran et al. 1998). Ruminant species also appear to perform as well on triticale based diets as they do on corn or barley based diets. This seems to be the result of lower gluten and beta-glucan levels in triticale rations, and a decreased probability of acidification in the gut (Salmon et al. 2004).

Triticale flour for human consumption has been reported to be excellent for use in tortillas and other unleavened breads, and more recently has been shown to be an acceptable substitute for soft wheats in products such as biscuits and cookies (Mergoum et al. 2004; Salmon et al. 2004). However, triticale flour is not yet an acceptable substitute for wheat flour in the production of breads. This is mainly due to the low gluten protein content of triticale, which can be 25% - 60% lower than wheat (Pena et al. 1998). Triticale flour used in bread making often results in dough which is sticky, absorbs less water, has poor gluten strength, cannot withstand prolonged mixing, and has lower dough strength than wheat flour based dough (Lorenz et al. 1972; Macri et al. 1986; McGoverin et al. 2011). This inferiority to wheat flour is mainly attributed to the combined presence of the rye genome (R) in triticale, and the absence of the wheat D genome which contains several genes which confer desirable bread-making attributes to wheat (Lukaszewski 2006).

Recently, spiking oil prices and environmental concerns have initiated a quest for alternative energy sources. One method receiving attention is the use of ethanol derived from renewable sources as a partial or whole substitute for fossil fuels. The ethanol feedstock of choice is usually dependent on the region. Sugar cane is commonly used in Brazil, while corn is the most common feedstock in the United States and eastern Canada. In western Canada wheat is the most commonly used ethanol feedstock (Goyal et al. 2011). Market volatility can result in variable prices for the wheat classes used in ethanol production. Wang et al. (1997) proposed that lower cost alternative grains such as rye and triticale could be used for ethanol production (McLeod et al. 1998).

Seeding date is an important part of integrated crop management systems. Early seeding allows crops to establish before weedy species, especially if control methods such as tillage or a herbicide application are used prior to seeding (Lenssen 2008). However, overall weed biomass may be decreased with delayed seeding because the control method applied prior to seeding has the opportunity to remove more weed biomass from the system (Blackshaw et al. 2005). Despite the presence of more weed biomass in earlier seeded treatments, crop yields in trials conducted by Blackshaw et al. (2005) were greater in early seeded treatments three out of four years. This suggests that the ideal seeding date is influenced more by crop species than by weed pressure.

Appropriate seeding rates are an important part of often complex integrated crop management systems. The influence of higher seeding rates can be enhanced by managing seeding date, pesticide use and rates, fertilizer applications, and residue management to optimize production and economic return (Smith et al. 2006). In addition to affecting yield, yield components and maturity, seeding rate has also been reported to have significant effects on other organisms within the sown field. Several studies in Alberta and western Canada focusing on integrated crop management have indicated that seeding rate is an important tool in the management of agricultural pests. A dense crop canopy with uniform distribution improves the ability of a crop to compete with, and suppress weeds (Blackshaw et al. 2008).

The following literature review focuses on the history and development of triticale as a cereal grain in western Canada, including current and future end-uses, and current agronomic practices and characteristics.

1.2 Triticale (× *Triticosecale* Wittmack*)*

1.2.1 Origin, History, and Genetics of Triticale

The first artificial wheat × rye cross was reported by A. Stephen Wilson in 1875. In a paper to the Botanical Society in Edinburgh, Wilson reported that he had successfully fertilized wheat with rye pollen, and that the resulting two offspring were "barren," and exhibited, "villosity below the ear," (Wilson 1876; Oettler 2005). "Villosity below the ear," refers to the accumulation of small hairs on the peduncle of triticale cultivars, a result of the presence of the dominant 5R chromosome from the rye parent (Oettler 2005). In 1883 an American, Elbert S. Carman, attempted several crosses and managed to produce one hybrid plant. The plant produced 10 heads, but was only partly fertile and developed a total of 19 seeds. This material has since been lost (Oettler 2005). A picture of this plant was published in the Rural New Yorker in 1884, and again by Leighty (1916). The picture also carefully noted the hairy peduncle as, "whitish down near the head," (Wilson 1876; Leighty 1916). In 1888 a German plant breeder, Wilhelm Rimpau, successfully generated a hybrid between wheat and rye by crossing the wheat cultivar 'Sachsischer rother Landweizen,' and the rye cultivar 'Schlanstedter Roggen' (Rimpau 1891). One fertile hybrid was produced, the seeds of which resulted in 12 fertile plants. These populations were increased and distributed to other breeders for further research (Oettler 2005). These hybrids are still used today in modern breeding programs (Meinel et al. 1988; Franke et al. 1989; Franke 1991). The first naturally occurring cross observed between wheat and rye was not reported until 1921. Meister (1921) reported the appearance of several hybrids at a research station in Saratov, Russia, in fields containing various cultivars of partially open pollinated wheat, separated by rows of rye.

The earliest work with intergeneric triticale hybrids was based on octoploid specimens (2n=8x=56; AABBRRDD) using *Triticum aestivum* L. as a female parent (Oettler 2005). Currently, commercially acceptable triticale cultivars are mainly hexaploid (2n=6x=42; AABBRR) (Oettler 2005). The first hexaploid triticale was likely generated by Jesenko (1913), by crossing *Triticum dicoccoides* (2n=4x=28; AABB) with a *Secale* ssp. (2n=2x=14; RR) (Aase and Powers 1926). *Triticum durum* L., now the most common tetraploid wheat used in crosses, was not used until 1924 when Schegalov described this cross (cited in Plotnikowa 1930; Oettler 2005). The hexaploid triticales using *Triticum durum* L. as a wheat parent have shown the most potential for use in commercial production (Kiss 1966; Larter et al. 1968; Zillinsky and Borlaug 1971).

Sterility was common in early triticales. The development of new laboratory techniques in the early twentieth century including *in vitro* culture techniques (Laibach 1925), improved the viability of the hybrid embryo and allowed the embryo to be rescued from the seed before it aborted. The use of colchicine as a method of doubling chromosome number as described by Blakeslee and Avery (1937) vastly increased the number of fertile amphidiploid F1 individuals that could be produced. These breakthroughs allowed many more lines of triticale to be produced by many different research groups in several areas of the world.

Plant breeders and agronomists quickly realized the potential of triticale to combine the desirable traits of wheat and rye in one organism. The goals of early triticale breeding programs were to incorporate the disease resistance and hardiness of rye, along with the yield capability, flour quality, and short stature of wheat (Ammar et al. 2004). As previously mentioned, initial crosses are made between a wheat parent and rye parent. The wheat parent is most often either tetraploid (4x) or hexaploid (6x) while the rye parent is diploid (2x). The lines resulting from this initial cross are termed primary triticales and are either hexaploid (6x) or octoploid (8x). Common intuition suggests that crossing a high performing bread wheat parent (6x) and a high performing rye parent (2x) should yield a high quality triticale line (8x). However, this is not necessarily the case, as interactions between the ABD wheat and R rye genomes alter many of the desirable traits in the resulting triticale line (Virdi and Larter 1984). The inherent unpredictability of the progeny of a cross makes primary triticale lines ([6x] or [8x]) unattractive for commercial breeding. As a result, the number of primary triticale lines being produced has dwindled because of the level of difficulty in producing them, as well as their lack of agronomic suitability (Oettler 2005). Breeders were much more successful using hexaploid secondary triticales. Secondary triticales are made by crossing two primary triticales, a secondary triticale with a primary triticale, or two secondary triticales (Table 1.1). Secondary triticales are easier to breed and grow, and do not require embryo rescue treatments like primary triticales, since a secondary triticale will always be diploid. (Kiss 1971; Varughese et al. 1996).

Primary triticales were unsuitable for commercialization mainly due to their poor fertility, shriveled kernels, meiotic instability and a high aneuploid frequency (Oettler 2005). These traits are much more common in octoploid triticales than in hexaploid lines

(Muntzing 1939). Thus, hexaploid secondary triticales are more suitable for commercialization as they do not display these disorders to the degree of octoploids.

In 1954, researchers at the University of Manitoba began combining the breeding efforts of triticale programs throughout the world with their own, by assembling and crossing samples of unique hexaploid and octoploid primary triticales from several different countries (Ammar et al. 2004). At the same time, breeding programs in Hungary and Russia lead by Kiss, and Pissarev respectively, were also crossing octoploid and hexaploid triticales and finding resulting lines which were agronomically superior to either parent (Muntzing 1979). The Kiss research group out of Hungary is credited as the first to successfully release a commercial triticale cultivar. Two cultivars, 'No. 57' and 'No. 64' were released in Hungary in 1968 and were grown on over 40,000 ha (Ammar et al. 2004). The first commercial cultivar released in Canada was by the University of Manitoba in 1969, and was designated 'Rosner.' Rosner was the result of the double crossing of four different hexaploid, primary triticales, all derived from unique crosses between a tetraploid wheat species (*Triticum durum* L.) and a diploid rye species (*S. cereale*) (Larter et al. 1970).

In 1958, Dr. Norman E. Bourlaug toured through trials of the University of Manitoba's breeding program. At the time, Dr. Borlaug was the leader of the Office of Special Studies of the Rockefeller Foundation, the predecessor to the International Maize and Wheat Improvement Center (CIMMYT) (Ammar et al. 2004). The impression left on Dr. Borlaug by the triticale breeding material lead to its incorporation in CIMMYT trials in Mexico. There two generations could be produced each year as opposed to the single generation that could be produced in Canada. This also allowed the incorporation of new photoperiod insensitive Mexican wheat lines into the background of triticale breeding lines, and helped to create cultivars adapted to a wider range of agro-climatic conditions than those experienced in central Manitoba (Zillinsky 1974a). Between the University of Manitoba and CIMMYT locations, potential triticales were subjected to intense variation in environmental and agronomic conditions. Two triticale generations per year were grown between three different shuttle breeding sites; one in Manitoba, Canada, one in Northern Mexico, and another in South Central Mexico. These sites allowed for selection based on varying day-length, irrigation versus rain-fed conditions, various disease species and pressures, changing soil types and pHs, and different growing season lengths. Differences in elevation between the three sites were over 2500 m, and there was a difference in latitude of nearly 32^o (Ammar et al. 2004).

The early triticale cultivars produced by the joint CIMMYT and University of Manitoba programs showed improvement over previous cultivars but were still inferior to semi-dwarf CIMMYT wheat lines. The grain yield of the best triticales was about half that of the semi-dwarf wheats (Zillinsky 1974a). However, the biomass produced by these triticales was, “at least as good as in the best of the wheats,” (Ammar et al. 2004). These and other early results of triticale breeding efforts were disappointing until a stroke of good fortune fell upon the crop.

In 1968 a chance cross occurred between an F_1 hybrid from a cross between two F_4 hexaploid triticales exhibiting high fertility, and an unidentified dwarf common wheat (Zillinsky 1974a). Eventually, descendants of this cross became known as ‘Armadillo’ triticale. Armadillo exhibited higher fertility, test weights, and grain yields, improved day-length insensitivity, earlier maturity, short plant height due to a single dwarfism gene, and improved nutritional quality (Zillinsky and Borlaug 1971). In Armadillo, the rye chromosome 2R was replaced by the 2D wheat chromosome, which brought with it several favourable baking characteristics of hexaploid wheat (Gustafson and Zillinsky 1973; Gustafson and Bennet 1976). Several favourable baking and milling parameters of wheat are the result of the presence of the D genome (Larter and Noda 1981; Kerber and Tipples 1969; Kaltsikes et al. 1968). Armadillo exhibited a propensity to pass on its favourable characteristics to its progeny; by 1970 CIMMYT breeders had incorporated genetic material from Armadillo into almost every advanced line in the triticale breeding program.

In 1974 the fifth iteration of the International Triticale Yield Nursery (ITYN) was seeded at 47 different sites around the globe, the results of this trial demonstrated that the best five triticale cultivars yielded 15% more grain than the bread wheat check (Ammar et al. 2004; Varughese et al. 1987). By 1978 one of the triticale lines in the ITYN yielded more grain than any of the top fifty CIMMYT bread wheats (Zillinsky 1985). In just over ten years, from 1967 to 1978, yields of the best triticales had gone from half that of semi-dwarf wheats to more than the highest yielding bread wheats in the world.

The CIMMYT program aimed to have triticale become a viable human consumption food-grain, which was agronomically adapted to areas of the developing world suffering from drought stress and nutrient shortages (Zillinsky 1974b). Multiple studies have been undertaken to illustrate the potential of triticale to substitute for wheat; including studies on baking quality, protein content, gluten quality, milling properties and flour yield (Villegas 1973; Weipert 1986; Ceglinska and Wolski 1990; Jonnala et al. 2001; Tohver et al. 2005 Lukaszewski 2006). However, the main use of triticale throughout the world currently is as an animal feed (Oettler 2005). In response to increasing potential for triticale as a biofuel feedstock, recent breeding efforts have focused on dual purpose cultivars suitable for forage and biomass production, as well as grain production (Wang et al. 1997; McLeod et al. 1998; Macas et al. 2002). At present, triticale has not become a mainstream cereal grain, however research is continuing on various facets of agronomy, breeding, end-uses and potential marketing opportunities to encourage the future development of the species as a viable cereal crop.

1.2.2 Global and Domestic Production

Globally triticale is produced in relatively small quantities. In 2009 worldwide production of triticale was 15.67 million t. This was the largest amount of triticale ever produced in a single year, and was more than a million t greater than 2008 production. In comparison, world wheat production in 2009 was 686 million t. However, the average world wheat yield in 2009 was 3039 kg/ha, and the average triticale yield was 3661 kg/ha (FAO 2011). In 2008 the European Union accounted for 79% of world triticale production. Poland was the largest single producer in 2008 with 4.46 million t (32% of global production), followed by Germany with 2.38 million t (17% of global production) (FAO 2010).

Production of triticale in Canada has decreased from a peak of 126,200 t in 1999 to 30,000 t in 2009 (Figure 1.1) (FAO 2011). In 2009 there were 12,100 ha of triticale harvested for grain in Canada, accounting for less than 1% of the 4.5 million ha of triticale harvested globally (FAO 2011). In 2009 Alberta accounted for 42% (12,700 t) of Canadian triticale production (AARD 2011). This production occurred on 4047 ha of harvested area with an average grain yield in Alberta of 3138 kg/ha (AARD 2011). It is important to note that the end uses of triticale most commonly involve the whole plant rather than just the grain. Uses such as silage and swath grazing account for a large proportion of the area seeded to triticale each year. In 2009 there were 16,187 ha seeded to triticale in Alberta alone, however only 25% of that was harvested as grain (AARD 2011).

Triticale is commonly used for animal feed and forage. Consumption of triticale for animal feed takes several forms, including grain for ruminants and monogastrics, grazing crops, silage, dual purpose forage/grazing, swath grazing, and green feed. Thus triticale grain that is produced in Canada is largely to meet domestic supply demands. The FAO reports no significant imports or exports of triticale to or from Canada between 2001 and 2008 (FAO 2011). Worldwide trade of triticale is minor, with the world's largest exporter, Germany, moving only 98,111 t in 2008, and the world's largest importer, the Netherlands, accepting 72,169 t in 2008 (FAO 2011).

1.2.3 Triticale Breeding

Most current triticale breeding programs approach triticale as a self-pollinating species despite its documented, although minor, ability to outcross (Oettler 2005). This classical approach to plant breeding adheres to the pedigree system as described in Larter et al. (1970); Wolski (1990); Oettler (2005). For example the first Canadian cultivar, Rosner, was a hexaploid triticale which was the result of a double cross of four amphiploid primary triticales each resulting from crosses between durum wheat cultivars and spring rye cultivars (Larter et al. 1970). The pedigree of Rosner as described by Larter et al. (1970), is as follows, "[*T. turgidum* var. *durum* (cv. Ghiza) × *S. cereal*] × [*T. turgidum* var. *durum* (cv. Carleton) × *S. cereal*] × (*T. turgidum* var. *persicum* × *S. cereal*) × (*T. turgidum* × *S. cereal* hybrid of unknown identity)." In addition, triticale breeding programs throughout the world have also begun to use double haploid and cytoplasmic male sterility techniques to further enhance their breeding efforts (Jessop et al. 1998).

Most novel triticale germplasm is produced at CIMMYT in Mexico, where the goal of the program is to generate germplasm that is suited to the marginal growing environments throughout the world (Mergoum et al. 1998). Thus, individual national breeding programs often use CIMMYT germplasm, thereafter selecting for characteristics favourable to their specific growing regions. For example, the triticale cultivar Pronghorn developed at the Field Crop Development Centre at Lacombe, Alberta, was the result of an initial cross between Wapiti, a Canadian triticale cultivar, and an F_2 triticale from CIMMYT (Salmon et al. 1997). Pronghorn is an example of a cultivar produced using the traditional pedigree breeding method. In this example Pronghorn was released to seed growers as an F_{13} generation (Salmon et al. 1997). Newer methods such as the double haploid breeding technique, which gives the breeder a pure homozygous line in one generation, allow new cultivars to be developed more rapidly than in the past (Tuvesson et al. 2000).

While this current system has short term rewards in the form of new triticale cultivars it is based mainly on the crossing of secondary triticales with each other, or backcrossing triticale lines with wheat or rye lines. This successfully creates new triticale lines, but does not expand the triticale gene pool. In order to continue expanding available triticale germplasm, primary triticales incorporating new genetic variability need to be synthesized. This is often a tedious task with a low success rate, and the efforts of CIMMYT and other groups to create new primary triticales are vital to future advances in triticale breeding.

In comparison to other cereal grains triticale is an evolutionary infant, however, successful breeding programs from the 1950's on have rapidly increased the potential and suitability of triticale as a commercial crop. The average yield increase in triticale in CIMMYT trials has been greater than 1.5% per year (Mergoum et al. 1998).

In addition to increases in yield, breeding programs have maintained several favourable characteristics inherent to triticale. Triticales that contain the complete R genome from rye have improved tolerance and yield stability in marginal growing environments. When compared to other cereals, triticale exhibits superior tolerance to drought stress, acidic and alkaline soils, phosphorous deficiency, micronutrient deficiencies and micronutrient toxicities (Pfieffer 1995). However, the inclusion of the complete R genome, while improving the aforementioned agronomic characteristics of triticale, tends to negatively affect the bread-making quality of triticale flour (Mergoum et al. 2004).

Canadian triticale cultivars released in the past have generally been considered dual purpose; cultivars can be harvested for grain or used as a form of forage. Newer cultivars are beginning to be bred for more specialized end uses. The cultivar 'Bumper' registered in 2008 is an example of a cultivar that is designed more for grain production as opposed to forage production. Bumper is shorter in stature than other Canadian triticale cultivars; this allows more nutrients to be partitioned into seed production rather than biomass accumulation. Thus, Bumper is more suitable as a high-yielding feed grain or ethanol bio-fuel feedstock, than as a grazing or silage cultivar (McLeod et al. 2011) (Appendix 1).

The future challenges for successful triticale breeding programs will be the continued drive for increased yield, accompanied by earlier maturity, disease resistance, and improved kernel hardness. Quality goals will be to fulfill specific end-use requirements such as biomass for forage applications, or appropriate glutenin composition for food uses, as well as decreasing the susceptibility of triticale to pre-harvest sprouting (McGoverin et al. 2011).

1.2.4 Physiology and Development of Triticale in Western Canada

Triticale is a relatively late maturing crop on the Canadian Prairies. In Alberta Pronghorn triticale requires 112 days to mature, while the Canadian Western Red Spring wheat check cultivar AC Barrie requires 109 days. Most Canadian Prairie Spring wheat cultivars mature earlier than triticale by one to ten days (Briggs 2001) (Appendix 1). Triticale emerges over a similar time frame as wheat, however the time for triticale to reach the double ridge stage, and to produce a terminal spikelet is often shorter than that of wheat (Lopez-Castaneda and Richards 1994). This often results in the emergence of the head from the boot in triticale before wheat planted on the same date. However, triticale generally has a longer interval from heading to anthesis and from anthesis to physiological maturity than wheat (Lopez-Castraneda and Richards 1994). The increased length of time required for triticale to develop from heading to maturity, and thereafter to ripening is due to the increased length of this heading to maturity interval. Increasing the efficiency of the grainfill period of triticale cultivars, without significantly decreasing yield, has been identified as a main goal of the CIMMYT breeding programs (Mergoum et al. 2004).

The architecture of the canopy of some triticale cultivars has been altered, through plant breeding efforts, from a planophile appearance to a more erectoid canopy (Czerednik and Nalborczyk 2001). Most Canadian cultivars exhibit erect juvenile growth patterns as well as erect, to intermediate mature growth habits, commonly with erect or semi-erect flag leaves (McLeod et al. 2011; Salmon et al. 2007; Mcleod et al. 2001; Salmon et al. 1997). The spatial structure of the canopy has a direct effect on several yield components, as well as abiotic factors in the field environment such as air movement, humidity, and solar radiation within the canopy (Czerednik and Nalborczyk 2001). Erectoid canopies have been shown to increase radiation use efficiency, as well as yield per unit of ground area (Asrar et al. 1984; Yunusa et al. 1993; Czerednik and

Nalborczyk 2001). Czerednik and Nalborczyk (2001) reported that winter triticale with an erectoid canopy had a radiation efficiency rating of 3.55g to 4.67g dry matter per MJ of absorbed radiation. A similar study with Australian spring wheat cultivars with an erectoid canopy reported a radiation use efficiency of 2.35g dry matter per MJ of absorbed radiation (Yunusa et al. 1993). It is important to note that there are distinct differences in radiation use efficiency between cereal species, and also between cultivars within species.

The high radiation use efficiency of triticale contributes to its high yield potential, however this energy is partitioned to the sinks of the plant in different proportions than observed in wheat or rye. Mugwira and Bishnoi (1980) reported that in wheat and rye about 39% of the above ground dry matter was in the form of grain, while in triticale only 24% was in the form of grain. Thus proportionately more of the photosynthate in triticale is used to produce biomass than grain yield, and the higher radiation use efficiency of triticale allows it to yield similarly, or better than wheat and rye, while still producing a greater amount of total biomass. The partitioning of photosynthates within triticale has begun to be addressed by breeding programs with cultivars such as the aforementioned Bumper which is shorter than previous cultivars (McLeod et al. 2011) (Appendix 1).

Triticale grain will reach physiological maturity approximately 24 to 26 days after anthesis (Bishnoi 1974). This is subject to variation due to cultivar and climate. In general grains will reach their maximum moisture content shortly after anthesis. Moisture content of the grain will then begin to decrease almost linearly until the grain is at 40% moisture content, at which point the rate of decrease in moisture content will increase until a level of 15% moisture content is reached (Bishnoi 1974). In Canada triticale should be harvested at, or dried to, a moisture content of 14% or less to avoid any storage problems (AARD 2011a).

1.3 Current and Potential Uses of Triticale Grain

1.3.1 Triticale as a Feed Grain

When triticale was first developed the goal was to incorporate the stress tolerance characteristics of rye with the yield and quality of wheat. Current triticale cultivars generally have superior stress tolerance and greater yield potential than wheat cultivars, however the inferior grain quality of triticale has yet to be fully addressed. As an animal feed, modern triticale cultivars compare favourably to wheat and corn, and do not suffer from the palatability issues of older cultivars (Myer and Lozano del Rio 2004; Beltranena et al. 2008). The crude protein content of triticale is usually higher than corn, and generally about the same as wheat (Table 1.2) (Myer and Lozano del Rio 2004). The range of crude protein content for triticale grain has been reported to vary from 9% to 20% of dry matter (McGoverin et al. 2011). Older cultivars of triticale often exhibit higher protein content than newer cultivars, as successful breeding efforts aimed at increasing the starch content of triticale for plumper kernels and better bread making characteristics have resulted in a lower average protein content (Stallknecht et al. 1996). Lysine and threonine, important amino acids for non-ruminant animals, have been found in greater concentrations in triticale grain than in wheat or rye (Stallknecht et al. 1996; Myer and Lozano del Rio 2004; McGoverin et al. 2011). Lysine is an essential amino acid and is often a limiting factor in porcine diets. Thus, feed rations with a higher concentration of lysine can result in improved animal performance from less feed biomass (Myer and Lozano del Rio 2004). The use of triticale in rations can decrease the amount of additional protein supplement required because of triticale's higher concentrations of limiting amino acids. Likewise, triticale is a good source of phosphorous. Similar to wheat, an estimated 40%-50% of the phosphorous in the grain is available for digestion by non-ruminants. This allows for a lower level of phosphorous supplementation in diets containing triticale grain rather than corn (NRC. 1998; Myer and Lozano del Rio 2004.)

In Canada, the primary use of triticale is as an animal feed. As previously mentioned, only 25% of the area seeded to triticale in Alberta in 2009 was harvested as grain, the bulk of triticale seeded was harvested for biomass in some manner, such as silage or swath grazing (AARD 2011). Triticale harvested as grain is used for seed, and also as an important part of animal feed rations. Triticale has been shown to be an appropriate alternative grain for use in non-ruminant diets, most commonly chickens and pigs (Jaikaran et al. 1998; Boros 1999). Hexaploid spring triticale has been determined to be as good as wheat, and better than rye in the diets of broiler chickens (Salmon et al. 2004). Hogs fed diets consisting mainly of triticale performed as well or better than hogs fed diets of mainly corn or hulless barley (Jaikaran et al. 1998). Ruminant species also appear to perform as well on triticale based diets as they do on corn or barley based diets.

This seems to be the result of lower gluten and beta-glucan levels in triticale rations, and a decreased probability of acidification in the gut (Salmon et al. 2004).

As previously mentioned, triticale is an acceptable component of broiler and chick rations, unlike rye which is not appropriate for poultry feed. Rye is high in arabinoxylans which are a main part of soluble dietary fibre and have a high water holding capacity (Boros 1999). Hexaploid triticale containing the R genome from rye and the AB genomes from wheat has been reported to have lower arabinoxylan content than rye, while maintaining the levels of beneficial limiting amino acids present in rye such as lysine, and threonine (Boros 1999).

When fed to swine, triticale grain can not only successfully replace corn and hulless barley in rations, but due to its higher lysine content can decrease the amount of protein supplement required to make a balanced ration (Hale and Utley 1985; Myer et al. 1989; Jaikaran et al. 1998; Myer and Lozano del Rio 2004; McGoverin et al. 2011). Previous research has indicated that the use of triticale in swine rations can decrease growth rate when compared to corn rations (Hale and Utley 1985; Brand et al. 1995). However, a more recent Canadian study determined that for weaned pigs there was no significant difference in average daily gain between pigs fed Canadian Western Red Spring wheat, Canadian Prairie Spring Red wheat, and spring or winter triticale (Beltranena et al. 2008).

Ruminant animals digest feed in a different manner than non-ruminants. A large portion of digestion within a ruminant animal is a result of the actions of microbes living within the rumen, the first compartment of the four part ruminant gut. These microbes break down fibre and proteins into units that can be used by the animal (Myer and Lozano del Rio 2004). A ruminant diet must therefore accommodate the needs of the animal, as well as the requirements of the fauna in the animal’s rumen. Triticale has been reported to be an acceptable feed for ruminant animals, and can successfully replace corn and barley in feed rations for beef cattle (Zobell et al. 1990; Goonewardene et al. 1994). More recent work has demonstrated that triticale has the potential to be superior to other cereals in ruminant rations due to its highly digestible starch content (Bird et al. 1999). However, the ability of rumen microbes to easily ferment starches in triticale may make it necessary to blend triticale with other less easily fermented cereal grains, such as corn, in order to create a stable, balanced ration (Myer and Lozano del Rio 2004). Triticale dry distillers’ grains, the waste product of triticale-based ethanol production, have been shown to perform as well as corn dry distillers grains when used in the diets of lactating dairy cattle (Greter et al. 2008). This could potentially open a two tiered market for future triticale production. Triticale grain as a potential ethanol feedstock will be discussed later.

1.3.2 Triticale as a Food Grain

After its discovery, triticale was predicted to become a cereal grain for the human consumption market. This was in no small part due to the goals of CIMMYT which were, and still are, to increase the ability of developing countries to produce their own food and improve levels of domestic nutrition (Zillinsky 1974b). In addition to favourable agronomic characteristics for low input production, triticale boasts a beneficial nutrient profile for supporting human nutrition requirements. Unfortunately, while being a healthy choice and agronomically superior to wheat in some aspects, triticale has yet to become a commonly grown cereal grain (Salmon et al. 2004). One of the most commonly cited reasons for triticale's lack of success has been the lack of an appropriate market for growers (Pena et al. 1998; Briggs 2001). The absence of a strong market for triticale is a result of the inherent differences between triticale and wheat which often make the direct substitution of triticale impossible. Most baked goods are traditionally made with wheat flour, and since there is no severe shortage of wheat there is little reason for industry to incur the costs of designing and implementing new technologies which would increase the viability of triticale as a human consumption grain. Instead efforts are being made to alter triticale to be more like wheat so substitution is possible (Salmon et al. 2004; Oettler 2005). Breeding programs throughout the world are attempting to improve the baking quality of triticale flour, while still retaining the agronomic advantages of triticale (Pena et al. 1998; Salmon et al. 2004). Even in countries plagued by inherent food shortages, triticale has not been openly adopted. Since the late 1990's Ethiopia has attempted to introduce triticale to consumers and producers in the highland region of the country where soil degradation, malnutrition, and poverty run rampant. Despite the agronomic suitability of triticale for the region it has not become popular, mainly due to a preference among locals for the more traditional lower-yielding crops of the region, such as tef (Gedamu-Gobena 2008). This preference for traditional foodstuffs is based not only on the taste difference between triticale and local crops, but also in the close relationship between regional culture and food (Gedamu-Gobena 2008).

Triticale flour is excellent for use in tortillas and other unleavened breads, and more recently has been shown to be an acceptable substitute for soft wheats in products such as biscuits and cookies (Mergoum et al. 2004; Salmon et al. 2004). However, triticale flour is not yet a popular substitute for wheat flour in the production of breads. This is mainly due to the low gluten protein content of triticale which can be 25% - 60% lower than wheat (Pena et al. 1998). Triticale flour used in bread making often results in dough that is sticky, absorbs less water, has poor gluten strength, cannot withstand prolonged mixing, and has lower dough strength than wheat flour based dough (Lorenz et al. 1972; Macri et al. 1986; McGoverin et al. 2011). This inferiority is mainly attributed to the combined presence of the R genome in triticale, and the absence of the D Genome which contains several genes which confer desirable bread-making attributes (Lukaszewski 2006). In addition, triticale exhibits a high propensity for pre-harvest sprouting, which increases the α-amylase content in the kernel, in turn causing a breakdown of starch within the kernel. This is exhibited by lower falling number values for triticale when compared to wheat, and the lower viscosity of mixtures of triticale flour and water, compared to wheat flour and water mixtures (Dedio et al. 1975; Oettler and Mares 1994; Mergoum et al. 2004; McGoverin et al. 2011).

As previously mentioned the genetic make-up of hexaploid triticale is commonly AABBRR, meaning the D genome from wheat has been replaced by the R genome of rye. The D genome has loci which code for a range of glutenins and gliadins, which are non-enzymatic storage proteins important to baking quality characteristics (Mergoum et al. 2004; McGoverin et al. 2011). The quality and quantity of these gluten forming proteins determines the bread-making quality of a flour (Lukaszewski 2006). Gluten forms when dough is being mixed and small protein sub-units are polymerized into long chains that then interact with lipids to give dough its characteristic elasticity and strength (Simmonds 1981; Lukaszewski 2006). The presence of the R genome in triticale in place of the D genome effectively removes one third of the loci coding for beneficial wheat storage proteins. As such, triticale flour has a lower amount of total gluten which decreases it's suitability for baking (Pena 1996; Lukaszewski 2006). The specific loci in the D genome responsible for storage proteins are *Glu-D1, Gli-D1, Glu-D3,* and *Gli-D2* which are located on the chromosomes of the homoeologous groups 1 and 6. (Lukaszewski 2006; Martinek et al. 2008; McGoverin et al. 2011). The presence of the R genome results in the replacement of these storage proteins with rye storage proteins called secalins.

(Shewry et al. 1984; Lukaszewski 2006). This replacement is accompanied by a decrease in baking quality, however, it has not yet been confirmed whether the decrease in baking suitability is the result of the presence of the secalins, or the absence of the glutenins and gliadins (Lukaszewski 2006). It has however been reported that the presence of some secalins does not always negatively affect baking quality. Kumlay et al. (2003) reported a slight improvement in dough made from wheat which had some of the *Glu-D1* loci replaced by the *Sec-R1* locus.

Attempts have been made to translocate genes from the D genome of wheat into the A, B, and R genomes of triticale; the resulting plants did show some improved quality values but usually suffered from decreased yield (Shewry et al. 1995; Martinek et al. 2008). This remains a challenge for breeding programs throughout the world. Attempts are underway to isolate the correct storage protein loci from the wheat D genome to include in triticale, and likewise which loci from the R genome need to be silenced in order to make triticale flour more suitable for human consumption (Lukaszewski 2006).

Work is also being done by several groups to determine the suitability of triticale and wheat flour blends in baked goods. Results have been encouraging, with blends of a 1:1 ratio giving acceptable results for both bread and tortilla production (Naeem et al. 2002; Serna-Saldivar et al. 2004). However, there were distinct differences among the results of sensory panels based on different cultivars, suggesting that appropriate flour blends would have to be product, and triticale cultivar specific. While these studies determined that it is possible to use triticale flour in these applications there is little current motivation for industry to accept a new cereal grain with unproven quality and an unreliable supply (Briggs 2001). It is possible that the increasing number of health conscious consumers may provide a demand for unique new products such as triticale flour based foods rather than traditional wheat based products. Such demand could potentially kick start the triticale industry by creating a viable end-user demand (Stallknecht et al. 1996; McGoverin et al. 2011).

1.3.3 Triticale as a Biofuel Feedstock

High quality ethanol for use in engines, most notably passenger vehicles, accounts for about 73% of the ethanol produced worldwide (Mojovic et al. 2009). Most of the remaining 27% of production is used in beverages and industrial processes (Mojovic et al. 2009). Ethanol can be produced from any organic matter that contains carbohydrates like starch, or simple sugars such as glucose and fructose (McGoverin et al. 2011). The ethanol feedstock of choice is usually dependent on the region. Sugar cane is commonly used in Brazil, while corn is the most common feedstock in the United States and eastern Canada. In western Canada wheat is the most commonly used ethanol feedstock (Goyal et al. 2011). Market volatility can result in variable prices for the wheat classes used in ethanol production; as such, Wang et al. (1997) proposed that lower cost alternative grains such as rye and triticale could be used for ethanol production (McLeod et al. 1998). Wang et al. (1997) found that both rye and triticale could be used for ethanol production with little or no process alteration, and little or no ethanol yield loss. Wang et al. (1997) reported that triticale produced about 362 – 367 L of ethanol per t of grain on a 14% moisture basis. The study also indicated that the addition of a small amount of urea as a nitrogenous supplement would decrease the fermentation time of triticale from 72 hours to approximately 48 hours, thus improving the production capacity. High viscosity hinders the ethanol production process and increases production costs due to the necessary addition of specialized enzymes (Choct and Annison 1992; McLeod et al. 2010). Increases in mash viscosity are commonly the result of higher concentrations of beta-glucans in barley and oat, and higher concentrations of pentosans in triticale and some wheats (Ingledew et al. 1995; Wang et al. 1997; McLeod et al. 2010). The triticale mash made from 3 parts water to 1 part grain did not require any additional enzyme pretreatment to lower the viscosity of the mash to acceptable levels. An enzyme pretreatment was required to lower the viscosity of similar rye mashes (Wang et al. 1997).

A more recent study by McLeod et al. (2010) reported that triticale did produce significantly fewer litres of ethanol per t of grain compared to an average ethanol production value of five different classes of wheat. However, when grain yield was taken into account, triticale and wheat did not differ in amount of ethanol produced per ha of production area. The same study concluded that when looked at by class rather than by species on the Canadian prairies, triticale would be more suitable as an ethanol feedstock than Canadian Western Amber Durum wheats, Canadian Western Red Spring wheats, hulled barley, and oats. However, due to yield and process efficiencies it was concluded that hulless barley, Canadian Western Soft White Spring Wheat, and white and red Canadian Prairie Spring wheat would out-perform triticale cultivars as ethanol feedstocks (McLeod et al. 2010). It is important to note that data for this study was collected between 1993 and 1996 using cultivars current at that time. Newer cultivars of wheat, triticale, barley and oats may perform differently in the field and during the fermentation process. Triticale exhibited a significant difference in ethanol yield based on cultivar, thus, selecting a triticale cultivar for ethanol production based on high starch content, and low pentosan concentration would be appropriate (McLeod et al. 2010).

Beres et al. (2009) undertook a study to benchmark the performance of triticale compared to several different wheats for industrial end-uses in Canada. Their study compared three triticale cultivars with two Canadian Prairie Spring wheats, three Canadian Western Soft White Spring wheats, one Canadian Western Red Spring wheat, and one General Purpose wheat from eastern Canada. The three triticale culativars, 'AC Ultima,' Pronghorn, and 'Tyndal' out yielded the Canadian Western Red Spring check, and yielded about the same as the Canadian Western Soft White Spring cultivars (Beres et al. 2009) (Appendix 1). In addition, when ethanol production was considered as an average over all the sites, there were distinct differences between species, classes within species, and between triticale cultivars. The highest performing cultivar was Pronghorn triticale, however it was not significantly different from Canadian Prairie Spring cultivars '5700PR,' and 'AC Crystal,' Canadian Western Soft White Spring culitvars 'AC Andrew,' and 'Bhishaj,' and the triticale AC Ultima (Beres et al. 2009). All of the above cultvars out performed Tyndal triticale which was not significantly different from the Canadian Western Red Spring check cultivar in terms of ethanol production. The authors reported that triticale is at least as good as other crop options for ethanol production and took care to note that cultivar variation among triticales makes some cultivars superior to others for specific end-uses. In this case Pronghorn, and AC Ultima, were superior to Tyndal for the production of ethanol in Canada (Beres et al. 2009) (Appendix 1).

In addition to the primary production of ethanol using triticale grain as a feedstock a recent study by Garcia-Aparicio et al. (2011) examined a secondary fermentation process using cereal bran from triticale. Cereal bran accounts for up to 19% of the volume of grain, and contains several sugars and starches which can be converted to ethanol, thus increasing the overall efficiency of the ethanol production system (Vidmantiene et al. 2006; Garcia-Aparicio et al. 2011). The starch content in the bran is easily accessible and can be hydrolyzed by amylases, however the sugars are mainly lignocellulosic in nature and require additional steps before they can be made available for fermentation. Hemicelluloses account for a significant portion of the overall weight of cereal bran, thus the recovery of these and their consumption by fermentation is important to the efficiency of this secondary fermentation process (Garcia-Aparicio et al. 2011). The appropriate combinations of pretreatments, in this case dilute acid hydrolysis, and then enzymatic hydrolysis allowed for the recovery and fermentation of the hemicellulosic sugars contained in the cereal bran (Wyman et al. 2005; Garcia-Aparicio et al. 2011). Garcia-Aparicio et al. (2011) predicted a theoretical increase in production of 14% with the inclusion of the secondary triticale bran fermentation process in conjunction with the primary triticale grain fermentation process. However, the authors state that due to the complexity of the process, further refinements would be required before an industrial scale process could become economical. In addition to increased ethanol yields, removal of the cereal bran from the dried distiller's grain with solubles increases the marketability of the dried distiller's grain. With the cereal bran left as a part of the dried distiller's grain, the high fibre content often limits the end use to cattle feed as opposed to other livestock, and limits the value and demand for the dried distiller's grains (Srinivasan et al. 2009; Garcia-Aparicio et al. 2011). By removing the cereal bran, the proportion of protein in the dried distiller's grain can increase to 60-65%, thus, increasing value and decreasing shipping, handling, and storage costs (Best et al. 2005; Srinivasan et al. 2009; Garcia-Aparicio et al. 2011).

As previously mentioned Canadian Western Soft White Spring Wheat has been reported to be superior to triticale for the production of ethanol in western Canada (McLeod et al. 2010). However, Phelps et al. (2008) reported an average yield of 5456 kg/ha for AC Andrew soft white spring wheat (Appendix 1). If this yield was applied over all the acres seeded to AC Andrew in 2009 it would account for less than 20% of the feedstock required by a single ethanol production facility with an annual feedstock requirement of 350,000 t, such as the Husky Energy Plant located at Lloydminster, Saskatchewan (Phelps et al. 2008; CWB 2010; Husky Energy 2010). This suggests that a large portion of the ethanol feedstock on the western Canadian prairies is made up of other classes of wheat such as Canadian Western Hard Red Spring, which is inferior to triticale for ethanol production (McLeod et al. 2010).

The ability to generate similar ethanol yields to wheat with triticale, and the lower price of triticale, make it an attractive option for use as an ethanol feedstock (Briggs 2001). However, before triticale can be adopted by ethanol producers, a stable high-quality supply of triticale grain must be available.

1.3.4 The Influence of Seeding Rate on the Yield and Quality of Triticale Grain

Holliday (1960) referred to yield as either vegetative or reproductive. He asserted that reproductive yield, (yield resulting from harvesting the reproductive structure(s) of a plant) was related to plant population, and that competition would result in a parabolic relationship between plant population and yield. Thus, as seeding rate increases, yield increases to a point of maximum production, and then yield begins to decrease as seeding rate continues to rise. Since we harvest the reproductive structures, or grains from triticale, yield should follow a parabolic response curve to changes in seeding rate (Jedel and Salmon 1993).

A study completed by Larter et al. (1971) compared the response of Rosner triticale and 'Manitou' wheat to differences in seeding dates and seeding rates. The work (completed at the University of Manitoba) determined that the ideal seeding rate for Rosner triticale was 100 kg ha^{-1} (276 seeds m^{-2}). At the time the accepted recommendation for wheat seeding rates was between 68 and 102 kg ha^{-1} (approximately 256 and 385 seeds m^{-2} respectively), thus it was concluded that the recommendations for wheat were acceptable for use with triticale as well. Larter et al. (1971) did take care to note that there was generally a larger kernel size for triticale which influenced the higher ideal seeding rate observed in the study compared to wheat (Table 1.3). Other agronomic and quality parameters measured during that study noted that as seeding rate increased the thousand kernel weight of both wheat and triticale decreased, but the protein content of the grains did not change.

A similarly designed study to that of Larter et al. (1971) was conducted using several different wheat cultivars, at three locations in north-central Alberta by Briggs and Aytenfisu (1979). In addition to yield and protein traits this study also evaluated changes in days to maturity of the wheat cultivars as a result of different seeding rates and seeding dates. Seeding rates starting at 30 kg ha^{-1} and rising in increments of 30 kg ha^{-1} up to a maximum of 180 kg ha^{-1} were employed at sites in Edmonton, Ellerslie, and Olds, Alberta. As seeding rate increased grain yield also increased, until plateauing around a seeding rate of 90-120 kg ha^{-1}. Percent protein concentration in the grain decreased with increasing seeding rates as did days to maturity. Between the lowest seeding rate of 30 kg ha^{-1} and the highest seeding rate of 180 kg ha^{-1} there was a difference in maturity of 5, 8, and 10 days respectively for the Edmonton, Ellerslie, and Olds trial locations. In addition to these main effects, Briggs and Aytenfisu (1979) also observed significant genotype × seeding rate interactions which suggests the possibility of agronomically ideal seeding rates that are variable based on cultivar selection, an observation that had been made previously by Cholick (1977).

Gebre-Mariam and Larter (1979) examined the effects of plant density on yield, yield components, protein content and also lysine content in both wheat and triticale. They used ‘Glenlea’ wheat as a check and compared three triticale cultivars, the Canadian cultivar, Rosner, Armadillo (70HN 458) from CIMMYT in Mexico, and ‘6TA204’ an American triticale cultivar from California. There was a negative linear relationship between increasing seeding rate and several yield components for the triticale cultivars and the wheat cultivar alike; including the number of tillers, the number of kernels per spike, and the thousand kernel weight of the seed. Grain yield for Glenlea wheat was greatest at the lowest seeding rate of 140 plants m^{-2}. Among the triticale cultivars there were no differences in yield for 6TA204 or Rosner at any of the seeding rates tested, 140, 280, and 420 plants m^{-2}, while Armadillo yielded more grain at the highest seeding rate. Significant interactions between genotype and environment led Gebre-Mariam and Larter (1979) to conclude that the effect of plant density was dependent on cultivar and environment, thus suggesting that each cultivar would have a different ideal seeding rate dependent upon the location. Gebre-Mariam and Larter (1979) also examined the effect of seeding rate on protein content and lysine content within the grain. As previously reported by Larter et al. (1971) seeding rate did not have an effect on overall protein content. While the triticale cultivars all had significantly higher levels of lysine than Glenlea the overall lysine content of the cereals was not influenced by changes in seeding rate.

The registration of Wapiti spring triticale in western Canada in 1987 made available for the first time a triticale cultivar capable of producing grain with a high test weight (Salmon et al. 1988; Jedel and Salmon 1993). Jedel and Salmon (1993) studied seeding rates of this new triticale cultivar on the Canadian prairies. The higher test weight of Wapiti was a direct result of changes in the grain kernel, as kernels did not shrivel as much as grains from previously registered triticale cultivars, thus resulting in higher test weights (Jedel and Salmon 1993). Seeding rates from 90 to 135 kg ha^{-1} (212 to 307 seeds m^{-2}) resulted in a positive relationship between yield and seeding rate. Jedel and Salmon (1993) reported a yield benefit of 8% when seeding rate was increased from

90 to 135 kg ha^{-1}, while test weight and protein content were not altered. There was a decrease of two days to maturity under greater seeding rates (Jedel and Salmon 1993). Seeding rate recommendations were thus altered to be between 120 to 140 kg ha^{-1} for triticale (Jedel and Salmon 1993). This seeding rate results in an ideal plant population of around 300 plants m^{-2} which is close to the currently used recommendation for triticale in western Canada of 310 plants m^{-2} (Salmon 2004).

In addition to altering yield, yield components and maturity, seeding rate has also been reported to have significant effects on other organisms within the sown field. Several studies in Alberta and western Canada focusing on integrated crop management have indicated that seeding rate is an important tool in the management of agricultural pests. A dense crop canopy with uniform distribution improves the ability of a crop to compete with and suppress weeds (Blackshaw et al. 2008). A thicker plant stand, as described above, is generally achieved by increasing the number of viable seeds placed in the ground per unit area (Mohler 2001; Blackshaw et al. 2008). Higher seeding rates increase intra-crop competition thereby lowering the tillering of individual plants and causing the canopy to close faster. This lessens the competitive ability of weeds in the field environment. Reduced tillering allows the crop to mature more quickly and more evenly, and has been reported to result in more uniform kernel size in cereals (Blackshaw et al. 2008). Reduced tillering as a result of a higher plant population also reduces drought susceptibility as the main-stems of cereals survive longer under drought conditions than tillers (Blackshaw et al. 2008).

Appropriate seeding rates are only a single facet of often complicated integrated crop management systems. The influence of higher seeding rates can be enhanced by managing seeding date, pesticide use and rates, fertilizer applications, and residue management to optimize production and economic return (Smith et al. 2006). Recent studies have been designed to try to determine the most economically efficient combination of these management strategies for different crops and different regions. O'Donovan et al. (2006) compared two spring wheat seeding rates and the resulting performance of herbicide applications on wild oats. They reported that seeding at the higher seeding rate of 150 kg ha^{-1} as opposed to 75 kg ha^{-1} increased grain yield by 19% and economic return by 16%. The higher seeding rate in conjunction with herbicide use led to a decrease in overall weed biomass, in addition to yield increases. O'Donovan et al. (2006) concluded there was a synergistic effect between the higher seeding rate and increased performance of the herbicide treatment, likely as a result of increased competition between the wheat and the weeds.

Beres et al. (2010) reported that spring triticale was as effective as barley at competing with dicot weeds in cropping systems, and as effective as wheat at suppressing monocot weeds. They noted that increasing seeding rates for better plant stand establishment would serve to further increase the competitive ability of spring triticale (Beres et al. 2010).

1.3.5 The Influence of Seeding Date on the Yield and Quality of Triticale Grain

Seeding date is an important part of integrated crop management systems. Early seeding allows crops to establish before weedy species, especially if control methods such as tillage or a herbicide application are used prior to seeding (Lenssen 2008). Smith et al. (2006) reported that seeding wheat in April near Lethbridge, Alberta, had a \$28 ha^{-1} advantage over seeding wheat in May of the same year.

The date of seeding is generally considered to have a greater impact on the overall yield of a crop species than seeding rate, especially in western Canada where the length of the growing season is a limiting factor (Larter et al. 1971). Some crop species are more sensitive to changes in sowing time than others; this is particularly evident with species such as triticale which mature later. Larter et al. (1971) seeded spring wheat and spring triticale at four different dates between April 20, and May 5 for two years at the University of Manitoba. Both wheat and triticale yielded highest at the earliest seeding date and both species exhibited linear decreases in yield with later seeding dates. The rate of decrease in yield was greater for triticale than wheat; during one year triticale yield decreased 59% while wheat yield decreased 28% between the first and last seeding dates. Triticale seeded at the earliest seeding date yielded 34% more grain than wheat, however by the third seeding date that yield advantage disappeared.

A similar study examining seeding dates was conducted by Puri et al. (1977) in northern California. They used four seeding dates for wheat, triticale, and barley. Wheat and triticale both yielded highest at the earliest seeding date. Barley which requires fewer days to mature, reached optimal yield when seeded two weeks after the initial seeding date. The average yield penalty for triticale seeded in the four week period after the initial seeding date was approximately 75 kg ha^{-1} per day.

Briggs and Aytenfisu (1979) included four different seeding dates in an experiment examining the effects of seeding date, seeding rate, and location within Alberta, on several different wheat yield and quality traits. In general this study suggested a tendency for earlier seeding dates to yield more grain with lower protein percentage, as yield and protein content are negatively correlated yield components.

McKenzie et al. (2011) reported on an experiment comparing the effect of seeding date on several different cereals grown under irrigation in southern Alberta. Two triticale cultivars, AC Ultima, and 'Bunker' were included in the trial as feed grains and for silage production (Appendix 1). In addition, cultivars from four Canadian wheat classes were grown in the trial including one Canadian Western Soft White Spring wheat cultivar. Barley was grown in the trial for feed, malt, and silage, and canola and flax were included in the trial as oilseed checks. Each crop was planted at four different seeding dates, the first being mid to late April, with the subsequent seeding dates ten to fourteen days later. McKenzie et al. (2011) reported that crop yield was strongly related to seeding date. There was no significant yield difference between the first two seeding dates, however the yield of the third seeding date was significantly lower than the first two (except for flax) and the fourth seeding date yielded significantly lower grain/seed for all crops. Among the cereals yields for durum wheat and feed barley were the most sensitive to seeding date, and decreased by 1.3% per day for every day after April 30. Canadian Western Red Spring wheat, and triticale yields were the least responsive to seeding date among the cereals, and decreased by 0.8% per day for every day after April 30 (McKenzie et al. 2011). Grain protein content was altered by seeding date, and was higher at the latest seeding date for each cereal (McKenzie et al. 2011). These results were similar to those reported by Briggs and Aytenfisu (1979) indicating the significant relationship between earlier seeding dates and yield, and the significant negative correlation between yield and protein content.

Triticale requires more days to mature than most Canadian Western Hard Red Spring wheats, previous studies indicate that the earlier triticale is seeded the higher the yield potential will be. Larter et al. (1971) asserted that triticale is more responsive to temperature at the seedling stage than wheat. At the seedling stage triticale will develop more tillers if the ambient temperature is cool. Thus, earlier seeding dates result in triticale reaching the seedling stage earlier in the season, and should therefore result in cooler temperatures during the seedling stage than would be endured by a crop seeded later in the year (Larter et al. 1971). The resulting increase in tillers, which should have enough time to successfully set seed, may account in part for the higher yields of early seeded triticale.

1.4 Conclusion

Triticale has the potential to become an important rotational crop in Alberta and western Canada. Its current main use as a form of forage can be supplemented with increased use as a feed grain and as a biofuel feedstock. Data gathered throughout central and southern Alberta indicate that triticale may have a distinct yield advantage over other feed grains, with several other unique agronomic, grain quality, and animal nutrition benefits. While triticale can out-yield cereal crops traditionally grown in Alberta it is hampered by a long growing season requirement, and lack of a stable marketing system. The development of a stable biofuel industry may increase the market demand for triticale either directly as a biofuel feedstock or indirectly as a feed grain to replace other feed grains consumed by the biofuel market. Further research to optimize the production of current triticale cultivars, in conjunction with research to determine the best cultivar available for each specific end-use is required due to the high degree of variability between triticale cultivars in Alberta.

1.5 Statement of Purpose

1.5.1 Purpose of Research

Recently, the development of new triticale cultivars in western Canada has focused mainly on improved forage production. In most cases, the comparative grain production potential of recently introduced triticale cultivars has not been fully evaluated over the varying climatic and soil conditions in Alberta. In addition, basic agronomic characters of newer triticale cultivars are often unavailable, or are broadly based on studies conducted on antiquated cultivars originally registered in the 1960's and 1970's. The short history of selection in triticale, as opposed to a long period of evolutionary development, increases the variation between triticale cultivars. This broad variation may make certain cultivars superior to others depending on each specific end-use. Establishing the appropriate basic agronomic practices and identifying superior modern cultivars for grain production is essential for the further development of triticale as a viable grain crop in Alberta. Understanding which cultivars are agronomically superior for grain yield and grain quality, depending on seeding date and seeding rate, will provide a starting point for the expansion of triticale in the feed grain and biofuel feedstock industries.

1.5.2 Thesis Objectives

The research objectives of this thesis are:

1) To evaluate modern triticale cultivars planted throughout Alberta based on grain yield, grain quality, and agronomic suitability.
2) To determine the effect of seeding date on maturity, grain yield and grain quality.
3) To determine the effect of seeding rate on maturity, grain yield and grain quality.
4) To determine the effect of triticale cultivar selection on maturity, grain yield, and quality.

1.5.3 Thesis Null Hypothesis

The null hypotheses of this thesis are:

1) Triticale cultivars do not differ in agronomic performance.
2) The grain yield, grain quality, and maturity of triticale cultivars are not altered by differences in seeding date.
3) The grain yield, grain quality, and maturity of triticale cultivars are not altered by differences in seeding rate.

1.6 Tables

Table 1.1
The ploidy of triticale lines resulting from crosses of parents of various species and ploidy levels.

Cross	Parent 1	Parent 2	Resulting Triticale
Primary	Hexaploid Wheat (6x)	Rye (2x)	Octoploid (8x)
Primary	Tetraploid Wheat (4x)	Rye (2x)	Hexaploid (6x)
Secondary	Octoploid Primary Triticale (8x)	Octoploid Primary Triticale (8x)	Octoploid Triticale (8x)
Secondary	Octoploid Primary Triticale (8x)	Hexaploid Primary Triticale (6x)	Hexaploid Triticale (6x)
Secondary	Hexaploid Primary Triticale (6x)	Hexaploid Primary Triticale (6x)	Hexaploid Triticale (6x)
Secondary	Octoploid Primary or Secondary Triticale (8x)	Hexaploid Primary or Secondary Triticale (6x)	Hexaploid Triticale (6x)
Secondary	Hexaploid Primary Triticale (6x)	Hexaploid Secondary Triticale (6x)	Hexaploid Triticale (6x)
Secondary	Hexaploid Secondary Triticale (6x)	Hexaploid Secondary Triticale (6x)	Hexaploid Triticale (6x)

Table 1.2

Grain composition of two triticale cultivars compared to the grain composition of wheat cultivars from the Canadian Prairie Spring red (CPSR), Canadian Prairie Spring white (CPSW), and Canadian Western Soft White Spring (CWSWS) wheat classes.

Crop:	**Triticale**	**Triticale**	**CPSR Wheat**	**CPSW Wheat**	**CWSWS Wheat**	
Cultivar:	AC Ultima	Pronghorn	AC Crystal	AC Vista	AC Reed	SE
Ash	1.79	1.84	1.75	1.66	1.71	0.05
Fat/Lipid	1.64	1.78	1.80	1.67	1.99	0.04
Moisture	9.70	9.50	9.30	9.20	9.50	0.40
Protein	13.60	13.70	15.10	15.60	13.70	1.13
Starch	66.30	65.40	66.10	66.10	66.40	1.36
IDF	12.76	11.38	10.96	11.11	10.59	0.26
SDF	2.51	2.71	2.52	2.77	2.74	0.11
TDF	15.27	14.09	13.48	13.88	13.33	0.33
Pentosans	8.71	8.26	7.68	8.28	8.13	0.86

SE = Standard Error. SDF = Soluble Dietary Fibre. IDF = Insoluble Dietary Fibre. TDF = Total Dietary Fibre. Means based on two years of data from nine locations across the western Canadian prairies. Values are percentage (w/w) of dry matter basis average of duplicate analysis. Not all data is presented. *(AARI Report Temelli, Salmon, and McLeod, 2003.)* Adapted with permission from: Triticale Grain Composition. (AARD. 2011b) Available at: http://www1.agric.gov.ab.ca/%24department/deptd ocs.nsf/all/fcd10575.

Table 1.3
The ideal seeding rates of Rosner triticale, and Manitou wheat as reported by Larter et al. (1971) converted from kg ha^{-1} to seeds m^{-2}.

	Seeding Rate (kg ha^{-1})	Calculated Thousand Kernel Weight (g).*	Seeding Rate in seeds m^{-2}.
Triticale - Ideal Seeding Rate.	100	36.2	276
Wheat – Ideal Seeding Rate. (Low)	68	26.5	256
Wheat – Ideal Seeding Rate. (High)	102	26.5	385

*The thousand kernel weight of the seed stock used by Larter et al. (1971) was not reported. These thousand kernel weights were calculated by averaging the thousand kernel weights of the seed harvested during the two years of the trial performed by Larter et al. (1971).

1.7 Figures

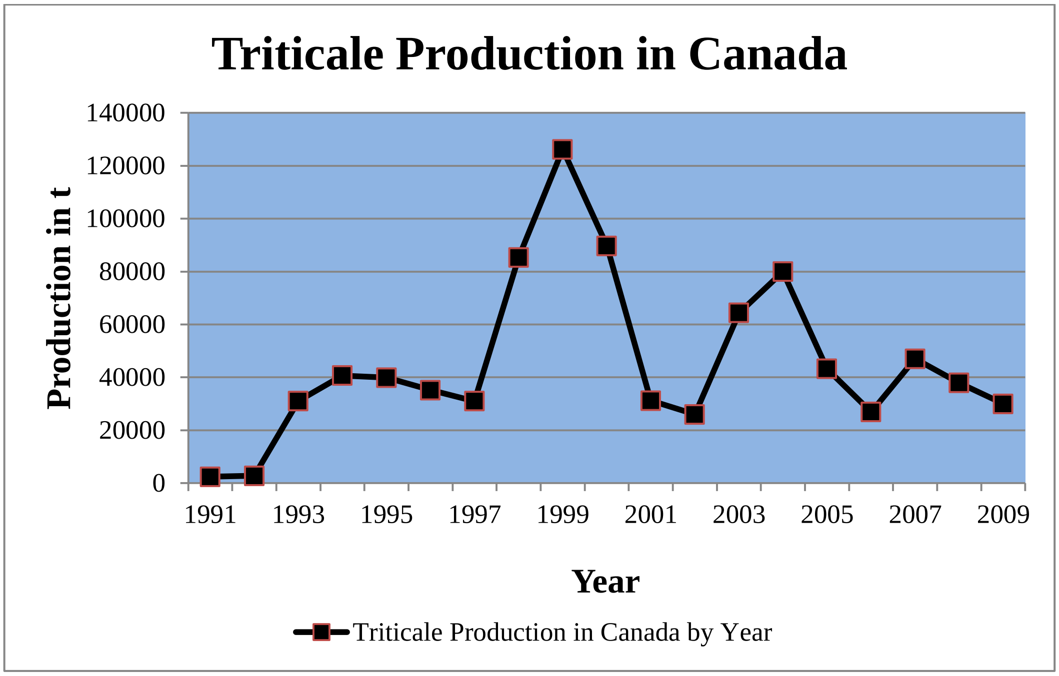

Figure 1.1
Triticale Production in Canada 1991 – 2009.
Adapted from: FAO 2011

1.8 Literature Cited

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Chapter 2

2.0 The Effect of Cultivar, Seeding Date, and Seeding Rate on Triticale in the Western Canadian Prairies.

This chapter has been submitted to The Journal of Agronomy for publication.

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2.1 Introduction

Triticale (× *Triticosecale* Wittmack) is a man-made intergeneric hybrid of wheat (*Triticum ssp.*) and rye (*Secale cereal*e *L.*) and was first documented in Scotland in 1875 by A.S. Wilson (Wilson 1876; Oettler 2005). Triticale combines the genetic potential of wheat and rye resulting in high grain yield potential, and improved disease resistance and stress tolerance. In 2009 the average world triticale and wheat grain yields were 3661 kg ha^{-1}, and 3039 kg ha^{-1}, respectively (FAO 2011). Currently triticale is a minor crop in Alberta, used mainly as a source of feed and forage. Triticale was seeded on 16,187 ha in Alberta during 2009, however less than 25% of the area seeded was harvested as grain (AARD 2011). This compares to 6.135 M ha seeded to spring and winter wheat across Alberta in 2009 (AARD 2011). Recently triticale has garnered interest as a feedstock for the production of ethanol (Beres et al. 2009; Goyal et al. 2011). The relative absence of a human consumption market for triticale makes it an attractive biofuel feedstock devoid of many of the social issues accompanying the food versus fuel debate.

Most modern triticale cultivars available in western Canada have been developed with the primary goal of improved forage production and quality; grain yield and grain quality improvements were considered secondary. As such, the grain production potential of modern triticale cultivars has not been fully evaluated over the range of Alberta's climatic and soil conditions. Several triticale cultivars have been released in the

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last twenty years in western Canada; however most of the agronomic evaluations performed on triticale were undertaken prior to 1995. As a result, most of the current agronomic information available for triticale production is based on cultivars now obsolete, or generalizations from studies performed on wheat.

Previous studies on triticale have indicated recommended seeding rates of 276 seeds m^{-2} (Larter et al. 1971), and 307 seeds m^{-2} (Jedel and Salmon 1993). These studies examined the triticale cultivars 'Rosner' the first commercial Canadian cultivar, released in 1969, and 'Wapiti,' the first Canadian triticale cultivar with a high test weight, released in 1987 (Larter et al. 1970; Salmon et al. 1988). Salmon et al. (1988) noted that at the seeding rates examined in their study (212 seeds m^{-2} to 307 seeds m^{-2}) the maximum yield of Wapiti may not have been achieved. Beres et al. (2010) seeded the triticale cultivar 'Pronghorn,' released in 1996, at 400 seeds m^{-2} and reported favourable yield increases over other spring and winter cereals. McKenzie et al. (2011) reported that triticale had a considerably higher seeding rate requirement than Canadian Western Red Spring wheat (CWRS), which contradicts the earlier findings of Larter et al. (1971) who recommended that the same seeding rate used for wheat could be applied to triticale.

Several studies have examined the effect of seeding date on triticale. Being a long season crop on the Canadian prairies triticale has been considered very sensitive to variation in seeding date. In southern Manitoba Larter et al. (1971), reported a 59% decrease in triticale grain yield when seeding was delayed from April 20 to May 5; wheat grain yield decreased by only 28% over the same period. Puri et al. (1977) performed a similar experiment and reported that optimal grain yield was achieved at the earliest seeding date with a yield penalty of approximately 75 kg ha^{-1} for each day triticale seeding was delayed after the initial seeding date. McKenzie et al. (2011) examined seeding date effects on several small grain cereals, including 'AC Ultima' and 'Bunker' triticale, under irrigation in southern Alberta, and reported that triticale and CWRS wheat were less responsive to later seeding dates than the other cereals examined. Grain yields of triticale and CWRS wheat decreased by 0.8% for each day that seeding occurred after April 30.

The objective of this study was to determine the suitability of modern triticale cultivars for grain production throughout Alberta in comparison to Soft White Spring wheat, and elucidate the effects of cultivar, seeding date, and seeding rate on the maturity, grain yield and grain quality of triticale.

2.2 Materials and Methods

Field experiments were conducted in 2010 and 2011 at each of three locations in Alberta, Canada: Lethbridge (lat. 49°70′N, long. 112°76′W), Lacombe (lat. 52°45′N, long. 113°74′W), and Edmonton (lat. 53°49′N long. 113°53′W). Additionally, two separate trials were conducted at Lethbridge in 2010 and 2011, one under irrigation, and one under rain-fed (dry land) conditions. Trials in Edmonton and Lacombe were limited to rain-fed conditions only. Each trial was a split-plot randomized complete block design with three blocks. The experiment had three treatment levels: two seeding dates (early and late) comprised the main plot unit, with a factorial arrangement of three seeding rates (250, 375, and 500 seeds m^{-2}), and six triticale cultivars: AC Ultima (McLeod et al. 2001), 'Bumper' (McLeod et al. 2011), Bunker (Salmon et al. 2007), Pronghorn (Salmon et al. 1997), 'Sunray' (Beres et al. 2012) and 'Tyndal' (Salmon et al. 2007a). The Canadian Western Soft White Spring wheat (CWSWS) cultivar 'AC Andrew' (Sadasivaiah et al. 2004) was also included in each trial as a high yielding spring wheat check. Thus, each experiment consisted of 36 treatment combinations grown in three blocks, and these experiments were grown at four agro-ecological sites over two years. In 2010 Sunray replaced Tyndal in the trials at Lethbridge, in 2011 Sunray and Tyndal were both included at all trial locations. The Lethbridge site is 350 km south of Lacombe and 500 km south of Edmonton. For the purpose of this paper we refer to Lethbridge as southern Alberta and Edmonton and Lacombe as central Alberta.

Soils in Edmonton and Lacombe are Orthic Black Chernozems, while the soil in Lethbridge is an Orthic Dark Brown Chernozem (AARD 2012a). Each plot was seeded into cultivated soil at a depth of 4-7cm using minimum disturbance double disk press drills (Fabro Enterprises Ltd., Swift Current, SK.). Plot size varied by location and was as follows: Lethbridge (2.76 m^2, 4 seeded rows) Lacombe (5.11 m^2, 8 seeded rows) and Edmonton (5.4 m^2, 6 seeded rows in 2010; 4.5 m^2, 5 seeded rows in 2011). All final yields were calculated in kg ha^{-1}. The addition of fertilizer was based on soil test results taken as cores from a depth of 0 to15 cm (Edmonton and Calgary Labs, Exova Canada Inc., Calgary, AB). Blended granular fertilizer phosphorous (11-52-0-0, P_2O_5), and when necessary, potassium (0-0-60-0 K_2O) were placed with the seed. Nitrogen in the form of urea (46-0-0-0 NH_2) was broadcast or banded depending on the seeding system at each location.

One seeding date (Early) was seeded as soon as field work was possible, generally in the first week of May, and the second seeding date (Late) was completed approximately 14 days later (Table 1). The intent of these divergent times was to plant all Early seeding dates before 15% of the specific location's GDD_{b0} (Growing Degree Days, Base temperature = $0^{o}C$) had elapsed, and seed each Late seeding date after 15% of the seasonal GDD_{b0} had elapsed. In reality, early seeding dates ranged from 4.7% to 13.3% of elapsed GDD_{b0} while the late seeding date ranged from 12.1% to 23.6% elapsed GDD_{b0} (Table 2.1). Seeding rates of 250, 375 and 500 seeds m^{-2} were chosen to represent the commonly recommended seeding rate for Alberta, and 150% and 200% the recommended rate, respectively. Jedel and Salmon (1993) recommended a seeding rate of 300 seeds m^{-2} for triticale, which was the highest seeding rate evaluated in their study that covered a seeding rate range of 212 – 307 seeds m^{-2} and focused on the now antiquated cultivar Wapiti (Salmon et al. 1988). Germination rate, and thousand kernel weight were determined for the specific seed lots used for each cultivar and seeding rates were calculated individually to ensure the appropriate number of viable seeds were used for each cultivar.

Herbicide was applied between Zadoks stage 13 – 21 (Zadoks et al. 1974) at each site to control weeds. The Edmonton and Lethbridge trials received Buctril M® (Bayer CropScience) (bromoxynil 280 gai ha^{-1} + MCPA 280 gai ha^{-1}), while the Lacombe trials were sprayed with Infinity® (Bayer CropScience) (pyrasulfatole 31.1 gai ha^{-1}+ bromoxynil 174 gai ha^{-1}).

2.2.1 Data Collection

Each plot was harvested at maturity with a Wintersteiger® plot combine, with all seed harvested and sub-sampled for further analysis. Plant height was measured from the soil surface to the tips of three adjacent spikes at randomly selected locations within each plot using the procedure of Jedel and Salmon (1993). Days to maturity were estimated as the number of days elapsed from seeding to a grain moisture content of approximately 35%, coinciding with Zadoks stage 87-91 (yellowed penduncle and hard dough-hard kernel) (Zadoks et al., 1974). Data on the number of tillers m^{-2} were collected from the Edmonton location. The number of tillers was counted in a randomly selected 0.5 m^{-2} segment of plot.

Total yield (kg ha^{-1}), test weight (kg hL^{-1}), and thousand kernel weight (g) were determined for each sample, as well as percent grain protein concentration at a grain moisture content of 12%. Protein concentration was determined with near-infrared spectroscopy (NIRS) performed at Alberta Agriculture in Lacombe (FOSS NIRSystems 6500 spectrometer, Foss Food Technology Inc. Eden Prairie MN.) for the Edmonton and Lacombe trials, and at Agriculture Canada in Lethbridge (Foss Decater Grainspec, Foss Food Technology Inc. Eden Prairie, MN), for the Lethbridge trials.

2.2.2 Data Analysis

All data were analyzed using the MIXED procedure of SAS (Release 9.2, SAS Institute Inc., Cary N.C. 2008). Triticale cultivar, seeding date and seeding rate were considered fixed, while location, year, and their interactions were considered random effects. Fisher's protected LSD test was used to compare means of the triticale cultivars. Linear and quadratic relationships in response to seeding rate were tested using contrast statements within the MIXED procedure of SAS. The analyses of seeding rate and seeding date data were performed on data collected on the triticale cultivars, significance was determined at an alpha level of 0.05. The analysis of cultivar effects included data collected on AC Andrew in order to compare the properties of triticale and CWSWS wheat. However, data collected on AC Andrew was not included in the analyses of seeding rate and seeding date to avoid basing agronomic recommendations for triticale on a dataset containing the qualities of a CWSWS wheat. Contrasts were run in the MIXED procedure of SAS with a Bonferroni error correction to determine differences between the triticale cultivars and AC Andrew, as well as differences between old and modern triticale cultivars (SAS Institute Inc. 2008).

As is commonly observed in agricultural field trials, the analysis of variance over all locations indicated that the different environments contributed a large portion of the variation observed in this experiment. There were a total of eight different environments (i.e. growing years) in this experiment, four in 2010 and four in 2011. The Lacombe site in 2011 was affected by early and mid-season flooding and data were dropped from subsequent analyses. Thus, our statistical analysis has been conducted on seven separate environments in total, four in 2010, and three in 2011. During 2010 the cultivar Sunray was grown in the two trials at Lethbridge only, and the cultivar Tyndal was grown only at Edmonton and Lacombe. In 2011 cultivars Tyndal and Sunray were both included at all locations. As such, the data were combined into three different sets for analysis; all three locations grown in 2011 were analyzed together, while the locations from 2010 were split into two datasets, one containing data from Edmonton and Lacombe (central Alberta), and another containing data from both trials completed at Lethbridge (southern Alberta).

2.3 Results

The spring and summer of 2010 were quite wet in south and south-central Alberta. Early rains in Lethbridge and Lacombe resulted in saturation of the soil at trial sites for consecutive days between the early and late seeding dates. Lethbridge and Lacombe had greater than average rainfall, and lower than average daily temperatures throughout the 2010 growing season (Table 2.1). Lacombe also experienced a killing frost in the third week of September, which significantly decreased the yield of plots seeded at the late seeding date in 2010. Above average rainfall was observed in Lethbridge and Lacombe in 2011 as well, resulting in the loss of the Lacombe trial. Conditions in Edmonton in both years were similar to the long-term averages (Table 2.1).

At all sites in 2011, and in central Alberta during 2010, increasing the seeding rate from 250 to 500 seeds m^{-2} resulted in a linear increase ($P < 0.05$) in yield (Table 2.2). In southern Alberta in 2010 seeding rate did not alter grain yield ($P > 0.05$) (Table 2.2). Days required for triticale to reach physiological maturity decreased linearly with increasing seeding rates at all sites in 2011 and in southern Alberta in 2010 (Table 2.2). Seeding rate did not alter maturity ($P > 0.05$) in central Alberta in 2010. The tiller count m^{-2} of triticale at the Edmonton site increased linearly with seeding rate in 2011, but not in 2010 (Table 2.2). Plant height was not altered by changes in seeding rate in either 2010 or 2011. Grain test weight increased linearly ($P < 0.05$) with seeding rate during 2010 in central Alberta, but was not altered by seeding rate in southern Alberta in the same year, or at any site in 2011 (Table 2.2). Triticale grain kernel weight decreased linearly ($P < 0.05$) with increasing seeding rates at all sites in 2011, and again during 2010 but only in southern Alberta (Table 2.2). In addition, in 2011 and in southern Alberta during 2010, the grain protein concentration of triticale was not affected by seeding rate (Table 2.2). Triticale protein concentration decreased linearly ($P < 0.05$) with increasing seeding rates in central Alberta during 2010. The interaction between seeding rate and seeding date was significant ($P < 0.05$) only for grain protein concentration, test weight, and tiller count in central Alberta during 2010 (Table 2.5).

Seeding date had no effect ($P > 0.05$) on triticale grain protein concentration at any site, likewise, no effect of seeding date was observed on grain yield or test weight in 2011, or in southern Alberta in 2010 (Table 2.3 and 2.4). However, resulting grain yield and test weight were both lower ($P < 0.01$) from the late seeding date in central Alberta during 2010, likely due to early frost at the Lacombe site (Table 2.5). Seeding late required more days ($P < 0.01$) for triticale to reach maturity at all sites in 2011, and in central Alberta in 2010 (Table 2.3 and 2.5), but fewer days in southern Alberta in 2010 (Table 2.4). Tiller count was greater ($P < 0.01$) in early seeded treatments at the Edmonton site in 2010 and 2011. Seeding date had no effect on plant height in central Alberta during 2010; while in 2011 triticale at all sites was taller ($P < 0.01$) when planted later (Table 2.3 and 2.5). In 2011 grain kernel weights were greater at the late seeding dates, while in central Alberta during 2010 kernel weights were greater under early seeding (Table 2.3 and 2.5). Kernel weights in southern Alberta during 2010 were not altered by changes in seeding date (Table 2.4).

Cultivars differed ($P < 0.05$) in trait characteristics at all sites except days to maturity in central Alberta during 2010 (Table 2.2). Significant interactions were also observed between cultivars and seeding dates in each data set. In 2011 most triticale cultivars did not differ in yield under early or late seeding dates, however, the cultivar Bumper yielded significantly higher at the late seeding date (Table 2.7). Similarly, in southern Alberta during 2010 most cultivars did not differ in yield when seeded early versus late, with the exception of the cultivar Pronghorn, which yielded more at the early seeding date (Table 2.7). In central Alberta in 2010 all cultivars yielded greater with early seeding, however some cultivars differed in yield compared to the other cultivars at the late seeding date: more specifically, the cultivar Pronghorn yielded less, while the cultivar Bumper yielded more grain, at the late seeding date (Table 2.7). The cultivar by seeding date interaction was also significant for test weight ($P < 0.001$) and thousand kernel weight ($P < 0.001$) in southern and central Alberta in 2010, tiller count ($P < 0.05$) and grain protein concentration ($P < 0.05$) in central Alberta in 2010, and plant height ($P < 0.001$) and days to maturity ($P < 0.05$) in 2011 (Table 2.3, 2.4 and 2.5). In each case, the cultivar by date interaction accounts for a large proportion of the total variation in the model for each parameter (Data not shown).

In general the triticale cultivars fell into two groupings based on their date of registration. The older cultivars AC Ultima, and Pronghorn performed similarly, as did the modern cultivars Bumper, Bunker, Sunray, and Tyndal. Older cultivars produced greater grain yields at all sites in 2011, but did not differ in yield from the modern cultivars in central or southern Alberta during 2010 (Table 2.3, 2.4 and 2.5). Older cultivars also tended to have greater tillering capacities, and grow taller than the modern cultivars (Table 2.3, 2.4 and 2.5). Modern cultivars exhibited superior grain quality attributes over the older cultivars, generally resulting in greater grain protein concentrations, kernel weights, and test weights (Table 2.3, 2.4 and 2.5). There were no differences between old and modern triticale cultivars in the days required to reach maturity, however AC Ultima matured earlier in 2011, and again in southern Alberta in 2010 (Table 2.3, 2.4). Among all cultivars tested, the modern cultivar Bunker consistently had the greatest grain protein concentration, kernel weight, plant height and fewest number of tillers, while the older cultivar AC Ultima exhibited the highest grain yields and earliest maturity.

The triticales had greater kernel weights and grew taller than the CWSWS wheat AC Andrew. However, AC Andrew had a greater test weight and higher tillering capacity than the triticales (Table 2.3, 2.4 and 2.5). AC Andrew had greater grain protein concentrations in 2011, and also in southern Alberta during 2010, but did not differ from the triticale cultivars when planted in central Alberta during 2010 (Table 2.3, 2.4 and 2.5). Triticale cultivars matured earlier than AC Andrew in 2011, and in central Alberta in 2010, however triticale matured later than AC Andrew in southern Alberta in 2010 (Table 2.3, 2.4 and 2.5). Overall grain yields for the triticale cultivars remained greater than AC Andrew in 2011 and in southern Alberta in 2010 (Table 2.3 and 2.4). In contrast, AC Andrew out-yielded triticale grain yields in central Alberta during 2010 (Table 2.5). There were serious outbreaks of *Puccinia striiformis* f. sp. tritici in southern Alberta in both study years. Data were not recorded on disease severity, but it is likely that the yield of AC Andrew was negatively affected by the presence of disease. Triticale is considered to have good resistance to several common diseases of wheat including *Puccinia striiformis* (Mergoum et al. 2004).

The incremental return on investment of higher seeding rates in 2011 was maximized at the 500 seeds m^{-2} seeding rate (Table 2.6). The 375 seeds m^{-2} seeding rate always resulted in a positive return on investment, and in central Alberta during 2010 the return on investment was maximized at the 375 seeds m^{-2} seeding rate (Table 2.6). The return on investment at the 500 seeds m^{-2} seeding rate in central Alberta in 2010 was only slightly positive (Table 2.6). Seeding rates of 375 seeds m^{-2} and 500 seeds m^{-2} equate to 176 kg ha^{-1} (~155 lbs. ac^{-1}) and 235 kg ha^{-1} (~210 lbs. ac^{-1}) respectively for a triticale seed lot with an average thousand kernel weight of 47 g. Values generated for return on investment suggest that maximum returns in 2010 occurred at seeding rates around 375 seeds m^{-2}, while in 2011 seeding rates of greater than 500 seeds m^{-2} were still generating positive incremental returns on investment (Figure 2.1).

Data from southern Alberta in 2010 did not show a significant change in yield or a linear trend as a result of increased seeding rate. In addition, the return on investment in southern Alberta generated by the higher seeding rates was only positive for the 375 seeds m^{-2} seeding rate (Table 2.6). This indicates that seeding rates up to, and including 500 seeds m^{-2} are not detrimental to the grain yield of triticale, but may negatively affect the return on investment (Table 2.4).

Return on investment calculations are based on a certified triticale seed cost of $8.00 per bushel, commodity triticale grain price of $4.00 per bushel, triticale bushel weight of 23.6 kg, and a triticale kernel weight of 47g per thousand kernels.

2.4 Discussion

Several conclusions can be derived from this study. First, the recommended seeding rate for triticale should be equal to or greater than 375 seeds m^{-2}. This seeding rate resulted in an improved incremental return on investment over seeding at 250 seeds m^{-2}, and a more consistent positive return on investment over seeding at 500 seeds m^{-2}. Second, any seeding date that allows for the accumulation of between 1700 and 1750 GDD_{b0} before the first killing frost is acceptable for triticale grain production in Alberta. Third, there is significant variation between triticale cultivars in grain yield, grain quality and agronomic suitability, with further variation among cultivars depending on location and growing conditions. Thus, triticale cultivar selection should be based on specific end use requirements, and further study is required to identify the optimal cultivars for individual triticale grain uses. In general, the older triticale cultivars (Pronghorn and AC Ultima) tended to have greater grain yields, while the modern cultivars (Bumper, Bunker, Sunray, and Tyndal) tended to have improved grain quality characteristics.

2.4.1 Effect of Seeding Rate on Triticale

Jedel and Salmon (1993) reported an 8% grain yield increase when the seeding rate of the triticale cultivar Wapiti was increased from approximately 212 seeds m^{-2} to 307 seeds m^{-2}, which is the basis of the current Alberta Agriculture and Rural Development recommended triticale seeding rate of 310 seeds m^{-2} (AARD 2012). Recent studies have adopted higher seeding rates for triticale closer to 400 seeds m^{-2} (Beres et al.

2010). In our current trials triticale grain yield increased linearly with seeding rate at five of seven environments. Triticale grain yield in 2011 increased 8% when the seeding rate increased from 250 seeds m^{-2} to 375 seeds m^{-2}, and by 13% when the seeding rate increased to 500 seeds m^{-2}.

Triticale is a long-season grain crop on the Canadian prairies, and the days required to reach maturity is often similar to, or greater than, those required by CWSWS wheat. We found up to a two day reduction in days to maturity with increases in seeding rate up to 500 seeds m^{-2}. This trend is similar to that found by Jedel and Salmon (1993), although the latter achieved their reduction through a more modest increase in seeding rate (from 212 seeds m^{-2} to 307 seeds m^{-2}).

Earlier studies indicate that increased seeding rates do not alter triticale grain protein concentration (Larter et al. 1971; Gebre-Mariam and Larter 1979), a finding generally supported by the present study. Interactions between grain protein concentration, seeding rate and seeding date were observed in central Alberta in 2010, likely the result of pre-harvest frost at the Lacombe site, which affected the ability of later seeded triticale to complete grain fill. Moreover, under these conditions, advanced maturity of plants seeded at 500 seeds m^{-2} allowed these plots to complete more grainfill and reach a higher protein concentration than those in the lowest seeding rates. In the absence of early frost, triticale cultivars exhibited their ability to tolerate competitive stresses by maintaining similar protein concentrations despite increased intraspecific competition under higher seeding rates (Larter et al. 1971, Gebre-Mariam and Larter 1979).

As a cereal grain, triticale is known to have a lower test weight than wheat (Oettler 2005). In central Alberta in 2010, test weight was influenced by changes in the seeding rate. The increase in test weight as a result of higher seeding rates documented in this study is desirable, as improving the test weight of triticale has long been a goal of domestic and international breeding programs (Mergoum et al. 1998).

The tendency for triticale to have large kernel sizes results in thousand kernel weights that are generally higher than wheat (Beres et al. 2010). Triticale seed thousand kernel weight had a negative linear relationship with seeding rate in five of seven environments. This contradicts previously reported results which concluded that seeding rate did not affect thousand kernel weights in the absence of a negative effect on yield (Jedel and Salmon 1993; Gebre-Mariam and Larter 1979). In 2011 triticale yields continued to increase with increasing seeding rates even as thousand kernel weights declined, suggesting yield increases were heavily tied to increases in tiller counts and/or associated kernel numbers. However, thousand kernel weights declined to a much greater extent with seeding rate increases in southern Alberta during 2010, and even led to slight grain yield reductions, indicating that the optimum seeding rate in this environment was exceeded at the 500 seeds m^{-2} seeding rate (Larter et al. 1971).

Increasing the seeding rate of triticale from 250 to 500 seeds m^{-2} resulted in positive linear increases in grain yield in five of seven environments. The other benefits observed in this study as a result of increased seeding rates (e.g. reduced time to maturity, increased test weights) suggest that increased recommended seeding rates for triticale would be beneficial to producers. Benefits of higher seeding rates have been reported by other studies including increased weed competitive ability, and pest tolerance (Beres et al. 2011; Beres et al. 2010). The notable ability of triticale to maintain protein concentration regardless of seeding rate allows for the realization of agronomic benefits associated with higher seeding rates without any detrimental effects on grain quality.

2.4.2 Effect of Seeding Date on Triticale

Seeding date effects on triticale grain yield were highly dependent on the environmental conditions later in the growing season. The fall of 2011 was warm and dry well into October, accounting for the similar yields between seeding dates in that year. However, early frosts and late rains in 2010 detrimentally affected both the yield and quality of late maturing triticale crops arising from late seeding, an effect especially evident at the Lacombe site. Although data from five of seven environments suggest that late seeded triticale has the ability to compensate for lower growing degree day (GDD) accumulation in the spring and thereby yield equivalent to early seeded treatments, in general, triticale should be seeded early to minimize the potential of frost damage. Operational seeding dates for minor crops such as triticale are often not determined by the agronomic requirements of the crop, but instead by other factors such as the availability of equipment based on the sequential seeding of other crops. The ability of triticale to yield equally well at either early or late seeding dates suggests that it has potential as a grain crop on the Canadian prairies. Based on physiological maturity data from 2011 and 2010, triticale requires between 1700 GDD_{b0} and 1750 GDD_{b0} to reach physiological maturity in Alberta (AARD 2011a, Cao and Moss 1989). Jedel and Salmon (1997) reported that triticale could be cut into windrows at 30-35% moisture content (physiologic maturity occurs at ~35% kernel moisture content) with little or no negative effects on yield or quality. In the same study, triticale dried at a faster rate than wheat after being windrowed (Jedel and Salmon 1997), which may help avoid losses to frost damage at the end of the growing season.

Larter et al. (1971) asserted that triticale is more sensitive to ambient environmental temperatures at the seedling stage than wheat, and will set comparatively more tillers if the temperature is cooler at the seedling stage. Therefore, early seeding may result in triticale reaching the seedling stage while temperatures are cooler, thereby leading to more tiller production. The greater number of tillers observed at the early seeding dates in 2011, and central Alberta in 2010 serve to support this assertion.

Greater triticale heights under late seeding in 2011 were accompanied by an increase in grain yield, despite the extra resources presumably used by the plant to grow taller. Czerednik and Nalborczyk (2001) reported that the radiation use efficiency of triticale was 1.78 to 2.34 times greater than that of spring wheat, which may partially account for the ability of triticale to exhibit increased yield despite having increased plant height.

Alberta has a relatively short growing season combined with a short frost free period. A majority of Alberta, including Edmonton, Lacombe, and Lethbridge expect the first frost event to occur between September 11 and September 20 each year (Appendix 4) (AARD 2011a). Based on the calculated requirement of 1700-1750 GDD_{b0} for triticale to reach physiologic maturity in the region, and the measured accumulation of GDD_{b0} from 2007 to 2011, the approximate latest successful seeding date of triticale is the second full week of May in central Alberta (Lacombe), the third full week of May in north-central Alberta (Edmonton), and before the first full week of June in southern Alberta (Lethbridge). Seeding prior to these dates should allow triticale to reach physiologic maturity before the occurrence of the first expected frost in each region (estimated as 20 September in Lethbridge, 15 September in Lacombe, and 11 September in Edmonton).

2.4.3 Effect of Cultivar

Cultivar was the most significant non-environmental factor in the experiment. The older cultivars released prior to 2000 maintained a slight yield advantage over the modern cultivars, while the newer cultivars tended to have improved grain quality, with values for protein, kernel weight, and test weight that were superior to the older triticale cultivars. Older cultivars also tended to be taller and produce more tillers. There were no differences observed between the old and new cultivars in days to maturity. In addition, due to the relatively low acreage of triticale grown, older cultivars have not been subject to the same intense selection pressure that a popular wheat cultivar may experience. Thus, resistance in older triticale cultivars may not yet have been overcome by pathogen populations as could be expected with a wheat cultivar of a similar age. The cultivar × date interaction in southern Alberta in 2010 is a result of Pronghorn yielding higher at the early seeding date than under late seeding (Table 2.7).

The soft white wheat cultivar AC Andrew is grown as an ethanol feedstock in western Canada. AC Andrew accounted for 68% of soft white wheat grown in Alberta in 2011, and 82% of soft white wheat grown in western Canada in 2011 (CWB 2011). In the present study the triticale cultivars had greater grain yields, and reached physiologic maturity in fewer days than AC Andrew in five of seven environments (Table 2.3, 2.4 and 2.5). However, the grain of AC Andrew had a protein content that was equal to, or greater than triticale in all environments. AC Andrew also had a greater test weight and a lower thousand kernel weight than the triticales. In all cases, the triticales produced lower tiller counts and grew taller than AC Andrew. The ability to yield as well, or better than soft white wheat, and the equivalent or decreased number of days to maturity exhibited by triticale in this trial, suggest that triticale could be a suitable substitute for CWSWS wheat as an ethanol feedstock in Alberta (McLeod et al. 2010; Beres et al. 2009). However, the variation present between triticale cultivars was sufficient to suggest that cultivar selection should be based on specific end-use requirements. Further research into which triticale cultivars are best suited for specific end uses is required.

2.5 Conclusions

Specific recommendations generated as a result of the present study are as follows: seeding rates of triticale should be increased to be equal to or greater than 375 seeds m^{-2} from the current Alberta Agriculture and Rural Development recommendation of 310 seeds m^{-2} (AARD 2012). Moreover, 375 seeds m^{-2} should be considered the minimum seeding rate when modern triticale cultivars with lower tillering capacity are seeded. Higher seeding rates also serve to decrease the number of days required by triticale to reach maturity, and result in grain yields equal to or greater than those observed when lower seeding rates are used. Increasing seeding rates to this level had no negative effect on grain protein concentration and can result in higher grain yields and higher grain test weights. Calculated returns on investment were always positive when triticale was seeded at 375 seeds m^{-2} compared to 250 seeds m^{-2}.

Triticale exhibited the ability to produce equivalent grain yields and maintain protein concentration whether seeded early or late. As such, any seeding date that allows for the accumulation of enough GDD_{b0} (1700-1750 GDD_{b0}) prior to the first fall frost is suitable for triticale grain production. This seeding date is dependent upon the specific location within the province (Appendix 4), and based on calculated normals, varies from May 14 in central Alberta to June 6 in southern Alberta – the Lethbridge area. If seeding occurs on or after these dates, the seeding rate should be increased beyond 375 seeds m^{-2}.

The triticale cultivars in this study performed similarly to AC Andrew, a CWSWS wheat commonly grown as an ethanol feedstock. Triticale cultivars yielded more grain and reached maturity earlier than AC Andrew in two of three datasets. There is significant variation between triticale cultivars in terms of grain yield, grain quality and overall agronomic suitability. Older triticale cultivars (Pronghorn, and AC Ultima) tended to have grain yields greater than modern cultivars, however modern cultivars exhibited greater grain protein, improved grain quality and higher stress tolerances. Thus, triticale cultivar selection should be based on specific end use requirements, and further study is required to identify the best cultivars for individual triticale grain uses such as animal feed, human consumption, and the production of biofuels.

2.6 Tables

Table 2.1
Environmental data for 2010 and 2011 (May 1 to October 15) at Edmonton, Lacombe, and Lethbridge, Alberta. Data courtesy of AgroClimatic Information Service, Alberta Agriculture and Rural Development.

Year	Environment	Seeding Date	Total GDD_{b0} ***	Percentage of GDD_{b0}*** Elapsed Prior to Seeding	Total Precipitation (mm)*	Normal Precipitation (mm)	Mean Temperature (°C)*	Normal Temperature (°C)
2010	Edmonton	May 11 (Early)	2388	8.79	326	321	13.3	13.4
2010	Edmonton	May 26 (Late)	2388	16.71	326	321	13.3	13.4
2010	Lacombe	May 12 (Early)	2068	8.22	459	334	11.7	12.5
2010	Lacombe	June 2 (Late)	2068	18.18	459	334	11.7	12.5
2010	Lethbridge Irrigated	May 18 (Early)	2474	11.56	394**	253	13.8	14.3
2010	Lethbridge Irrigated	May 25 (Late)	2474	14.51	394**	253	13.8	14.3
2010	Lethbridge Rain-fed	May 22 (Early)	2474	13.30	343	253	13.8	14.3
2010	Lethbridge Rain-fed	June 14 (Late)	2474	23.61	343	253	13.8	14.3
2011	Edmonton	May 5 (Early)	2467	4.74	303	321	14.3	13.4
2011	Edmonton	May 19 (Late)	2467	12.12	303	321	14.3	13.4
2011	Lethbridge Irrigated	May 16 (Early)	2597	8.70	429**	253	15.1	14.3
2011	Lethbridge Irrigated	June 6 (Late)	2597	17.44	429**	253	15.1	14.3
2011	Lethbridge Rain-fed	May 13 (Early)	2597	7.35	327	253	15.1	14.3
2011	Lethbridge Rain-fed	June 13 (Late)	2597	20.91	327	253	15.1	14.3

*Total precipitation and mean temperature from May 1 to October 15. **Total precipitation includes irrigation applied in-crop. ***Total growing degree days using a base temperature of 0°C as described by Cao and Moss (1989). Adapted from: AARD (2011a) AgroClimatic Information Service, Alberta Agriculture and Rural Development. Available at: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/cl1294

Table 2.2
Probability values from the analysis of variance for each dataset for the fixed effects of triticale cultivar, seeding date and seeding rate. Environments, replicates within each environment, and interactions between random and fixed effects are all considered to be random.

Effect	Yield (kg ha^{-1})	Maturity (Days)*	Protein (%)	Test Weight (kg hL^{-1})	Thousand Kernel Weight (g)	Height (cm)**	Tillers (m^{-2})***
All Sites2011							
Cultivar (C)	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Seeding Date (D)	0.39	**<0.01**	0.73	0.07	**<0.05**	**<0.001**	**<0.01**
Seeding Rate (R)	**<0.001**	**<0.001**	0.80	0.05	**<0.05**	0.94	**<0.001**
R_{Linear}	**<0.001**	**<0.001**	0.66	0.09	**<0.05**	0.90	**<0.001**
$R_{Quadratic}$	0.27	0.80	0.62	0.08	0.11	0.74	0.59
C × D	**<0.05**	**<0.05**	0.86	0.44	0.94	**<0.001**	0.86
C × R	0.75	0.17	0.96	0.49	0.63	0.90	0.20
R × D	0.64	0.60	0.33	0.37	0.45	0.11	0.93
C × D × R	0.60	0.14	0.69	0.53	0.97	0.83	0.18
Central Alberta 2010							
Cultivar (C)	**<0.001**	0.40	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.01**
Seeding Date (D)	**<0.01**	**<0.001**	0.23	**<0.01**	**<0.05**	0.47	**<0.001**
Seeding Rate (R)	0.10	0.32	0.07	**<0.001**	0.38	0.36	0.27
R_{Linear}	**<0.05**	0.19	**<0.05**	**<0.001**	0.55	0.18	0.12
$R_{Quadratic}$	0.45	0.45	0.76	0.21	0.21	0.62	0.64
C × D	**<0.05**	0.22	**<0.05**	**<0.001**	**<0.001**	0.68	**<0.05**
C × R	0.87	0.80	0.95	0.99	0.95	0.35	0.89
R × D	0.07	0.05	**<0.05**	**<0.01**	0.34	0.59	**<0.05**
C × D × R	0.89	0.35	0.89	0.92	0.86	0.76	0.97
Southern Alberta 2010							
Cultivar (C)	**<0.05**	**<0.01**	**<0.001**	**<0.001**	**<0.001**		
Seeding Date (D)	0.68	**<0.001**	0.96	0.17	0.09		
Seeding Rate (R)	0.49	**<0.05**	0.35	0.68	**0.0037**		
R_{Linear}	0.58	**<0.01**	0.29	0.65	**<0.001**		
$R_{Quadratic}$	0.28	0.93	0.29	0.45	0.72		
C × D	**<0.001**	0.80	0.11	**<0.001**	**<0.001**		
C × R	0.99	0.74	0.82	0.98	0.90		
R × D	0.37	0.72	0.20	0.98	0.95		
C × D × R	0.93	0.46	0.24	0.99	0.94		

$\alpha = 0.05$. (*) Maturity data were collected at Edmonton in 2010 and 2011, and at the Lethbridge rain-fed site in 2010. (**) Height data were collected at Edmonton and Lacombe in 2010, and in Edmonton in 2011. (***) Tiller count data were collected in Edmonton in 2010 and 2011.

Table 2.3
LS Mean values and significance of treatment interactions for triticale at all sites in 2011.

Cultivar (YOR)	Yield (kg ha^{-1})	Maturity (Days)[a]	Protein (%)	Test Weight (kg hL^{-1})	Thousand Kernel Weight (mg)	Height (cm)[a]	Tillers (m^{-2})[a]
AC Andrew (2001)¥	5391	114	11.0	76	375	93	576
AC Ultima (1999)	6830	111	9.7	71	487	115	512
Bumper (2008)	6422	111	9.5	73	485	104	508
Bunker (2006)	6422	112	10.6	71	527	130	372
Pronghorn (1996)	7022	113	10.0	69	470	122	508
Sunray (2011)	6379	114	9.9	67	456	109	464
Tyndal (2006)	5727	112	10.4	71	482	113	444
F-Test	***	***	***	***	***	***	***
SED	125	0.6	0.16	0.7	7	1	20
Contrasts							
Old Cultivars[Ɨ]	6926	112	9.8	70	479	118	512
Modern Cultivars[Ŧ]	6238	112	10.13	70	488	115	444
F-Test	***	NS	**	NS	*	***	***
Contrast							
AC Andrew	5391	114	11.0	76	375	93	576
Triticales	6467	112	10.0	70	485	115	467
F-Test	***	***	***	***	***	***	***
Seeding Date							
Early	6002	111	10.1	69	468	110	484
Late	6932	113	10.0	71	501	121	452
F-Test	NS	**	NS	NS	*	***	**
Seeding Rate							
250 Seeds m^{-2}	6034	113	10.0	70	492	115	436
375 Seeds m^{-2}	6523	112	10.1	70	480	116	472
500 Seeds m^{-2}	6844	111	10.0	71	482	115	496
F-Test	***	***	NS	NS	*	NS	***
Linear	***	***	NS	NS	*	NS	***
Quadratic	NS	NS	NS	NS	NS	NS	NS
Cultivar × Date	*	*	NS	NS	NS	***	NS
Cultivar × Rate	NS	NS	NS	NS	NS	NS	NS
Rate × Date	NS	NS	NS	NS	NS	NS	NS
Cultivar × Date × Rate	NS	NS	NS	NS	NS	NS	NS

(***) Significant at 0.001. (**) Significant at 0.01. (*) Significant at 0.05. (NS) Not significant. (SED) Standard error of the difference. (YOR) Year of release of cultivar. (¥) AC Andrew CWSWS wheat is present as a check, data generated for AC Andrew were not used in the statistical analyses pertaining to the triticale cultivars. (Ɨ) Old cultivars, AC Ultima and Pronghorn. (Ŧ) Modern triticale cultivars, Tyndal, Bunker, Bumper and Sunray. (NS) No significant difference. Significance of interactions is based on the F-Test statistic. ([a]) Data collected at Edmonton site only.

Table 2.4
LS Mean values and significance of treatment interactions for triticale in southern Alberta in 2010.

Cultivar (YOR**)**	**Yield (kg ha^{-1})**	**Maturity (Days)[a]**	**Protein (%)**	**Test Weight (kg hL^{-1})**	**Thousand Kernel Weight (mg)**
AC Andrew (2001)¥	3537	125	10.8	74	361
AC Ultima (1999)	4939	125	9.6	70	487
Bumper (2008)	5176	126	9.3	71	497
Bunker (2006)	4602	126	10.3	69	506
Pronghorn (1996)	4426	126	10.0	65	459
Sunray (2011)	4740	125	10.0	67	438
F-Test	*	**	***	***	***
SED	226	0.3	0.15	0.6	9
Contrast					
Old Cultivars[Ɨ]	4676	125	9.8	67	473
Modern Cultivars[Ŧ]	4834	125	9.9	69	481
F-Test	NS	NS	NS	***	NS
Contrast					
AC Andrew	3537	125	10.8	74	361
Triticales	4776	125	9.9	68	477
F-Test	***	**	***	***	***
Seeding Date					
Early	4927	130	9.9	71	507
Late	4615	121	9.9	66	449
F-Test	NS	***	NS	NS	NS
Seeding Rate					
250 Seeds m^{-2}	4666	126	10.0	68	490
375 Seeds m^{-2}	4880	125	9.8	69	476
500 Seeds m^{-2}	4766	125	9.8	68	467
F-Test	NS	*	NS	NS	**
Linear	NS	**	NS	NS	***
Quadratic	NS	NS	NS	NS	NS
Cultivar × Date	***	NS	NS	***	***
Cultivar × Rate	NS	NS	NS	NS	NS
Rate × Date	NS	NS	NS	NS	NS
Cultivar × Date × Rate	NS	NS	NS	NS	NS

(***) Significant at 0.001. (**) Significant at 0.01. (*) Significant at 0.05. (NS) Not significant. (SED) Standard error of the difference. (YOR) Year of release of cultivar. (¥) AC Andrew CWSWS wheat is present as a check, data generated for AC Andrew were not used in the statistical analyses pertaining to the triticale cultivars. (Ɨ) Old cultivars, AC Ultima and Pronghorn. (Ŧ) Modern triticale cultivars, Tyndal, Bunker, Bumper and Sunray. (NS) No significant difference. The significance of interactions is based on the F-Test statistic. ([a]) Data collected on rain-fed site only.

Table 2.5
LS Mean values and significance of treatment interactions for triticale in central Alberta in 2010.

Cultivar (YOR)	**Yield (kg ha^{-1})**	**Maturity (Days)[a]**	**Protein (%)**	**Test Weight (kg hL^{-1})**	**Thousand Kernel Weight (mg)**	**Height (cm)**	**Tillers (m^{-2})[a]**
AC Andrew (2001)¥	7279	107	9.8	67.9	370	89	532
AC Ultima (1999)	6003	106	9.4	65.5	418	106	428
Bumper (2008)	5210	106	9.2	63.7	407	101	424
Bunker (2006)	5518	106	10.4	63.7	455	120	396
Pronghorn (1996)	5722	106	9.6	62.9	402	112	480
Tyndal (2006)	6250	106	9.7	65.6	444	105	420
F-Test	***	NS	***	***	***	***	**
SED	175	0.4	0.15	0.5	7	2	20
Contrast							
Old Cultivars[Ɨ]	5862	106	9.5	64	410	109	454
Modern Cultivars[Ŧ]	5659	106	9.8	64	435	109	413
F-Test	NS	NS	*	NS	***	NS	**
Contrast							
AC Andrew	7279	107	9.8	67.9	370	89	532
Triticales	5740	106	9.7	64.3	409	109	429
F-Test	***	***	NS	***	***	***	***
Seeding Date							
Early	7048	105	9.5	67.5	454	107	456
Late	4432	107	9.9	61.0	396	111	400
F-Test	**	***	NS	**	*	NS	***
Seeding Rate							
250 Seeds m^{-2}	5574	106	9.8	63.6	425	110	412
375 Seeds m^{-2}	5799	106	9.7	64.0	421	109	432
500 Seeds m^{-2}	5847	106	9.5	65.2	429	108	440
F-Test	NS	NS	NS	***	NS	NS	NS
Linear	*	NS	*	***	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS	NS	NS
Cultivar × Date	*	NS	*	***	***	NS	*
Cultivar × Rate	NS	NS	NS	NS	NS	NS	NS
Rate × Date	NS	NS	*	**	NS	NS	*
Cultivar × Date × Rate	NS	NS	NS	NS	NS	NS	NS

(***) Significant at 0.001. (**) Significant at 0.01. (*) Significant at 0.05. (NS) Not significant. (SED) Standard error of the difference. (YOR) Year of release of cultivar. (¥) AC Andrew CWSWS wheat is present as a check, data generated for AC Andrew were not used in the statistical analyses pertaining to the triticale cultivars. ([Ɨ]) Old cultivars, AC Ultima and Pronghorn. ([Ŧ]) Modern triticale cultivars, Tyndal, Bunker, Bumper and Sunray (NS) No significant difference. The significance of interactions is based on the F-Test statistic. ([a]) Data Collected at Edmonton site only.

Table 2.6
Yield and incremental return on investment (ROI) changes based on increased seeding rates of triticale.

Seeding Rate	All Sites 2011	Southern Alberta 2010	Central Alberta 2010
250 seeds m^{-2} (1.0×) Yield (kg ha^{-1})	6034	4666	5574
375 seeds m^{-2} (1.5×) Yield (kg ha^{-1})	6523	4880	5799
(% of 1.0× Yield)	108%	105%	104%
ROI* ($ ha^{-1})	$62.96	$16.35	$18.22
500 seeds m^{-2} (1.0×) Yield (kg ha^{-1})	6844	4766	5847
(% of 1.0× Yield)	113%	102%	105%
ROI* ($ ha^{-1})	$97.46	-$22.88	$6.44

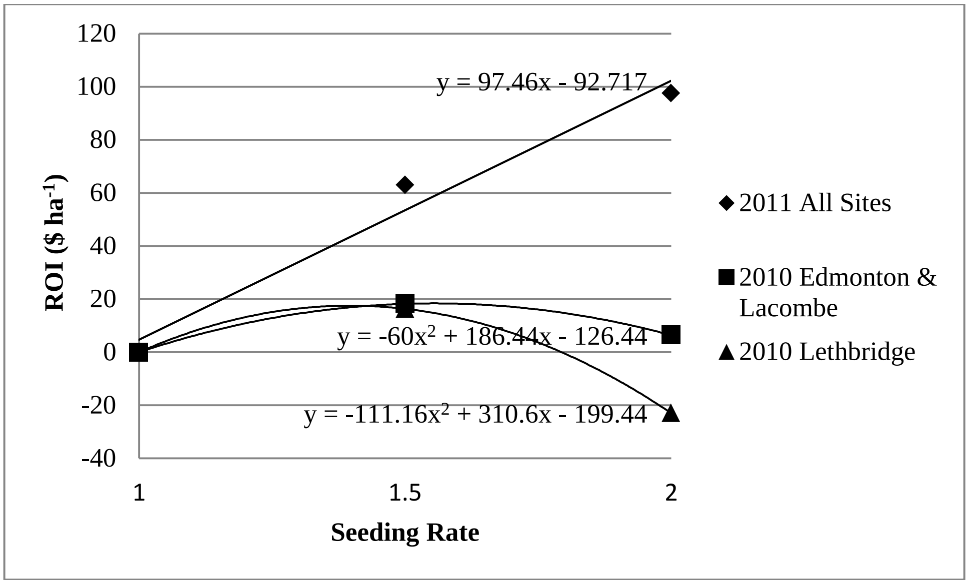
*Incremental return on investment (ROI). ROI calculations are based on a certified triticale seed cost of $8.00 per bushel, commodity triticale grain price of $4.00 per bushel, triticale bushel weight of 23.6 kg, and a triticale thousand kernel weight of 47g.

Table 2.7
LS mean estimates for grain yield (kg ha^{-1}) of cultivars at each seeding date in each dataset.

	2011			Central Alberta 2010			Southern Alberta 2010		
Cultivar	**Early**	**Late**	**sed $_{Date}$**	**Early**	**Late**	**sed $_{Date}$**	**Early**	**Late**	**sed $_{Date}$**
AC Andrew	5191	5572	893	8096	6462	706	3308	3699	433
AC Ultima	6429	7232	1147	7232	4774	508	4916	4962	653
Bumper	5737	7105	996	6276	4143	705	5127	5224	725
Bunker	6072	6772	1050	6902	4133	682	4811	4392	782
Pronghorn	6479	7565	1091	7323	4120	838	5347	3503	1174
Sunray	5900	6858	972	N/A	N/A	N/A	4487	4992	676
Tyndal	5398	6057	1146	7507	4991	580	N/A	N/A	N/A
F-Test	***	***		***	***		***	***	
$SED_{Cultivars}$	961	815		997	892		1020	1365	

(N/A) Cultivar was not seeded, and is not included in the dataset. (***) Significant at 0.001. (**) Significant at 0.01. (*) Significant at 0.05. (NS) Not significant. (sed) Standard error of the difference.

2.7 Figures



*Incremental return on investment (ROI), calculations are based on a certified triticale seed cost of $8.00 per bushel, commodity triticale grain price of $4.00 per bushel, triticale bushel weight of 23.6 kg, and a triticale thousand kernel weight of 47g.

Figure 2.1
Linear and quadratic equations generated for the average incremental return on investment (ROI) at each location based on increasing seeding rate.

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Chapter 3

3.0 Triticale Grain Production in Alberta: Evaluation of Cultivars, Seeding Rates, and Seeding Dates.

Triticale has been grown in Alberta since 1969, however, it is most commonly produced as a source of feed and forage rather than as a cereal grain. Recent growth of the ethanol industry in Alberta has led to the re-evaluation of triticale as a potential cereal grain feedstock equivalent to Canadian Western Soft White Spring wheat (CWSWS) cultivars such as 'AC Andrew.' Triticale is an attractive cereal feedstock for ethanol production because it is not currently an important grain for human consumption, and it has high grain yield potential. Triticale can also be added into crop rotations that already include hard red spring wheat without some of the disease concerns that would accompany the addition of a soft white spring wheat to the same rotation. A study was performed in 2010 and 2011 to determine the suitability of currently available spring triticale cultivars for grain production in Alberta relative to AC Andrew.

3.1 Evaluation of Triticale for Grain Production – Cultivar Selection

Triticale cultivars performed favourably against CWSWS wheat in Alberta. Triticale yielded more grain, and reached maturity in significantly less days than CWSWS wheat at 5 of 7 sites. In general triticale had lower grain protein concentrations, greater kernel weights, lower grain test weights, greater plant height, and produced fewer tillers than CWSWS wheat (Table 3.1). Actual yield and grain protein concentration data is presented in Table 3.2.

The triticale cultivars evaluated in this study can be divided into two groups; old cultivars consisting of 'Pronghorn' and 'AC Ultima,' and modern cultivars including 'Bumper,' 'Bunker,' 'Sunray,' and 'Tyndal.' The old cultivars tended to yield higher, and produce more tillers than the modern cultivars, however the modern cultivars exhibited improved grain quality characteristics including greater grain protein concentrations, greater grain test weights, greater kernel weights, and reduced plant height. There were no differences in maturity observed between old and modern cultivars.

There is a high degree of variation between triticale cultivars which suggests cultivar selection may be best made based on specific end-use requirements and further study is required to determine which cultivars are best suited to specific end-uses.

3.2 Evaluation of Triticale for Grain Production - Seeding Rate Response

Current recommendations suggest triticale should be seeded at approximately 310 seeds m^{-2}. All triticale cultivars in this study were seeded at three different seeding rates 250, 375, and 500 seeds m^{-2}. Increasing seeding rates resulted in linear increases in grain yield, and test weight, and linear decreases in the number of days required to reach maturity and kernel weight. Increasing seeding rate did not significantly influence grain protein concentration. Thus, the benefits of increasing the recommended seeding rate of triticale – increased grain yield, increased test weight, fewer days to reach physiologic maturity, and lower kernel weights - can be realized without any significant detriment to grain protein concentration. Analysis of the incremental return on investment (ROI) of higher seeding rates also proved favourable for higher triticale seeding rates (Figure 3.1).

Based on the incremental ROI and agronomic benefits associated with increased seeding rates it is recommended that the suggested seeding rate of triticale be increased to a minimum of 375 seeds m^{-2}, especially if a modern triticale cultivar with lower tillering capacity is planted.

3.3 Evaluation of Triticale – Seeding Date Response

Triticale is a long season crop on the Canadian prairies, however the results of this study indicate that it can mature in fewer days than CWSWS. Based on data from 2010 and 2011, triticale requires the accumulation of 1700-1750 growing degree days (base $0^{o}C$) (GDD) to mature in Alberta. Therefore, any seeding date that allows this number of GDD to accumulate before the first killing frost should be sufficient. In this study triticale was seeded at two different seeding dates, early, in the first week of May, and late, approximately 14 days after the early seeding date. Triticale exhibited the ability to yield equally when seeded either early or late in 5 of 7 environments. The exception to this was in Edmonton and Lacombe in 2010 when early frost resulted in significantly higher yields from triticale seeded at the early seeding date. Based on recorded GDD accumulation throughout Alberta in 2007 – 2011 and the expected date of the first frost event, triticale should be seeded prior to May 14 in the Lacombe region, prior to May 21 in the Edmonton region, and prior to June 6 in the Lethbridge region (Figure 3.2).

3.4 Conclusions

The following recommendations are suggested for successful triticale grain production in Alberta: seeding rates of equal to or greater than 375 seeds m^{-2} should be used, up from the current Alberta Agriculture and Rural Development recommended rate of 310 seeds m^{-2}. Higher seeding rates decrease the number of days required by triticale to reach maturity, and result in grain yields and grain test weights equal to or greater than those recorded at lower seeding rates. Increasing seeding rates to 375 seeds m^{-2} did not reduce grain protein concentration. Calculated ROI was always positive when triticale was seeded at 375 seeds m^{-2} compared to 250 seeds per m^{-2} (Figure 3.1).

Triticale has exhibited the potential to produce equivalent grain yields and maintain a constant grain protein concentration whether seeded early or late. As such, any seeding date which allows for the accumulation of enough GDD (1700-1750 GDD) prior to the first fall frost is suitable for triticale grain production (Figure 3.2).

The triticale cultivars in this study performed similarly to AC Andrew, a CWSWS commonly grown as an ethanol feedstock. There is a significant amount of variation between triticale cultivars in terms of grain yield, grain quality and agronomic suitability. Older triticale cultivars tend to have grain yields higher than modern cultivars, however modern triticale cultivars exhibit higher grain protein contents, and improved grain quality characteristics. Thus, triticale cultivar selection should be based on specific end use requirements, and further study is required to identify the best cultivars for individual triticale grain uses such as animal feed, human consumption, and the production of biofuels.

3.5 Tables

Table 3.1
Significant differences in agronomic and grain quality parameters between triticale and soft white spring wheat in Alberta in 2010, and 2011.

Data Set	Yield (kg/ha)	Maturity (Days)	Protein (%)	Tkw (mg)	Twt (kg/hL)	Height (cm)	Tillers (m^{-2})
All Sites 2011	SW < TCL	SW > TCL	SW > TCL	SW < TCL	SW > TCL	SW < TCL	SW > TCL
Central AB. 2010	SW > TCL	SW > TCL	*NS*	SW < TCL	SW > TCL	SW < TCL	SW > TCL
Southern AB. 2010	SW < TCL	SW < TCL	SW > TCL	SW < TCL	SW > TCL	X	X

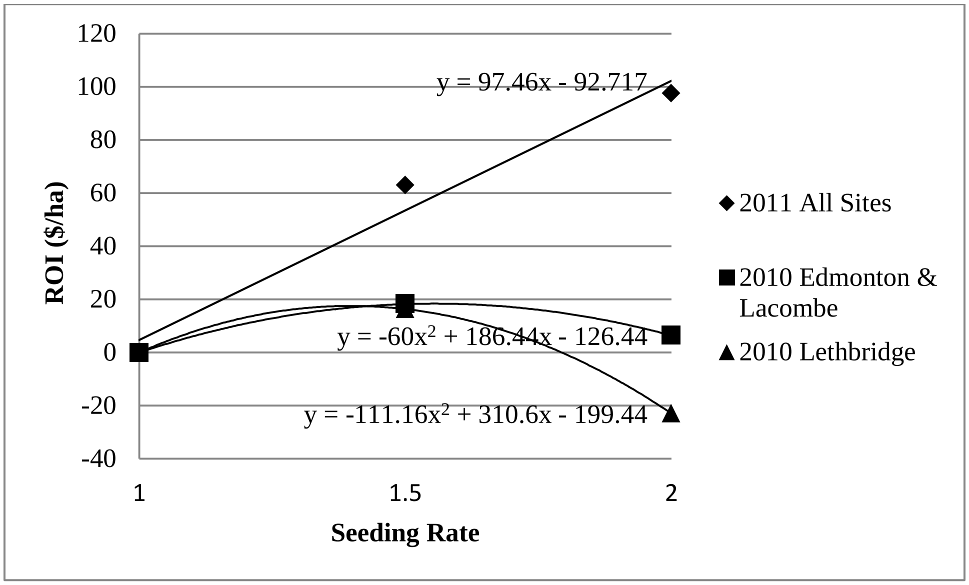
(TCL) Triticale. (SW) Soft White Spring Wheat. (*NS)* No significant difference. (X) Data not collected. $\alpha = 0.05$. (All Sites 2011) consists of combined data from three sites, Edmonton, Lethbridge rain-fed, and Lethbridge irrigated. (Central AB. 2010) consists of Data from two sites, Edmonton and Lacombe. (Southern AB. 2010) consists of data from two sites, Lethbridge rain-fed and Lethbridge irrigated.

Table 3.2
Cultivars included in study, grain yields, and grain protein concentrations.

Cultivar (YOR)	Grain Yield ($kg\ ha^{-1}$) Alberta 2011	Central Alberta 2010	Southern Alberta 2010	Grain Protein Concentration (%) Alberta 2011	Central Alberta 2010	Southern Alberta 2010
AC Andrew SWS (2001)	5391*e*	7279*a*	3537*e*	11.0*a*	9.8*b*	10.8*a*
Pronghorn TCL (1996)	7022*a*	5722*d*	4426*d*	10.0*d*	9.6*c*	10.0*c*
AC Ultima TCL (1999)	6830*b*	6003*c*	4939*b*	9.7*e*	9.4*d*	9.6*d*
Bunker TCL (2006)	6422*c*	5518*e*	4602*cd*	10.6*b*	10.4*a*	10.3*b*
Tyndal TCL (2006)	5727*d*	6250*b*	N/A	10.4*c*	9.7*bc*	N/A
Bumper TCL (2008)	6422*c*	5210*f*	5176*a*	9.5*f*	9.2*d*	9.3*e*
Sunray TCL (2011)	6379*c*	N/A	4740*bc*	9.9*d*	N/A	10.0*c*
F-Test	***	***	*	***	***	***
SED	125	175	226	0.16	0.15	0.15

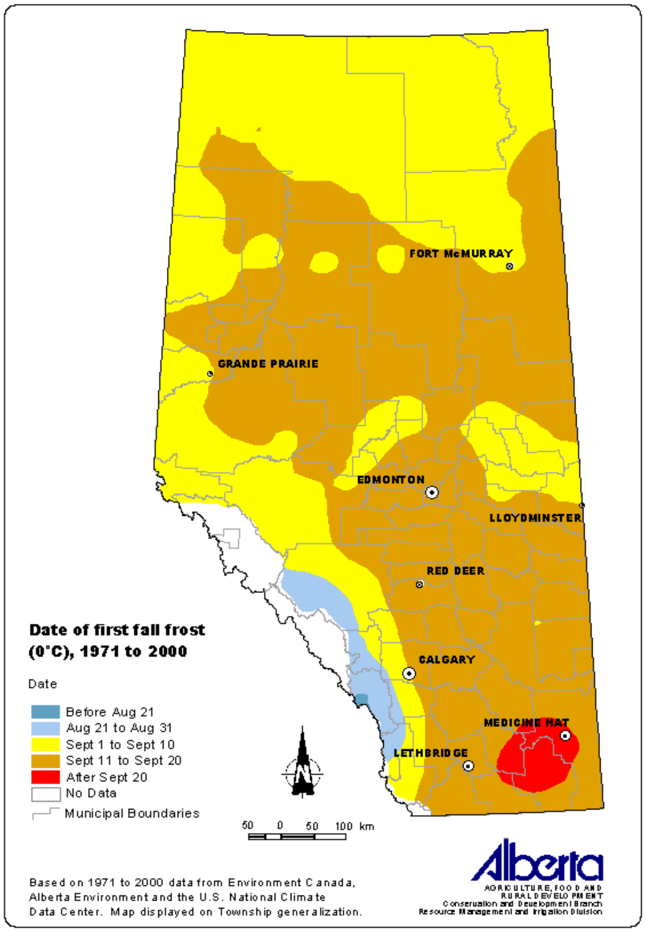
(YOR) Year of Release. (SWS) Soft white spring wheat. (TCL) Triticale. (N/A) Not seeded at specific location/year. Means in each row with different letters indicate significant differences ($P \leq 0.05$). (***) Significant at 0.001. (**) Significant at 0.01. (*) Significant at 0.05. Alberta 2011 includes: Edmonton, Lethbridge rain-fed, and Lethbridge irrigated sites. Central Alberta 2010 includes: Edmonton and Lacombe sites. Southern Alberta 2010 includes: Lethbridge rain-fed and Lethbridge irrigated sites.

3.6 Figures



*Return on Investment (ROI), calculations are based on a certified triticale seed cost of $8.00 per bushel, commodity triticale grain price of $4.00 per bushel, triticale bushel weight of 23.6 kg, and a triticale thousand kernel weight of 47g. Seeding rates of 250 seeds m^{-2} equivalent to 1.0x, 375 seeds m^{-2} equivalent to 1.5x, and 500 seeds m^{-2} equivalent to 2.0x.

Figure 3.1
Linear and quadratic equations generated for the average return on investment (ROI) at each location based on increasing seeding rates.



The dates by which triticale must be seeded at each location in Alberta in order to reach physiologic maturity (accumulate ~1750 GDD_{b0}) before the first expected frost at Edmonton, Lacombe, and Lethbridge, Alberta from 2007 to 2011 respectively.

Year	Edmonton*	Lacombe**	Lethbridge***
2011	May 22	May 13	June 12
2010	May 17	April 20	May 31
2009	May 27	May 5	June 12
2008	May 26	May 11	June 6
2007	May 30	May 16	June 18
Long Term Normals****	**May 21**	**May 14**	**June 6**

(*) First expected frost September 11. (**) First expected frost September 15. (***) First expected frost September 20. (****) Normals are estimates of the long term average based on the Alberta Agro-Climatic database. Image taken with permission from: AARD (2011a) http://www.agric.gov.ab.ca/app116/quick.jsp#.

Figure 3.2
Date of first expected frost, and calculated seeding deadlines for triticale grain production in Alberta.

4.0 Appendices

Appendix 1: Cultivar descriptions.

Pronghorn Triticale:

Pronghorn is a spring triticale released in 1996 by the Alberta Agriculture, Food and Rural Development, Field Crop Development Center in Lacombe, Alberta. Pronghorn is a hexaploid, standard height, early-maturing cultivar, it is awned, and has tapering spikes. Pronghorn exhibits good tolerance to drought and is resistant to shattering, it has some lodging resistance, and is rated as susceptible to sprouting. When registered, Pronghorn became the highest yielding triticale grown in western Canada. The test weight reported for Pronghorn triticale was 68 kg hL^{-1}, and plant height was reported as 106 cm. Maturity was reported as 117 days. The initial recommendation was for Pronghorn to be grown in the black and brown soil zones of Saskatchewan, and the brown soil zones of Alberta, its decreased days to maturity also made it potentially suitable for the black soil zones of Alberta. Pronghorn triticale is considered the check against which new triticales are tested in western Canada.

Adapted from: Salmon et al. (1997).

AC Ultima Triticale:

AC Ultima is a spring triticale registered in 1999 by Agriculture and Agri-food Canada, Swift Current, SK. AC Ultima is a hexaploid triticale originally developed by CIMMYT in Mexico. It was first brought to Canada in 1993 as an entry in the 25th International Triticale Screening Nursery (ITSN). Favourable results in the ITSN lead to further evaluation and eventual registration of AC Ultima. AC Ultima has high grain yield, early maturity, heavier kernels, shorter height and excellent lodging resistance compared to older Canadian triticale cultivars. Initial performance data showed AC Ultima to have grain yield and maturity equal to Pronghorn, in this trial, 105 days and 106 days respectively. AC Ultima was reported to have higher test weights and higher kernel weights than Pronghorn, it also had superior Hagberg Falling Number values compared to the triticale check cultivars indicating improved resistance to preharvest sprouting. AC Ultima has long tapered awned spikes, and large soft kernels.

Adapted from: McLeod et al. (2001).

Tyndal Triticale:

Tyndal is a spring triticale registered in 2006 by the Alberta Agriculture and Food, Field Crop Development Center in Lacombe, Alberta. Tyndal is a hexaploid triticale with the reduced awn or awnletted trait. In registration trials Tyndal out yielded Pronghorn while maintaining similar kernel and test weights. Tyndal was shorter than Pronghorn at 92 cm, and matured in 106 days. Silage tests indicated that Tyndal produced 4% more biomass than Pronghorn and, due to its reduced awns, is more suitable for use as a green feed. Tyndal is recommended for use in the light black and brown soil zones of the Canadian prairies.

Adapted from: Salmon et al. (2007).

Bunker Triticale:

Bunker is a spring triticale registered in 2006 by the Alberta Agriculture and Food, Field Crop Development Center, Lacombe Alberta. Bunker is a hexaploid, tall, awnletted triticale. The grain yield of Bunker was equivalent to that of Pronghorn, however, Bunker produced more tonnage of silage per acre than Pronghorn. The thousand kernel weight and test weight of grain produced by Bunker was superior to that of Pronghorn. Bunker can be taller than Pronghorn, and matures slightly later, according to the registration trials Bunker requires 107 days to reach maturity. Bunker is recommended for use in the light black and brown soils of the Canadian prairies.

Adapted from: Salmon et al. (2007).

Bumper Triticale:

Bumper is a spring triticale registered in 2008 by Agriculture and Agri-food Canada, Swift Current, SK. Bumper is a hexaploid, awned triticale. Similar to AC Ultima, it was developed by CIMMYT and introduced to Canada in the ITSN in 2002. Bumper showed excellent adaptation to prairie soils and growing conditions with registration trials exhibiting yields similar to Pronghorn, and AC Ultima in all soil zones, with no difference in days to maturity. Bumper was significantly shorter than Pronghorn and AC Ultima, and had better lodging resistance, and a greater test weight than either of the check cultivars. The kernel weight of Bumper was equal to Pronghorn and AC Ultima, however the Hagberg Falling Number value was significantly less than that of

AC Ultima. Bumper has a medium length tapering spike, and is noted to be suitable for use as a high yielding feed grain, and as a high-quality, high yielding ethanol feedstock.

Adapted from: McLeod et al. (2011).

'Sunray' Triticale:

Sunray is a newly registered hexaploid spring triticale, which is adapted to grow on the Canadian prairies. Sunray was initially developed by CIMMYT in Mexico, and was screened for adaptation to Canadian growing conditions at the Lethbridge Research Centre of Agriculture and Agri-Food Canada. Sunray received registration in 2011. In registration trials Sunray yielded similar to the check triticale cultivars, was slightly shorter at 96 cm, and matured two days earlier than Pronghorn, in addition, Sunray performed similarly to the check cultivars in terms of lodging resistance, kernel weight, and test weight. The Hagberg Falling Number value for Sunray was lower than that of AC Ultima, but still superior to the value of Pronghorn. One of the selection criterion for Sunray was reduced ergot infection. Registration trials indicate ergot infection was lower for Sunray than the check cultivars. Sunray is recommended for use as a high yielding feed grain cereal, niche human consumption markets, and as a high yielding ethanol feedstock.

Adapted from: Beres et al. (2012).

AC Andrew Soft White Spring wheat:

AC Andrew is a Canadian Western Soft White Spring wheat cultivar developed by the Lethbridge Research Center of Agriculture and Agri-Food Canada, and was registered in 2001. Registration trials for AC Andrew note the cultivar's stature, 91.5 cm, and a yield improvement over the Canadian Western Soft White Spring wheat check cultivars of at least 15% (8130 kg ha^{-1} in registration trials). In addition, AC Andrew is reported to have very good resistance to lodging, and shattering, and a maturity rating of 112 days. The average protein content of AC Andrew was similar to check cultivars at 11.4%. In 2010/2011 AC Andrew accounted for 77.1%, and 96.5% of the area seeded to Canadian Western Soft White Spring wheat in Alberta and Saskatchewan respectively, and 95% of the area seeded to Canadian Western Soft White Spring wheat on the prairies (CWB 2011).

Adapted from: Sadasivaiah et al. (2004).

Appendix 2: Location Means Tables.

Edmonton 2010

Cultivar	Yield (kg ha^{-1})	Maturity (Days)	Protein (%)	Test Weight (kg hL^{-1})	Tillers (m^{-2})	Thousand Kernel Weight (mg)	Height (cm)
AC Andrew	8176	107	9.8	70	532	406	86
AC Ultima	6440	106	9.8	68	428	418	103
Bumper	5984	106	9.7	66	424	434	97
Bunker	6382	106	10.4	67	396	494	112
Pronghorn	6881	106	9.8	65	480	427	104
Tyndal	6235	106	9.9	66	420	456	98
F-Test	***	***	**	***	***	***	***
LSD	468	0.3	0.40	1.4	44.8	16.2	5.2
Seeding Date							
Early	7302	105	10.1	69	468	443	101
Late	6064	108	9.7	65	428	435	99
F-Test	***	***	**	***	**	NS	NS
Standard Error	135	0.20	0.12	0.42	12.92	4.7	1.52
Seeding Rate							
250 Seeds/m^2	6276	106	10.0	66	428	432	100
375 Seeds/m^2	6776	106	10.0	67	452	436	100
500 Seeds/m^2	6997	106	9.8	68	456	449	101
F-Test	***	NS	NS	***	NS	*	NS
Linear	***	NS	NS	***	NS	**	NS
Quadratic	NS	NS	NS	NS	NS	NS	NS
Standard Error	166	0.24	0.14	0.51	15.84	5.7	1.86
Variety * Rate	NS	NS	NS	NS	NS	NS	NS
Rate * Date	NS	*	NS	NS	*	***	NS
Variety * Date	*	NS	***	***	*	***	NS
Variety * Rate * Date	NS	NS	NS	NS	NS	NS	NS
CV	10.53	0.96	6.08	3.26	15.06	5.54	7.88
Overall Mean	6683	106.2	9.9	67	448	439	100.0

(*) indicates significance at 0.05. (**) indicates significance at 0.01. (***)indicates significance at 0.001.

Edmonton 2011

Cultivar	Yield (kg ha^{-1})	Maturity (Days)	Protein (%)	Test Weight (kg hL^{-1})	Tillers (m^{-2})	Thousand Kernel Weight (mg)	Height (cm)
AC Andrew	7322	114	9.8	74	576	390	93
AC Ultima	9168	111	8.2	70	512	494	115
Bumper	7870	111	8.7	71	508	464	104
Bunker	8462	112	10.1	71	372	565	130
Pronghorn	8983	113	9.2	68	508	463	122
Tyndal	8278	112	9.5	71	444	521	113
Sunray	8274	114	9.1	66	464	464	109
F-Test	***	***	***	***	***	***	***
LSD	404	1.3	0.14	0.58	38.8	10	2.37
Seeding Date							
Early	7891	111	9.2	68	496	448	107
Late	8782	114	9.2	73	468	512	118
F-Test	***	***	NS	***	**	***	***
Standard Error	108	0.34	0.04	0.15	10.44	2.7	0.64
Seeding Rate							
250 Seeds/m^2	8142	114	9.3	70	452	491	112
375 Seeds/m^2	8328	112	9.2	71	484	479	113
500 Seeds/m^2	8540	111	9.2	71	512	471	112
F-Test	*	***	NS	***	***	***	NS
Linear	**	***	*	***	***	***	NS
Quadratic	NS	NS	NS	*	NS	NS	NS
Standard Error	133	0.41	0.05	0.19	12.76	3.3	0.78
Variety * Rate	NS	*	NS	NS	NS	*	NS
Rate * Date	NS	NS	NS	NS	NS	NS	NS
Variety * Date	NS	***	***	NS	NS	***	***
Variety * Rate * Date	NS	**	NS	NS	NS	NS	NS
CV	7.30	1.68	2.33	1.23	12.11	3.14	3.18
Overall Mean	8337	112.3	9.2	70	482.8	480	112.2

(*) indicates significance at 0.05. (**) indicates significance at 0.01. (***)indicates significance at 0.001.

Lacombe 2010

Cultivar	Yield (kg ha^{-1})	Maturity (Days)	Protein (%)	Test Weight (kg hL^{-1})	Tillers (m^{-2})	Thousand Kernel Weight (mg)	Height (cm)
AC Andrew	6383	.	9.7	66	.	334	92
AC Ultima	5566	.	9.0	63	.	417	110
Bumper	4435	.	8.7	62	.	380	106
Bunker	4653	.	10.4	61	.	416	128
Pronghorn	4563	.	9.5	60	.	377	120
Tyndal	6264	.	9.5	65	.	433	111
F-Test	***		***	***		***	***
LSD	263	.	0.23	0.83	.	8.6	1.79
Seeding Date							
Early	7144	.	9	68	.	446	108
Late	3477	.	9.9	57	.	339	115
F-Test	***		***	***		***	***
Standard Error	76	.	0.07	0.24	.	2.5	0.52
Seeding Rate							
250 Seeds/m^2	5382	.	9.6	63	.	400	112
375 Seeds/m^2	5302	.	9.5	62	.	387	112
500 Seeds/m^2	5248	.	9.3	64	.	392	109
F-Test	NS		**	***		***	***
Linear	NS		***	***		**	***
Quadratic	NS		NS	**		**	*
Standard Error	93	.	0.08	0.29	.	3.1	0.63
Variety * Rate	NS		NS	NS		NS	NS
Rate * Date	***		***	***		***	**
Variety * Date	***		***	***		***	***
Variety * Rate * Date	NS		NS	NS		NS	NS
CV	7.43	.	3.58	1.99	.	3.31	2.41
Overall Mean	5311	.	9.5	63	.	393	111.2

(*) indicates significance at 0.05. (**) indicates significance at 0.01. (***)indicates significance at 0.001.

Lethbridge Rain-Fed 2010

Cultivar	Yield (kg ha^{-1})	Maturity (Days)	Protein (%)	Test Weight (kg hL^{-1})	Tillers (m^{-2})	Thousand Kernel Weight (mg)	Height (cm)
AC Andrew	3984	125	11.3	77	.	391	.
AC Ultima	5185	125	9.5	71	.	452	.
Bumper	5749	126	9.2	74	.	461	.
Bunker	5274	126	9.8	73	.	486	.
Pronghorn	5695	126	9.2	71	.	456	.
Sunray	5402	125	9.6	70	.	427	.
F-Test	***	***	***	***		***	
LSD	512	0.53	0.50	0.53	.	18.8	.
Seeding Date							
Early	4955	130	9.9	72	.	436	.
Late	5475	121	9.7	74	.	455	.
F-Test	***	***	NS	***		***	
Standard Error	148	0.15	0.15	0.15	.	5.4	.
Seeding Rate							
250 Seeds/m^2	5124	125	9.8	73	.	461	.
375 Seeds/m^2	5346	125	9.8	73	.	442	.
500 Seeds/m^2	5174	125	9.8	73	.	435	.
F-Test	NS	NS	NS	NS		***	
Linear	NS	*	NS	NS		***	
Quadratic	NS	NS	NS	NS		NS	
Standard Error	181	0.19	0.18	0.19	.	6.7	.
Variety * Rate	NS	NS	NS	NS		NS	
Rate * Date	NS	NS	NS	NS		NS	
Variety * Date	NS	NS	**	***		NS	
Variety * Rate * Date	NS	NS	NS	NS		NS	
CV	14.76	0.64	7.72	1.09	.	6.34	.
Overall Mean	5215	125.2	9.8	73	.	446	.

(*) indicates significance at 0.05. (**) indicates significance at 0.01. (***)indicates significance at 0.001.

Lethbridge Rain-Fed 2011

Cultivar	Yield (kg ha^{-1})	Maturity (Days)	Protein (%)	Test Weight (kg hL^{-1})	Tillers (m^{-2})	Thousand Kernel Weight (mg)	Height (cm)
AC Andrew	3705	.	11.5	77	.	386	.
AC Ultima	4761	.	10.2	72	.	465	.
Bumper	4588	.	9.4	72	.	473	.
Bunker	4617	.	10.4	70	.	467	.
Pronghorn	4964	.	9.9	68	.	452	.
Tyndal	3641	.	10.4	70	.	436	.
Sunray	4600	.	10.3	69	.	449	.
F-Test	***		***	***		***	
LSD	459	.	0.60	1.02	.	27.1	.
Seeding Date							
Early	4150	.	10.4	72	.	440	.
Late	4653	.	10.2	71	.	454	.
F-Test	***		NS	***		NS	
Standard Error	124	.	0.16	0.27	.	7.3	.
Seeding Rate							
250 Seeds/m^2	3838	.	10.1	71	.	448	.
375 Seeds/m^2	4509	.	10.3	71	.	446	.
500 Seeds/m^2	4858	.	10.5	72	.	448	.
F-Test	***		NS	*		NS	
Linear	***		*	*		NS	
Quadratic	NS		NS	NS		NS	
Standard Error	152	.	0.20	0.34	.	9.0	.
Variety * Rate	NS		NS	NS		NS	
Rate * Date	NS		NS	NS		NS	
Variety * Date	NS		NS	NS		NS	
Variety * Rate * Date	NS		NS	NS		NS	
CV	15.60	.	8.82	2.15	.	9.10	.
Overall Mean	4417	.	10.3	71	.	447	.

(*) indicates significance at 0.05. (**) indicates significance at 0.01. (***)indicates significance at 0.001.

Lethbridge Irrigated 2010

Cultivar	Yield (kg ha^{-1})	Maturity (Days)	Protein (%)	Test Weight (kg hL^{-1})	Tillers (m^{-2})	Thousand Kernel Weight (mg)	Height (cm)
AC Andrew	3101	.	10.3	70	.	328	.
AC Ultima	4771	.	9.7	68	.	518	.
Bumper	4668	.	9.5	68	.	530	.
Bunker	3917	.	10.9	65	.	516	.
Pronghorn	3123	.	10.7	59	.	455	.
Sunray	4140	.	10.4	63	.	442	.
F-Test	***		***	***		***	
LSD	580	.	0.24	1.30	.	16.5	.
Seeding Date							
Early	4364	.	10.2	71	.	535	.
Late	3450	.	10.3	60	.	406	.
F-Test	***		NS	***		***	
Standard Error	172	.	0.07	0.39	.	4.9	.
Seeding Rate							
250 Seeds/m^2	3767	.	10.2	66	.	475	.
375 Seeds/m^2	3987	.	10.2	66	.	472	.
500 Seeds/m^2	3967	.	10.4	66	.	464	.
F-Test	NS		NS	NS		NS	
Linear	NS		NS	NS		NS	
Quadratic	NS		NS	NS		NS	
Standard Error	216	.	0.09	0.49	.	6.1	.
Variety * Rate	NS		NS	NS		NS	
Rate * Date	NS		NS	NS		NS	
Variety * Date	***		***	***		***	
Variety * Rate * Date	NS		NS	NS		NS	
CV	21.27	.	3.35	2.88	.	5.15	.
Overall Mean	3954	.	10.2	66	.	464	.

(*) indicates significance at 0.05. (**) indicates significance at 0.01. (***)indicates significance at 0.001.

Lethbridge Irrigated 2011

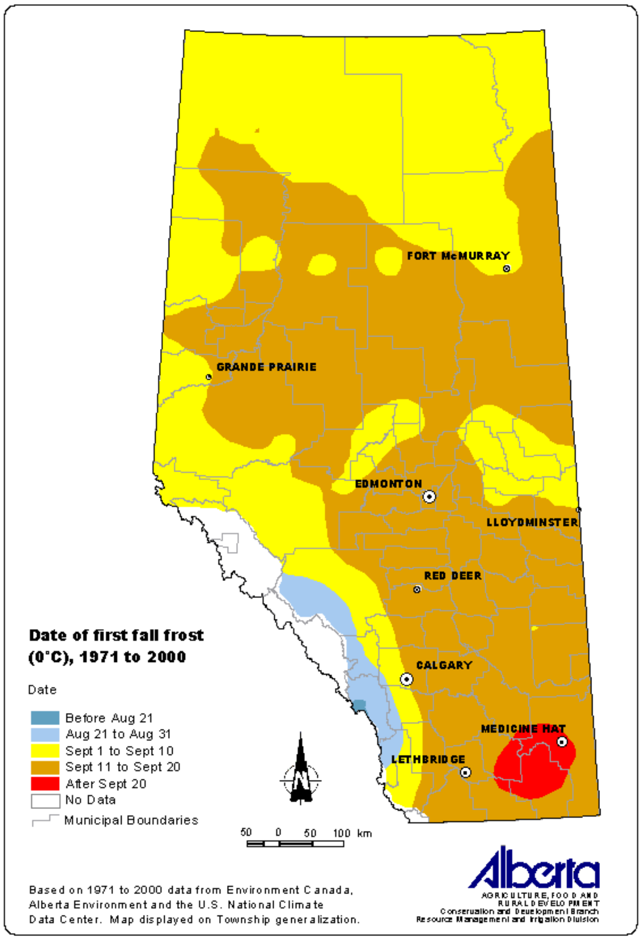
Cultivar	Yield (kg ha^{-1})	Maturity (Days)	Protein (%)	Test Weight (kg hL^{-1})	Tillers (m^{-2})	Thousand Kernel Weight (mg)	Height (cm)
AC Andrew	5192	.	11.9	77	.	349	.
AC Ultima	6563	.	10.7	72	.	502	.
Bumper	6807	.	10.5	74	.	520	.
Bunker	6188	.	11.3	72	.	549	.
Pronghorn	7119	.	10.9	69	.	495	.
Tyndal	5263	.	11.3	71	.	490	.
Sunray	6263	.	10.5	66	.	455	.
F-Test	***		***	***		***	
LSD	491	.	0.66	3.79	.	21.8	.
Seeding Date							
Early	5618	.	11.2	70	.	473	.
Late	6780	.	10.9	72	.	487	.
F-Test	***		NS	NS		*	
Standard Error	132	.	0.18	1.02	.	5.9	.
Seeding Rate							
250 Seeds/m^2	5660	.	11.1	72	.	487	.
375 Seeds/m^2	6261	.	11.1	70	.	472	.
500 Seeds/m^2	6676	.	10.9	72	.	480	.
F-Test	***		NS	NS		NS	
Linear	***		NS	NS		NS	
Quadratic	NS		NS	NS		NS	
Standard Error	162	.	0.22	1.25	.	7.2	.
Variety * Rate	NS		NS	NS		NS	
Rate * Date	NS		NS	NS		NS	
Variety * Date	NS		NS	NS		NS	
Variety * Rate * Date	NS		NS	NS		NS	
CV	11.95	.	9.01	8.01	.	6.86	.
Overall Mean	6199	.	11.0	71	.	480	.

(*) indicates significance at 0.05. (**) indicates significance at 0.01. (***) indicates significance at 0.001.

Appendix 3: Percentage of model sum of squares accounted for by each effect from ANOVA.

Effect	Yield (kg/ha)	Maturity (Days)	Protein (%)	Test Weight (kg/hL)	Thousand Kernel Weight (g)	Height (cm)	Tillers (m^{-2})
All Sites 2011							
Cultivar (C)	3.3	17.7	13.9	28.2	24.9	63.5	59.0
Seeding Date (D)	4.2	33.8	0.5	8.4	14.2	29.6	6.1
Seeding Rate (R)	2.2	13.1	<0.1	1.8	0.7	<0.1	13.8
C × D	0.3	8.5	0.4	1.5	0.2	4.6	1.2
C × R	0.2	9.8	0.8	2.9	1.5	0.6	9.1
R × D	<0.1	0.7	0.5	0.6	0.3	0.5	<0.1
C × D × R	0.2	10.3	1.6	2.8	0.6	0.7	9.4
Central Alberta 2010							
Cultivar (C)	4.4	2.4	26.6	4.8	15.0	41.4	27.0
Seeding Date (D)	56.7	77.2	5.6	43.6	28.6	2.3	25.7
Seeding Rate (R)	0.5	1.4	1.9	2.0	0.3	0.5	4.3
C × D	1.1	3.5	3.8	8.2	3.3	0.5	17.5
C × R	0.4	2.7	1.0	0.2	0.4	2.1	5.8
R × D	0.6	3.7	2.5	1.0	0.3	0.2	11.4
C × D × R	0.4	5.4	1.3	0.3	0.6	1.2	3.8
Southern Alberta 2010							
Cultivar (C)	3.6	0.5	20.4	12.4	14.8		
Seeding Date (D)	1.2	96.3	<0.1	12.2	17.9		
Seeding Rate (R)	0.4	0.3	0.6	<0.1	1.6		
C × D	9.0	<0.1	3.2	5.2	5.7		
C × R	0.4	0.2	1.4	0.1	0.4		
R × D	0.6	<0.1	1.0	<0.1	<0.1		
C × D × R	0.9	0.3	4.0	0.2	0.4		

Appendix 4: Date of first expected frost, and calculated seeding deadlines for triticale grain production in Alberta.



The dates by which triticale must be seeded at each location in Alberta in order to reach physiologic maturity (accumulate ~1750 GDD_{b0}) before the first expected frost at Edmonton, Lacombe, and Lethbridge, Alberta from 2007 to 2011 respectively.

Year	Edmonton*	Lacombe**	Lethbridge***
2011	May 22	May 13	June 12
2010	May 17	April 20	May 31
2009	May 27	May 5	June 12
2008	May 26	May 11	June 6
2007	May 30	May 16	June 18
Long Term Normals****	**May 21**	**May 14**	**June 6**

(*) First expected frost September 11. (**) First expected frost September 15. (***) First expected frost September 20. (****) Normals are estimates of the long term average based on the Alberta Agro-Climatic database. Image taken with permission from: AARD (2011a) http://www.agric.gov.ab.ca/app116/quick.jsp#.