# EXAMINING THE GROWTH AND NITROGEN ECONOMY OF ORGANICALLY SELECTED SPRING WHEAT CULTIVARS

By

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## ABSTRACT

Wiebe, Laura A., The University of Manitoba, 2014. Examining The Growth and Nitrogen Economy of Organically Selected Spring Wheat Cultivars. Major Professor; Martin H. Entz.

The nitrogen uptake of organically selected and conventional spring wheat cultivars was assessed throughout the growing season. High protein yielding advanced lines (F8) were selected from the Agriculture and Agri-Food Canada and the University of Manitoba's joint organic breeding program. Fourteen lines were examined in 2009 and eleven were examined in 2010. An additional organically selected line BW881 from the University of Saskatchewan's organic breeding program was included in 2009. The organic breeding lines were compared with check cultivars ('5602 HR', 'Kane', 'McKenzie', 'Cadillac' in 2009 and 2010, and 'AC Barrie' in 2009 only). Combined analysis of the four study site years found significant differences between the organic and check cultivars. The organic lines were found to have higher average yield, grain N yield, kernel density, HI, and NHI while the check cultivars were found to have higher average grain protein. No significant differences were observed between organic lines and the check cultivars for biomass and N biomass accumulation. The strong performance of the organic breeding lines compared to their conventional counterparts for several key parameters is a positive indication of the benefits of specialized breeding programs. The organic lines were more efficient at transferring accumulated biomass into the final grain product. The higher organic grain N yields also indicated that the organic lines were more efficient at transferring accumulated N into the grain. The higher yield of the organically selected lines indicates that they were better able to cope with the environmental stresses associated with organic growing conditions. The organically selected lines did not extract significantly higher amounts of soil N than the check cultivars but were more efficient at remobilizing accumulated N into the final grain product than the conventionally selected checks.

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# 1. INTRODUCTION

Organic agriculture is a production system that does not utilize synthetic fertilizers, synthetic pesticides, or genetically modified organisms (Mason and Spaner 2006). The lower input costs, rising consumer demand, and increased grower independence are just some of the reasons growers are making the decision to farm organically (Entz *et al.* 2001). In addition Organic farming is thought to be an environmentally friendly and more sustainable farming system (Pang and Letey 2000). Lynch (2009) reviewed empirical evidence on the environmental impacts of organic agriculture, organic farming systems were found to have improved soil organic matter storage and soil health, increased plant and wildlife biodiversity, increased energy efficiency, and reduced off-farm nutrient losses.

Wheat (*Triticum aestivum L*) is one of the most important crop species worldwide. In Canada there were approximately 9.8 million hectares of total wheat seeded in 2014 (StatsCan 2014). In 2011 there were approximately 6.8 million hectares of spring wheat (excluding durum) seeded in Canada. The area of wheat harvested worldwide was over 214 million hectares in 2007 (FAOStat 2007). In 2012, field crops made up 38.5% of the organically managed farm land in Canada with approximately 291 500 hectares (Levert, 2014). Wheat was the most important organic field crop in Canada and represented one quarter of the organic field crop acreage with 82 186 hectares (Levert, 2014).

Currently, breeding of most new varieties is done under conventional management conditions. Studies have indicated that the environmental conditions of organic management differ significantly from those of conventional management, and

that there is much greater environmental variability within organic agriculture (Mason and Spaner 2006, Murphey *et al.* 2007, Mason *et al.* 2007, Kirk *et al.* 2012). Organic soil fertility levels are one such environmental variability that can differ significantly from conventionally managed environments. Soil N fertility under conventional management may be more precisely controlled using additions of highly soluble synthetic N fertilizers while organic management utilizes slow-release organic N sources. Mason and Spaner (2006) suggest that the environmental differences and the associated stresses that the plants experience under the two types of management are significant enough to require breeding programs specifically targeted to the intended growing environment. Plants growing under organic conditions experience different stresses such as a decrease in the available nutrients, increased weed pressure, and increased insect and disease pressures. An organic breeding program would focus on improving the nutrient use efficiency, adaptation to soil microbes, improved competition with weeds, and resistance to insects and diseases (Murphy *et al.* 2007). Both organic and low input farming systems would benefit from crops bred for improved nitrogen use efficiency (Dawson *et al.* 2008).

Low input and organic systems derive N from sources that are different than conventional systems, where soluble synthetic nitrogen fertilizers are common (Dawson *et al.* 2008). In organic systems the nitrogen available is from biologically-fixed or manure sources that are mediated through soil microbial activity (Good *et al.* 2004). Wheat is a fast growing crop species that has high nitrogen demands (Glass 2003). Plant use of nitrogen includes uptake, assimilation, translocation and remobilization (Good *et al.* 2004). Typically, wheat is thought to take up 80-90% of its final nitrogen by anthesis and that the nitrogen within the plant is remobilized during grain filling to the ears (Barneix *et al.* 1992). One question is whether the

lower N availability in organic systems can provide adequate early season N to satisfy wheat N needs, and in particular is there genetic variation for early N uptake within wheat.

A higher protein yielding line may be more efficient at taking up more nitrogen, better at remobilizing the nitrogen within the plant or some combination of the two factors (Wang *et al.* 2003, Barraclough *et al.* 2014). Barraclough *et al.* 2014 observed a substantial genotypic range in post-anthesis N uptake of 15 – 60 kg $ha^{-1}$. They also observed a wide genotypic range in the amount of N remobilized from vegetative organs during grain filling with 20-34 kg $ha^{-1}$ N remobilized under no added N and a range of 99-153 kg $ha^{-1}$ of N remobilized when grown with 200 kg N $ha^{-1}$ fertilizer added. While many studies focus on the above ground N it is also thought that organic cultivars should have larger and more extensive root systems for increased nutrient uptake in order to cope with the lower nutrient levels of organic fields (Lammerts van Bueren *et al.* 2002).

Plant breeders developing new cultivars of Canadian Western Red Spring Wheat (CWRS) have a challenging task of improving yields while maintaining the necessary protein content required for bread quality (Wang *et al.* 2003). Mason *et al.* (2007) reported that cultivars grown under organic management tended to have higher dough strength compared with when they were grown under conventional management. They also found that the organically grown cultivars had comparable protein and overall yield to the conventionally grown cultivars and met the grading requirements for CWRS. Recently there has been an increase in consumer demand for organic wheat products, which are perceived as being more nutritious (Mason *et al.* 2007). The question of whether organic food is more nutritious than conventionally

produced food has arisen again and again. Some studies suggest that organically produced food has higher essential mineral content and may be more nutritious than conventionally produced food (Smith 1993, Worthington 1999).

Creating high yielding lines is one of the top priorities of any breeding program. Quality for end use as well as yield and yield stability are important characteristics needed when breeding for organic agriculture (Wolfe *et al.* 2008). Organically bred lines need to perform well and be competitive with yields attained in conventional production. With increasing concerns about the environmental impacts of conventional agriculture there is an even greater need for wheat varieties that can grow well under organic conditions while maintaining high yields and quality. Organic lines that are more efficient at taking up and translocating nitrogen to the grain are needed in order to meet the necessary yield and quality requirements.

## Rationale

The purpose of this project is to assess the growth and nitrogen economy of organically selected wheat lines. The goal is to assess if breeding under organic conditions is selecting for genotypes with improved yield and nitrogen capture characteristics. In particular this study aims to determine whether the organically selected cultivars are able to translocate more of the accumulated carbon and nitrogen into the final grain improving the overall harvest index (HI) and nitrogen harvest index (NHI) respectively. This study examined advanced organic breeding lines (F8 in 2009 and F9 in 2010) from the University of Manitoba and Agriculture and Agri-Food Canada's joint spring wheat organic breeding program. Measuring yield and protein content give an indication of the genetic potential of these lines but more detailed information about when nitrogen is taken up throughout the growing season

will be valuable in determining what lines would be best suited for different environments. This agronomic and N economy information will improve our understanding of how the organic cultivars are performing and will be helpful when making future selections..

Study Hypotheses:

1. Organically selected wheat genotypes will be selected to better able to cope with the stresses associated with organic growing conditions, and as a result will yield higher than check cultivars when grown in organic environments.

2. Wheat selected under slow-release organic N sources (green manures) will have superior soil N capture abilities than wheat lines selected under conditions of highly soluble N.

3. Organically selected wheat genotypes will remobilize and translocate accumulated N during grain filling more efficiently than conventionally selected wheat lines selected under conditions of highly soluble N.

# 2. LITERATURE REVIEW

## 2.1 Organic Agriculture

The Canadian General Standards Board defines organic agriculture as "… a holistic system designed to optimize the productivity and fitness of diverse communities within the agroecosystem, including soil organisms, plants, livestock and people." (CGSB 2006). Organic agriculture is a production system that does not utilize synthetic fertilizers, synthetic pesticides, or genetically modified organisms (Mason and Spaner 2006). Instead organic growers must rely on diverse crop rotations to provide nutrients to the system. The lower input costs, rising consumer demand, and increased grower independence are just a few of the reasons growers are making the decision to farm organically (Entz *et al.* 2001). Farmers also cite environmental sustainability as one of the reasons they choose to farm organically. Organic farming is thought to be an environmentally friendly and more sustainable farming system (Hole *et al.* 2005). Lynch (2009) reviewed empirical evidence on the environmental impacts of organic agriculture, organic farming systems were found to have improved soil organic matter storage and soil health, increased plant and wildlife biodiversity, increased energy efficiency, and reduced off-farm nutrient losses.

### 2.1.1 Soil Fertility

The increase of global food production in the past four decades has been associated with a substantial increase in the use of synthetic nitrogen fertilizers. A

review by Glass (2003) reported a twenty-fold increase in synthetic N fertilizer use over the past fifty years, while the recovery rates of crop species remain quite low. Raun *et al.* (2002) reported worldwide N fertilizer recovery rates ranged between 30 and 50%. These relatively poor recovery rates mean a large percentage of the applied N is unreachable to the crop or is being lost from the system. The increased use of synthetic fertilizers has had a detrimental effect on the environment, impacting the diversity and functioning of neighboring non-agricultural plant, animal, and bacterial ecosystems (Glass 2003, Hole *et al.* 2005). The increasing global population and projected increases on the food supply system makes improving production efficiency while protecting the environment a top priority.

Organic systems differ from conventional farming systems in a number of key ways including: soil fertility, weed management and distribution of soil microflora (Entz *et al.* 2004). According to Baresel *et al.* (2008) the greatest differences between organic and conventional management systems are found in soil management practices and in processes within the rhizosphere. Low input and organic systems have different sources of nitrogen than conventional systems that utilize high levels of synthetic nitrogen fertilizers (Dawson *et al.* 2008). Green manure cover crops are used in organic systems as a soil amendment and nutrient source for subsequent crops. Organic systems rely on legume green manures as a way to increase the soil N content. A recent survey of Canadian organic and conventional farm practices found that 84% of organic farmers utilize green manure cover crops (Nelson *et al.* 2010). A primary benefit of using green manure N source is the long-term replenishment of stable organic N reserves in the soil (Janzen *et al.* 1990). They observed that between 24 and 59% of the green manure applied N was recovered from the surface soil, and was predominantly in organic form. Comparatively only 12 to 24% of the ammonium

applied fertilizer was recovered from the surface soil layer, approximately half the amount recovered from green manure N. The organic matter content is a key measure of soil health and quality, soils that are able to sequester more carbon also sequester N. This strategy to increase the indigenous N supply is the power of organically managed soils, through C and N additions and is the primary nutrient management tool for organic growers.

Release of N from crop residue, green manure, and livestock manure does not follow the same patterns as inorganic fertilizer. Janzen *et al.* (1990) compared the use of legume green manures and ammonium fertilizer subsequently cropped to spring wheat. They found that the subsequent spring wheat crop recovered 14% of the green manure N compared with 36% of the fertilizer N. The initial release of plant-available N is determined by N concentration and decomposition rate, which is faster under warm moist conditions (Olson-Rutz *et al.* 2011). The soil microbial community plays an important role in nutrient cycling and soil fertility and is of great importance in organic cropping systems (Hansen *et al.* 2001). There can be significant differences in the availability of macronutrients during the growing season between organic and conventional systems (Lammerts van Bueren *et al.* 2011).

### 2.1.2 Weed Management and Ecology

The lack of synthetic inputs can create additional production challenges for organic growers as it can limit their weed management options. Organic growers use diverse rotations, soil-fertility building crops, and mechanical weed control more than their conventional counterparts (Lampkin *et al.* 2000). Organic weed management is

often undertaken through a whole system approach where crop rotation is the main focus (Bond and Grundy 2001). Weed populations are often reported as being much higher in organic systems than in conventional systems (Hole *et al.* 2005). Hald (1999) reported that the density of weeds or non-crop flora in conventional cereal fields was a third of the density in organic cereal fields. A number of studies however, have reported higher species richness including more rare and declining species and in some cases observed lower total weed populations in organic systems (Ngouajio and McGiffen 2002, Hole *et al.* 2005). Grass weed species tend to show less variation in density between organic and conventional fields while broad-leaved weed species that are more readily controlled by conventional herbicide treated fields show greater differences (Moreby *et al.* 1994, Hald 1999, Rydberg and Milberg, 2000). Ngouajio and McGiffen (2002) discussed weed seed and seedling predation as well as physical and allelopathic effects of cover crops as being factors that contribute to weed suppression in organic agriculture. Organic systems also utilized undersowing of crops and the inclusions of cover crops like clover-ryegrass in the rotation to limit the weed density in organic fields (Welsh *et al.* 1999).

In addition to increased weed species diversity, higher numbers of rare or endangered weed taxa have been found on long-term organic farms compared with conventional farms. These findings have resulted in the suggestion that organic production systems may contribute to maintaining plant biodiversity in agroecosystems (Stinner 2007). A review conducted by Hole *et al.* (2005) examined the impact of organic farming on biodiversity. In their review Hole *et al.* (2005) reported that of the 76 studies they reviewed the majority clearly demonstrated an increase in species abundance and/or richness across a wide-range of taxa of both flora and fauna. An increase in biodiversity within organic fields may mean that there

is increased competition in a wider number of niches within the crop canopy. Wheat genotypes adapted for organic field conditions may have to possess multiple characteristics that increase their competitive ability against a wider variety of weed flora. Some studies have suggested taller varieties are correlated with improved competitive ability, because they are better able to compete for light (Cudney *et al.* 1991). Leaf architecture, leaf area index, and the rate of canopy closure are also characteristics that impact the competitive ability of a plant (Wolfe *et al.* 2008).

### 2.1.3 Crop Yields in Organic Systems

The absence of synthetic fertilizers makes achieving competitive yields more of a challenge for organic growers but certainly not an unattainable goal. Numerous experimental comparisons between organic and conventional systems have cited a wide range of yield differences. The range of yield differences between production systems depends on the site and crop (Annicchiarico *et al.* 2010). A 6-year study of 14 organic farms in the eastern portion of the northern Great Plains found that hard red spring wheat, oat, flax and field pea crops yielded 77%, 73%, 78% and 67% of long-term conventional averages, respectively (Entz *et al.* 2001). Organic hard red spring wheat yields in the study ranged from 672-2690 kg $ha^{-1}$. Murphy *et al.* (2007) reported an average reduction of 25% of organic yields relative to conventional. Arncken *et al.* (2012) reported a three year average reduction of 42% of organic winter wheat yields relative to conventional yields. A 22 year study at the Rodale Institute Farming System Trial compared organic and conventional farming systems. A review of the 22 year Rodale study by Pimental *et al.* (2005) concluded that while dependent on the crop, soil and weather conditions organically managed crop yields

can equal those of conventional production systems. Yields obtained under organic management are also impacted by length of time the land has been managed organically (Scow *et al.* 1994). While the first few organic transition years tend to see a higher yield reductions corn yields from an organic animal, organic legume, and conventional systems were found to be comparable after a five year transition period (Pimental *et al.* 2005).

### 2.1.4 Specialized Breeding Programs

When possible, organic growers are expected to use certified organic seed and transplants. Not only are organic growers limited in the availability of varieties bred specifically for organic environments, they are also limited in the availability of certified organic seed from seed growers. A lack of readily available organically grown seed is an issue for growers with many relying on grain they have grown themselves as their spring seed source. The use of organic seed is thought to be vital in maintaining the integrity of the system (Wolfe *et al.* 2008). Currently organic agriculture relies for the most part on varieties from conventional breeding programs (Wolfe *et al.* 2008).

The development of most new varieties is currently done under conventional conditions. Studies have indicated that the environmental conditions of organic management differ significantly from those under conventional management, and that there is much greater environmental variability within organic agriculture (Mason and Spaner 2006, Murphy *et al.* 2007, Mason *et al.* 2007, Kamran *et al.* 2014). Mason and Spaner (2006) suggest that these differences and the associated stresses that the plants

experience under the two types of management are significant enough to require breeding programs specifically targeted to the intended growing environment. Kirk *et al.* (2012) confirmed that the direct selection in organically managed field conditions is preferable to indirect selection in conventionally managed field conditions. Kirk *et al.* (2012) reported that populations selected under organic management had higher yields, protein content and kernel weights when grown under organic management compared to conventionally selected populations. Plants growing under organic conditions experience different stresses such as a decrease in the available nutrients, increased weed pressure, and increased insect and disease pressures.

Breeding for Organic agriculture must take into account the whole system management and selections should be guided by the needs of the whole system as well as the end use product (Wolfe *et al.* 2008). In-vitro techniques are considered by the International Federation of Organic Agriculture Movements (IFOAM) to be in conflict with organic agriculture's principles of 'naturalness' and are not currently utilized in organic breeding programs. According to IFOAM organic plant breeders must utilize genetic material that has not been contaminated by products of genetic engineering (IFOAM, 2012). The principles state that the genome is to be respected as an impartible entity, banning any technical interventions into the genome such as ionizing radiation, or the transfer of isolated DNA, RNA or proteins (IFOAM, 2012). The use of marker assisted selection is a possible tool for organic breeders however the constraints of a relatively small market size and concerns of potential conflicts with respecting plant integrity has limited their use in current organic breeding programs (Wolfe *et al.* 2008).

According to Murphy *et al.* (2007) an organic breeding program should ideally focus on improving the nutrient use efficiency, adaptation to soil microbes, improved competition with weeds, and resistance to insects and diseases. Current organic breeding programs are striving to develop varieties that are agronomically competitive with their conventional counterparts without sacrificing quality. Organic cereal crop breeding in Canada is currently being conducted with funding from the Organic Science Cluster and is focused on identifying superior Canadian Western Spring wheat and food quality oats that are better adapted for organic production systems in Canada. Work is being carried out by a number of Canadian researchers including: Jennifer Mitchell Fetch at Agriculture and Agri-Food Canada, Pierre Hucl at the University of Saskatchewan, Dean Spaner at the University of Alberta, and Martin Entz at the University of Manitoba (OACC, 2014). One of the key ways to maintain and increase organic grain protein content and subsequently baking quality is by improving the nitrogen utilization efficiency of new organic genotypes. Knowledge of nitrogen accumulation to the grain is valuable to breeding programs striving to improve yield and quality (Andersson *et al.* 2004).

Kirk *et al.* (2012) compared organic and conventional selection environments for spring wheat to assess whether or not direct selection in organic environments was superior to indirect selection in conventionally managed environments. Selections were made in wheat populations from a common $F_2$ seed source that was split and grown under both organic and conventional management. The subsequent organic and conventional populations were then both tested under both management types. Results showed that wheat selected under organically managed environments produced populations that yielded higher when tested under organic environments than populations with indirect selections under conventional management. Kirk *et al.*

(2012) asserted that selection in organic environments constitutes selection under increased stress compared to the highly controlled through inputs environments of conventional agriculture. Selection under the increased stress environments of organic systems may result in more competitive lines that are better adapted to lower nutrient levels, which has the potential to benefit both organic and conventional growers.

There is a general perception that organically grown products are healthier and more nutritious than their conventionally produced counter parts. Lammerts van Bueren *et al.* (2011) assert that plant breeders developing varieties for the organic sector should incorporate selection for nutritional quality parameters in their breeding programs. A study by Murphy *et al.* (2008) examined the grain yield and concentration of eight minerals including iron, calcium, zinc, and magnesium from sixty-three historical and modern wheat cultivars. They observed that while grain yield increased over time the concentrations of all minerals (with the exception of Calcium) have decreased in the modern cultivars. The highly significant variation in mineral content found in this study among the wheat cultivars indicates the potential for genetic improvement.

## 2.2 Wheat

### 2.2.1 Origin and Importance

Wheat (*Triticum aestivum* L.) is a member of the Graminae family native to western Asia (Cornell, 1998). The cultivation of wheat and its ancient relatives can be traced back to the middle east as far back as 10 000 to 8000 BCE. The earliest

cultivated species were diploid einkorn and tetraploid emmer wheats (Shewry, 2009). Wheat species of the genus *Triticum* are classified according to their ploidy level, as diploid, tetraploid and hexaploid wheat species. Common wheat *Triticum aestivum* is a hexaploid bread wheat and is the most widely grown species of wheat making up 95% of the wheat grown worldwide (Shewry, 2009). Club (*Triticum compactum*) and durum (*Triticum* durum) species make up the other 5% of cultivated wheat species (Cornell, 1998; Shewry, 2009). Durum wheat is also sometimes referred to as pasta wheat reflecting its primary end use (Shewry, 2009).

Wheat is a significant food crop worldwide, and provides more nutrients for humans than any other source of food (Curtis 2002, Peña 2002). The unique properties of doughs formed from wheat flour account in large part for its global dominance. The properties of wheat dough depend on the interactions of the prolamin storage proteins which form a gluten protein fraction (Shewry, 2009). The exact number of gluten protein components has not been confirmed but studies suggest that there may be approximately 100 components. These 100 components have been estimated to make up roughly 80% of total grain protein (Seilmeier *et al.*, 1991). The total grain protein content is considered an indicator of flour strength and bread making quality as it corresponds with the gluten content (Ceseviciene *et al.* 2011). Gluten is the dough forming protein of wheat flour and is an elastic protein complex, which is able to trap gasses and form air bubbles during baking resulting in a leavened loaf. These unique gluten proteins allow wheat dough to be processed into a wide range of baked products making it one of the most important crop species worldwide (Khan and Shewry, 2009).

### 2.2.2 Production

Wheat is sown over a vast area worldwide due to its adaptation to diverse environmental conditions. In 2008 the top wheat producing countries in the world were China, India, The United States of America, Russia, and Canada (FAOSTAT, 2009). In 2011 the area of wheat grown worldwide was estimated to be more than 220 million hectares. Global wheat production in 2011 was approximately 7.04 billion tonnes (FAOSTAT, 2011). In Canada there was approximately 10 million hectares of wheat seeded in 2011 and Canadian wheat production was over 25 million tonnes (FAOSTAT, 2011). In 2012, field crops made up 38.5% of the organically managed farm land in Canada with approximately 291 500 hectares (Levert, 2014). Wheat was the most important organic field crop in Canada and represented one quarter of the organic field crop acreage with 82 186 hectares (Levert, 2014).

Canada is known as a producer of high quality wheat. Canadian western red spring wheat varieties (CWRS) are typically used for bread making and possess good milling properties (Khan and Shewry, 2009). It has been shown that bread loaf volume is directly related to wheat protein content (Khan and Shewry, 2009). CWRS wheat has a high export demand by countries looking to improve the baking qualities of their flour products (Curtis 2002). Major importers of Canadian wheat include; Mexico, Japan, Iraq, the United States, and Colombia. Between 2011 and 2012 Canada exported over 13 million tonnes of wheat (Canadian Grain Commission, 2012).

### 2.2.3 Wheat Growth and Yield

#### 2.2.3.1 Wheat Growth

Growth of the wheat plant is influenced by environmental factors such as nutrient availability, photoperiod, temperature, as well as water availability affects crop physiology throughout the growing season. Temperature affects wheat growth from germination to maturity. Certain development stages are more influenced by temperature than others. The effect of temperature is based on thermal time, which is an expression of the summation of differences between daily mean temperature and base temperature (Miralles and Slafer 1999). Seedling elongation and emergence has been found to increase linearly between 5 and 25 °C (Addae and Pearson 1992). Low temperatures early in the growing season can lead to delayed emergence and may limit competitive ability and nutrient uptake. The period between emergence and floral initiation is known to be highly dependent on temperature, the more thermal time accumulated, the faster the crop advances (Miralles and Slafer 1999). Elevated temperatures throughout the grain-filling period can shorten the grain filling period; increasing the likelihood of decreased kernel size (Wrigley *et al.*, 1994). Given the likelihood of kernel size decrease, yield losses can occur in years where the period of grain filling coincides with hot conditions. Dough strength tends to increase as temperature during grain fill increases from 15 to 30 ºC, but a temperature over 30 ºC generally decreases dough strength (Wrigley *et al.*, 1994). Weak correlations have been observed between increased temperatures during grain filling and protein content, which is directly related to dough strength (Johnson *et al.* 1972, Rao *et al.* 1993).

Shortage of water is one of the key factors limiting cereal yields on the Canadian prairies (Campbell *et al.* 1981). Adequate soil water availability is the primary requirement for seed germination and seedling development (Dennett 1999). Early season drought stress can lead to poor germination and reduced seedling emergence. Water stress post emergence, delays leaf emergence, may reduce tillering, and can decrease the number of spikelets (Miralles and Slafer 1999). The most critical stage for water stress is during the reproductive phase. Water deficits during the reproductive phase can decrease photosynthetic activity and reduce the number of kernels that develop. Entz and Fowler (1990) reported that reduced productivity associated with pre-anthesis drought stress was related to a reduction in dry matter accumulation, kernel production and HI. Water stress during grain filling accelerates senescence, resulting in decreased grain weight (Miralles and Slafer 1999, Fageria *et al.* 2008).

2.2.3.3 Biomass and Harvest Index

The amount of above ground biomass accumulated throughout the growing season is the plants energy source for grain filling and has been found to correlate with yield components. A study by Bindraban *et al.* (1998) found that biomass at anthesis explained 72% of the variation in kernel number but that the relationship was strongly cultivar specific. Malhi *et al.* 2006 reported that conventionally grown spring wheat biomass accumulation a maximum of 7600 - 9000 kg $ha^{-1}$ from an experiment in Saskatchewan. Bullied *et al.* (2002) while examining the grain yield and N benefits to sequential wheat crops from a single year of forage crops reported similar above ground spring wheat biomass levels ranging from 7100 to 8600 kg $ha^{-1}$. In a review of

the literature it was found that a large proportion of papers excluded discussions on biomass instead focusing on yield, HI, and grain protein. This may reflect a previously held notion by crop improvers that above ground biomass itself was not a key parameter. This idea however is shifting as many crop physiologists now view biomass as key to yield increases particularly in crops where future HI improvements are limited. In a review of breeding and cereal yield progress Fischer and Edmeades (2010) asserted that current genetic progress in increasing potential cereal yields is linked to increased biomass.

The relationship between above ground biomass accumulation and yield can be further explored by calculating the harvest index, the proportion of grain weight to total plant biomass. The harvest index indicates how efficiently a plant converts dry matter into grain yield (Fischer and Kohn 1966). Harvest Index appears more a more stable parameter than yield when measured in different environments (Hay 1995). The review by Hay (1995) reported spring wheat harvest index values from a number of previous studies which were found to be between 30 and 50%. As breeding efforts continue the HI values of new cereal varieties are approaching 50% (Fischer and Edmeades 2010).

#### 2.2.3.2 Yield Components

Three primary yield components are responsible for determining yield in wheat: head density (the number of heads per unit area), kernels per head, and kernel weight. Management practices have different effects on the three yield components. Management practices altering one yield component will likely lead to changes in the other components as a result of internal and interplant competition (Campbell *et al.*,

1977). Increasing the number of kernels per unit area could also increase the yield potential of wheat (Bindraban *et al.*, 1998). Shekoofa and Emam (2008) found an association between the density of fertile tillers and yield. Work by Bulman & Hunt (1988), found a linear association between higher total spike density and higher yield, while kernel weight was not the major factor in increasing yields in their study. Low tiller numbers can only be partly overcome by kernels per spike and kernel weight. The observed stronger relationship between kernel number (KNO) and yield than kernel weight and yield indicates that wheat may be more sink limited when it comes to yield potential. Breeding efforts targeting increased yields may therefore want to focus on selecting for genotypes with an increased number of kernels per head and increased production of fertile tillers.

Previous studies have shown that a critical period in the determination of kernel density (KNO) coincides with a period of high stem and head growth. A limitation in KNO because of floret abortion may be a result of competition between the stem and ear for resources (Bindraban *et al.*, 1998 and references therein). Entz and Fowler (1990) discussed the relationship between KNO and the production of dry matter at anthesis. They observed that at high stress levels, KNO was associated with increases in dry matter at anthesis. The ratio of KNO per unit of dry matter at anthesis has been referred to as the kernel production efficiency of a cultivar (Fischer, 1979).

Breeding programs are looking for cultivars with both high yield potential and stability across a variety of conditions (Mohammadi and Amri 2013). Yield can be static or dynamic (i.e. changes in a predictable manner). A genotype has a stable yield if it performs consistently despite changes of the environmental conditions, static stability would see no changes between environments, while dynamic stability

would see yield increase or decrease in a predictable manner (Tollenaar & Lee, 2002). The stability of performance can be viewed as the ability to exhibit a minimal interaction with the environment (Eberhart and Russell 1966).

Finlay and Wilkinson's stability analysis uses the mean of all genotypes being evaluated in an environment as that environments environmental yield index (Finlay and Wilkinson 1963). Finlay and Wilkinson (1963) used a model that had the variety yields regressed on an environment index defined as the difference between the mean yield of the environment and the overall mean. In their model the regression coefficient for each variety or genotype was used as the measure of stability (Finlay and Wilkinson 1963).The variance of a cultivar when grown in different environments has also been used as a measure of stability, a low variance considered to be indicative of a stable cultivar (Abdulai *et al.* 2007). Eberhart and Russell (1966) estimated the mean square of deviation from the regression as an additional stability parameter, with the regression coefficient and the deviations from regression describing the performance of a genotype over various environments. A popular model the additive main effects and multiplicative interaction model (AMMI) has been utilized widely for analysis of performance stability (Badu-Apraku *et al.* 2003).

### 2.2.4 Wheat Quality

Wheat quality is based on its flour's bread making capabilities. According to Lammerts van Bueren *et al.* (2008) quality definitions can differ depending on the market class and the desired baking product. Grain protein content is one of the main components of bread-making quality. Additional quality parameters related to bread-making quality include protein quality, single kernel hardness, falling number, ash

content, flour colour, dough and gluten strength as well as full baking and milling tests. There are two main ways to improve baking quality: one is to improve protein quality and the other possibility is by improving nitrogen efficiency and thus the increasing grain protein content (Baresel *et al.* 2008).

The gluten complex consists of monomeric gliadin, which provides dough-viscosity and extensibility, and polymeric glutenin, which is responsible for dough strength and elasticity (Wieser, 2006). Protein content alone while an important bread making quality factor, is not a sufficient indicator of final loaf volume. Instead flour quality is more precisely dependent on a specific balance of gliadin and glutenin for bread making properties (Barak *et al.* 2013). Ceseviciene *et al.* (2011) examined the effects of production systems and cultivars on technological properties of winter wheat and found that grain from organic winter wheat had significantly lower protein and gluten contents. Conversely Mason *et al.* (2007) reported that cultivars grown under organic management tended to have higher dough strength compared with when they were grown under conventional management, which may have been a factor of decreased yields under organic management. Organic breeding programs need to focus on maintaining grain protein levels while increasing yields so that the grain produced can meet baking quality standards.

## 2.3 Nitrogen

### 2.3.1 Overview

Nitrogen (N) is an essential nutrient for the growth of plants. Nitrogen has a critical role in plant metabolism and can be a main yield limiting factor (Borghi 1999). Nitrogen is an important component of organic compounds such as proteins, nucleic acids, and chlorophyll (Fageria and Baligar 2005). While N makes up a small proportion of the plants total weight it is a crucial component as over 90 percent of plant N is tied up as protein protein (Borghi 1999). The internal structure of wheat contains large amounts of proteins meaning that growing plants have high N requirements (Cook and Veseth, 1991, Glass, 2003). A healthy crop of wheat in North America generally needs about 0.1 kg $ha^{-1}$ of N for every 1 kg of grain produced (Cook and Veseth, 1991 page 32). An average 2690 kg $ha^{-1}$ (40 bu/ac) crop of wheat will contain approximately 85-105 kg $ha^{-1}$ of N in the seed (Alberta Agriculture and Rural Development, Manitoba Soil Fertility Guide). Entz *et al.* (2001) reviewed the soil nutrient status on 14 organic farms in the eastern portion of the northern Great Plains and found average soil nitrate levels (0-60 cm) ranged from 60-131 kg $ha^{-1}$.

### 2.3.2 Soil-Plant N cycling

Transitioning for commercial fertilizer to organic forms leads to changes in soil fertility and other factors that can affect plant growth. Organically managed soil has been found to have higher organic matter content, higher N mineralization

potential, and higher microbial biomass levels than soil supplemented with synthetic fertilizers (Scow *et al.* 1994, Drinkwater *et al.* 1995). Wheat takes up nitrogen predominantly as ammonium and nitrate (Cook and Veseth, 1991). Nitrates are mobile in the soil because they have a negative charge and are leached by water. Ammonium has a positive charge and is less mobile in the soil; the roots of the plant must grow through the soil to reach the ammonium. Ammonium can be taken up by the roots but this uptake is likely too slow to meet the high nitrogen demands of the plant. All nitrates taken up by the plant are converted to ammonium once inside the plant and the ammonium is used in amino acids that make up the plant proteins (Cook and Veseth, 1991 page 32). Briefly, nitrate absorbed is reduced to nitrite in the cytosol by the enzyme nitrate reductase (NR), the nitrite once transported to the plastid or chloroplast is reduced to ammonium by the enzyme nitrite reductase (NiR), from there the ammonium is assimilated into amino acids (Foukles *et al.* 2009).

Matching soil inorganic N supply with temporal crop demands is an important factor to achieve high yields. Pang and Letey (2000) analyzed the dynamics of N mineralization of two manures (chicken and beef) and N uptake using corn (*Zea mays* L.) and wheat. They compared the temporal N-mineralization (availability to the plant) with N uptake curves of the two crops. They observed that for corn the potential N uptake for corn was greater than the available mineralized N during a significant period that would result in a yield reduction. Corn had a high early season uptake curve with a sharp peak while wheat had a comparatively flat N uptake curve. They found that the low and relatively flat uptake peak of wheat meant that the N demands of wheat did not exceed cumulative mineralized N. The maximum N uptake rate of corn was 10 kg $ha^{-1}$ $d^{-1}$ while the maximum N uptake rate of wheat was 3.5 kg $ha^{-1}$ $d^{-1}$. They concluded that wheat was a more suitable crop for organic soil

conditions than corn as it would not require excessive N in the soil in order to meet peak demands that could subsequently lost through leaching. Wheat genotypes with N uptake curves that better match the N mineralization rates of organic soils will perform better under organic management.

### 2.3.3 Nitrogen Uptake and Partitioning

Nitrogen uptake in wheat is dependent on the development stage of the crop and on the environment present at the different stages. A plant's use of nitrogen includes uptake, assimilation, translocation and remobilization (Good *et al.* 2004). The ability of a plant to accumulate N during the growing season is affected by a several factors. The root development, growth and duration of root hairs, nitrate reductase activity, and microorganisms of the rhizosphere in particular arbuscular mycorrhiza may affect N uptake (Baresel *et al.* 2008). The maximum rate of nutrient uptake and the maximum amount of nutrient uptake has been found to occur at tillering to stem elongation, and beginning of anthesis to mid milk stage, respectively (Malhi *et al.* 2006). Malhi *et al.* (2006) stressed that the supply of nutrients must be sufficient during early growth stages to ensure optimum crop yield. The amount of N present in the final grain is determined by the uptake of N during the growing season.

A study conducted by Wang *et al.* (2003) indicated that nitrogen uptake in the semi-arid prairie region is normally complete by anthesis. Other studies have reported that wheat accumulates approximately 80 – 90 % of its total plant N prior to reaching anthesis and the nitrogen within the plant is remobilized during grain filling to the ears (Barneix *et al.* 1992, Cregan and van Berkum, 1984). The contribution of post-

anthesis N accumulation to grain N content has been generally found to be low. The capacity of the plant to accumulate nitrogen (Corbellini and Borghi, 1985; Dhugga and Waines, 1989), the timing and rate of root senescence (Hageman and Shrader, 1979) as well as nitrogen and water availability during later growth stages have been suggested to be limiting factors for improving the post-anthesis accumulation of N in wheat.

Environmental conditions also impact the N uptake in wheat. High temperatures during grain fill affects the ability of the plant to efficiently translocate N from other plant parts, so more N may be lost from the plant, rather than put into the grain (Melaj *et al.*, 2003). These losses of N can occur in the form of volatilization from plant tissues during maturation (Palta & Fillery, 1993). In addition elevated temperatures during the maturation of wheat have been found to accelerate the rate of tissue senescence and leaf loss, which may be another potential source of N loss (Harding *et al.* 1990).

### 2.3.4 Nitrogen and Yield

Most of the N taken up by the roots is in the form of nitrate. Nitrate is assimilated into the plant to form organic compounds like proteins that are essential for plant structure and function (Miralles and Slafer 1999). Nitrogen availability impacts wheat development throughout its life cycle from tillering and continues until mid-milk (Zadoks 75 – Simmons 2014). Longnecker *et al.* (1993) examined the effects of N deficiency on leaf and tiller emergence, they looked at four levels of N supply (50, 200, 300 and 800 µM N) and observed a reduction in the rate of leaf

emergence in the lowest N treatment. They also observed a reduction in tiller bud initiation under the lowest N treatment and a delay or reduction in tiller emergence in all but the highest N treatment. Miralles and Slafer (1999) also reported that if an N deficiency occurs during tillering, there is a decrease in the number of tillers. A deficiency during terminal spikelet initiation results in a decrease in the number of spikelets per spike and the number of kernels per spike (Miralles and Slafer 1999). Longnecker *et al.* (1993) reported a delay in terminal spikelet production of approximately 2 days under reduced N treatments. An N deficiency during flowering could result in a decrease in seed setting and reduce final kernel number and limit yield potential (Cox *et al.* 1985).

Nitrogen is the most important nutrient in determining yield potential and is the most common limiting factor of productivity of agroecosystems (Fageria *et al.* 2006). A negative correlation between protein concentration and grain yield has been widely observed (Payne, 1983). Andersson and Johansson (2006) defined yield as a measure that reflects the activity of processes contributing starch deposition in the grain, while protein concentration reflects processes relating to N metabolism. Dry matter and N accumulation in the grain are separate processes; N in the grain is mostly from senescence of organs, while dry matter comes mostly from current photosynthesis (Simpson *et al.*, 1983; Melaj *et al.*, 2003). In many cases nitrogen limits crop growth and yield especially when N availability does not coincide with physiological demands of the developing plant. Post-anthesis utilization of assimilates and energy may result in competition between the production of dry matter and protein (Bhatia and Rabson, 1976).

Plant N has been shown to correlate positively with biomass yield, grain yield,

and grain protein yield (Desai and Bhatia 1978). Melaj *et al.* (2003) found that increased N led to higher yield by an increase in the number of kernels per square meter, while individual kernel weight was reduced. It is commonly reported that a negative relationship exists between grain protein and grain yield and harvest index (Cox *et al.* 1985; Slafer *et al.* 1990). Commonly referred to as the dilution effect grain protein can be reduced with yield increases if no additional N is available or provided.

### 2.3.5 Nitrogen and Grain Quality

Grain nitrogen content is determined by how much of the nitrogen in the plant tissues was translocated to the grain. During the grain filling stage a large amount of the final grain N is remobilized from other parts of the plant (Barneix et al 1992). N stored in the vegetative tissues as proteins becomes important during grain filling as the N uptake of the roots cannot meet the grain N demands (Foulkes *et al.* 2009). Nitrogen remobilization in wheat depends on environmental factors and genotype (Barbottin *et al.* 2005). The N remobilization in wheat is dependent on the amount of N assimilated in vegetative tissues of the plant at anthesis.

The grain protein concentration of wheat and other cereals has been found to rarely exceed 14% of the total dry weight (Payne, 1983). The grain protein range of commercial varieties is limited, with most UK bread making wheats for example differing by only about 2% dry weight (Snape *et al.*, 1993). The protein concentration in the grain of wheat is a genetic characteristic and can be altered by environmental conditions (Barneix *et al.* 1992). The strong environmental impact on protein content

can account for two-thirds of the variation in grain protein content and contributes to the difficulty in breeding for increased protein (Shewry, 2009).

Studies have found a positive relationship between applied N rates and protein levels, however the magnitude of the effect showed a clear dependence on year, which is likely related to soil moisture and plant uptake of N late in the season (Batey & Reynish, 1976). Barbottin *et al.* (2005) found that nitrogen remobilization in wheat was significantly affected by both genotype and environment: genotypes with resistance to disease had stable N remobilization from vegetative organs while under disease pressure, while genotypes susceptible to disease showed decreased remobilization efficiency. Susceptible cultivars would have higher incidence and severity of disease infection and the affected plant tissues would be unable to function normally and N remobilization would be decreased. Under favorable environmental conditions (lacking limitations) during grain fill, no effect of genotype was observed, but genotypic differences occurred under conditions of stress during grain fill. Differences in remobilization efficiency can be expected to have an effect on N as well as crude protein levels in the grain. The N supply related to different management systems has also been found to impact the grain N content. Organically grown bread wheat has been found to average between 1.5 and 1.9% grain N while conventionally grown bread wheat varieties averaged between 2.2 and 2.3% grain N (Gooding *et al.*, 1999; Berry *et al.*, 2003). These findings suggest that the N supply to the organic crop was limited compared to the N supply in the conventionally grown wheat (Berry *et al.*, 2002)

### 2.3.6 Nitrogen Use Efficiency

Nitrogen Use Efficiency (NUE) of cereal crops may be considered from three interrelated points of view: agronomy (in terms of grain yield produced per unit of N supply), environment (possible contamination of ground water, eutrophication of surface waters, or ozone depletion by release of $N_2O$), economics (maximization of farmers' income) (Raun and Johnson, 1999; Huggins and Pan, 1993; Bock, 1984). Andersson *et al.* (2004) asserted that good nitrogen use efficiency is of particular importance in cereal production in order to facilitate lower input costs and decreasing pollution to the environment.

Nitrogen use efficiency has been defined in the literature as the yield of grain per unit of available nitrogen in the soil, or more simply the ratio of grain N uptake to N availability (Baresel *et al.* 2008, Moll *et al.* 1982). Nitrogen use efficiency can be broken up into two basic components, uptake efficiency (UPE) and utilization efficiency (UTE) (Muurinen *et al.* 2007). The UPE of a plant is its ability to remove N from the soil, which is typically present in the form of nitrate or ammonium ions (Lea & Azevedo 2006). The UTE refers to the plants ability to transfer the acquired N to the grain, mostly as protein (Lea & Azevedo 2006). Other studies refer to the uptake efficiency as recovery efficiency (RE) and utilization efficiency as internal efficiency (IE) (Salvagiotti *et al.* 2009). Nitrogen use efficiency is an indication of the plants ability to translocate the available N in the soil to the final grain product (Salvagiotti *et al.* 2009). Good *et al. (*2004) suggests that NUE is more complex and estimations of NUE should be dependent on the crop.

The current NUE of wheat globally is still quite low with average recovery rates of applied N fertilizer ranging from 30-50% (Raun *et al.* 2002). One factor determining NUE is the amount of N redistributed to the grain from vegetative parts, which can account for 75-80% of the nitrogen accumulated in the grain at maturity (Andersson and Johansson 2006, Fageria *et al.* 2008). This redistribution of nitrogen occurs during senescence, which is a highly regulated and organized process. The redistribution of nitrogen from above groundplant parts to the grain has been widely studied while the redistribution of nitrogen from plant roots has not been studied to the same extent and as a result is not as well understood.

The roots of wheat plants are the last organs to senesce and are still active during the grain-filling phase (Andersson *et al.* 2004). Andersson *et al.* (2004) examined post-anthesis N redistribution from the roots of spring wheat. In their study they found that N redistributed from the roots contributed 8.7 – 24.3% of the total N amount in the grain at maturity depending on the cultivar. While the above groundtissues were beginning the senescence period post-anthesis, the roots maintained their capacity to absorb N (Andersson *et al.*, 2004). Andersson and Johansson (2006) reported that 10-20% of the total amount of N in the plants is present in the roots at maturity. The NUE in the whole plant is greatly affected by the proportion of N in the roots that is redistributed. Andersson *et al.* (2004) reported that the transport capabilities of the roots were maintained for 12 days after complete "yellowness". The NUE of a cultivar could be improved by increasing the proportion of N redistributed from the roots to the grain this may be achieved by selecting for cultivars with prolonged transport capabilities.

#### 2.3.6.1 Benefits of Improved NUE

Increased nitrogen use efficiency is desirable to prevent N losses from the system. Decreasing N losses that occur through leaching protects ground and surface waters and is of ecological importance (Salvagiotti *et al.*, 2009). Studies have shown lower leaching of nitrates from organic production systems compared to conventional systems (Stinner 2007). In addition to the ecological benefits of improved NUE there is also an important economic incentive as the prices of fossil fuels required to produce synthetic N fertilizer continue to rise.

#### 2.3.6.2 Nitrogen Harvest Index

Nitrogen Harvest Index (NHI) is the ratio of the nitrogen accumulated in the final grain to the total amount of nitrogen accumulated in the plant (Fageria and Baligar 2005). The NHI usually expressed as a percentage, indicates the amount of N remobilized from vegetative tissues into the grain, which is an important component of NUE. In most calculations of NHI, the N uptake of above ground plant parts (including grain) are considered and below ground biomass (roots) are not included. The NHI indicates how efficiently the plant utilized the accumulated N for grain production.

The nitrogen harvest index of bread wheat rarely exceeds 0.8 according to previous studies looking at the genetic variation of above ground N redistribution from shoots to grains (Andersson *et al.* 2004, Corbellini & Borgi, 1985; Heithold *et al.* 1990, Cox *et al.* 1985). Studies conducted by Ehdaie *et al.* (2010) and Rieux *et al.* (2013) both reported NHI values for spring wheat between 0.71 and 0.77, while Desai

and Bhatia (1978) reported NHI range of 0.58 – 0.83 for durum wheat. Previous studies have found that NHI values for above ground components in wheat decreased with increasing N nutrition (Andersson *et al.*2005, 2004 Halloran, 1981; Ugalde, 1993). Cox *et al.* 1985 examined the genetic variation for nitrogen assimilation and translocation in wheat, they examined 96 F5 lines under low N and high applied N conditions. They observed higher average NHI values from the low N experiments, finding an increase of approximately 0.1 over the average NHI value from the high applied N trial.

Index of physiological efficiency of absorbed N (PEN), defined as the ratio of grain produced to the total N absorbed by the above ground parts of the plant indicates how the N absorbed by a plant is used to produce grain. In a study evaluating the PEN in Oats, Isfan (1993) found that grain yield was positively correlated (r=0.95) to PEN values and suggested that PEN may be used in breeding programs to identify potentially high yielding genotypes that are capable of exploiting N inputs most efficiently. Isfan (1993) reported higher PEN of several oat cultivars values at zero or lower fertilizer rates. The mean PEN values of the oat cultivars were 61.2, 59.4, 46.1, 35.6, and 32.3 at added N rates of 0, 80, 160, 240, and 320 (mg $kg^{-1}$ of soil), respectively.

2.3.6.3 Challenges of improving NUE

Nitrogen use efficiency is a complex trait that is the product of a number of factors and their interactions. Studies have shown that NUE is affected by changes in production factors such as different preceding crops, the tillage system, or water availability (Salvagiotti *et al.*, 2009). A review by Lea & Azevedo (2006) discussed

that the uptake of nitrate and ammonium ions is a more complex process than originally thought. They concluded that the existence of families comprising a large number of genes which are encoding very similar proteins will make it difficult to ascertain which genes are directly involved in the uptake of nitrogen and which genes may be able to directly influence NUE.

Genetic associations between grain yield and NUE components have been found in numerous studies examining NUE under contrasting conditions of low and high N inputs (Foulkes *et al.*, 2009). Le Gouis *et al.* (2000) found that uptake efficiency accounted for more of the genetic variation in NUE than rembolization efficiency in their study examining 20 winter wheat cultivars. They also found varietal differences for grain yield in their zero N added treatments. While one of their older study cultivars, Cappelle bred in the 1940s (when use of chemical fertilizers was not common) showed relatively high N uptake efficiency from their zero N added treatment, they also had modern cultivars with equivalent or better performances. A modern genotype Arche was the highest yielding cultivar from both the zero N added and added N treatments indicating that some genotypes bred with the use of added synthetic fertilizers are able to perform well in conditions of low N availability. The study also indicates that the older varieties such as Cappelle with high N uptake efficiency under conditions of low N may provide useful genetic material to incorporate into breeding programs targeting organic or low input environments.

Studies have found a link between sulfur (S) levels and NUE. A study by Salvagiotti *et al.* (2009) looked at the impact of increasing S fertilization rates on the NUE of a bread wheat cultivar. Salvagiotti *et al.* (2009) found that the addition of S fertilizer led to an increase in N uptake compared to the highest rate of uptake

achieved with only Nitrogen fertilization. They found that there was an increase in recovery efficiency with the addition of S fertilizer but did not see an increase in the internal efficiency. A survey of the soil nutrient status of 14 organic farms conducted by Entz *et al.* (2001) found S levels averaged 101 kg $ha^{-1}$ and was found to be comparable to typical soil S levels from conventional fields in the same region. Soil nutrient levels including S could be lower in rotations that favour high extraction forage crops such as alfalfa (hay removed) (Entz *et al.*, 2002) The lowest available S level from the survey of Entz *et al.* (2001) was from a farm that had a long-term organic cropping history.

The morphological characteristics of root systems affect the N uptake in plants (Ehdaie *et al.*, 2010). Several plant species are able to modify their root architecture in order to better access heterogeneously distributed nutrients in the soil. This modification typically involves increased production of lateral roots within the areas of higher nutrient concentration in the soil (Walch-Liu *et al.*, 2006 – from Lea & Azevedo 2006). A study from the University of California found that genotypes with increased root biomass per plant also had increases of N content in the plant and the grain as well as increases in grain yield (Ehdaie and Waines, 2008).

In general, a wheat plant produces approximately six seminal roots, and about 10-15 crown or adventitious roots (Foulkes *et al.* 2009). Spring wheat plants typically reach a maximum rooting depth of between 80 and 120 cm (Siddique *et al.*, 1989; Ehdaie *et al.* 2010). Nitrate is leached down the soil profile making rooting depth an important trait influencing N capture capacity (Foulkes *et al.*, 2009). Improvements soil N acquisition would likely come from increases in root axis number, rooting depth, rooting density, and root longevity (of particular importance for post-anthesis

N uptake) (Foulkes *et al.*, 2009). Differences have been reported in the rooting depth of wheat genotypes (Miralles *et al.* 1997), but rooting depth does not appear to have been changed systematically by breeding (Foulkes *et al.*, 2009).

# 3. MATERIALS AND METHODS

## 3.1 Site Description

Field experiments were conducted over 4 site-years in 2009 and 2010. In 2009, experiments were located at University of Manitoba's Research station in Glenlea MB and on an organic farm near Oxbow SK. In 2010 experiments were established at the University of Manitoba's Research station in Carman MB, and the same organic farm in Oxbow SK.

Table 1: Management, location, and soil texture information for each experimental site.

| Site Name | Land Management | Latitude (N) | Longitude (W) | Soil Association *(texture)* |
|---|---|---|---|---|
| Carman | organic | 49º 29' | 98º 0' | Hibsin *(fine sandy loam)* |
| Glenlea | organic | 49º 38' | 97º 8' | Red River or Scantenbury *(clay)* |
| Oxbow | organic | 49º 13' | 102º 10' | Oxbow *(loam)* |

Soil samples were collected from three depths (0-15cm, 15-60 cm, 60-120 cm) at each site prior to or just shortly after seeding and were sent to Agvise laboratories in Norwood, North Dakota for analysis. See Table 2 for soil nutrient status and previous crop information.

Table 2: Soil nutrient status and crop history of experimental sites in 2009 and 2010.

| Site Location | Year | N (0-15 cm) | N (15-60 cm) | N (60-120 cm) | P-Olsen | K | Zn | pH | OM (%) | Previous Crop |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ---------(Kg/Ha)--------- | | | ----------(ppm)---------- | | | | | |
| Glenlea | 2009 | 17.9 | 151.2 | 89.6 | 6.0 | 91.0 | 0.4 | 7.4 | 1.7 | Pea Green Manure |
| Oxbow | 2009 | 45.9 | 137.8 | 35.8 | 9.0 | 363.0 | 0.9 | 7.2 | 3.2 | Fallow with pea green manure |
| Carman | 2010 | 32.7 | 95.9 | 67.0 | 6.0 | 397.0 | 0.6 | 5.7 | 4.6 | Green manure |
| Oxbow | 2010 | 29.7 | 66.2 | 33.5 | 18.0 | 310.0 | 2.2 | 7.9 | 3.1 | Alfalfa |

N – Nitrate, P – Olsen

The three sites used in this study were managed according to organic production principles. The Glenlea site is part of the Long-Term Rotation that was established in 1992 and is Canada's oldest organic-conventional cropping comparison study. The Carman site is part of The Organic Crop Field Laboratory, which consists of just over 4 hectares of land and has been under organic management since 2002. The Oxbow site was at Moose Creek Organic Farm, a 1456 ha farm operated by Ian Cushon located approximately10 km northwest of Oxbow, Saskatchewan, and has been managed organically since 1985.

Weather data collected by Manitoba Agriculture, Food and Rural Initiatives (MAFRI 2011), Environment Canada's climate data online (Environment Canada 2011a), and weather normals (Environment Canada 2011b) are presented in Tables 3 and 4. The three research sites were selected to provide a range of weather conditions found on the Canadian Prairies. Data for Carman 30-year normals are based on values from Graysville weather station (approximately 14 km from Carman site). Weather data for Glenlea 2009 is taken from the Winnipeg (The Forks) weather station (approximately 32 km from Glenlea site). The weather data for the Oxbow site was from the Estevan weather station (approximately 65 km from Oxbow site)

Table 3: Average daily temperatures during the growing season (May 1st – August 31st) at each experiment site (Environment Canada 2011b), and 30-year normals (Environment Canada 2011a).

| Research Site | Average Daily Temperature (°C) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Normal[1] | | | | 2009 | | | | 2010 | | | |
| | May | June | July | Aug | May | June | July | Aug | May | June | July | Aug |
| Carman | 12.4 | 17.2 | 19.7 | 18.1 | 9.5 | 13.7 | 17.7 | 18.5 | 11.6 | 16.7 | 20.1 | 19.3 |
| Glenlea | 12.4 | 17 | 19.3 | 18.4 | 9.6 | 17.1 | 18.4 | 18.8 | - | - | - | - |
| Oxbow | 12.1 | 16.8 | 19.5 | 18.6 | 9.9 | 15.1 | 16.5 | 17 | 10.1 | 16.1 | 18.5 | 18.5 |

[1]30-year normals.

Table 4: Precipitation during the growing season (May 1st – August 31st) at each experiment site (Environment Canada 2011b), and as a percent of 30-year normals (Environment Canada 2011a).

| Month | Precipitation (mm) | | | | | | | Percent of normal (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Normal[1] | | | 2009 | | 2010 | | 2009 | | 2010 | |
| | *Carman* | *Glenlea* | *Oxbow* | *Glenlea* | *Oxbow* | *Carman* | *Oxbow* | *Glenlea* | *Oxbow* | *Carman* | *Oxbow* |
| May | 61.1 | 62.1 | 55.6 | 78.1 | 6.6 | 132.1 | 88.5 | 125.8 | 11.9 | 216.2 | 159.2 |
| June | 75.5 | 93.8 | 76.3 | 82.8 | 66.4 | 50.4 | 133.6 | 88.3 | 87 | 66.8 | 175.1 |
| July | 73.5 | 80.1 | 65 | 120.6 | 37.6 | 47.2 | 55.4 | 150.6 | 57.8 | 64.2 | 85.2 |
| August | 66.8 | 67.7 | 49.5 | 52 | 71.6 | 152.3 | 86.4 | 76.8 | 144.6 | 228 | 174.5 |
| Total | 276.9 | 303.7 | 246.4 | 333.5 | 182.2 | 382 | 363.9 | 109.8 | 73.9 | 138 | 147.7 |

[1]30-year normals.

### 3.2 Experimental Design and Treatments

This study compared 20 wheat cultivars in 2009 and 15 genotypes in 2010 (Table 5). Cultivars examined included advanced breeding lines (F8 in 2009 and F9 in 2010) of the population BC07B-ORG from the University of Manitoba and Agriculture and Agri-Food Canada's joint spring wheat organic breeding program details of which are described by Kirk *et al.* (2012). Crosses were made for Agriculture and Agri-Food Canada's bread wheat breeding program in 2002. These organically managed breeding nurseries were dependent on naturally occurring disease infection. Conventional Canadian Western Red Spring Wheat (CWRS) cultivars were included in the study as checks for comparison. An organic line BW 881 from the breeding program at the University of Saskatchewan was also included. BW 881 has since been registered as 'CDC Kernen'.

To provide a uniform seed source for the experiments, seeds from these cultivars grown at Glenlea, Carman, and Oxbow in 2008 were evenly blended based on kernel weight and germination rates for seeding the 2009 sites. Seed produced at each location in 2009 was retained and used to seed at the same site it was collected from for the 2010 trials. Cultivars indicated with an asterisk (Table 5) were omitted

from the study in the 2010 site years. Contamination of a few cultivar seed sources occurred during sub-sampling so the affected cultivars were omitted from the study, as they were no longer pure cultivar samples.

Table 5: Wheat cultivars included in study and their pedigree information

| Line | Pedigree | AAFC Org Breeding Program Name |
|---|---|---|
| ORG 1 * | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-3-UUU-16-N |
| ORG 2 | 98B25-AS6D01 /ND744U | 08OS301_BC07B-ORG-NZ-12-UUU-13-N |
| ORG 3 | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-3-UUU-14-N |
| ORG 4 | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-12-UUU-09-N |
| ORG 5 * | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-14-UUU-04-N |
| ORG 6 | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-14-UUU-19-N |
| ORG 7 | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-30-UUU-05-N |
| ORG 8 | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-30-UUU-15-N |
| ORG 9 | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-30-UUU-12-N |
| ORG 10 * | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-3-UUU-17-N |
| ORG 11 | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-30-UUU-01-N |
| ORG 12 | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-3-UUU-03-N |
| ORG 13 | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-30-UUU-04-N |
| ORG 14 | 98B25-AS6D01 /ND744U | 08BOS301_BC07B-ORG-NZ-30-UUU-17-N |
| CDC Kernen * | CDC Bounty/FHB4 | |
| Kane | AC Domain/McKenzie | |
| McKenzie | Columbus/Amidon | |
| 5602HR | AC Barrie/Norpro | |
| AC Cadillac | BW90*3/BW553 | |
| AC Barrie * | Neepawa/Columbus/BW90 | |

* Lines omitted from study in 2010

Genotypes were compared in a randomized complete block experiment with four replicates at all study sites. Each treatment plot was 8 rows wide with 15cm row spacing. In season sampling was conducted from one half and the other half was kept undisturbed for yield evaluations. Border rows of fall rye were seeded between plots and sub-plots and border plots of wheat were sown on either side of each trial to minimize edge effects.

### 3.3 Field Trial Management

The land was prepared for seeding using cultivation to create a smooth uniform seedbed. Plots were seeded using a disk drill (Fabro Industries, Swift

Current). Wheat was seeded into moisture (approximately 2.5 – 5 cm) at all sites with an approximate density of 333 viable kernels/$m^2$. Table 6 provides additional information on seeding and harvest operations.

Table 6: Schedule of field operations during the growing seasons of 2009 and 2010.

| Site Location | Year | Plot Area ($m^2$) | Seeding Date | Harvest Date |
|---|---|---|---|---|
| Glenlea | 2009 | 7.3 | 3-Jun | 25-Sep |
| Oxbow | 2009 | 7.3 | 20-May | 27-Aug |
| Carman | 2010 | 7.3 | 13-May | 23-Aug |
| Oxbow | 2010 | 6.1 | 14-May | 26-Aug |

### 3.4 Data Collection

Plant population density was evaluated when the wheat plants were at the 2-3 leaf stage at all sites with the exception of Oxbow in 2009 where emergence counts were taken later due to uneven emergence. Emergence values were calculated based on counts of 2-3 x 1meter lengths per plot.

There was a considerable Fusarium Head Blight (FHB) *Fusarium graminearm* infection at Glenlea in 2009, so FHB ratings were conducted. The FHB Index was calculated by multiplying the plot incidence and plot severity and then dividing by 100. Plot incidence measures the percentage of heads (10 per plot) that had some FHB infection based on careful visual assessment. Plot severity was measured by evaluating five heads of wheat per plot and scoring what percent of the head was showing visual symptoms of FHB infection.

FHB Index = (% Plot Incidence x % Severity) / 100 [Eq. 1]

Height measurements were taken once stem elongation was completed (between anthesis and maturity). Plant height was measured as the distance from the soil surface to the tip of the spike, excluding awns if present. Three measurements were taken per plot, with plant height for each plot being the average of the three measurements.

Above ground biomass samples were collected at three times during the growing season to assess the nitrogen uptake of the different genotypes. One meter lengths from the center two rows of each plot were cut at ground level (0- 2.5 cm) for each sample. Tissue samples were collected at stem elongation, anthesis, and the soft dough stage in 2009. In 2010 tissue samples were collected at anthesis, soft dough, and maturity in 2010. Tissue samples were dried at 70°C for 48 hours after being collected. Dried biomass samples from each sampling were weighed to assess dry matter (DM) value for each sample.

Immediately prior to final grain harvest, the ends of the plots were trimmed and plot area was measured in order to calculate yield on a common area basis. Plots were harvested using a Wintersteiger plot harvester at all sites with the exception of Oxbow in 2009 where grain yield samples were taken by hand. Samples were dried on a forced air drying bed or on drying racks prior to cleaning. Grain samples were cleaned to remove excess chaff and weed seeds using a Carter Day Dockage Tester (model- 31624/W-3301). The dockage tester contained a no. 1 riddle, 9/64 tri double cut sieve, and an S-909 S1/2 164 R.086 sieve. Kernel weights were also obtained for all samples of each site year. To obtain kernel weights a sub-sample of approximately 10g was weighed (exact weight was recorded) then the sample was counted using a seed counter (The Old Mill Company – Electronic Counter, Model 850-2). Once the

exact number of kernels was counted the subsample weight was divided by the total number of kernels. The kernel density was expressed as kernel number (KNO) per unit of area (ha). The KNO per unit of dry matter (kg) at anthesis (KNO:DMa) was calculated by dividing the number or kernels produced per hectare by the kilograms of yield per hectare.

$$KNO / DMa = \frac{\text{KNO / ha}}{\text{Anthesis Biomass Weight / ha}} \qquad \text{[Eq. 2]}$$

Grain Harvest Index (HI) was also calculated to assess how efficiently the different genotypes converted dry matter into grain yield.

$$HI(\%) = \frac{\text{Grain Weight / unit area}}{\text{Biomass Weight / unit area}} \; x\, 100 \qquad \text{[Eq. 3]}$$

An index of grain yield per unit of dry matter accumulated at anthesis was calculated to further explore the relationship between biomass accumulation and yield focusing on the biomass accumulated during the vegetative growth period biomass which we will refer to as a mid-season harvest index (MS-HI).

$$MS-HI(\%) = \frac{\text{grain yield}}{\text{dry matter @ anthesis}} x\, 100 \qquad \text{[Eq. 4]}$$

The nitrogen content was measured for the above ground biomass and grain samples. Dried biomass tissue samples were ground using Wiley Mill No.1 with a 2mm screen (Arthur H. Thomas Co., Philadelphia). A sub-sample of each grain sample was ground using a cyclone sample mill (Tecator/Udy - SF 518076). A sub-sample of the ground tissue and flour samples were analyzed for nitrogen content

using LECO FP-528 (LECO, St. Joseph) combustion analyzer. Nitrogen accumulation was measured from the biomass samples and was calculated as:

$$N\ accumulation = \text{Dry matter } x \text{ N concentration} \quad \text{[Eq. 5]}$$

The total nitrogen accumulation (TNA kg N/ha) in the above ground tissue (straw and grain) was measured to assess the nitrogen accumulation capacity of the different genotypes.

$$TNA = \frac{\%\ \text{N in biomass @ maturity}}{100}\ x\ \text{Biomass accumulated @ maturity} \quad \text{[Eq. 6]}$$

Grain N yield (N kg/ha) was also calculated using the grain N percentage and grain yield values.

$$Grain\ \text{N}\ Yield = \frac{\text{Grain N}\ \%}{100}\ x\ \text{Yield (kg/ha)} = \text{N (kg/ha)} \quad \text{[Eq. 7]}$$

Using the TNA and grain N yield the Nitrogen Harvest Index (see formula below) was calculated to help assess the nitrogen economy of the different genotypes. The Nitrogen Harvest Index (NHI) is a measure of the plants remobilization efficiency and shows the partitioning of total plant N into grain N.

$$NHI(\%) = \frac{\text{Grain N Yield}}{\text{TNA}}\ x100 \quad \text{[Eq 8]}$$

To further investigate the relationship between nitrogen uptake and yield grain N yield as a proportion of N uptake at anthesis and was calculated.

$$\text{Grain N Yield per N up @ Anthesis} = \frac{\text{Grain N Yield}}{\text{Biomass N @ Anthesis}}\ x100 \quad \text{[Eq. 9]}$$

### 3.5 Data Analysis

Differences in Yield, N grain yield, kernel density (KNO), tissue nitrogen, harvest index, nitrogen harvest index, N uptake per unit of dry matter at anthesis, and N grain yield per N accumulated at anthesis, biomass, and biomass N of the different cultivars were evaluated separately from each site year. Differences among cultivars were tested using analysis of variance for all measurements. Data sets were analyzed using the PROC Mixed procedure with the Statistical Analysis Software program (SAS Institute 2001). Analysis of individual site years was completed and is included in Appendix section. We used mixed model ANOVA and considered treatments as fixed effects and replications as random effects for all measurements. Normality of distribution assumptions of ANOVA were tested by using the PROC Univariate procedure. Differences were considered significant at $p < 0.05$.

Normality analysis indicated that the data of several parameters from various site years were not normally distributed, according to Shapiro-Wilk test W-statistic values. Outliers were identified as > 3 standard deviations away (+/-) from the mean using Grubb's test for outliers and were excluded from analysis. A number of data transformations including LOG, LN, and Square Root were performed and the normality statistics are reported in the Appendix B Tables 23-27. Transformations (Log base 10, Natural Log, and Square root) were performed in an attempt to normalize the data (Tables 23-27). Transformations as well as the omission of site year Oxbow (2009) failed to normalize the data. Data presented is untransformed. Of note due to environmental conditions and emergence irregularities Oxbow (2009) had data collection methodology that differed from practices employed from the other

three site years. Earlier biomass sampling dates (stem elongation, and anthesis), as well as stand density is missing from Oxbow (2009) for those parameters. The data from the remaining three site years was combined

Homogeneity of variances was tested for data from all four site years using Bartlets Test for Homogeneity in Proc GLM with the Statistical Analysis Software program (SAS Institute 2001). In order to combine the four site years and perform a combined analysis of the data the variances within the data were tested to ensure they were not significantly different. Using Bartlets test for homogeneity p values greater than 0.05 failed to reject the null hypothesis that the variances were equal. Data from the four site years was found to be homogenous for all parameters with the exception of plant heights and thousand kernel weights. Based on these findings the data for plant heights and thousand kernel weights was not combined and is presented as individual site years. Data from the four site years was combined for all other parameters.

Combined analysis of multiple site year data was performed using the PROC Mixed procedure with the Statistical Analysis Software program (SAS Institute, 2001). Data from all four site-years were combined. Cultivar differences, site year differences as well as interaction between site year and cultivars were tested using analysis of variance. Contrasts and estimates between the average of the organic lines and the average of the check cultivars were performed for all parameters. Correlations between all study parameters were also calculated from the combined data of the organic lines only using the PROC Corr procedure with the Statistical Analysis Software program (SAS Institute, 2001).

# 4. RESULTS AND DISCUSSION

## 4.1 Agronomic Performance

### 4.1.1 Emergence and Stand Density

Wheat plant population density was measured to ensure that plot populations of the different cultivars did not differ significantly (Table 7). Plant populations of each experimental plot were evaluated by counting rows of emerged plants at the 1-3 leaf growth stage. There were significant differences observed between site years, these differences were likely attributable to environmental conditions that either favored or limited germination and emergence. Average stand density from the four site years ranged from 212 – 285 plants $m^{-2}$. With the exception of Glenlea (2009) the average stand densities were within the 230-280 plants $m^{-2}$ recommended by the Manitoba Agriculture, Food and Rural Initiatives (2013). Seedling vigor and increased emergence rates under stress would be an advantageous characteristic for an organic variety. Organic growers do not utilize seed treatment fungicides, as a way to overcome damping off due to soil borne diseases such as *Cochliobolus sativus, Fusarium* spp., *Rhizoctonia* spp. and *Pythium* spp. Organic growers must rely on the use of varieties with inherent disease resistance and increased vigor. No significant stand density differences were observed between cultivars when averaged across the four site years. No significant interaction between site year and cultivar was observed (Table 7). The site year did not have a significant effect on the relative stand density of the cultivars. Emergence and stand density were found to be consistent across experimental sites.

Glenlea (2009) had lower average plant populations compared to the other site years with an average plant stand of 212 plants $m^{-1}$ while the other site years had average plant stands above 250 plants $m^{-1}$ (Table 7). Glenlea has heavier clay soils that may have developed a harder crust due to below average precipitation following seeding. Although a stand reduction was observed the differences between cultivars was not significant. Oxbow (2009) had uneven emergence due to a lack of moisture following seeding. Precipitation data from the nearby Estevan,SK Environment Canada weather station indicated that pre-seeding conditions were extremely dry receiving only 6mm of precipitation in May. Plant stand density evaluations were not possible at the Oxbow (2009) trial due to the irregularity of emergence within plots.

### 4.1.2 Biomass Production

Significant differences in biomass production throughout the growing season were observed among site-years throughout the growing season (Table 7). Average soft dough biomass ranged from 5329.3 kg $ha^{-1}$ at Oxbow (2010) to 10362 kg $ha^{-1}$ at Carman (2010). Differences in growing environments significantly affected the biomass production of the different cultivars. Weed competition appears to have been a significant limiting factor in terms of biomass production at Oxbow (2010), which had elevated weed pressure also had the lowest overall biomass production at the soft dough stage.

Combined site analysis showed no significant differences between cultivars throughout the growing season. The cultivars did not differ significantly in biomass production at anthesis, soft dough, or maturity. The organically selected lines were able to

accumulate the same level of biomass as the check cultivars. Early season above ground dry matter (stem elongation) was measured only at the Glenlea (2009). Significant differences in biomass produced at stem elongation were observed (Appendix Table 22). The Organic lines had a slightly higher average biomass at stem elongation with an increase of 3.2% or 29.4 kg/ha over the check cultivar average. Sampling at stem elongation was omitted in 2010 in favour of additional late season sampling at maturity. A strong indication of cultivar performance based on early season biomass accumulation was not observed in this study.

The maximum average cultivar biomass values in the present study ranged between 7595.5 and 8536.7 kg $ha^{-1}$. Maximum average cultivar biomass production was observed at soft dough or maturity depending on the cultivar. Previous studies have reported maximum biomass production of Canadian spring wheat ranging from 7500 – 12000 kg $ha^{-1}$ under conventional management (Malhi *et al.* 2006, Wang *et al.* 2003). The maximum biomass values in the present study while on the lower end are comparable to previous reports. Noulas *et al.* (2013) examined the course of biomass and nitrogen accumulation in spring wheat genotypes grown without N fertilizer or under high fertilizer N (250 kg N $ha^{-1}$). They also observed no significant differences in biomass at anthesis between genotypes in the zero N applied trial. No significant site year by cultivar interactions were observed at anthesis, soft dough, or maturity biomass production (Table 7). Therefore, the relative biomass production of the cultivars appears to be consistent across site years.

Table 7: Combined Analysis of Agronomic Parameters from Glenlea and Oxbow in 2009, and Carman and Oxbow in 2010.

| | Stand Density | | Anthesis Biomass Weight | | Soft Dough Biomass Weight | | Maturity Biomass Weight | | Harvest Index | | Yield per DM at Anthesis | | Kernel Density | | KNO:DMa | | Yield | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | plants $m^{-2}$ | APOC | kg $ha^{-1}$ | APOC | kg $ha^{-1}$ | APOC | kg $ha^{-1}$ | APOC | | APOC | | APOC | $m^{-2}$ | APOC | | APOC | kg $ha^{-1}$ | APOC |
| Site-year | | | | | | | | | | | | | | | | | | |
| Glenlea 2009 | 212.1 b | 87.3 | 5213.8 b | 93.9 | 8491.5 b | 107.8 | - | - | 0.39 c | 97.9 | 0.63 a | 126.8 | 10817.0 b | 111.3 | 21338 a | 118.7 | 3216.2 b | 109.5 |
| Oxbow 2009 | - | | - | | 7900.4 c | 100.3 | - | - | 0.43 b | 108.5 | - | | 9141.0 c | 94.0 | - | | 3280.1 b | 111.7 |
| Carman 2010 | 253.2 a | 104.3 | 6711.0 a | 121 | 10362.0 a | 131.6 | 9238.5 a | 122.0 | 0.48 a | 120.5 | 0.66 a | 131.5 | 13632.0 a | 140.2 | 20715 a | 115.2 | 4337.3 a | 147.7 |
| Oxbow 2010 | 264.3 a | 108.8 | 4226.6 c | 76.1 | 5329.3 d | 67.7 | 5560.9 b | 73.5 | 0.32 d | 80.1 | 0.45 b | 90.7 | 6053.5 d | 62.3 | 14893 b | 82.8 | 1836.9 c | 62.5 |
| Cultivar | | | | | | | | | | | | | | | | | | |
| ORG 2 | 242.3 | 99.7 | 5452.0 | 98.2 | 8536.7 | 108.4 | 7511.8 | 99.2 | 0.42 abcd | 104.7 | 0.62 abc | 124.5 | 10332.0 abcd | 106.3 | 18905 bcd | 105.1 | 3559.9 a | 121.2 |
| ORG 3 | 240.9 | 99.2 | 5541.7 | 99.8 | 7504.9 | 95.3 | 8131.0 | 107.0 | 0.44 abc | 109.8 | 0.65 ab | 129.6 | 10691.0 abc | 110.0 | 20547 abc | 114.3 | 3512.1 ab | 119.6 |
| ORG 4 | 248.4 | 102.2 | 5245.4 | 94.4 | 8113.7 | 103.0 | 6532.0 | 86.3 | 0.44 abc | 109.2 | 0.61 abcd | 121.3 | 10217.0 abcd | 105.1 | 19356 bcd | 107.6 | 3352.3 ab | 114.1 |
| ORG 6 | 240.6 | 99.0 | 4865.7 | 87.6 | 7595.5 | 96.5 | 6572.8 | 86.8 | 0.39 cd | 98.2 | 0.60 abcde | 119.5 | 9236.0 e | 95.0 | 19846 abc | 110.4 | 2917.2 d | 99.3 |
| ORG 7 | 236.4 | 97.3 | 5481.1 | 98.7 | 8032.0 | 102.0 | 7524.9 | 99.4 | 0.46 ab | 116.2 | 0.60 abcde | 120.2 | 10936.0 ab | 112.5 | 19374 abc | 107.7 | 3568.1 a | 121.5 |
| ORG 9 | 233.4 | 96.1 | 5120.6 | 92.2 | 7699.5 | 97.8 | 7650.1 | 101.0 | 0.40 bcd | 99.3 | 0.66 ab | 131.3 | 10665.0 abcd | 109.7 | 22610 a | 125.7 | 3221.9 bcd | 109.7 |
| ORG 10 | 250.0 | 102.9 | 5569.9 | 100.0 | 8447.5 | 107.3 | 7293.3 | 96.3 | 0.41 abcd | 101.9 | 0.55 cdef | 110.7 | 10101.0 bcde | 103.9 | 17769 cd | 98.8 | 3321.0 abc | 113.1 |
| ORG 11 | 248.2 | 102.2 | 5499.2 | 99.0 | 8210.2 | 104.3 | 6833.9 | 90.3 | 0.47 a | 117.5 | 0.62 abc | 124.0 | 11189.0 a | 115.1 | 21132 ab | 117.5 | 3456.7 ab | 117.7 |
| ORG 12 | 229.5 | 94.5 | 5453.4 | 98.2 | 8087.9 | 102.7 | 7742.0 | 102.0 | 0.45 abc | 111.4 | 0.60 abcde | 119.5 | 10269.0 abcd | 105.6 | 18394 bcd | 102.3 | 3494.1 ab | 119.0 |
| ORG 13 | 263.7 | 108.6 | 5352.0 | 96.4 | 8528.2 | 108.3 | 7614.0 | 101.0 | 0.42 abcd | 104.8 | 0.62 abc | 124.2 | 10545.0 abcd | 108.5 | 19584 bcd | 108.9 | 3504.7 ab | 119.3 |
| ORG 14 | 242.8 | 99.9 | 4914.6 | 88.5 | 8060.3 | 102.4 | 7311.1 | 96.6 | 0.44 abc | 110.9 | 0.70 a | 139.6 | 10185.0 bcde | 104.8 | 21302 ab | 118.5 | 3453.0 ab | 117.6 |
| CADILLAC | 238.7 | 98.3 | 4963.6 | 89.4 | 7598.7 | 96.5 | 8269.7 | 109.0 | 0.37 d | 91.6 | 0.57 bcdef | 114.9 | 9718.3 cde | 100.0 | 19292 bcd | 107.3 | 3004.2 cd | 102.3 |
| KANE | 246.7 | 101.6 | 5754.7 | 104.0 | 7808.5 | 99.2 | 7068.5 | 93.4 | 0.36 d | 90.3 | 0.52 def | 104.7 | 9723.3 cde | 100.0 | 18012 cd | 100.2 | 2895.4 d | 98.6 |
| MCKENZIE | 239.1 | 98.4 | 6044.9 | 109.0 | 8305.4 | 105.5 | 7829.0 | 103.0 | 0.35 d | 88.3 | 0.49 f | 98.7 | 9689.1 de | 99.7 | 16652 d | 92.6 | 2914.8 d | 99.2 |
| 5602HR | 247.1 | 101.7 | 5454.2 | 98.2 | 7783.5 | 98.9 | 7111.4 | 93.9 | 0.41 abcd | 101.5 | 0.51 ef | 102.0 | 9755.4 cde | 100.3 | 17978 cd | 100.0 | 2932.7 d | 99.8 |
| Source of Variation | ---------- *P* > F ---------- | | | | | | | | | | | | | | | | | |
| Site-year (SY) | **0.0075** | | **<.0001** | | **<.0001** | | **0.0015** | | **0.025** | | **0.002** | | **<.0001** | | **0.0003** | | **<.0001** | |
| Cultivar | 0.6915 | | 0.0558 | | 0.6607 | | 0.4004 | | **0.009** | | **0.0019** | | **0.0018** | | **0.0213** | | **<.0001** | |
| SY X Cultivar | 0.8716 | | 0.0983 | | 0.1898 | | 0.0629 | | 0.11 | | 0.2493 | | **0.0014** | | 0.3232 | | **0.004** | |
| Contrast | ---------- *P* > F ---------- | | | | | | | | | | | | | | | | | |
| Check vs. Organic | 0.9479 | | 0.0933 | | 0.3733 | | 0.4277 | | **<.0001** | | **<.0001** | | **0.0004** | | **0.0015** | | **<.0001** | |
| Estimate | -0.3525 | | 240.84 | | -200.2 | | 231.74 | | -0.06 | | -0.097 | | -679.45 | | -2017 | | -455.94 | |

† Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

†† APOC denotes As Percent Of Check (values are expressed as a percentage of the conventional check cultivar average – 'Cadillac', 'Kane', 'Mckenzie', and '5602HR')

### 4.1.3 Harvest Index

The harvest index of a cultivar can be considered as the efficiency in transferring accumulated biomass into the final grain product (Fischer and Kohn, 1966). Many researchers attribute higher yields to enhanced HI (Austin *et al.,* 1980; Siddique *et al.,* 1989; Slafer *et al.* 1990). Higher HI values have also been correlated with increased kernel number per spikelet and spike (Siddique *et al.,* 1989). In the present study, significant positive correlations between HI and Yield r = 0.60 and between HI and KNO r = 0.55 were observed from the organic lines (Table 8).

Significant differences in HI were observed among the four site years (Table 7). Carman (2010) had the highest average HI at 0.48, while Oxbow (2010) had the lowest average HI value at 0.32. In addition to having the highest average HI, Carman (2010) was also the highest biomass producing and the highest yielding site year. Oxbow (2010) on the other hand was our site year with the lowest average biomass accumulation and lowest average yields (Table 7). This indicates that the cultivars were less efficient at transferring biomass into the final grain product when biomass production was reduced or limited. Oxbow (2010) can be considered a higher stress site year with increased weed pressure (Table 10). Under the elevated environmental stress at Oxbow (2010) the cultivars did not accumulate as much biomass and failed to transfer the same proportion of accumulated biomass into grain yield as cultivars growing under more ideal conditions such as Carman (2010). At Carman (2010) 48% of the accumulated biomass was transferred to grain yield while at Oxbow only 32% of accumulated biomass was transferred to the final grain yield. These results indicate that the cultivars display a reduction in biomass transfer efficiency when grown under elevated stress conditions.

Combined analysis of all four site years showed significant cultivar differences for HI (Table 7). The organic line 11 had the highest HI with values of 0.47 while the check cultivar 'McKenzie' had the lowest HI at 0.35. A contrast performed comparing the average organic line HI and the average check cultivar HI showed a significant difference between the two averages. The estimate value shows that the organic lines have average HI values 6.0% greater than the average of the check cultivars. The significant difference between the organic lines and the check cultivars suggests that the organic lines are more efficient at transferring biomass into the final grain product. We observed earlier that there were no significant differences in biomass accumulation between the organic lines and check cultivars. This observation paired with the findings of higher average harvest index values indicates that the organic lines are able to produce additional yield from the same amount of biomass.

Hay (1995) indicated that harvest index may be a superior parameter to utilize when comparing the performance of breeding lines across varying environments, as it has been found to be more consistent than yield when measured in different environments. The interaction between cultivar and site year was not significant for HI (Table 7). The cultivars did not differ significantly in average HI between site years. A significant cultivar by site year interaction was however observed for yield. The fact that there was no significant interaction between cultivar and site year for HI indicates that HI was a more consistent parameter. These findings support Hay's assertion that the harvest index performance of a cultivar may be more consistent across varying environments than yield. It is also important to take into account the variability within an environment. While the interaction between cultivar and site year was not significant for HI it was observed that the cultivar HI was still

fairly variable with average cultivar HI values ranging from 88.3 – 117.5% (29.2%) of the check cultivar average. Yield was found to have a slightly narrower range of average cultivar values with cultivars averaging 98.6 – 121.2% (22.4%) of the check cultivar average.

When site years were considered individually, HI of the organic lines versus the check cultivars showed advantages. The cultivars did not differ significantly in relative HI performance across the varying experimental sites. Looking at the individual site year HI data (Table 18) the organic lines had higher average HI values at both Carman (2010) and Oxbow (2010) compared with the check cultivars. At Oxbow (2010), the organic lines had an average HI or 0.35, while the check cultivar average was 0.28. The differences observed from Carman (2010) between the organic lines and check cultivars were not as large but the organic lines were still obtaining higher average HI values than the check cultivars at 0.49 and 0.45 respectively. Therefore under increased weed stress or when grown under higher yielding conditions the organic lines were consistently better adapted to transfer biomass to the final grain.

### 4.1.4 Mid-Season Harvest Index

Mid-Season harvest index is a measure of the yield per unit of dry matter accumulated at anthesis. Fischer and Kohn (1966) reported that grain yield was strongly correlated with total dry weight at anthesis ($r = 0.88$). Significant differences were found between site years with Oxbow (2010) having a significantly lower average mid-season harvest index than other sites (Table 7). No significant interaction between cultivar and site year was observed indicating that the cultivars did not differ significantly in their response to

Table 8: Correlation matrix of organic cultivars from combined data from Glenlea and Oxbow in 2009, and Carman and Oxbow in 2010.

| | Yield | Grain N Yield | Grain N % | Protein | Anthesis Biomass N Weight | Soft Dough Biomass N Weight | Maturity Biomass N Weight | Anthesis Biomass % N | Soft Dough Biomass % N | Maturity Biomass % N | Harvest Index | Nitrogen Harvest Index | Height | Anthesis Biomass Weight | Soft Dough Biomass Weight | Maturity Biomass Weight | KNO/Ha | TKW | Kernels /m2 | N yield per unit of N at Anthesis | Yield per unit of DM at Anthesis | KNO per unit of DM at Anthesis | Stand Density |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Yield** | 1 | 0.9546 | 0.45277 | 0.45269 | 0.84028 | 0.59651 | 0.84678 | 0.7095 | 0.41002 | 0.79938 | 0.60408 | 0.07554 | 0.14106 | 0.76543 | 0.66653 | 0.79292 | 0.94022 | 0.27427 | 0.94022 | 0.27181 | 0.62708 | 0.49296 | -0.05283 |
| | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.3409 | 0.0716 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0004 | <.0001 | 0.0027 | <.0001 | <.0001 | 0.5649 |
| **Grain N Yield** | 0.9546 | 1 | 0.68745 | 0.68738 | 0.85952 | 0.6671 | 0.85909 | 0.79709 | 0.5077 | 0.81923 | 0.52744 | 0.00402 | 0.29606 | 0.72735 | 0.68562 | 0.78205 | 0.94554 | 0.12895 | 0.94554 | 0.29548 | 0.63607 | 0.52352 | -0.17173 |
| | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.9597 | 0.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0999 | <.0001 | 0.0011 | <.0001 | <.0001 | 0.0596 |
| **Grain N %** | 0.45277 | 0.68745 | 1 | 1 | 0.59658 | 0.53882 | 0.73322 | 0.75976 | 0.52481 | 0.74328 | 0.14292 | -0.13831 | 0.52122 | 0.36913 | 0.45533 | 0.58518 | 0.56315 | -0.23473 | 0.56315 | 0.25698 | 0.43538 | 0.44363 | -0.46117 |
| | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0679 | 0.0802 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0025 | <.0001 | 0.0046 | <.0001 | <.0001 | <.0001 |
| **Protein** | 0.45269 | 0.68738 | 1 | 1 | 0.5965 | 0.53864 | 0.73322 | 0.75972 | 0.52463 | 0.74328 | 0.14293 | -0.13819 | 0.52132 | 0.36907 | 0.45525 | 0.58518 | 0.56316 | -0.23494 | 0.56316 | 0.25702 | 0.43539 | 0.44375 | -0.46127 |
| | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0679 | 0.0804 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0025 | <.0001 | 0.0046 | <.0001 | <.0001 | <.0001 |
| **Anthesis BiomassN Weight** | 0.84028 | 0.85952 | 0.59658 | 0.5965 | 1 | 0.78062 | 0.84189 | 0.80952 | 0.62191 | 0.74439 | 0.41785 | -0.25007 | 0.14773 | 0.88743 | 0.79668 | 0.77484 | 0.82334 | 0.3163 | 0.82334 | -0.20759 | 0.25581 | 0.15573 | -0.13552 |
| | <.0001 | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0065 | 0.0922 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0004 | <.0001 | 0.0229 | 0.0048 | 0.0894 | 0.1228 |
| **Soft Dough Biomass N Weight** | 0.59651 | 0.6671 | 0.53882 | 0.53864 | 0.78062 | 1 | 0.84803 | 0.69413 | 0.85856 | 0.755 | 0.00989 | -0.57649 | 0.10877 | 0.67122 | 0.82115 | 0.77715 | 0.59203 | 0.10418 | 0.59203 | 0.10896 | 0.43432 | 0.3332 | -0.15779 |
| | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 | 0.901 | <.0001 | 0.1543 | <.0001 | <.0001 | <.0001 | <.0001 | 0.1884 | <.0001 | 0.2423 | <.0001 | 0.0002 | 0.0741 |
| **Maturity Biomass N Weight** | 0.84678 | 0.85909 | 0.73322 | 0.73322 | 0.84189 | 0.84803 | 1 | 0.77342 | 0.72248 | 0.8866 | 0.33572 | -0.34302 | 0.01556 | 0.743 | 0.85772 | 0.91595 | 0.811 | 0.46681 | 0.811 | 0.18074 | 0.65576 | 0.55453 | -0.1114 |
| | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | 0.0035 | 0.0032 | 0.8876 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.126 | <.0001 | <.0001 | 0.3101 |
| **Anthesis Biomass % N** | 0.7095 | 0.79709 | 0.75976 | 0.75972 | 0.80952 | 0.69413 | 0.77342 | 1 | 0.67543 | 0.72267 | 0.33838 | -0.18968 | 0.38741 | 0.46846 | 0.61737 | 0.6671 | 0.72917 | 0.15638 | 0.72917 | 0.01303 | 0.55755 | 0.51379 | -0.26383 |
| | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 | 0.0002 | 0.0405 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0881 | <.0001 | 0.8876 | <.0001 | <.0001 | 0.0023 |
| **Soft Dough Biomass % N** | 0.41002 | 0.5077 | 0.52481 | 0.52463 | 0.62191 | 0.85856 | 0.72248 | 0.67543 | 1 | 0.68975 | 0.08538 | -0.59792 | 0.1313 | 0.45366 | 0.45982 | 0.62181 | 0.43152 | 0.01434 | 0.43152 | 0.10808 | 0.40098 | 0.35617 | -0.17596 |
| | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | | <.0001 | 0.2816 | <.0001 | 0.0851 | <.0001 | <.0001 | <.0001 | <.0001 | 0.8568 | <.0001 | 0.2461 | <.0001 | <.0001 | 0.0461 |
| **Maturity Biomass % N** | 0.79938 | 0.81923 | 0.74328 | 0.74328 | 0.74439 | 0.755 | 0.8866 | 0.72267 | 0.68975 | 1 | 0.47285 | -0.247 | 0.15405 | 0.64042 | 0.73795 | 0.65231 | 0.77144 | 0.40525 | 0.77144 | 0.26143 | 0.63087 | 0.54783 | -0.05538 |
| | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | | <.0001 | 0.1592 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0003 | <.0001 | 0.0255 | <.0001 | <.0001 | 0.6147 |
| **HI** | 0.60408 | 0.52744 | 0.14292 | 0.14293 | 0.41785 | 0.00989 | 0.33572 | 0.33838 | 0.08538 | 0.47285 | 1 | 0.51979 | -0.01647 | 0.42035 | -0.04014 | 0.13149 | 0.54689 | 0.2077 | 0.54689 | 0.29036 | 0.44695 | 0.37486 | 0.02278 |
| | <.0001 | <.0001 | 0.0679 | 0.0679 | <.0001 | 0.901 | 0.0035 | 0.0002 | 0.2816 | <.0001 | | <.0001 | 0.8342 | <.0001 | 0.6098 | 0.2543 | <.0001 | 0.0076 | <.0001 | 0.0013 | <.0001 | <.0001 | 0.8042 |
| **NHI** | 0.07554 | 0.00402 | -0.13831 | -0.13819 | -0.25007 | -0.57649 | -0.34302 | -0.18968 | -0.59792 | -0.247 | 0.51979 | 1 | -0.14925 | -0.24224 | -0.42171 | -0.39529 | 0.00347 | 0.17849 | 0.00347 | 0.2137 | 0.07934 | 0.0988 | 0.06065 |
| | 0.3409 | 0.9597 | 0.0802 | 0.0804 | 0.0065 | <.0001 | 0.0032 | 0.0405 | <.0001 | 0.0365 | <.0001 | | 0.0588 | 0.0085 | <.0001 | 0.0005 | 0.9651 | 0.0235 | 0.9651 | 0.0207 | 0.3951 | 0.2892 | 0.5141 |
| **Height** | 0.14106 | 0.29606 | 0.52122 | 0.52132 | 0.14773 | 0.10877 | 0.01556 | 0.38741 | 0.1313 | 0.15405 | -0.01647 | -0.14925 | 1 | -0.00963 | 0.09262 | -0.0878 | 0.35467 | -0.58585 | 0.35467 | 0.21796 | 0.35827 | 0.38621 | -0.27216 |
| | 0.0716 | 0.0001 | <.0001 | <.0001 | 0.0922 | 0.1543 | 0.8876 | <.0001 | 0.0851 | 0.1592 | 0.8342 | 0.0588 | | 0.9131 | 0.2215 | 0.416 | <.0001 | <.0001 | <.0001 | 0.0168 | <.0001 | <.0001 | 0.0016 |
| **Anthesis Biomass Weight** | 0.76543 | 0.72735 | 0.36913 | 0.36907 | 0.88743 | 0.67122 | 0.743 | 0.46846 | 0.45366 | 0.64042 | 0.42035 | -0.24224 | -0.00963 | 1 | 0.75757 | 0.71525 | 0.73588 | 0.33935 | 0.73588 | -0.26296 | 0.00603 | -0.10406 | -0.04439 |
| | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0085 | 0.9131 | | <.0001 | <.0001 | <.0001 | 0.0001 | <.0001 | 0.0037 | 0.9479 | 0.258 | 0.6147 |
| **Soft Doigh Biomass Weight** | 0.66653 | 0.68562 | 0.45533 | 0.45525 | 0.79668 | 0.82115 | 0.85772 | 0.61737 | 0.45982 | 0.73795 | -0.04014 | -0.42171 | 0.09262 | 0.75757 | 1 | 0.82049 | 0.6502 | 0.15311 | 0.6502 | 0.1107 | 0.40511 | 0.29184 | -0.17147 |
| | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.6098 | <.0001 | 0.2215 | <.0001 | | <.0001 | <.0001 | 0.0503 | <.0001 | 0.2287 | <.0001 | 0.0012 | 0.0493 |
| **Maturity Biomass Weight** | 0.79292 | 0.78205 | 0.58518 | 0.58518 | 0.77484 | 0.77715 | 0.91595 | 0.6671 | 0.62181 | 0.65231 | 0.13149 | -0.39529 | -0.0878 | 0.71525 | 0.82049 | 1 | 0.76678 | 0.42918 | 0.76678 | 0.11144 | 0.6063 | 0.51726 | -0.10565 |
| | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.2543 | 0.0005 | 0.416 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | 0.3379 | <.0001 | <.0001 | 0.3273 |
| **KNO/Ha** | 0.94022 | 0.94554 | 0.56315 | 0.56316 | 0.82334 | 0.59203 | 0.811 | 0.72917 | 0.43152 | 0.77144 | 0.54689 | 0.00347 | 0.35467 | 0.73588 | 0.6502 | 0.76678 | 1 | -0.05887 | 1 | 0.27409 | 0.63203 | 0.57157 | -0.12221 |
| | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.9651 | <.0001 | <.0001 | <.0001 | <.0001 | | 0.454 | <.0001 | 0.0025 | <.0001 | <.0001 | 0.1817 |
| **TKW** | 0.27427 | 0.12895 | -0.23473 | -0.23494 | 0.3163 | 0.10418 | 0.46681 | 0.15638 | 0.01434 | 0.40525 | 0.2077 | 0.17849 | -0.58585 | 0.33935 | 0.15311 | 0.42918 | -0.05887 | 1 | -0.05887 | 0.08559 | 0.18849 | -0.12831 | 0.25467 |
| | 0.0004 | 0.0999 | 0.0025 | 0.0025 | 0.0004 | 0.1884 | <.0001 | 0.0881 | 0.8568 | 0.0003 | 0.0076 | 0.0235 | <.0001 | 0.0001 | 0.0503 | <.0001 | 0.454 | | 0.454 | 0.3526 | 0.0392 | 0.1625 | 0.0048 |
| **Kernels/ $m^2$** | 0.94022 | 0.94554 | 0.56315 | 0.56316 | 0.82334 | 0.59203 | 0.811 | 0.72917 | 0.43152 | 0.77144 | 0.54689 | 0.00347 | 0.35467 | 0.73588 | 0.6502 | 0.76678 | 1 | -0.05887 | 1 | 0.27409 | 0.63203 | 0.57157 | -0.12221 |
| | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.9651 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.454 | | 0.0025 | <.0001 | <.0001 | 0.1817 |
| **N Yield per unit of N at Anthesis** | 0.27181 | 0.29548 | 0.25698 | 0.25702 | -0.20759 | 0.10896 | 0.18074 | 0.01303 | 0.10808 | 0.26143 | 0.29036 | 0.2137 | 0.21796 | -0.26296 | 0.1107 | 0.11144 | 0.27409 | 0.08559 | 0.27409 | 1 | 0.7698 | 0.7476 | -0.08884 |
| | 0.0027 | 0.0011 | 0.0046 | 0.0046 | 0.0229 | 0.2423 | 0.126 | 0.8876 | 0.2461 | 0.0255 | 0.0013 | 0.0207 | 0.0168 | 0.0037 | 0.2287 | 0.3379 | 0.0025 | 0.3526 | 0.0025 | | <.0001 | <.0001 | 0.3346 |
| **Yield per unit of DM at Anthesis** | 0.62708 | 0.63607 | 0.43538 | 0.43539 | 0.25581 | 0.43432 | 0.65576 | 0.55755 | 0.40098 | 0.63087 | 0.44695 | 0.07934 | 0.35827 | 0.00603 | 0.40511 | 0.6063 | 0.63203 | 0.18849 | 0.63203 | 0.7698 | 1 | 0.94684 | -0.12979 |
| | <.0001 | <.0001 | <.0001 | <.0001 | 0.0048 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.3951 | <.0001 | 0.9479 | <.0001 | <.0001 | <.0001 | 0.0392 | <.0001 | <.0001 | | <.0001 | 0.1577 |
| **KNO per unit of DM at Anthesis** | 0.49296 | 0.52352 | 0.44363 | 0.44375 | 0.15573 | 0.3332 | 0.55453 | 0.51379 | 0.35617 | 0.54783 | 0.37486 | 0.0988 | 0.38621 | -0.10406 | 0.29184 | 0.51726 | 0.57157 | -0.12831 | 0.57157 | 0.7476 | 0.94684 | 1 | -0.21141 |
| | <.0001 | <.0001 | <.0001 | <.0001 | 0.0894 | 0.0002 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.2892 | <.0001 | 0.258 | 0.0012 | <.0001 | <.0001 | 0.1625 | <.0001 | <.0001 | <.0001 | | 0.0205 |
| **Stand Density** | -0.05283 | -0.17173 | -0.46117 | -0.46127 | -0.13552 | -0.15779 | -0.1114 | -0.26383 | -0.17596 | -0.05538 | 0.02278 | 0.06065 | -0.27216 | -0.04439 | -0.17147 | -0.10565 | -0.12221 | 0.25467 | -0.12221 | -0.08884 | -0.12979 | -0.21141 | 1 |
| | 0.5649 | 0.0596 | <.0001 | <.0001 | 0.1228 | 0.0741 | 0.3101 | 0.0023 | 0.0461 | 0.6147 | 0.8042 | 0.5141 | 0.0016 | 0.6147 | 0.0493 | 0.3273 | 0.1817 | 0.0048 | 0.1817 | 0.3346 | 0.1577 | 0.0205 | |

Significant cultivar differences were observed for mid-season harvest index, with the organic lines having significantly higher mid-season HI than the check cultivars. This is a positive indication that the organic lines are more effectively transferring biomass accumulated early in the season into the final grain product. No significant cultivar differences in biomass production at anthesis were observed. Therefore, the higher organic mid-season harvest index is indicating that the organic lines are more effectively translating accumulated biomass into yield. In addition a significant positive correlation of 0.63 was observed among the organic lines between mid-season harvest index and grain yield (Table 8)

### 4.1.5 Kernel Density

Kernel density or the number of kernels per unit area (KNO) is a key component of yield. A greater understanding of the factors that contribute to KNO are important when identifying ways to increase yield potential (Bindraban *et al.* 1998). According to Fischer *et al.* (1977) kernel density is the most important component in determining final grain yield. Significant differences between average KNO values were observed between site years. Carman (2010) had the highest average KNO with 13632 kernels $m^{-2}$ and Oxbow (2010) had the lowest average KNO with 6053 kernels $m^{-2}$ and was 56% lower than Carman (2010).

Significant cultivar differences in KNO were observed (Table 7). A contrast between the organic lines and check cultivars was significant and found that the organic lines produced an average of 679 more kernels $m^{-2}$. Similar to the findings of Entz & Fowler (1990) in the present study KNO was found to be a primary yield component in this study, as indicated by the high positive correlation between KNO and yield (Table 8). Positive correlations were also observed between KNO and biomass and HI (Table 8). Donmez *et al.*

(2001) assessed the genetic gain in yield attributes of winter wheat and also observed positive correlations between KNO and grain yield, biomass, and HI. It has often been discussed whether grain yield in cereals is limited in the post-anthesis period by source, the supply of assimilate, or by the sink, the capacity of the growing grains to store assimilates (Fischer and HilleRisLambers, 1978). The higher average organic KNO suggests that the organic lines are developing a larger sink than the check cultivars, or are less sensitive to sink reduction in response to stress.

### 4.1.6 Kernel Weight

Analysis for homogeneity of variances found the variance of cultivar kernel weight was significantly different across study site years. Combined analysis was not performed for cultivar kernel weight and individual site year analysis for cultivar height is presented in Table 8. There were significant differences between cultivars for kernel weight (Table 8). Organic line 2 had the highest average Kernel Weight (KWT) at 37.03 mg, and this advantage was observed at three of the four site years. Contrast analysis performed between the organic lines and check cultivars revealed the organic lines to have significantly higher KWTs at all four site years. A slight positive correlation with a pearson r value of 0.29 was observed between KWT and yield of the organic lines (Table 8). Previous work by Donmez *et al.* (2001) found that kernel weight of winter wheat was not correlated with any of the yield attributes they examined including yield.

One possible explanation for the larger organic KWT observed in this study could be that the organic lines had greater disease resistance and as a result had a lower proportion of disease damaged smaller seeds in their yield samples. The organic lines were found to have

lower FHB infection levels compared with the check cultivars when FHB was evaluated at Glenlea (2009) (Table 12). Foliar leaf diseases were not evaluated in this study. If the organic lines possess improved leaf disease resistance in addition to the potential improved FHB resistance, the organic lines may have had less infected tissue and experienced lower disease stress. Foliar leaf infections can decrease the photosynthetic leaf area, thus reducing the rate of assimilate production, and could cause earlier senescence. According to Fischer and HilleRisLambers (1978) potential kernel weight can be limited by heavy foliar disease infections.

A longer grain filling period or delayed senescence may have contributed to larger average TKWs among the organic lines. Kernel weight is formed during maturation and is impacted by late season moisture and temperature (Donmez *et al.* 2001). Days to maturity were not evaluated in this study but the organic lines may have exhibited a delayed senescence and continued to transfer assimilates into the grain for a longer period than the check cultivars. It would be interesting to assess the relative maturity of the cultivars as Kamran *et al.* (2014) reported that early maturity in organic systems with improved early season vigor would allow greater competitiveness under a limited nutrient supply. Early maturity helps avoid early or late season frost as such most Canadian spring wheat cultivars are early maturing and possess strong vernalization genes (Kamran *et al.* 2014).

A trade-off between increased KNO and decreased kernel weight is sometimes observed (Fischer and HilleRisLambers, 1978; Sadras 2007). However, the combined site analysis in the present study showed significant cultivar differences in kernel density, and a higher average for lines selected under organic conditions relative to the check cultivar average (Table 7). This fits with the previous findings in this study of higher average organic

line yields relative to the check cultivars. It was observed that under the same growing conditions the organic lines are producing a greater number of larger kernels than the check cultivars. The biomass results presented earlier (Table 7) showed no significant differences between cultivars in biomass accumulation, hence an equivalent assimilate source. The larger kernel size, along with greater kernel density of the organic lines is indicating greater translocation efficiency among the organic lines. Kirk *et al.* (2012) also found that lines selected under organic management had higher kernel weights than checks selected under conventional management.

Table 9: Average Kernel weights (KWT) of organic and check cultivars from Glenlea and Oxbow in 2009, and Carman and Oxbow in 2010.

| | Glenlea 2009 | | Oxbow 2009 | | Carman 2010 | | Oxbow 2010 | |
|---|---|---|---|---|---|---|---|---|
| Cultivar | ---------- mg ---------- | | | | | | | |
| ORG 2 | 33.83 | abc | 40.73 | bc | 36.81 | a | 36.77 | a |
| ORG 3 | 33.04 | abcd | 38.14 | ef | 35.87 | ab | 31.46 | cde |
| ORG 4 | 32.17 | bcdefg | 39.98 | bcd | 35.51 | abc | 34.61 | ab |
| ORG 6 | 31.68 | cdefgh | 38.94 | de | 33.03 | defg | 32.92 | bcd |
| ORG 7 | 32.34 | abcdef | 39.60 | cd | 34.39 | bcd | 33.59 | bc |
| ORG 9 | 29.46 | h | 36.68 | gh | 32.54 | efg | 31.24 | de |
| ORG 10 | 32.90 | abcde | 40.31 | bc | 33.87 | ab | 33.55 | bc |
| ORG 11 | 30.41 | fgh | 37.54 | fg | 33.12 | def | 31.15 | de |
| ORG 12 | 34.44 | a | 40.85 | ab | 35.86 | ab | 34.71 | ab |
| ORG 13 | 31.75 | cdefg | 41.07 | ab | 35.84 | ab | 33.89 | b |
| ORG 14 | 34.21 | ab | 41.99 | a | 35.57 | ab | 34.82 | ab |
| CADILLAC | 31.21 | defgh | 36.01 | h | 33.44 | def | 30.43 | e |
| KANE | 30.75 | efgh | 34.42 | I | 32.03 | fg | 31.13 | de |
| MCKENZIE | 32.02 | bcdefg | 33.21 | I | 32.91 | defg | 29.50 | e |
| 5602HR | 30.07 | gh | 36.79 | gh | 31.44 | g | 29.77 | e |
| ***P > F*** | 0.0006 | | <0.0001 | | <0.0001 | | <0.0001 | |
| **Contrast** | ----------*P > F*---------- | | | | | | | |
| Checks vs. Organic | 0.0045 | | <0.0001 | | <0.0001 | | <0.0001 | |
| **Estimate** | -1.3717 | | -4.5144 | | -2.3109 | | -3.3086 | |

† Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

### 4.1.7 Kernel Number per unit of Dry Matter at Anthesis

The kernel number per unit of dry matter produced at anthesis (KNO:DMa) has been referred to as a measure of the kernel production efficiency (Fischer, 1979). There were significant cultivar differences in the number of kernels produced per unit of dry matter accumulated at anthesis (Table 7). Organic line 9 had the highest kernel production efficiency producing an average of 22610 kernels per kg of biomass at anthesis while the check cultivar 'McKenzie' had the lowest with 16652 kernels per kg of biomass. The contrast between the organic lines and check cultivars showed significantly higher average kernel production efficiency in the organic lines. The organic lines were able to produce an average of 2016 more kernels per unit (kg) of dry matter produced at anthesis than the check cultivars. Previous studies have found that kernel production efficiency tends to decrease under increased stress (Entz and Fowler, 1990). Entz and Fowler (1990) reported values of 20 000 – 24 000 kernels per kg of dry matter at anthesis for winter wheat, which are slightly higher than the cultivar average range observed in the present study of 16 652 – 22 610 kernels $m^{-2}$. Because the organic lines and check cultivars were exposed to the same biotic and abiotic stresses, the increased kernel production efficiency in this study may be an indication of higher stress tolerance by the organic lines.

Significant differences were observed among site years with Oxbow (2010) having the lowest average kernel production efficiency with a site average of 14 893 and Glenlea (2009) had the highest average kernel production efficiency at 21 338. There was no significant interaction between cultivar and site year observed, indicating that the kernel production efficiency among genotypes was consistent among sites.

### 4.1.8 Height

Analysis for homogeneity of variances found the variance of cultivar heights was significantly different across study site years. Combined analysis was not performed for cultivar height and individual site year analysis for cultivar height is presented in Table 10. Significant differences between cultivars were found at all four site years. The contrast performed between the organic lines and check cultivars found significant differences at all four site years. The check cultivars were significantly taller than the organic cultivars across all sites. 'Cadillac' was the tallest cultivar with an average height of 106.3 cm. The higher average height of the check cultivars is of interest, as it has been previously reported that taller varieties are more competitive, and thus better suited for organic conditions (Gooding *et al.* 1993a; Cudney *et al.* 1991). It has been widely accepted that increased crop height provides improved competitive ability through increased light interception and superior weed shading abilities. The shorter organic lines showed superior agronomic performance, therefore it is likely that they are compensating with alternative traits such as leaf architecture and plant shape that contribute to their overall competitive ability. Several researchers (Wolfe *et al.* 2008; Lammerts van Bueren *et al.* 2011; Hoad *et al.* 2006) have observed that a shorter planophile cultivar with a high leaf area index and vigorous early season growth may be more competitive than a tall variety that lacks those traits. The lower average height of the organic lines is consistent with the fact that the selections were made within the organic population (BC07B-ORG) examined in the present study for moderate height during early generation ($F_2 – F_3$) selections.

Average site year heights differed considerably with the tallest site year average from Glenlea 2009 and the shortest site year average from Oxbow 2010 (Table 10). Glenlea 2009

was a high moisture and high N fertility site compared to the other site years while Oxbow 2010 was our lowest N fertility site. The favourable soil fertility and high moisture at Glenlea in 2009 likely contributed to higher average plant heights, indicating the impact that environmental conditions can have on the performance of cultivars. All study sites can be considered N rich and the higher check cultivar heights observed are likely attributed to the N rich conditions.

Improvements in harvest index often correspond with decreases in plant height and lodging (Brancourt-Hulmel *et al.* 2003). The shorter stature of the organic lines relative to the average of the check cultivars may be a result of selections for improved harvest index values. Increased harvest index values have been associated with increased yields (Brancourt-Hulmel *et al.* 2003). Decreased plant height may result in a decrease in lodging and reduce potential yield losses to lodging and increased disease in lodged or partially lodged stands. Lodging was not assessed in this study and was only observed at Oxbow (2010) in the fourth rep where there was increased wild oat pressure. The lodging observed corresponded to patches of increased wild oat densities and no cultivar differences were apparent. Therefore, lodging was probably not the cause for the lower yields.

Table 10: Plant heights at maturity of organic lines and check cultivars from Glenlea and Oxbow in 2009, and Carman and Oxbow in 2010.

| | Glenlea 2009 | | Oxbow 2009 | | Carman 2010 | | Oxbow 2010 | |
|---|---|---|---|---|---|---|---|---|
| Cultivar | ---------- cm ---------- | | | | | | | |
| ORG 2 | 102.4 | cde | 79.6 | bcd | 89.7 | efg | 95.7 | c |
| ORG 3 | 98.8 | fg | 77.1 | cdef | 91.5 | def | 87.7 | f |
| ORG 4 | 103.0 | cd | 77.1 | cdef | 90.3 | defg | 91.8 | cdef |
| ORG 6 | 100.5 | def | 75.6 | def | 85.8 | g | 90.6 | def |
| ORG 7 | 100.5 | def | 78.2 | bcde | 93.1 | cde | 95.0 | cd |
| ORG 9 | 95.9 | h | 75.0 | def | 95.0 | cd | 92.0 | cdef |
| ORG 10 | 98.8 | fg | 80.9 | bc | 87.0 | fg | 88.9 | ef |
| ORG 11 | 100.3 | efg | 77.0 | cdef | 93.3 | cde | 95.6 | c |
| ORG 12 | 98.6 | fg | 78.7 | bcd | 87.9 | fg | 87.7 | f |
| ORG 13 | 97.8 | gh | 73.5 | ef | 90.9 | def | 94.5 | cd |
| ORG 14 | 101.8 | de | 77.9 | cde | 93.8 | cde | 92.9 | cde |
| CADILLAC | 117.8 | a | 89.2 | a | 109.0 | a | 109.2 | a |
| KANE | 100.0 | efg | 72.8 | f | 95.1 | cd | 95.3 | c |
| MCKENZIE | 109.6 | b | 76.2 | cdef | 102.0 | b | 103.5 | b |
| 5602HR | 104.4 | c | 82.9 | b | 96.9 | c | 100.8 | b |
| ***P > F*** | <0.0001 | | <0.0001 | | <0.0001 | | <0.0001 | |
| **Contrast** | ----------*P > F*---------- | | | | | | | |
| Check vs. Organic | <0.0001 | | 0.0059 | | <0.0001 | | <0.0001 | |
| **Estimate** | 8.0955 | | 2.9454 | | 9.9858 | | 10.1625 | |

† Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

### 4.1.9 Weed competition

Weed competition varied across site years depending on weed seed bank density and diversity, as well as environmental conditions. Weed density was not evaluated from all four site years as levels of weed populations were generally low and consistent across replicates. Oxbow (2010) was the only site year with higher than average weed pressure as the trial area overlapped a patch of wild oats. The high wild oat population present contributed to a decrease in biomass production and also was a factor in some of the lodging we experienced in our third and fourth replicates from Oxbow (2010). Biomass samples collected at the soft dough stage were separated into wheat and weeds and each component was dried and weighed. No significant cultivar differences in weed biomass were observed (Table 11).

Results showed that the organic lines were able to produce higher grain yield than the check cultivars despite having similar levels of weed biomass.

In the case of the elevated weed pressure at the Oxbow (2010) experiment it would be interesting to know if there were different morphological characteristics that were allowing the organic lines to better compete with the wild oats. Characteristics such as leaf angle and leaf area were not measured as part of the present study but would be of interest in future work. Horizontal leaf architecture, greater canopy closure and wider leaf blades have been cited as beneficial characteristics for improved weed competitiveness (Wolfe *et al.* 2008). In addition the below ground rooting system characteristics would likely contribute to the competitive ability of cultivars. An increased rooting depth or rooting biomass would allow a cultivar preferential access to soil nutrients. The rate of root growth as well as rate of early season growth would also be characteristics which may contribute to enhanced weed tolerance. Significant cultivar differences in early season growth were not observed in this study but root growth was not evaluated. Satorre and Snaydon (1992) compared the root and shoot competition of spring cereals and wild oats and observed that root competition affected cereals more than shoot competition. They observed that there was little genetic variation in root attributes that affect competitive ability between or within cereal species, indicating room for improvement via selection in future breeding programs (Satorre and Snaydon, 1992). While increased height has been associated with enhanced competitive ability by some (Cudney *et al.* 1991) the organic lines were found to have shorter average plant heights than the check cultivars.

Table 11: Weed biomass from Oxbow 2010 collected at Soft Dough stage.

| Cultivar | Weed Biomass |
|---|---|
| | kg ha$^{-1}$ |
| ORG 2 | 2350.3 |
| ORG 3 | 1711.5 |
| ORG 4 | 2015.8 |
| ORG 6 | 1484.5 |
| ORG 7 | 2185.2 |
| ORG 9 | 1584.9 |
| ORG 10 | 2059.2 |
| ORG 11 | 1793.8 |
| ORG 12 | 2230.3 |
| ORG 13 | 2291.1 |
| ORG 14 | 2170.4 |
| CADILLAC | 1826.6 |
| KANE | 2391.4 |
| MCKENZIE | 2591.4 |
| 5602HR | 2274 |
| ***P > F*** | 0.9215 |
| **LSD** | |
| **Contrast** | *P > F* |
| **Checks vs Organic** | 0.294 |
| **Estimate** | 282.06 |

† Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

### 4.1.10 Disease Pressure

Fusarium head blight *Fusarium graminearum* (FHB) was present at the Glenlea (2009) site year. Fusarium was evaluated in all plots and an FHB index was calculated taking into account the incidence and severity of infection present in each plot. There were significant differences between genotypes in incidence, severity, and FHB index (Table 12). The FHB index [Eq 1] takes into account both the incidence of FHB in the plot and the severity of the infection. The check cultivar 'Cadillac' had the highest average FHB index with an average of 52.2%. The organic lines ORG 11 and ORG 14 had significantly lower disease indexes with average values of 19.0% and 16.4%, respectively. Contrast analysis of the organic lines vs. the check cultivars found the organic lines had significantly lower

average FHB index with the average organic line FHB index 11.2% lower than the check cultivar average. Organic growers rely on genetic resistance to diseases as one of their tools for reducing disease levels as they cannot utilize synthetic fungicides. Genetic resistance to key cereal diseases is desirable for an organic cultivar (Wolfe *et al.* 2008). Improved resistance can mean lower levels of FHB damaged kernels and neurotoxin deoxynivalenol (DON) which both reduce the quality and grade of a wheat sample. A reduction of quality due to FHB damaged kernels or elevated DON levels would have detrimental economic consequences for organic growers. Throughout this study no other substantial disease issues were observed. Locally, common leaf diseases rust and tan spot were present in a few site years but with overall low incidence and severity.

It is possible that the organic lines have a higher inherent resistance to FHB and were better able to withstand the disease pressure present in the Glenlea (2009) experiment. Selections were made for improved FHB resistance within the organic population BC07B-ORG from which the breeding lines of the present study originated. The conventional check cultivars in the study varied in in FHB resistance ratings. '5602HR' is rated as MR or moderately resistant to FHB resistance while the remaining check cultivars have a rating of I or intermediate resistance to FHB resistance (Graf *et al.* 2003, Manitoba Seed Growers' Association, 2014). It is possible that the organic lines began flowering at a different time that the check cultivars. While measurements were taken when the majority of the trial was in anthesis individual flowering dates of each cultivar were not recorded. FHB infection occurs during flowering and earlier or delayed flowering of a cultivar may have reduced infection levels depending on when the conditions for infection were highest.

Table 12: Fusarium graminearum infection incidence, severity and FHB Index of spring wheat cultivars at Glenlea (2009).

| Cultivar | FHB Incidence | | FHB Severity | | FHB Index | |
|---|---|---|---|---|---|---|
| | % | | % | | % | |
| ORG 2 | 96.9 | cd | 37.9 | bc | 37.0 | bc |
| ORG 3 | 99.4 | ab | 34.9 | bc | 34.7 | bc |
| ORG 4 | 97.5 | bcd | 30.9 | bcd | 30.0 | bcd |
| ORG 6 | 98.8 | abc | 38.8 | abc | 38.2 | bc |
| ORG 7 | 96.9 | cd | 30.3 | bcde | 29.6 | bcd |
| ORG 9 | 98.1 | abcd | 25.6 | cde | 25.1 | cd |
| ORG 10 | 100 | a | 32.9 | bcd | 32.9 | bc |
| ORG 11 | 94.4 | e | 20.1 | de | 19.0 | d |
| ORG 12 | 98.8 | abc | 35.8 | bc | 35.1 | bc |
| ORG 13 | 99.4 | ab | 29.6 | bcde | 29.4 | bcd |
| ORG 14 | 98.1 | abcd | 16.6 | e | 16.4 | d |
| CADILLAC | 100 | a | 52.2 | a | 52.2 | a |
| KANE | 96.3 | de | 38.5 | abc | 37.3 | bc |
| MCKENZIE | 99.4 | ab | 34.2 | bc | 33.9 | bc |
| 5602HR | 99.4 | ab | 40.6 | ab | 40.3 | ab |
| ***P > F*** | 0.0012 | | 0.0021 | | 0.0018 | |
| **Contrast** | ---------- *P > F* ---------- | | | | | |
| **Checks vs. Organic** | 0.1509 | | 0.0004 | | 0.0003 | |
| **Estimate** | 0.74 | | 11.05 | | 11.2 | |

† Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

### 4.1.11 Yield

A significant difference in average yield was observed from each of the four site years. Oxbow (2010) was the lowest yielding site year with a site average of 1837 kg $ha^{-1}$ (Table 7). The elevated weed pressure, in particular wild oats present at Oxbow (2010), likely contributed to the lower yields. Carman (2010) had the highest average yield at 4337 kg $ha^{-1}$. While mid-range in terms of N fertility of the sites in this study, it had the highest soil organic matter content at 4.6%. The higher yields from Carman (2010) are also likely attributable in part to the particularly favourable growing conditions that season. Carman (2010) received 382 mm rain between May and August, which was 138% of the 30 year

average precipitation. Carman (2010) also had slightly above average temperatures in July and August.

Results of combined analysis for yield showed significant differences between cultivars. The organic line ORG 7 was the highest yielding line on average across the four site years, with an average yield of 3568 kg $ha^{-1}$ (Table 7). The top five average yields were all organic cultivars while the lowest yielding cultivar was the conventional variety 'Kane', which had an average yield of 2895 kg $ha^{-1}$. Cadillac' was the only check cultivar that yielded higher than an organic line. 'Cadillac' however surpassed ORG 6 the lowest yielding organic cultivar by only 35.4 kg $ha^{-1}$. A significant contrast difference was the result of higher grain yields for the organic lines. The average organic yield was approximately 456 kg $ha^{-1}$greater than for the check cultivars. These findings are consistent with the work of Kirk *et al.* (2012) who also observed wheat selected in organic environments to be higher yielding than conventionally selected populations when tested under organic management.

The overall agronomic performance of the organic lines was strong in this study (Table 7). Because yield performance is such a key indicator of cultivar potential, it is important to know how the organic lines are achieving higher yields relative to the check cultivars in this study. Table 8 provides correlation coefficients and associated probabilities of the organic lines for key study parameters. Organic yields were found to have a strong positive correlation with kernel density with an r value of 0.94 (Table 8). This significant correlation between yield and kernel density indicates that the organic cultivars are achieving high yields through the increased production of kernels per unit of area. The organic lines had higher average kernel densities than the check cultivars (Table 7). Kernel weight had a slight positive correlation with yield with an r value of 0.27 (Table 8). While higher organic kernel

weights were also observed (Table 9) the correlation values indicate that the yield of the organic lines was more dependent on kernel number than kernel size. Entz and Fowler (1990) also observed that kernel weight did not influence grain yield to the same degree as KNO.

The significant site year by cultivar interaction observed in the present study is indicative that genotypes performed differently under different environmental conditions. The same cultivar that was the highest yielding line at one site did not perform as strongly or consistently in another environment. These findings support the arguments by several researchers that there is the need for local breeding programs that focus on selecting the fittest genotypes for the stresses of the intended growing environment. Kamran *et al.* (2014) evaluated the relative performance of Canadian spring wheat cultivars under organic and conventional field conditions and found a significant cultivar by environment interaction. They concluded that the significant cultivar by environment interaction indicates that cultivars differed in their ability to tolerate nutrient, weed and disease pressure. It is important to note that none of our site years would be considered N limiting as they all had adequate soil N levels (Table 2). It was important to test the yield potential of the organic cultivars at organic sites with good soil fertility and favourable growing conditions in order to allow them to perform to their full potential. The significant site year by cultivar interaction is indicative of the impact that unique environmental conditions including but apparently not limited by soil nutrient levels. The unique biotic and abiotic factors that affect cultivars growing at each site impact the relative performance of each cultivar. These differing stresses apply unique selection pressures and the cultivar that is better able to cope with the various stresses will display a greater fitness of performance in that environment. While a significant

genotype by environment interaction was observed it is beyond the scope of the present study to identify the underlying reason or reasons for this significant interaction.

#### 4.1.11.1 Cultivar Yield Performance Consistency

The ability of a cultivar to adapt and overcome different stresses or conditions can be assessed by considering yield performance consistency across differing conditions. The observation of a significant interaction of site year and yield prompted a more detailed consideration of genotype ranking across the four sites. Were certain cultivars able to perform better with a higher average mean across all site years, or was there a change in the relative ranking of yield performance based on the environmental characteristics of each site year? Table 13 shows individual site year analysis for yield of each cultivar at each of the four site years. A consistent trend in the yield performance of the cultivars across sites was not observed.

Each of the four experimental sites had a different cultivar with the highest average yield. Across all four site years an organic line was the highest yielding cultivar. Several organic lines were consistently among the top yielding lines across multiple site years. For example organic lines 2, 13 and 14 were all among the top 5 yielding lines at three out of four site years. While the one organic line was not the top yielding line across all environments it appears that several of the lines are adapted to have strong yield performance in varying environments. The organic line 2 was the highest and second highest yielding line at Oxbow (2010) and Oxbow (2009), respectively. Oxbow (2009) had limited moisture early in the growing season and Oxbow (2010) had higher weed pressure than other experimental sites. The high yield of organic line 2 in these two environments suggests that this cultivar is better

able to withstand environmental stresses relative to the other organic lines and check cultivars. Further work is required to better understand the underlying factors of the genotype by environment interaction.

Looking at the standard deviation of a cultivar yield across environments provides us an indication of the stability of yield performance. Organic line 2 in addition to ranking among the top give yielding lines across site years had one of the lowest standard deviations indicating that it was a more stable in its yield performance across environments. Organic line 6 was not the highest ranking in yield but had the lowest standard deviation. This lower variation indicates that it was the most stable cultivar in terms of yield performance across site years. Organic line 3 had the highest standard deviation and appears to be less stable in yield performance when grown in varying environmental conditions. A cultivar that has a lower standard deviation between differing environments may be better suited for use across a wide region while a cultivar with a higher standard deviation may be more variable across environments but may have a higher yield potential when grown in the right environment.

As discussed earlier, Oxbow (2010) was considered a higher stress environment with lower fertility (relative to the other site years) and increased weed pressure. Under the increased stress conditions of Oxbow (2010) the organic lines performed better than the check cultivars (Table 14). The four check cultivars had the four lowest yield values with each of the organic lines yielding higher. The superior yield performance of the organic cultivars at Oxbow (2010) is a positive indication that the organic cultivars are better adapted for stressful growing environments. The organic lines had higher average harvest index values than the check cultivars (Table 7) and observed no significant differences in biomass accumulation. This suggests that the organic lines were better able to remobilize assimilates

into the grain even while under elevated stress. The organic lines were higher yielding under conditions of early season moisture limitation indicating they may have a higher degree of drought tolerance than the check cultivars. The organic lines also yielded higher under elevated weed pressure. While the organic lines had similar levels of weed biomass as the check cultivars they were able to better cope with this weed pressure and subsequently had less of a yield reduction relative to the check cultivars.

Barraclough *et al.* (2014) examined genotypic variation in uptake partitioning and remobilization of nitrogen during grain-filling in wheat. They separated their above ground biomass samples into stem, leaves, sheaths, and head components at various growth stages and were able to track the proportions. Conducting a similar study would isolate the biomass weight per plant part and may provide additional insights into which tissues the assimilates are being remobilized from during grain filling. It may be that the organic lines are more efficient than the check cultivars at remobilizing from particular plant parts. Or conversely it may be observed that elevated drought stress or weed competition results in a greater reduction in remobilization of the check cultivars.

Table 13: Average Cultivar yields from Glenlea and Oxbow in 2009, and Carman and Oxbow in 2010. The highest yielding cultivar at each site is indicated in bold.

| Cultivar | Glenlea 2009 | Oxbow 2009 | Carman 2010 | Oxbow 2010 | Cultivar Standard Deviation |
|---|---|---|---|---|---|
| | ---------- Yield (kg ha $^{-1}$) ---------- | | | | |
| ORG 1 | 3234.9 | 3458.2 | . | . | |
| ORG 2 | 3434.8 | 3931.2 | 4132 | **2468.6** | 742 |
| ORG 3 | 3330.3 | 3337.1 | **4978.7** | 1922 | 1249 |
| ORG 4 | **3535.8** | 3409.2 | 4405.7 | 1879.4 | 1050 |
| ORG 5 | 3083.8 | 3433.5 | . | . | |
| ORG 6 | 3130.8 | 2826.1 | 3463.6 | 2025.4 | 615 |
| ORG 7 | 3400.4 | **3979** | 4326.6 | 2232.4 | 918 |
| ORG 8 | 3370.8 | 3376 | . | . | |
| ORG 9 | 3078 | 2787.7 | 4686.5 | 2040.2 | 1115 |
| ORG 10 | 3243.7 | 3679.3 | 4099.8 | 1908.1 | 949 |
| ORG 11 | 3312.7 | 3592.9 | 4539.4 | 2023.7 | 1038 |
| ORG 12 | 3419.5 | 3591.9 | 4632 | 1946.1 | 1105 |
| ORG 13 | 3161 | 3592.9 | 4820.9 | 2090.3 | 1230 |
| ORG 14 | 3487.9 | 3275.5 | 4661.3 | 2031.9 | 1077 |
| AC BARRIE | 3480.2 | 3264.9 | . | . | |
| CADILLAC | 3123.4 | 3185.5 | 4036 | 1201.2 | 1198 |
| CDC KERNEN | 2694.4 | 3186.4 | . | . | |
| KANE | 3093.4 | 2174.3 | 4242.4 | 1796.6 | 1089 |
| MCKENZIE | 2640.1 | 2701.8 | 4235.1 | 1804.7 | 1012 |
| 5602HR | 2850.6 | 3137.8 | 3798.9 | 1613.8 | 914 |
| ***P > F*** | 0.0071 | 0.7153 | 0.0001 | 0.0041 | |
| **LSD** | 316.5 | | 792.33 | 677.19 | |
| **Contrast** | ---------- ***P > F*** ---------- | | | | |
| Organic vs Checks | 0.0005 | 0.9029 | 0.0003 | 0.0145 | |

† Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

## 4.2 Nitrogen Dynamics

### 4.2.1 Soil Nitrogen

Soil nitrogen was evaluated in the spring prior to seeding for each of the study site years. Wheat has relatively high N requirements; an average 2700 kg ha$^{-1}$ crop of wheat at maturity will contain approximately 95 kg ha$^{-1}$ of N (Alberta Ag, 2013). Carman (2010), Oxbow (2009), and Glenlea (2009) had top - subsoil (0-60 cm) N levels of 129, 184, and 169 kg ha$^{-1}$ respectively which are all above the estimated minimum of the required 95 kg ha$^{-1}$.

Oxbow (2010) was the lowest fertility site year with just over 96 kg $ha^{-1}$ of N in the top - subsoil (0-60 cm). All site years with the exception of Oxbow (2010) were on land following a green manure or fallow and green manure rotation. According to the MAFRI 2013 spring wheat production guide an application of 0-33.5 kg $ha^{-1}$ of N is recommended following a fallow or legume breaking (MAFRI, 2013). Oxbow (2010) was following the termination of an Alfalfa stand and appears to have been limited in soil N compared to the other three site years.

The relatively low N fertility at Oxbow (2010) was a bit surprising as Alfalfa is typically an N rich crop. According to Oklahoma state University Forage Legumes and Nitrogen Production (Caddel *et al.*, 2014 ) in good growing conditions with adequate moisture a 4500-5600 kg/ha, 60-90 cm tall alfalfa stand can contribute up to 112-168 kg/ha of N to subsequent plantings. One possible explanation for the low N levels at Oxbow (2010) is the low level of precipitation in 2009. Table 4 provides the seasonal precipitation levels at our four site years and shows that Oxbow (2009) was a dry site year receiving only 74% of the 30 year average precipitation. In particular, it was observed that the beginning of the growing season was particularly dry receiving only 11.9% of the normal precipitation in May of 2009. The dry conditions especially early in season would have limited stand establishment and likely contributed to a reduction in alfalfa yields in 2009. The dry conditions may have limited alfalfa production or yield of the crop in 2009 and as a result there would have been less residual soil N for subsequent crops.

### 4.2.2 Nitrogen Uptake and Accumulation

In order to test the second hypotheses that wheat selected under slow-release organic N sources (green manures) will have superior soil N capture abilities than wheat lines selected under conditions of highly soluble N, the N uptake was measured from biomass sampling throughout the growing season. Nitrogen concentration in the tissue, as well as N biomass accumulation of the different cultivars was compared.

#### 4.2.2.1 Nitrogen Accumulation at Stem Elongation

Stem elongation nitrogen uptake was assessed in 2009 at Glenlea and Carman. No significant differences were observed between cultivars (Appendix Table 16). The lack of significant differences in early season N accumulation suggests that cultivars exhibited similar growth characteristics related to soil N capture. Stem elongation nitrogen biomass values ranged from 27.8 – 48.5 kg N ha $^{-1}$. Vaisman *et al.* (2011) reported stem elongation N biomass accumulation of between 27 and 110 kg N ha$^{-1}$ following a green manure with spring tillage; conditions similar to the present study. Stem elongation assessments were eliminated from the sampling procedure in 2010 in favor of collecting samples at maturity based on indications from 2009 data that differences between cultivars in N uptake were greater later in the growing season.

#### 4.2.2.2 Nitrogen Accumulation at Anthesis

Significant site year differences were observed for both N biomass accumulation and N tissue concentration at anthesis (Table 14). There were considerable differences in the N

fertility of the experimental sites (Table 2). Not surprisingly Oxbow (2010) the lowest N fertility site year had the lowest average N accumulation at anthesis. In addition to differences in initial soil N status, the soil moisture availability at the different experimental sites would have likely contributed to the significant differences in pre-anthesis N accumulation. Clarke *et al.* (1990) observed that the total plant N uptake was proportional to the available water, and was strongly associated with biomass accumulation.

There were no significant differences observed between cultivars for N accumulation by anthesis (Table 14). There was no significant site year by cultivar interaction for N biomass at anthesis, indicating that the cultivars were consistent in N accumulation at anthesis across site years.

4.2.2.3 Nitrogen Accumulation at Soft Dough

While site years in the present study differed significantly in average N accumulation and N concentration at soft dough, no significant differences between cultivars were observed (Table 14). No significant site year by cultivar interaction was observed for N accumulation at soft dough; again the cultivars display consistent N accumulation at soft dough across environments. Individual site year analysis showed significant differences between cultivars from Glenlea (2009) and Oxbow (2010) (Appendix Table 16). Interestingly these two site years that exhibited significant differences in cultivar N uptake had uniquely elevated stress levels. Glenlea (2009) as earlier mentioned had FHB disease pressure that would have been creating a stress for the plants. 'Cadillac' the cultivar with the highest FHB index (Table 12) was also the cultivar with the lowest soft dough N biomass. Oxbow (2010) our low soil N higher weed pressure site also had the greatest cultivar differences.

Table 14: Combined Analysis of Nitrogen Parameters from Glenlea and Oxbow in 2009, and Carman and Oxbow in 2010.

| | Anthesis biomass N | | Anthesis biomass N | | Soft Dough biomass N | | Soft Dough biomass N | | Maturity Biomass N | | Maturity biomass N | | Protein | | N Yield/ N uptake @ anthesis | | Nitrogen Harvest Index | | Grain N Yield | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | kg ha$^{-1}$ | APOC | % | APOC | kg ha$^{-1}$ | APOC | % | APOC | kg ha$^{-1}$ | APOC | % | APOC | % | APOC | | APOC | | APOC | kg ha$^{-1}$ | APOC |
| Site-year | | | | | | | | | | | | | | | | | | | | |
| Glenlea 2009 | 88.8 b | 107.1 | 1.71 a | 116.9 | 103.8 b | 114 | 1.23 a | 109.4 | - | - | - | - | 15.5 a | 110.4 | 1 a | 114.1 | 0.92 b | 105.6 | 87.5 b | 118.4 |
| Oxbow 2009 | - | | - | | 86 c | 94.2 | 1.07 b | 95.8 | - | - | - | - | 12.8 c | 91.0 | - | | 1.09 a | 125.3 | 73.7 c | 99.7 |
| Carman 2010 | 115.1 a | 138.9 | 1.71 a | 117.4 | 134.3 a | 147 | 1.28 a | 114.3 | 122.4 a | 153.6 | 1.29 a | 129.4 | 14.2 b | 101.0 | 0.97 a | 109.9 | 0.86 b | 98.9 | 108.6 a | 147 |
| Oxbow 2010 | 48.9 c | 59 | 1.16 b | 79.8 | 44.1 d | 48.3 | 0.82 c | 72.9 | 45.1 b | 56.6 | 0.82 b | 82.3 | 11.6 d | 82.6 | 0.83 b | 94.2 | 0.94 ab | 108.4 | 36.9 d | 49.9 |
| Cultivar | | | | | | | | | | | | | | | | | | | | |
| ORG 2 | 92.0 | 110.9 | 1.65 a | 113 | 93.9 | 103 | 1.07 | 95.7 | 88.1 | 110.5 | 1.09 | 109.4 | 13.9 abcd | 98.7 | 0.94 | 106.8 | 1.06 b | 121.3 | 88.0 a | 119.1 |
| ORG 3 | 86.9 | 104.9 | 1.55 abc | 106.4 | 92.4 | 101 | 1.19 | 106.1 | 95.4 | 119.7 | 1.10 | 110.4 | 14.1 ab | 100.5 | 1.01 | 114.7 | 1.01 bc | 115.6 | 88.6 a | 119.9 |
| ORG 4 | 85.1 | 102.7 | 1.56 abc | 106.6 | 99.4 | 109 | 1.15 | 102.4 | 79.4 | 99.6 | 1.03 | 102.8 | 13.9 abcd | 98.6 | 0.96 | 108.8 | 0.89 bc | 102.9 | 83.1 abc | 112.5 |
| ORG 6 | 75.2 | 90.7 | 1.52 abcd | 104.4 | 77.2 | 84.6 | 0.98 | 87.2 | 82.4 | 103.4 | 1.13 | 113.0 | 14.0 abc | 99.5 | 1.01 | 114.8 | 1.02 b | 117.0 | 72.6 d | 98.3 |
| ORG 7 | 93.1 | 112.3 | 1.66 a | 113.5 | 91.9 | 101 | 1.13 | 100.9 | 82.7 | 103.8 | 1.04 | 104.1 | 13.6 bcde | 96.6 | 0.90 | 102.2 | 1.01 b | 116.6 | 85.6 ab | 115.9 |
| ORG 9 | 83.7 | 101.0 | 1.59 ab | 109 | 86.4 | 94.7 | 1.08 | 96.4 | 86.1 | 108.0 | 1.12 | 111.5 | 13.4 def | 95.0 | 0.98 | 111.0 | 0.93 bc | 107.1 | 76.7 bcd | 103.9 |
| ORG 10 | 82.1 | 99.0 | 1.39 d | 95.2 | 96.7 | 106 | 1.08 | 96.8 | 78.6 | 98.6 | 1.02 | 101.6 | 12.8 f | 90.9 | 0.93 | 105.5 | 0.84 bc | 96.5 | 76.1 cd | 103 |
| ORG 11 | 83.9 | 101.3 | 1.49 bcd | 102 | 81 | 88.7 | 1.02 | 90.7 | 76 | 95.4 | 1.07 | 107.4 | 12.8 f | 91.3 | 0.94 | 106.8 | 0.95 bc | 109.6 | 79.2 abcd | 107.2 |
| ORG 12 | 84.6 | 102.1 | 1.51 abcd | 103.7 | 87.3 | 95.6 | 0.98 | 87.7 | 94.2 | 118.3 | 1.15 | 115.1 | 13.5 cde | 95.7 | 0.94 | 107.3 | 1.37 a | 157.2 | 83.2 abc | 112.7 |
| ORG 13 | 84.7 | 102.2 | 1.55 abc | 106 | 109.7 | 120 | 1.21 | 108.3 | 83.5 | 104.7 | 1.03 | 103.3 | 13.6 abcde | 97.0 | 1.00 | 113.4 | 0.90 bc | 103.7 | 85.4 ab | 115.7 |
| ORG 14 | 83.6 | 100.8 | 1.6 ab | 109.7 | 95.2 | 104 | 1.12 | 100.3 | 82 | 102.8 | 1.00 | 100.0 | 13.3 ef | 94.3 | 1.02 | 116.0 | 0.92 bc | 106.2 | 82.5 abc | 111.7 |
| CADILLAC | 78.9 | 95.2 | 1.54 abcd | 105.7 | 80.6 | 88.2 | 0.99 | 88.3 | 78.6 | 98.7 | 0.86 | 85.7 | 14.2 a | 101.2 | 0.92 | 104.6 | 1.02 b | 117.7 | 76.6 bcd | 103.7 |
| KANE | 87.8 | 105.9 | 1.49 bcd | 101.7 | 98.2 | 108 | 1.2 | 106.9 | 83.5 | 104.7 | 1.11 | 110.7 | 14.0 abc | 99.6 | 0.88 | 100.1 | 0.78 bc | 90.0 | 72.8 d | 98.5 |
| MCKENZIE | 85.5 | 103.1 | 1.4 cd | 96.2 | 103.1 | 113 | 1.22 | 108.6 | 85 | 106.7 | 1.00 | 100.2 | 13.8 abcde | 98.4 | 0.86 | 98.2 | 0.73 c | 83.6 | 72.0 d | 97.4 |
| 5602HR | 79.5 | 95.9 | 1.43 cd | 97.6 | 88.3 | 96.8 | 1.08 | 96.5 | 77.3 | 97.0 | 1.02 | 102.2 | 14.1 ab | 100.4 | 0.87 | 99.3 | 0.96 bc | 110.6 | 74.0 cd | 100.1 |
| Source of Variation | ---------- *P* > F ---------- | | | | | | | | | | | | | | | | | | | |
| Site-year (SY) | **<0.0001** | | **<.0001** | | **<.0001** | | **0.0015** | | **0.0003** | | **0.0008** | | **<0.0001** | | **0.004** | | 0.4987 | | **<0.0001** | |
| Cultivar | 0.6055 | | **0.0212** | | 0.3707 | | 0.2442 | | 0.9891 | | 0.7813 | | **<0.0001** | | 0.6829 | | **0.006** | | **0.0003** | |
| SY X Cultivar | 0.6984 | | 0.7986 | | 0.7215 | | 0.7300 | | 0.7264 | | 0.7776 | | 0.1228 | | 0.1079 | | **0.0104** | | **0.0270** | |
| Contrast | ---------- *P* > F ---------- | | | | | | | | | | | | | | | | | | | |
| Checks vs. Organic | 0.5467 | | **0.0088** | | 0.9124 | | 0.4983 | | 0.5816 | | 0.1463 | | **<0.0001** | | **0.0076** | | **0.0371** | | **<0.0001** | |
| Estimate | -1.7955 | | -0.0888 | | 0.5418 | | 0.02918 | | -3.2202 | | -0.066 | | 0.5184 | | -0.0896 | | -0.1168 | | -8.0269 | |

† Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

†† APOC denotes As Percent Of Check (values are expressed as a percentage of the conventional check cultivar average – 'Cadillac', 'Kane', 'Mckenzie', and '5602HR')

4.2.2.4 Nitrogen Accumulation at Maturity

Significant site year differences were observed for both N biomass accumulation and N tissue concentration at maturity (Table 14). Combined analysis of the 2010 site years found no significant differences between cultivars for N accumulation or N concentration at maturity (Table 14). No significant site year by cultivar interaction was observed. While there were significant differences in average site year N accumulation the cultivars did not differ significantly in their relative N accumulation at maturity across site years. Organic cultivars had an average N accumulation of 83.3 kg N $ha^{-1}$ while the check cultivars averaged 79.7 kg N $ha^{-1}$. Average N concentration in the tissue of cultivars ranged from 0.86 – 1.15%, the average of the organic cultivars was 1.07% and the average of the check cultivars was 1.00%. Since the cultivar differences in this study were not found to differ significantly, the exploration of N organic and check cultivar differences at maturity would benefit from future research. Future studies may include lower N sites where the plants would be exposed to an N stress selection pressure.

Wheat accumulated between 80 and 90% of its final N by anthesis (Barneix *et al.* 1992, Cregan and van Berkum, 1984). In the present study, the biomass N accumulation increased for 13 out of the 15 cultivars between anthesis and soft dough samplings indicating that either N accumulation was continuing post anthesis or that N was being remobilized from the roots (Table 14). A reduction in biomass N was observed at maturity for the majority of the cultivars. The reduced biomass N at maturity may be due to N lost in senesced tissue and also may be because a greater proportion of the accumulated N was already translocated into the grain. Noulas *et al.* (2014) found that the biomass N at anthesis

was lower than at maturity indicating that the genotypes in their study were continuing to accumulate N in the biomass after anthesis.

The N tissue concentration sampling procedure had limitations as whole plant samples at maturity were not separated by plant parts so the sub-samples analyzed for N may have contained proportionally less grain particles. Limitations of the tissue analysis are discussed at greater length in the nitrogen harvest index section.

### 4.2.3 Grain Protein

Grain protein concentration is an important measure of wheat quality and cultivar performance. There is an economic benefit to growers of grain with increased grain protein. Higher protein grain samples are graded higher and are priced accordingly at a premium. In this study, significant differences in grain protein concentration among site years was observed (Table 14). Oxbow (2010) in particular was a low yielding and not surprisingly lower quality site year with an average protein value of 11.57% as it was our lowest N fertility site (Table 2). The contrast between organic lines and check cultivars found the check cultivars to have significantly higher average protein content with an estimated increase of 0.5% over the organic lines.

There were significant differences between cultivars (Table 14). The conventional variety ‘Cadillac’ had the highest average protein of 14.2% while the organic lines 10 and 11were found to have the lowest average grain protein with an average of 12.8%. The average cultivar proteins in this study ranged between 12.8 and 14.2% and would be considered to be sufficient export quality according the Canadian Grains Commission grain

grading guide. Average protein content of the cultivars in this study fell within the average value range of 11.4 – 15.2% for the Western Red Spring wheat category (Canadian Grain Commission, 2013).

Work by Kirk *et al.* (2012) comparing organic and conventionally selected lines found the organically selected populations had higher protein content than the check populations. In the present study the organic lines had lower average protein than the check cultivars but were higher yielding indicating the possibility of the N dilution effect occurring. The check cultivars were lower yielding and as such may have had a higher grain protein concentration due to the lower kernel number and kernel size relative to the average organic lines (Tables 7 & 8). Kirk *et al.* (2012) also argued that protein dilution due to increased yield is likely more of a concern in conventionally managed wheat because organic yields are typically lower. Nelson *et al.* (2011) compared spring wheat genotypes under organic and conventional systems and observed higher protein levels but lower yields from the genotypes in the organic system. In the present study, however, we observed that the average yield of the organic lines surpassed that of the check cultivars. As the yield performance of organically selected cultivars improves it becomes even more important to also select for increased grain protein potential. Wolfe *et al.* (2008) stated that the grain protein in organic agriculture needs to be higher in order to compensate for the relatively lower N availability compared to conventional systems. In the present study however, the N fertility of experiment sites was not considered to have been limiting (Table 2).

One way that conventional growers are able to maintain grain protein with increasing yields is by applying supplemental N during the growing season. The application of supplemental synthetic N is not an option in organic systems, so in order to maintain high

grain quality from a high yielding cultivar the gains in protein concentration must increase as yield does. Organic rotations tend to have crops with higher N requirements such as wheat following nutrient building crops such as legume green manures. Entz *et al.* (2001) surveyed the soil nutrient status on 14 organic farms and observed that wheat was most likely to follow a green manure crop due to the enhanced soil N status Campbell *et al.* (1993) reported that this enhanced soil N status positively affects wheat yield and protein concentration. Cultivars that are better adapted to organic growing conditions may make better use of the available N, and have the ability to transfer that N into the final grain.

No significant site year by cultivar interaction was observed for grain protein. This indicates that grain protein concentration of the cultivars in this study were consistent across experimental sites.

### 4.2.4 Nitrogen yield per unit of N accumulated at Anthesis

The index of nitrogen yield per unit of N accumulated at anthesis was assessed for the different cultivars in order to gain a better understanding of the efficiency with which early season N was transferred to the grain product. Previous studies stating that the majority of N is taken up in the wheat plant by anthesis (N/Na) make a valuable indicator for N accumulation potential. A high N/Na index value would indicate that a high proportion of accumulated N is retained in the final grain, while a low N/Na index value may indicate that less N was transferred to the final grain. A low N yield per unit of N accumulated at anthesis may also indicate that a larger proportion of final grain N was accumulated later in the season between anthesis and maturity.

The N yield per unit of N accumulated at anthesis differed significantly among site years but significant cultivar differences were not observed (Table 14). Oxbow (2010) had a lower site year average which was likely due to the lower N fertility relative to other study sites and the increased wild oat pressure. The wild oats would have been competing with the wheat cultivars for access to soil N and as a result the wheat cultivars did not accumulate as much N as they were able to at other experimental sites.

The contrast performed between the organic lines and the check cultivars showed a significant difference between the averages of the two groups. The organic lines were estimated to be 9.0% greater than the check cultivars. The organic lines had a higher N yield per unit of N accumulated at anthesis, indicating improved N utilization efficiency compared to the conventionally selected cultivars in this study. The biomass N data (Table 14) shows that there were no significant cultivar differences in biomass N accumulation at anthesis, soft dough, or maturity. The organic lines were better able to transfer units of N taken up earlier in the growing season into the grain. As we observed earlier the organic lines were also more efficient at translating accumulated biomass (carbon) at anthesis to final grain yield (Table 7). These results indicate that the organic lines of this study are more efficient at transferring both biomass and N accumulation into yield. No significant cultivar by site year interaction was observed, indicating that the cultivars were performing consistently in their relative N/Na across environments.

### 4.2.5 Nitrogen Harvest Index

The NHI is the ratio of the nitrogen accumulated in the final grain to the total amount of nitrogen accumulated in the plant (Fageria and Baligar, 2005). NHI values can provide a

useful indication of the amount of N remobilized from storage tissues into the grain and is an important component of N use efficiency. Significant differences in NHI were not observed among site years. The average NHI from the five site years ranged from 0.92 – 1.25 with Carman (2010) showing the lowest site average. There were significant cultivar NHI differences observed. Organic line 12 had the highest average NHI with a value of 1.37, while the lowest average NHI was that of 'McKenzie' at 0.75 (Table 14). Contrast performed between the average NHI of the organic lines and the check cultivars was significant and found higher average NHI values from the organic lines. The organic lines had a higher average NHI of 0.98 compared with the 0.89 average of the check cultivars. The higher organic NHI values indicate that the organic lines were more efficiently utilizing accumulated N for grain production than the check cultivars.

Combined analysis (Table 14) found a significant site year by cultivar interaction for NHI, indicating that the cultivars were not consistent in performance across site years. While not limited in soil N our experimental sites had a range of N fertility that may have contributed to the cultivars varying performance across sites. Noulas *et al.* (2013) found increased NHI of cultivars when grown under conditions of no added fertilizer vs under added synthetic fertilizer conditions. They also observed a significant genotype by N fertility interaction indicating that that the soil N status significantly impacted cultivar N accumulation and remobilization. In the present study, the average site year NHI (Table 14) averages do not match the ranking of N fertility (Table 2). Based on the findings of Noulas *et al.* (2013) it could be expected that the site year with the lowest soil N would have the highest average NHI. In the present study however Oxbow (2009) had the highest average NHI but also had the second highest soil N, indicating that other factors in addition to soil N affected the cultivar's ability to accumulate and remobilize N.

#### 4.2.5.1 Nitrogen Harvest Index Methodology Constraints

The Nitrogen Harvest Index (NHI) values of the various genotypes (Table 14) were found to be greater than the normal range. Values of greater than 1.0 indicate that there is more nitrogen present in the grain than was present in the whole plant. Previous studies examining the genetic variation of N redistribution have reported that the NHI values rarely exceed 0.8 in bread wheat (Corbellini & Borghi 1985, Heitholt *et al.* 1990). Cox *et al.* (1986) examined the genetic variation for N assimilation and translocation in wheat and reported NHI values of 0.59 to 0.83. Their study examined 96 F5 lines under low N and high applied N conditions. They reported higher average NHI values from the low N experiment, average NHI of the 96 was approximately 0.1 greater from the low N compared with the high applied N trial. It is believed that the procedure utilized in preparing samples for nitrogen content analysis is responsible for these irregularities in values. There was a disproportional ratio of tissue types represented by weight in the sub sample, which led to an inaccurate estimation of total plant nitrogen. When analyzing ground tissue samples for N content a small sub sample was collected from a coin envelope (#5 ~ 8x14cm). The lighter finer pieces of stem and leaf biomass were on top while the larger grain fragments migrated to the bottom corners of the envelopes, even after mixing the sample the amount of biomass removed tended to have a greater proportion of non-grain biomass as the particles were finer and lighter than the particles of grain that were unable to be ground smaller than 2mm.

One way prevent this from being an issue again in the future a sample splitter could be used to ensure that the final sample analyzed contained an accurate proportion of tissue types. There are also sampling procedures where each plant part (i.e. stem, leaves, and head) is dried and ground separately and recombined by proportional weight for analysis. This

procedure, while more labour intensive would also provide additional insight into the proportion of total plant N stored in each plant part. The sampling procedure as outlined by Noulas *et al.* (2013) involved separation of grains, chaff (rachis plus glumes and awns), and straw from the samples taken at maturity. Dry weights were taken of each component and chaff and straw were combined and analyzed together for N concentration. Adopting a similar procedure for future work of this nature would be recommended to ensure more reliable N concentration measurements.

While the sub-sampling procedure likely resulted in lower levels of grain particles in the whole plant samples this protocol was employed for all samples. The NHI values calculated, while greater than they should have been compared to other values in the literature, were processed in the same manner and thus may be compared to assess relative differences between the cultivars.

### 4.2.6 Grain Nitrogen Yield

The grain N yield takes into account both the N concentration of the grain and the overall grain yield. Significant grain N yield differences were observed among the four site years. While the cultivar differences were found also to be significant there was no significant site year x cultivar interaction. This indicates that while some of the site years differed in average grain N yield, the cultivars were not performing significantly differently across the four site years in terms of grain N yield. This finding is positive as it indicates that the organic cultivars were performing consistently for grain N yield across the four study environments.

A fairly wide range in average grain N yield was observed among site years. The average N yields ranged from 36.9 kg N $ha^{-1}$ to 108.6 kg N $ha^{-1}$ from Oxbow (2010) and Carman (2010) respectively. It would be of interest to include a wider range of N fertility sites in future research to observe the cultivar performance under limited N fertility. While the N fertility in the present study was not reasonably expected to be limiting the differences in cultivar performance between experimental sites indicates that examining a broader range of N fertility would provide valuable information about the N use of the organic lines.

The average cultivar grain N yields ranged from 72 to 88.6 kg $ha^{-1}$. Bullied *et al.*(2002) reported comparable grain N yields of wheat with average grain N yields of 76.1 kg $ha^{-1}$ following chickling vetch and lentils, and 56.1 kg $ha^{-1}$ following single year hay legumes. Organic line 2 had the highest average grain N yield based on combined analysis of the four site years (Table 14). Organic line 2 had an average grain N yield of 89.2 kg $ha^{-1}$, which was an increase of 10.5 % compared to the highest grain N yielding check cultivar, 'Cadillac'. The organic cultivars had a significantly higher average grain N yield, 8.03 kg $ha^{-1}$ greater than the check cultivar average. Only 'Cadillac' ranked among the top ten N yielding cultivars while the three lowest N yielding lines were the remaining three check cultivars (Table 14). Since the total N accumulated did not differ significantly between the organic and check cultivars (Table 14) the higher grain N yields of the organic lines indicates that they may have greater N remobilization capabilities compared to the check cultivars. While the organic lines had a significantly higher average NHI values compared to the check cultivars (Table 14) the correlation analysis between NHI and Grain N yield of the organic lines was not significant (Table 8). As there were problems associated with the techniques used to evaluate NHI in this study further examination of the N remobilization capacity of the

organic lines may provide additional clarification on how the organic lines are achieving these higher grain N yields.

The organic lines and check cultivars did not differ significantly in biomass N accumulation and the organic lines had higher average yields (Table 7). It was interesting that although the organic cultivars were higher yielding (Table 7) and had lower grain protein (Table 14) the organic cultivars still extracted more N per unit area that the check cultivars as indicated by our higher average organic grain N yield. While the lower protein concentration observed in the organic cultivars could suggest an N dilution may be occurring the total N extraction capacity of the organic cultivars was greater than that of the check cultivars. The check cultivars had lower average yields, lower average kernel size, and lower kernel density (Tables 7 and 8). As a result the check cultivars may have had higher grain protein concentrations because the grains were smaller and there were fewer of them to transolcate N into. The higher N concentration in the grain of the check cultivars also reflects the reduced carbon translocation efficiency of the check cultivars. There were no significant differences observed in the biomass accumulated throughout the growing season (Table 7) between the organic and check cultivars, meaning that the organic cultivars also did a better job at translating the accumulated carbon into yield than the check cultivars.

# 5. CONCLUSIONS

The main objective of this study was to evaluate the relative performance of the organic lines and compare them with check cultivars when grown under organic management. The findings of this study confirm the importance of specialized breeding programs that make selections in the targeted growing environment. This study found significant differences in both agronomic performance and nitrogen capture abilities of the organic lines and check cultivars.

1. The first study hypothesis was that organically selected cultivars are able to cope with the increased and unique stresses of organic growing environments and as a result will yield higher than conventional varieties when grown in organic environments. Combined analysis of our four study site years found significant differences in the yield performance of the organic lines and check cultivars. The average yield of organic lines was higher than the check average. A contrast of the average yield of the organic lines vs. the check cultivars found the organic lines yielded an average 455.9 kg $ha^{-1}$ higher than the conventionally selected check cultivars. The superior yield performance of the organic lines indicates that the hypothesis that organically selected cultivars are better adapted to the stresses of organic growing environments was correct.

2. The second study hypothesis was regarding soil N capture abilities of the different cultivars. Wheat selected under slow release N sources (green manures) will have superior soil N capture abilities than wheat selected under conditions of highly soluble N. Nitrogen uptake was assessed throughout the growing season. No significant differences in soil N

capture were observed between the organic lines and the check cultivars. The organic lines and check cultivars did not differ significantly in the biomass N accumulated throughout the growing season. Therefore the organic lines did not possess superior capturing soil N capture capabilities than the check cultivars.

3. The third study hypothesis was that organically selected wheat cultivars will remobilize and translocate N during grain filling more efficiently than conventional wheat lines selected under conditions of highly soluble N. When trying to categorize the NUE capabilities of the cultivars, NHI and grain N yield were particularly important parameters to examine. The NHI and grain N yield are looking at the amount of N that has been transferred to the final grain. Combined analysis of our four study site years found significant differences between the organic lines and the check cultivars and the average organic NHI and grain N yield. The higher average organic NHI and grain N yield confirms the hypothesis that the organically selected cultivars are better able to remobilize N during grain filling than the check cultivars.

The grain N yield of a cultivar is taking into account both the nitrogen accumulation and yield performance. Combined analysis of our four study site years found significant differences between cultivars, and found that the organic lines had significantly higher grain N yields with an average of 8.02 kg $ha^{-1}$ more N than the check cultivars. We observed in this study that the organic lines had an increased yield of not just carbohydrates as indicated by the higher grain yields but also increased accumulation of N as indicated by the higher organic grain N yields. The organic lines and check cultivars did not differ significantly in biomass or N accumulation but had higher average yields and grain N yields indicating the organic lines had superior C and N remobilization capabilities compared with the check

cultivars. Further research should be directed at better understanding the mechanisms that contribute to the enhanced C and N remobilization efficiency. In particular sampling that includes examination of the below ground biomass may provide meaningful insight into the N accumulation and mobilization. In addition separating above ground biomass evaluations into individual plant parts may improve understanding of the internal storage of mobilization of both C and N from the different plant parts.

# 6. GENERAL DISCUSION

The findings of this study indicate that the selection of breeding lines under organic management has resulted in hard red spring wheat cultivars that are better adapted for growth in organic systems. The organic lines were found to have both higher average grain yield and higher grain N yield, indicating both a strong agronomic performance and N remobilization capacity relative to the check cultivars. The check cultivars were found to have higher average grain protein concentration than the organic lines. The higher yields of the organic lines may be causing an N dilution and may account for the decreased protein concentration observed relative to the check cultivars.

The core objective of this study was to assess the growth and nitrogen economy of the organic lines relative to the check cultivars under organic management. As we collected data on key agronomic and nitrogen economy parameters it led to the question of what does an ideal organic line look like? In the present study the organic lines demonstrated both superior yield and grain N yield relative to the check cultivars. Improved C and N mobilization efficiency to the final grain were two key characteristics that contributed to the enhanced performance of the organic lines. Studies discussing objectives of specialized and organic breeding programs have cited that it is the combination of several characteristics that are of particular value in selecting the best cultivar for organic environments (Mason and Spaner, 2006; Wolfe *et al.,* 2008). Based on the findings of the present study a number of characteristics were identified to improve organic cultivar performance. An "Organic Ideotype" would possess all or some combination of the following features: enhanced early season growth (both above and below ground tissues), increased tillering capacity, a denser

growth habit with increased horizontal leaf angle, wider leaf blades, increased biomass production, increased soil N capture, moderate height, increased stem strength, increased kernel number, superior C and N remobilization efficiency, and enhanced natural disease resistance.

The first study objective was to examine the agronomic performance of the organic lines relative to the check cultivars. The organic cultivars had higher average yields than the check cultivars in this study. A strong correlation was observed between kernel number and grain yield (Table 8), indicating that yield potential of the organic cultivars was related to the kernel number. While the organic lines were found to have a higher average kernel density than the check cultivars, the scope of this study did not investigate where the greater kernel numbers in the organic cultivars were coming from. Was the increased kernel number of the organic cultivars a result of a larger head size with more kernels per head? Or did the organic cultivars have a greater number of tillers that survived to maturity and contribute more kernels per unit area? Evaluating the number of spikelets per head as well as the number of tillers per plant would provide future studies with additional insight into how the organic lines are achieving the increased kernel densities. It would also be interesting to know the tillering capacity of the different cultivars because it may impact seeding density recommendations. A high tillering cultivar may be able to be seeded at a lower rate to maximize production while reducing seed costs.

No significant differences in biomass accumulation were observed between organic lines and check cultivars (Table 7). The organic lines had a lower average height than the check cultivars (Table 10), so if the organic lines were shorter but produced equivalent above ground biomass it is likely that additional leaf tissue made up for the decreased stem size.

Increased proportion of leaf tissue to stem in the organic lines relative to the check cultivars could be part of the reason that the organic cultivars were more efficient at transferring accumulated carbon into a higher final yield. The potential increased leaf tissue could mean additional photosynthetic area that could be a greater source of photosynthate during the grain filling phase. Assessments of the flag leaf would be particularly valuable as the flag leaf is a primary source of assimilates during grain filling The biomass measurements in this study considered whole plant weights at the sampling times but did not assess the biomass production in terms of plant components i.e., leaf tissue, stem, and head. It would be interesting to see if the organic lines have significantly different proportions relative to the check cultivars by weight.

The present study observed superior dry matter partitioning of the organic lines relative to the check cultivars. The average yield per unit of dry matter at anthesis or mid-season harvest of the organic cultivars was positively correlated with grain yield r = 0.62 (Table 8). Contrast analysis of mid-season harvest index values showed that the organic lines were significantly higher than the check cultivars. Significant cultivar differences were also observed for HI (Table 7). A contrast comparing the average organic line HI and the average check cultivar HI showed the organic lines had significantly higher HI values. The significant difference between the organic lines and the check cultivar HI suggests that the organic lines are more efficient at transferring biomass into the final grain product. The average kernel number per unit of dry matter at anthesis (KNO/DMa) or kernel production efficiency of the organic cultivars was also significantly higher than the check cultivars (Table 7).

It was observed earlier that there were no significant differences in biomass accumulation between the organic lines and check cultivars (Table 7). The equivalent

biomass accumulation of the organic and check cultivars paired with the findings in this study of higher average mid-season harvest index, harvest index, and KNO/DMa values indicates that the organic lines in the present study were able to produce additional yield from the same amount of above ground biomass. How were the organic lines able to transfer more biomass into the grain? Were they more efficient at remobilizing carbon from below ground? Did the organic cultivars have larger more extensive rooting systems? Future studies that separate the plant parts by weight at maturity and include below ground biomass evaluations may provide better insight into the tissues from which this additional biomass is being transferred by the organic lines.

The second main objective of this study was to examine the nitrogen economy of the different cultivars. The present study examined the N tissue concentration and N biomass accumulation throughout the growing season and only observed significant cultivar differences in N biomass concentration at anthesis (Table 14). The organic cultivars did not differ significantly from the check cultivars in final N concentration or accumulated biomass N (Table 14). The organic cultivars had significantly higher final grain N yields than the check cultivars (Table 14). The organic cultivars in the present study did not demonstrate superior soil N capture capabilities relative to the check cultivars in the above ground tissue analyzed. The increased grain N yield of the organic cultivars paired with equivalent above ground biomass N indicated that the organic lines found a way to transfer a greater proportion of its accumulated N to the final grain product. The higher average organic NHI values observed confirmed that the organic lines demonstrated superior N remobilization capacity relative to the check cultivars (Table 14). What remains unclear is exactly how the organic cultivars were able to transfer more N to the final grain. Were there additional N sources stored in the roots that were remobilized from below ground tissue to the final grain? Was

more N mobilized from leaves and other above ground tissues of the organic cultivars prior to senescence?

In order to be able to test the organic lines and check cultivars across a number of site years the present study focused efforts on examining the above ground biomass and production. As is often the case in research there are always limitations in what can be examined in a given study. In order to further explore the question of the relative N access and assimilation capacity, the below ground biomass should be examined. In the present study the above ground biomass was used to provide a relative indication but certainly does not account for the whole picture. Of particular interest would be examination of not only the overall root biomass of each cultivar but also the morphology and architecture of the rooting systems and the relationship the two factors have with N extraction and NUE. In addition adopting sampling procedures that separated plant parts and recombined them by weight for N analysis would provide more reliable nitrogen uptake and use efficiency data.

Arbuscular mycorrhizal fungi (AMF) are important soil organisms that aid in the uptake of phosphorus (P) from soil. While soil P levels in recently transitioned soils are rarely an issue AMF are particularly important in long term organic systems where soil P levels can be found to be deficient (Wolfe *et al.* 2008). We observed differing P levels in soil across the four site years, Glenlea 2009 and Carman 2010 were tied for the lowest soil P at 6 ppm (Table 2). Under low-input and organic management a key benefit of AMF is the increased capability to take up mineralized soil nutrients (Mäder *et al.* 2000). Phosphorus has low mobility in the soil making exploration or rooting systems and increased root hairs key in increasing P uptake (Wolfe *et al.* 2008). Arbuscular mycorrhizal fungi colonization increases the absorbing surface of the plant at a lower energy cost to the plant relative to the production

of additional rooting length and root hairs (Bolan 1991). A comparison of the mycorrhizal colonization of the organic lines versus the check cultivars would help shed more light on any below ground growth differences. The capacity to form increased AMF associations would be beneficial to the organic lines, and may be a helpful screening tool for selecting advanced breeding lines with improved nutrient uptake capacities.

Improved ability to compete with weeds is a particularly important trait for an organic cultivar since the use of synthetic pesticides is not in the tool box for organic growers. Selection for varieties that display improved competitive ability can help reduce additional costs that often accompany the need for additional weed management (Bastiaans *et al.*, 2008). Improved competitive ability is often achieved through a combination of a number of different advantageous traits rather than one characteristic (Kruepl *et al.*, 2007; Wolfe *et al.* 2008). A comparison of leaf architecture, and early season vigor of the organic lines could provide valuable indications of their potential competitive ability.

In the present study the weed biomass was evaluated at Oxbow (2010) only, the organic and check cultivars did not differ significantly in the weed biomass (Table 10). Thus the organic lines did not display superior weed suppression but competed more successfully with established weeds. Since the organic lines had a higher average yield while coping with equivalent weed densities it suggests that the organic lines were better able to cope with elevated weed stress. While some studies have suggested taller varieties are correlated with improved competitive ability, because they are better able to compete for light (Cudney *et al.* 1991), the present study found the organic lines were shorter than the check cultivars. This study found that there was no significant correlation between height and yield of the organic cultivars (Table 14) and did not support the findings of Cudney *et al.* (1991). Wolfe *et al.*

2008 supported the findings of the present study discussing that increased height does not necessarily indicate an increased competitive ability. Leaf architecture and canopy closure can have an equally beneficial impact than just increasing height, a tall variety with erect slim leaves will not provide as much shade and thus not block weed growth as well as a fast growing more bushy variety with wider leaf blades and a more horizontally leaf arrangement and increased leaf area index (Wolfe *et al.* 2008). The leaf area index and angle of the cultivars was not evaluated in this study and should be included in future studies evaluating agronomic performance of organic cultivars.

The reduced plant height of the organic cultivars that we observed in this study may result in better 'harvestability'. A shorter variety may have improved stem strength and reduced lodging potential means that a grower can travel faster when harvesting, gaining efficiencies in both time investment and fuel costs. Conventional growers are currently favoring a number of varieties such as 'Carberry' that have reduced height and improved lodging resistance as one of their key characteristics that growers are looking for. Organic growers similar to conventional growers are looking for ways to mitigate losses in their operation and to save costs where possible. A shorter variety that is less prone to lodging may help them achieve yields off the field rather than losing sections to lodging. While stem thickness and strength was not evaluated reduction in lodging risk may be indirectly selected for via selections for shorter cultivars.

An ideal organic cultivar will have enhanced early season growth and tillering capacity. Seeding rates are commonly increased in organic systems to have thicker plant stands that can better compete with weeds (Beavers *et al.* 2008). An organic variety with increased tillering ability would allow growers to reduce their seeding rate (an input cost) and

maintain a dense crop stand. An ideal organic cultivar would incorporate early season nitrogen uptake with increased early season root growth. An ideal organic cultivar would also have rapid early season above ground growth allowing for increased ground cover and enhanced weed competition. Future research examining emergence rates and rate of leaf emergence may help identify superior organic cultivars.

Larger seed size may also be beneficial for early season growth in organic environments as there are larger energy stores to draw upon. LopezCastaneda *et al.* (1996) examined seed and seedling characteristics contributing to variation in early vigor among temperate cereals. They found that while looking at seeds with similar masses an increased embryo size was the single most important factor that accounted for differences in vigor. Selecting for larger seed size may indirectly select for larger embryos and enhanced seedling vigor. The present study found higher average organic kernel weights at all four site years compared to the check cultivars (Table 8). More advanced screening could be done to select for genotypes that had a higher proportion of embryo tissue in the seed by weight. Richards and Lukacs (2002) observed that the seedling characteristics most closely associated with increased seedling vigor were a large embryo, large primary leaves on the main shoot, a high specific leaf area (leaf area to leaf weight ratio), and large coleoptile tillers. These seedling characteristics could be screened for and included in the selection process when trying to identify cultivars with the potential for increased seedling vigor and as a result increased early season growth.

Disease resistance is a critical issue for both conventional and organic breeding programs (Wolfe *et al.* 2008). Conventional growers can utilize fungicides to control diseases but organic growers must rely on natural disease resistance in combination with

cultural practices to reduce disease pressure. An ideal organic cultivar will possess greater natural disease resistance. Organic growers currently utilize several cultural practices including tillage and rotation to minimize disease pressure in their fields. The use of regionally specific varieties can be useful as the number of local main diseases can be reduced (Wolfe *et al.* 2008). Soil borne diseases can be of particular concern for organic growers as they can significantly impact the ability to establish an adequate crop stand. Fusarium head blight (FHB) caused by *Fusarium graminearum, F. culmorum,* and other *Fusarium* species is of particular importance and concern to organic cereal growers. Yield losses and mycotoxin levels in grain specifically deoxynivalenol (DON) are of economic concern to growers. While cultural practices of tillage and longer rotations can mitigate the risks of FHB infections, seasonal conditions such as increased moisture around flowering can drastically increase the incidence and severity of infections (Burrows *et al.* 2012). Organic products are sought after in part for their high quality and nutritional value making mycotoxin contamination even more detrimental. The organic population examined in the present study had early generation selections that selected for improved FHB resistance. The lower average FHB incidence observed at Glenlea (2009) indicates that the selections under organic conditions for improved FHB resistance are successfully improving the FHB resistance of the organic cultivars. Organic breeding programs should continue to focus selection efforts on increasing FHB resistance in varieties suitable for organic systems (Wolfe *et al.* 2008). Organic nurseries rely on natural disease infestations and perhaps placing future trials under mist irrigation could create more favourable conditions for disease growth and thus apply further selection pressure on the organic lines.

While the present study did not examine the baking quality of the organic lines or check cultivars baking quality is of importance for spring wheat genotypes. Improved baking

quality is also of economic importance as the end use of the grain products is impacted by the ability or organic varieties to meet particular quality standards. Quality of bread made from organic wheat is known to be limited due to decreased protein content in organic wheat flour relative to conventional wheat flour (Gooding *et al.* 1993b). Protein content is not the only factor influencing bread making quality the properties of the dough are related to the composition of gluten proteins, both the gliadins and glutenins (Singh and MacRitchie, 2001). Organic breeding programs focused on improving wheat quality should make selections based on the flour and bread making quality characteristics such as dough mixing behavior, protein polymerization, and structural properties in addition to overall protein content (Hussain *et al.* 2012).

The superior performance of the organic lines in this study relative to the check cultivars demonstrates the ability of selections made under organic management to improve the fitness of cultivars for the intended growing environment. Organic growers are currently limited in what varieties they can grow with few organic varieties available for use on their farms. As environmental and social concerns put additional emphasis on sustainability the need for organic varieties is only going to increase. Organic standards are shifting towards demanding the use of organic seed. Providing growers with locally adapted varieties that are better able to adapt to the unique stresses found in organic systems should be a core focus area of cereal breeding programs. This study as well as the work of numerous others has confirmed the importance and value of specialized organic breeding programs that are better able to make selections to improve key traits relevant to improving cultivars for use organic systems (Mason and Spaner, 2006; Kirk *et al.* 2012).

## 7. **LITERATURE CITED**


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# 8. Appendix A

Table 15: Average grain Nitrogen yield at Glenlea and Oxbow in 2009, and at Carman and Oxbow in 2010.

| Cultivar | Glenlea 2009 | Oxbow 2009 | Carman 2010 | Oxbow 2010 |
|---|---|---|---|---|
| | ---------- kg ha$^{-1}$ ---------- | | | |
| ORG 1 | 86.9 | 79.21 | | |
| ORG 2 | 95.2 | 90.94 | 106.39 | 49.98 |
| ORG 3 | 91.3 | 80.85 | 127.64 | 41.38 |
| ORG 4 | 94.6 | 78.33 | 113.37 | 36.04 |
| ORG 5 | 89.3 | 77.39 | | |
| ORG 6 | 86.1 | 62.47 | 90.535 | 44.22 |
| ORG 7 | 87.1 | 88.37 | 109.2 | 48.63 |
| ORG 8 | 87.6 | 68.42 | | |
| ORG 9 | 86.1 | 59.41 | 113.01 | 39.05 |
| ORG 10 | 84.8 | 78.39 | 96.6075 | 34.04 |
| ORG 11 | 84.1 | 76.90 | 107.39 | 38.18 |
| ORG 12 | 95.0 | 80.07 | 106.93 | 40.27 |
| ORG 13 | 85.8 | 81.74 | 122.59 | 40.33 |
| ORG 14 | 67.7 | 70.36 | 120.19 | 39.10 |
| AC BARRIE | 96.7 | 77.54 | | |
| CADILLAC | 92.4 | 73.63 | 102.61 | 25.96 |
| CDC KERNEN | 72.6 | 69.88 | | |
| KANE | 86.3 | 49.90 | 108.43 | 37.72 |
| MCKENZIE | 73.3 | 58.96 | 109.47 | 37.63 |
| 5602HR | 80.8 | 76.16 | 94.6225 | 34.50 |
| ***P > F*** | 0.0396 | 0.0115 | 0.0926 | 0.0492 |
| **LSD** | 16.23 | 19.325 | 22.22 | 12.3849 |
| **Contrast** | ---------- *P > F* ---------- | | | |
| Organic vs Checks | 0.3403 | 0.0141 | 0.0926 | 0.0076 |

Table 16: Nitrogen accumulated in biomass throughout the growing season at Glenlea and Oxbow in 2009, and at Carman and Oxbow in 2010.

| | Glenlea 2009 | | | Oxbow 2009 | Carman 2010 | | | Oxbow 2010 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Stem Elongation N | Anthesis N | Soft Dough N | Soft Dough N | Anthesis N | Soft Dough N | Maturity N | Anthesis N | Soft Dough N | Maturity N |
| Cultivar | ---------- Kg Ha $^{-1}$ ---------- | | | | | | | | | |
| ORG 1 | 45.8 | 94.1 | 125.4 | 55.6 | | | | | | |
| ORG 2 | 45.2 | 92.3 | 127.1 | 82.0 | 126.7 | 114.9 | 127.4 | 58.1 | 54.2 | 48.9 |
| ORG 3 | 47.6 | 86.7 | 116.2 | 71.7 | 121.7 | 141.0 | 136.7 | 53.5 | 44.5 | 54.1 |
| ORG 4 | 38.2 | 93.0 | 111.7 | 101.1 | 124.7 | 153.3 | 125.5 | 40.2 | 33.3 | 34.5 |
| ORG 5 | 45.5 | 99.5 | 158.8 | 94.6 | | | | | | |
| ORG 6 | 48.5 | 79.9 | 109.8 | 61.8 | 97.5 | 105.1 | 113.8 | 49.1 | 34.5 | 50.0 |
| ORG 7 | 41.7 | 98.8 | 80.7 | 82.7 | 127.0 | 147.0 | 120.5 | 54.7 | 62.5 | 45.0 |
| ORG 8 | 29.2 | 85.4 | 127.6 | 107.4 | | | | | | |
| ORG 9 | 35.8 | 84.8 | 99.4 | 77.7 | 119.8 | 124.7 | 125.6 | 47.8 | 46.3 | 46.7 |
| ORG 10 | 38.5 | 95.0 | 103.2 | 99.4 | 114.8 | 155.1 | 112.2 | 37.7 | 31.9 | 45.0 |
| ORG 11 | 30.6 | 78.1 | 84.6 | 81.1 | 126.3 | 105.6 | 105.3 | 48.5 | 55.0 | 46.8 |
| ORG 12 | 38.8 | 96.2 | 99.3 | 82.9 | 114.1 | 133.7 | 141.4 | 44.8 | 35.6 | 47.1 |
| ORG 13 | 45.3 | 102.4 | 115.3 | 128.2 | 102.7 | 150.5 | 113.5 | 50.4 | 48.8 | 48.4 |
| ORG 14 | 37.9 | 90.6 | 94.6 | 100.1 | 107.6 | 154.3 | 132.1 | 44.5 | 34.3 | 31.8 |
| AC Barrie | 36.6 | 78.7 | 108.7 | 64.9 | | | | | | |
| Cadillac | 27.8 | 87.0 | 77.8 | 77.9 | 106.0 | 139.4 | 122.0 | 42.8 | 34.0 | 37.4 |
| CDC Kernen | 40.4 | 81.0 | 86.5 | 102.6 | | | | | | |
| Kane | 47.1 | 102.8 | 132.7 | 92.8 | 112.9 | 121.9 | 124.8 | 49.1 | 45.2 | 42.2 |
| McKenzie | 37.5 | 77.7 | 96.0 | 90.1 | 119.8 | 159.9 | 132.1 | 60.0 | 68.8 | 38.0 |
| 5602HR | 35.9 | 84.0 | 129.0 | 77.4 | 105.6 | 117.8 | 93.9 | 50.1 | 31.9 | 60.7 |
| ***P > F*** | 0.1382 | 0.3554 | 0.0475 | 0.8822 | 0.7981 | 0.5849 | 0.9534 | 0.0796 | 0.0075 | 0.1179 |
| **LSD** | | | 43.37 | | | | | | 20.84 | |

Table 17: Nitrogen Harvest Index (%) at Glenlea and Oxbow in 2009, and at Carman and Oxbow in 2010.

| | Nitrogen Harvest Index | | | |
|---|---|---|---|---|
| Cultivar | Glenlea 2009 | Oxbow 2009 | Carman 2010 | Oxbow 2010 |
| ORG 1 | 73 | 158 | | |
| ORG 2 | 81 | 132.75 | 114.98 | 89.67 |
| ORG 3 | 89.5 | 120.46 | 97.54 | 98.37 |
| ORG 4 | 90.75 | 93.75 | 77.00 | 105.49 |
| ORG 5 | 60 | 100.25 | | |
| ORG 6 | 88.25 | 104.25 | 90.15 | 132.17 |
| ORG 7 | 119 | 126 | 78.24 | 73.30 |
| ORG 8 | 71.75 | 86 | | |
| ORG 9 | 93 | 96.25 | 91.93 | 91.03 |
| ORG 10 | 84.5 | 81 | 66.88 | 110.07 |
| ORG 11 | 106.75 | 96.75 | 103.75 | 66.60 |
| ORG 12 | 97.75 | 231 | 80.98 | 137.67 |
| ORG 13 | 81.5 | 112.5 | 85.27 | 79.70 |
| ORG 14 | 81 | 73.5 | 79.95 | 123.97 |
| AC BARRIE | 99.75 | 134.75 | | |
| CADILLAC | 129 | 117.75 | 72.08 | 81.68 |
| CDC KERNEN | 85.75 | 77.75 | | |
| KANE | 71.5 | 71.75 | 89.68 | 84.80 |
| MCKENZIE | 81.75 | 70.25 | 74.85 | 61.00 |
| 5602HR | 63.75 | 114.75 | 84.38 | 131.10 |
| ***P > F*** | 0.1922 | 0.0199 | 0.4907 | 0.0015 |
| **LSD** | | 73.38 | | 37.31 |
| **Contrast** | ---------- *P > F* ---------- | | | |
| Organic vs. Checks | 0.7692 | 0.4227 | 0.3383 | 0.1452 |

Table 18: Harvest Index (%) at Carman and Oxbow in 2009 and 2010, and Glenlea in 2009.

| | ---------- Harvest Index (%) ---------- | | | |
|---|---|---|---|---|
| Cultivar | Glenlea 2009 | Oxbow 2009 | Carman 2010 | Oxbow 2010 |
| ORG 1 | 32.07 | 44.87 | . | . |
| ORG 2 | 35.89 | 44.74 | 49.96 | 35.27 |
| ORG 3 | 39.80 | 52.62 | 50.48 | 30.92 |
| ORG 4 | 40.95 | 42.19 | 55.74 | 38.17 |
| ORG 5 | 30.96 | 39.78 | . | . |
| ORG 6 | 34.10 | 36.34 | 47.77 | 38.81 |
| ORG 7 | 50.47 | 50.77 | 46.57 | 35.29 |
| ORG 8 | 40.86 | 40.98 | . | . |
| ORG 9 | 37.63 | 40.54 | 48.03 | 30.24 |
| ORG 10 | 34.38 | 48.80 | 46.59 | 30.75 |
| ORG 11 | 48.29 | 44.16 | 52.91 | 41.27 |
| ORG 12 | 40.86 | 53.92 | 44.86 | 36.68 |
| ORG 13 | 35.09 | 46.83 | 53.96 | 28.40 |
| ORG 14 | 39.25 | 39.23 | 48.17 | 39.87 |
| AC BARRIE | 36.75 | 50.07 | . | . |
| CADILLAC | 44.59 | 41.05 | 38.08 | 19.53 |
| CDC KERNEN | 36.48 | 38.61 | . | . |
| KANE | 35.37 | 29.43 | 45.61 | 33.34 |
| MCKENZIE | 29.64 | 37.07 | 40.60 | 34.00 |
| 5602HR | 31.51 | 47.33 | 53.94 | 25.91 |
| ***P > F*** | 0.095 | 0.3065 | 0.4927 | 0.0180 |
| **LSD** | | | | 10.12 |

Table 19: Kernel density (seeds/m2) from Carman and Oxbow in 2009 and 2010, and Glenlea in 2009.

| | ---------- Kernel Density (#/$m^2$) ---------- | | | |
|---|---|---|---|---|
| Cultivar | Glenlea 2009 | Oxbow 2009 | Carman 2010 | Oxbow 2010 |
| ORG 1 | 10218.0 | 8780.9 | | |
| ORG 2 | 10924.0 | 10395.0 | 12012.0 | 7217.3 |
| ORG 3 | 10823.0 | 9362.5 | 14924.0 | 6426.0 |
| ORG 4 | 12020.0 | 9153.0 | 13341.0 | 5837.4 |
| ORG 5 | 11015.0 | 10277.0 | | |
| ORG 6 | 10643.0 | 7800.6 | 11263.0 | 6570.1 |
| ORG 7 | 11308.0 | 10799.0 | 13529.0 | 7163.3 |
| ORG 8 | 11671.0 | 9471.7 | | |
| ORG 9 | 11218.0 | 8128.0 | 15427.0 | 6963.2 |
| ORG 10 | 10597.0 | 9816.4 | 12893.0 | 6094.4 |
| ORG 11 | 11717.0 | 10276.0 | 14748.0 | 6959.3 |
| ORG 12 | 10689.0 | 9456.7 | 13858.0 | 6007.7 |
| ORG 13 | 10704.0 | 9425.7 | 14478.0 | 6583.5 |
| ORG 14 | 8261.7 | 8386.9 | 14106.0 | 6300.2 |
| AC BARRIE | 10858.0 | 9557.1 | | |
| CADILLAC | 10763.0 | 9505.1 | 12950.0 | 4105.9 |
| CDC KERNEN | 9621.4 | 9381.9 | | |
| KANE | 10815.0 | 6782.1 | 14245.0 | 6159.8 |
| MCKENZIE | 8872.3 | 8700.1 | 13829.0 | 6576.7 |
| 5602HR | 10182.0 | 9157.8 | 12880.0 | 5817.1 |
| ***P > F*** | 0.044 | 0.0934 | 0.0031 | 0.0798 |
| **LSD** | 1900.55 | | 1568.858 | |

Table 20: Nitrogen yield per N uptake at Anthesis (%) at Carman and Glenlea in 2009, and Carman and Oxbow in 2010.

| | 2009 N Yield/ N uptake at Anthesis (%) | | |
|---|---|---|---|
| Cultivar | Glenlea 2009 | Carman 2010 | Oxbow 2010 |
| ORG 1 | 92.8 | | |
| ORG 2 | 106.3 | 85.8 | 88.6 |
| ORG 3 | 110.0 | 105.0 | 83.1 |
| ORG 4 | 102.3 | 93.6 | 89.1 |
| ORG 5 | 91.0 | | |
| ORG 6 | 110.8 | 96.4 | 94.7 |
| ORG 7 | 91.5 | 86.4 | 92.9 |
| ORG 8 | 106.0 | | |
| ORG 9 | 108.8 | 95.9 | 85.1 |
| ORG 10 | 93.3 | 87.0 | 100.3 |
| ORG 11 | 108.8 | 87.0 | 83.4 |
| ORG 12 | 98.8 | 94.4 | 88.8 |
| ORG 13 | 84.3 | 129.6 | 81.2 |
| ORG 14 | 78.8 | 112.5 | 88.1 |
| AC BARRIE | 124.5 | | |
| CADILLAC | 110.5 | 99.0 | 66.3 |
| CDC KERNEN | 89.8 | | |
| KANE | 87.0 | 96.6 | 78.3 |
| MCKENZIE | 95.8 | 94.0 | 64.1 |
| 5602HR | 98.0 | 88.0 | 72.5 |
| ***P > F*** | 0.4856 | 0.1615 | 0.0256 |
| **LSD** | | | 22.82 |

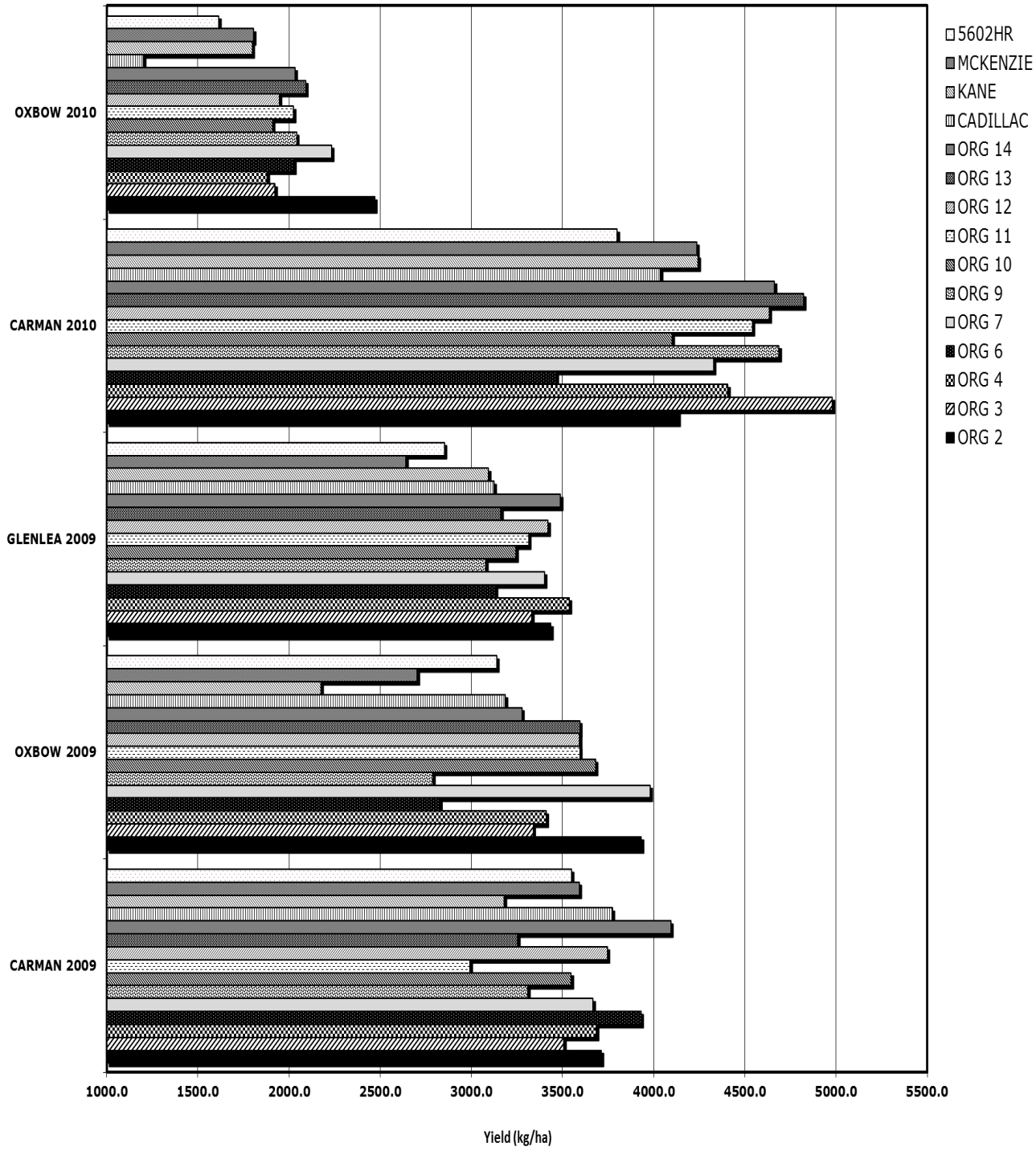
Table 21: Yield per unit of dry matter accumulated at anthesis from Carman and Glenlea in 2009, and Carman and Oxbow in 2010.

| | ----- Yield/ DM at Anthesis ----- | | |
|---|---|---|---|
| Cultivar | Glenlea 2009 | Carman 2010 | Oxbow 2010 |
| ORG 1 | 0.55 | | |
| ORG 2 | 0.71 | 0.63 | 0.50 |
| ORG 3 | 0.69 | 0.78 | 0.41 |
| ORG 4 | 0.69 | 0.64 | 0.47 |
| ORG 5 | 0.57 | | |
| ORG 6 | 0.69 | 0.58 | 0.50 |
| ORG 7 | 0.64 | 0.64 | 0.50 |
| ORG 8 | 0.77 | | |
| ORG 9 | 0.70 | 0.72 | 0.50 |
| ORG 10 | 0.54 | 0.60 | 0.51 |
| ORG 11 | 0.71 | 0.64 | 0.47 |
| ORG 12 | 0.63 | 0.65 | 0.48 |
| ORG 13 | 0.53 | 0.80 | 0.51 |
| ORG 14 | 0.54 | 0.77 | 0.61 |
| AC BARRIE | 0.72 | | |
| CADILLAC | 0.66 | 0.68 | 0.35 |
| CDC KERNEN | 0.60 | | |
| KANE | 0.53 | 0.62 | 0.38 |
| MCKENZIE | 0.55 | 0.53 | 0.37 |
| 5602HR | 0.56 | 0.56 | 0.37 |
| ***P > F*** | 0.26 | 0.03 | 0.01 |
| **LSD** | | 0.15 | 0.12 |
| **Contrasts** | ---------- *P > F* ---------- | | |
| Organic vs. Checks | 0.4072 | 0.018 | < 0.0001 |

Table 22: Biomass accumulated throughout the growing season at Carman and Oxbow in 2009 and 2010, and at Glenlea in 2009.

| | Glenlea 2009 | | | Oxbow 2009 | Carman 2010 | | | Oxbow 2010 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Stem Elongation | Anthesis | Soft Dough | Soft Dough | Anthesis | Soft Dough | Maturity | Anthesis | Soft Dough | Maturity |
| Cultivar | Kg Ha$^{-1}$ | | | | | | | | | |
| ORG 1 | 1105.26 | 5956.42 | 10141 | 8037.01 | . | . | . | . | . | . |
| ORG 2 | 1013.16 | 4913.65 | 9606.91 | 9268.1 | 6601.97 | 9167.53 | 8747.23 | 4840.48 | 6104.45 | 6276.32 |
| ORG 3 | 1087.99 | 5050.99 | 8440.79 | 6458.06 | 6629.12 | 9923.45 | 10130 | 4944.93 | 5197.4 | 6132.38 |
| ORG 4 | 935.86 | 5159.54 | 8836.35 | 8116.78 | 7093.77 | 10973 | 8306.6 | 3657.18 | 4624.62 | 4791.16 |
| ORG 5 | 964.64 | 5405.43 | 10055 | 8752.47 | | . | . | . | . | . |
| ORG 6 | 1111.84 | 4745.07 | 9252.47 | 8050.17 | 5924.35 | 8346.45 | 7535.3 | 3927.6 | 4732.75 | 5610.16 |
| ORG 7 | 995.89 | 5358.56 | 6893.09 | 7877.47 | 6749.2 | 11063 | 9287.4 | 4335.53 | 6294.4 | 5762.32 |
| ORG 8 | 700.66 | 4523.85 | 8327.3 | 9347.86 | . | . | . | . | . | . |
| ORG 9 | 860.2 | 4743.42 | 8386.51 | 7047.7 | 6645.57 | 10292 | 9764 | 3972.85 | 5071.57 | 5536.18 |
| ORG 10 | 973.68 | 6064.97 | 9443.26 | 7813.32 | 6886.52 | 11255 | 8908.15 | 3758.7 | 5277.95 | 5678.45 |
| ORG 11 | 758.22 | 4824.84 | 7173.52 | 9418.59 | 7171.05 | 10015 | 8687.45 | 4501.65 | 6233.52 | 4980.25 |
| ORG 12 | 911.18 | 5396.38 | 8675.17 | 7763.16 | 7180.1 | 11298 | 10384 | 3783.7 | 4615.15 | 5100.32 |
| ORG 13 | 1096.22 | 6085.53 | 9041.94 | 8645.56 | 6118.45 | 10823 | 9011.68 | 3852 | 5602.8 | 6216.27 |
| ORG 14 | 907.9 | 5175.17 | 7634.05 | 8353.62 | 6082.25 | 11560 | 9773.55 | 3319.45 | 4694.07 | 4848.7 |
| AC BARRIE | 911.18 | 4885.69 | 9530.43 | 6547.7 | . | . | . | . | . | . |
| CADILLAC | 638.98 | 4882.4 | 7005.76 | 8050.17 | 5887.35 | 10206 | 10566 | 3888.59 | 4954.17 | 5710.16 |
| CDC KERNEN | 1003.26 | 4619.25 | 7659.54 | 8251.65 | . | . | . | . | . | . |
| KANE | 1171.05 | 5804.28 | 8790.3 | 7624.71 | 6901.325 | 9642.7 | 9415.7 | 4558.38 | 5179.25 | 4721.2 |
| MCKENZIE | 883.22 | 4885.69 | 9115.13 | 7231.09 | 8083.02 | 10620 | 10592 | 5166.1 | 6254.92 | 5065.8 |
| 5602HR | 968.75 | 5115.96 | 9076.48 | 6791.12 | 6711.35 | 10246 | 7469.47 | 4535.35 | 5020.57 | 6753.3 |
| ***P > F*** | 0.0411 | 0.0686 | 0.0051 | 0.7365 | 0.2185 | 0.2619 | 0.1936 | 0.0651 | 0.5972 | 0.272 |
| **LSD** | 289.475 | | 1754.02 | | | | | | | |
| **Contrast** | *P > F* | | | | | | | | | |
| Organic vs Checks | 0.3757 | 0.6505 | 0.8375 | 0.0648 | 0.3859 | 0.5816 | 0.4537 | 0.0434 | 0.9193 | 0.941 |

Figure 1: Yield performance of organic lines compared with check cultivar cultivars from four site years.



# 9. Appendix B

Table 23: Normality analysis of Site Year, Glenlea 2009.

| | (Glenlea, 2009) | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | Original Data | | *LN Trans* | *LOG Trans* | *SQRT* | **Oxbow 09 & McKenzie Removed** |
| | *W statistic* | *Normality* | *W statistic* | *W statistic* | *W statistic* | *W statistic* |
| Yield (kg/ha) | 0.0496 | Non Normal | 0.1807 | 0.1848 | 0.1025 | 0.0291 |
| Grain N Yield (kg/ha @ 0% | 0.4072 | Normal | 0.269 | 0.2757 | 0.3298 | 0.3181 |
| Grain Protein (%) | 0.8873 | Normal | 0.8519 | 0.8352 | 0.8792 | 0.8522 |
| Anthesis biomass N (kg/ha) | 0.7956 | Normal | 0.2067 | 0.2049 | 0.5453 | 0.8834 |
| Soft Dough biomass N (kg/ha) | 0.4183 | Normal | 0.8857 | 0.8878 | 0.8327 | 0.332 |
| Maturity Biomass N (kg/ha) | NA | NA | NA | NA | NA | |
| Anthesis Biomass % Nitrogen | 0.0666 | Normal | 0.6121 | 0.6034 | 0.2699 | 0.1301 |
| Soft Dough Biomass % Nitrogen | 0.6748 | Normal | 0.495 | 0.5019 | 0.593 | 0.7768 |
| Maturity Biomass % Nitrogen | NA | NA | NA | NA | NA | |
| Harvest Index | 0.0092 | Not Normal | 0.159 | 0.1625 | 0.0634 | 0.0058 |
| NHI (using Soft Dough Weights) | 0.0607 | Normal | 0.8657 | 0.8649 | 0.302 | 0.0554 |
| Height (cm) | 0.4218 | Normal | 0.4094 | 0.3962 | 0.4121 | 0.3609 |
| Anthesis Biomass (kg/ha) | 0.749 | Normal | 0.1441 | 0.1481 | 0.4191 | 0.7811 |
| SD Biomass (kg/ha) | 0.4631 | Normal | 0.1116 | 0.111 | 0.2961 | 0.6323 |
| Maturity Biomass | NA | NA | NA | NA | NA | |
| KNO/ha | | | 0.258 | 0.2724 | 0.0637 | <0.0001 |
| TKW (g) | 0.0001 | Not Normal | <0.0001 | <0.0001 | <0.0001 | 0.0002 |
| # Kernels/m2 | 0.0093 | Not Normal | 0.2574 | 0.2724 | 0.0637 | 0.0207 |
| N Yield/N uptake @ anthesis | 0.0433 | Not Normal | 0.4991 | 0.499 | 0.2094 | 0.0468 |
| Yield/Unit DM @ anthesis | 0.0186 | Not Normal | 0.2936 | 0.304 | 0.0798 | 0.0282 |
| KNO/unit of DM @ anthesis | | | 0.4222 | 0.4291 | 0.1029 | 0.0242 |
| Stand Density (plants/m2) | 0.1563 | Normal | 0.016 | 0.0161 | 0.051 | 0.1746 |

Table 24: Normality analysis of Site Year Oxbow 2009.

| | (Oxbow, 2009) | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | Original Data | | *LN Trans* | *LOG Trans* | *SQRT* | **Oxbow 09 & McKenzie Removed** |
| | *W statistic* | *Normality* | *W statistic* | *W statistic* | *W statistic* | *W statistic* |
| Yield (kg/ha) | 0.6944 | Normal | 0.9304 | 0.9282 | 0.9451 | NA |
| Grain N Yield (kg/ha @ 0% | 0.8582 | Normal | 0.9084 | 0.9076 | 0.9489 | NA |
| Grain Protein (%) | 0.4506 | Normal | 0.2526 | 0.22 | 0.3324 | NA |
| Anthesis biomass N (kg/ha) | NA | NA | NA | NA | NA | NA |
| Soft Dough biomass N (kg/ha) | 0.0085 | Not Normal | 0.0613 | 0.0602 | 0.0268 | NA |
| Maturity Biomass N (kg/ha) | NA | NA | NA | NA | NA | NA |
| Anthesis Biomass % Nitrogen | NA | NA | NA | NA | NA | NA |
| Soft Dough Biomass % Nitrogen | 0.1533 | Normal | 0.3656 | 0.3661 | 0.2139 | NA |
| Maturity Biomass % Nitrogen | NA | NA | NA | NA | NA | NA |
| Harvest Index | 0.1152 | Normal | 0.0455 | 0.0452 | 0.0554 | NA |
| NHI (using Soft Dough Weights) | 0.0065 | Not Normal | 0.0975 | 0.0959 | 0.2067 | NA |
| Height (cm) | 0.2685 | Normal | 0.2975 | 0.309 | 0.2755 | NA |
| Anthesis Biomass (kg/ha) | NA | NA | NA | NA | NA | NA |
| SD Biomass (kg/ha) | 0.0057 | Not Normal | 0.0927 | 0.0889 | 0.0303 | NA |
| Maturity Biomass | NA | NA | NA | NA | NA | NA |
| KNO/ha | | | 0.8722 | 0.8698 | 0.8189 | NA |
| TKW (g) | 0.9079 | Normal | 0.9893 | 0.9826 | 0.967 | NA |
| # Kernels/m2 | 0.8221 | Normal | 0.8746 | 0.8698 | 0.8189 | NA |
| N Yield/N uptake @ anthesis | NA | NA | NA | NA | NA | NA |
| Yield/Unit DM @ anthesis | NA | NA | NA | NA | NA | NA |
| KNO/unit of DM @ anthesis | NA | NA | NA | NA | NA | NA |
| Stand Density (plants/m2) | NA | NA | NA | NA | NA | NA |

Table 25: Normality analysis of Site Year Carman 2010.

| | (Carman, 2010) | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | Original Data | | *LN Trans* | *LOG Trans* | *SQRT* | **Oxbow 09 & McKenzie Removed** |
| | *W statistic* | *Normality* | *W statistic* | *W statistic* | *W statistic* | *W statistic* |
| Yield (kg/ha) | 0.0104 | Non Normal | 0.0005 | 0.0005 | 0.0025 | 0.0139 |
| Grain N Yield (kg/ha @ 0% | 0.0325 | Non Normal | 0.0007 | 0.0007 | 0.006 | 0.0331 |
| Grain Protein (%) | 0.3278 | Normal | 0.1925 | 0.1858 | 0.2641 | 0.3387 |
| Anthesis biomass N (kg/ha) | 0.1505 | Normal | 0.2469 | 0.2491 | 0.1952 | 0.2069 |
| Soft Dough biomass N (kg/ha) | 0.4931 | Normal | 0.4303 | 0.434 | 0.6286 | 0.1814 |
| Maturity Biomass N (kg/ha) | 0.7802 | Normal | 0.8783 | 0.2948 | 0.5904 | 0.8639 |
| Anthesis Biomass % Nitrogen | 0.2042 | Normal | 0.6027 | 0.5999 | 0.3883 | 0.2475 |
| Soft Dough Biomass % Nitrogen | 0.6081 | Normal | 0.8783 | 0.8856 | 0.7997 | 0.0507 |
| Maturity Biomass % Nitrogen | 0.9989 | Normal | 0.7931 | 0.7995 | 0.9941 | 0.9985 |
| Harvest Index | 0.0186 | Not Normal | 0.2713 | 0.2695 | 0.09 | 0.0239 |
| NHI (using Soft Dough Weights) | 0.0048 | Not Normal | 0.0897 | 0.0909 | 0.031 | 0.0037 |
| Height (cm) | 0.202 | Normal | 0.2003 | 0.1924 | 0.2114 | 0.0867 |
| Anthesis Biomass (kg/ha) | 0.6233 | Normal | 0.7148 | 0.7167 | 0.7006 | 0.7243 |
| SD Biomass (kg/ha) | 0.257 | Normal | 0.0628 | 0.0631 | 0.14461 | 0.3173 |
| Maturity Biomass | 0.2426 | Normal | 0.7835 | 0.7861 | 0.5675 | 0.2928 |
| KNO/ha | | | 0.0004 | 0.0004 | 0.0019 | 0.0029 |
| TKW (g) | 0.0857 | Normal | 0.0325 | 0.0378 | 0.0552 | 0.0921 |
| # Kernels/m2 | 0.0085 | Not Normal | 0.0004 | 0.0004 | 0.0019 | 0.0123 |
| N Yield/N uptake @ anthesis | 0.0777 | Normal | 0.4841 | 0.4897 | 0.253 | 0.0708 |
| Yield/Unit DM @ anthesis | 0.231 | Normal | 0.7846 | 0.7771 | 0.429 | 0.2738 |
| KNO/unit of DM @ anthesis | | | 0.6034 | 0.6106 | 0.4254 | 0.3522 |
| Stand Density (plants/m2) | 0.0873 | Normal | 0.3386 | 0.3386 | 0.1884 | 0.0847 |

Table 26: Normality analysis of Site Year Oxbow 2010.

| | (Oxbow, 2010) | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | Original Data | | *LN Trans* | *LOG Trans* | *SQRT* | **Oxbow 09 & McKenzie Removed** |
| | *W statistic* | *Normality* | *W statistic* | sy*trt | *W statistic* | *W statistic* |
| Yield (kg/ha) | 0.1546 | Normal | 0.6483 | 0.6476 | 0.6934 | 0.176 |
| Grain N Yield (kg/ha @ 0% | 0.18 | Normal | 0.5483 | 0.5393 | 0.1108 | 0.3399 |
| Grain Protein (%) | 0.5181 | Normal | 0.5868 | 0.6075 | 0.5495 | 0.5269 |
| Anthesis biomass N (kg/ha) | 0.599 | Normal | 0.7828 | 0.784 | 0.7109 | 0.7819 |
| Soft Dough biomass N (kg/ha) | 0.2413 | Normal | 0.1364 | 0.1352 | 0.2362 | 0.0374 |
| Maturity Biomass N (kg/ha) | 0.6684 | Normal | 0.4837 | 0.7326 | 0.7451 | 0.7615 |
| Anthesis Biomass % Nitrogen | 0.704 | Normal | 0.8439 | 0.844 | 0.7997 | 0.8944 |
| Soft Dough Biomass % Nitrogen | 0.3602 | Normal | 0.4837 | 0.4761 | 0.4026 | 0.2192 |
| Maturity Biomass % Nitrogen | 0.1342 | Normal | 0.214 | 0.2216 | 0.2611 | 0.0888 |
| Harvest Index | 0.2796 | Normal | 0.7625 | 0.7612 | 0.274 | 0.5123 |
| NHI (using Soft Dough Weights) | 0.749 | Normal | 0.8638 | 0.8658 | 0.9458 | 0.7841 |
| Height (cm) | 0.6822 | Normal | 0.6305 | 0.6079 | 0.7012 | 0.5853 |
| Anthesis Biomass (kg/ha) | 0.5542 | Normal | 0.7216 | 0.7231 | 0.6086 | 0.973 |
| SD Biomass (kg/ha) | 0.2803 | Normal | 0.2759 | 0.2734 | 0.3216 | 0.593 |
| Maturity Biomass | 0.8318 | Normal | 0.0689 | 0.0693 | 0.5332 | 0.532 |
| KNO/ha | | | 0.0521 | 0.0508 | 0.2223 | 0.4134 |
| TKW (g) | 0.4917 | Normal | 0.344 | 0.371 | 0.4057 | 0.7347 |
| # Kernels/m2 | 0.0839 | Normal | 0.0532 | 0.0508 | 0.2223 | 0.1668 |
| N Yield/N uptake @ anthesis | 0.6144 | Normal | 0.003 | 0.0031 | 0.1015 | 0.714 |
| Yield/Unit DM @ anthesis | 0.9914 | Normal | 0.0005 | 0.0005 | 0.096 | 0.9479 |
| KNO/unit of DM @ anthesis | | | 0.0005 | 0.0005 | 0.0413 | 0.1565 |
| Stand Density (plants/m2) | 0.8884 | Normal | 0.8544 | 0.8483 | 0.8777 | 0.894 |

Table 27: Summary of Site year *Cultivar interactions of original and transformed data sets.

| | Combined Analysis | | | | |
|---|---|---|---|---|---|
| **Parameter** | Original Data | *LN Trans* | *LOG Trans* | *SQRT* | **Oxbow 09 & McKenzie Removed** |
| | sy*trt | sy*trt | sy*trt | sy*trt | sy*trt |
| Yield (kg/ha) | 0.0383 | 0.0016 | 0.0016 | 0.0145 | 0.1145 |
| Grain N Yield (kg/ha @ 0% | 0.3851 | 0.0314 | 0.0313 | 0.1928 | 0.6863 |
| Grain Protein (%) | 0.2796 | 0.2709 | 0.2654 | 0.2811 | 0.2659 |
| Anthesis biomass N (kg/ha) | 0.5346 | 0.1746 | 0.1743 | 0.3368 | 0.603 |
| Soft Dough biomass N (kg/ha) | 0.3041 | 0.0362 | 0.0362 | 0.1572 | 0.0633 |
| Maturity Biomass N (kg/ha) | 0.7264 | 0.1108 | 0.1104 | 0.3677 | 0.7401 |
| Anthesis Biomass % Nitrogen | 0.5225 | 0.3035 | 0.3089 | 0.406 | 0.6819 |
| Soft Dough Biomass % Nitrogen | 0.2381 | 0.0982 | 0.0987 | 0.1756 | 0.171 |
| Maturity Biomass % Nitrogen | 0.7776 | 0.5032 | 0.4991 | 0.6509 | 0.7111 |
| Harvest Index | 0.0976 | 0.0057 | 0.0057 | 0.0343 | 0.0608 |
| NHI (using Soft Dough Weights) | 0.0021 | 0.0336 | 0.0337 | 0.0115 | 0.0021 |
| Height (cm) | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.0316 |
| Anthesis Biomass (kg/ha) | 0.0333 | 0.0215 | 0.0215 | 0.0271 | 0.0709 |
| SD Biomass (kg/ha) | 0.065 | 0.0834 | 0.0846 | 0.0662 | 0.0077 |
| Maturity Biomass | 0.0629 | 0.0685 | 0.0678 | 0.0552 | 0.1163 |
| KNO/ha | . | 0.001 | 0.001 | 0.0051 | . |
| TKW (g) | <0.0001 | 0.0004 | 0.0004 | 0.0002 | 0.2889 |
| # Kernels/m2 | 0.01 | 0.001 | 0.001 | 0.0051 | 0.0629 |
| N Yield/N uptake @ anthesis | 0.4415 | 0.1348 | 0.1345 | 0.2812 | 0.4428 |
| Yield/Unit DM @ anthesis | 0.2495 | 0.0294 | 0.0293 | 0.1076 | 0.2841 |
| KNO/unit of DM @ anthesis | 0.1664 | 0.0385 | 0.0379 | 0.0873 | 0.2349 |
| Stand Density (plants/m2) | 0.9046 | 0.8851 | 0.8847 | 0.8996 | 0. 8724 |