

**ON-FARM SOYBEAN CULTIVAR EVALUATION FOR SUITABILITY TO  
ORGANIC PRODUCTION IN SOUTHERN MANITOBA**

**BY**

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A Thesis  
Submitted to the Faculty of Graduate Studies of  
The University of Manitoba  
in partial fulfilment of the degree of

**MASTER OF SCIENCE**

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Winnipeg, Manitoba

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## ACKNOWLEDGEMENTS

Firstly, my whole hearted appreciation goes to Dr. Martin Entz. Thank you for initiating and cultivating awesome research and an amazing research lab. Thank you for your constant generosity, guidance, and support through this process, and affording me the opportunities to increase my knowledge and skills in agriculture. I will be forever grateful.

My committee members, Dr. Rob Gulden and Dr. Don Flaten, and to Dr. Jennifer Mitchell-Fetch – for offering ideas and support throughout my master’s experience. Thank you to Dr. Rob Gulden, who was always willing to spare some time to answer my continuous statistics questions.

Special thanks go to Natural Systems Agriculture technical staff. Thank you Keith Bamford for always challenging me to be the best scientist every day, the conversations that enriched my soul, and the patience to teach me how to drive and operate various equipment implements. Thank you to Joanne Thiessen Martens for happily helping with my experiments from beginning to end. Anne Kirk and Iris Vaisman for providing supportive answers to my questions, and helping me feel extremely welcome in Winnipeg. Thank you to the many summer students, Natasha, Lucette, Will, Jeremy, Chase, Bailey, Naomi, and Rebekah who endlessly toiled away in the plots and provided entertaining car rides from site to site.

Appreciative thanks to the Bugeras, Applebys, Evans, Desrochers, and Deruyks who allowed my experiments to take place on their land, without your engagement this work would not be possible.

Thank you to fellow graduate students and friends here and away who kept me sane and shared the pain!

I would like to thank my whole family, but specifically my mother, Shirley Lamarre. Who alone provided my sisters and I the opportunities to freely follow our goals instilled a deep sense of hard work ethic. Thank you to my husband, Jason, for moving to Winnipeg for me without hesitation. For providing me with support through encouraging words, tough love, food, and keeping it breezy.

Thank you to all the farmers of the world. For nourishing our bodies and the land.

The financial support of the Natural Science and Engineering Research Council of Canada (NSERC), Growers International Organic Sales Inc., and The Manitoba Pulse and Soybean Growers is gratefully acknowledged.

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## **ABSTRACT**

Carkner, Michelle, K. M.Sc. The University of Manitoba, June, 2016. On-farm Soybean Cultivar Evaluation for Suitability to Organic Production in Southern Manitoba. Major Professor; Martin N. Entz.

Lack of technical knowledge and proper soybean cultivars are barriers for organic farmers to take advantage of increased organic soybean demand in Manitoba from domestic and international markets. The objective of the present study was to evaluate the performance of 12 early season non-GM food grade soybean cultivars under organic management in southern Manitoba. Cultivars were seeded on four organic farms and one transition to organic farm in southern Manitoba in 2014 and 2015. The mean cultivar yield ranged from 1384 to 1807 kg ha<sup>-1</sup>, with a mean of 1536 kg ha<sup>-1</sup>. Cultivars 'Savanna' and 'Toma' were high performers, but exhibited low stability across sites. Partial Least Squares Regression Analysis indicated that soybean mature height, and biomass at R5 positively contributed to final grain yield. Early height positively contributed to biomass at R5 but negatively affected final grain yield. Soil nitrate content negatively contributed to final grain yield. Weed competitiveness was of particular interest in this study. Contrary to previous reports, cultivars that exhibited early season vigour often resulted in lower yields, biomass accumulation, and increased weed presence as compared to other cultivars.

## 1. INTRODUCTION

Organic agriculture has become one of the most widely adopted and successful forms of alternative agriculture in Canada and around the world. The Canadian General Standards Board (CGSB) defines organic agriculture as, "... a holistic system designed to optimize the productivity and fitness of diverse communities with the agro-ecosystem, including soil organisms, plants, livestock and people. The principal goal of organic production is to develop operations that are sustainable and harmonious with the environment" (CGSB, 2015). Organic farming systems often carry out such practices as elimination of synthetic pesticides and fertilizers, longer and complex crop rotations, heavy reliance on cover crops, tight nutrient cycling, crop-livestock integration, and ecological approaches to pest control (Pimentel et al., 2005). Organic farming systems have often been associated with increased microbial activity, less off-farm nutrient losses, lower greenhouse gas (GHG) emissions, and higher soil carbon (Pimentel et al., 2005; Braman 2012). In 2014, there were 903 948 hectares under organic production in Canada, or 1.3% share of total agriculture land (COTA, 2016).

Organic legume field crops are becoming important to the organic industry as an organic protein feed source to meet demand for organic livestock increases in Canada and globally (soy2020, 2005; IFOAM, 2016). Additionally, legume field crops are a valuable contribution to organic farm rotations as they are able to supply their own nitrogen demands and provide income. Currently, the Canadian prairies account for 99% of organic protein crops grown in Canada (COTA, 2016).

Soybean (*Glycine max* Merr.) is not a common grain legume field crop grown on Canadian organic prairie farms, as only 119 hectares of soybeans were sown in 2014 (COTA, 2016). Increasing organic soybean hectares requires technical knowledge and suitable cultivars that have been tested under organic conditions. At the moment, non-genetically modified (GM) cultivars are bred and performance tested under conventional conditions. The results may not be suitable for organic farms as conditions on these farms differ from conventional farms in a variety of ways. Murphy et al. (2007) reported that sub-optimal performance of conventionally bred wheat (*Triticum aestivum* L.) cultivars under organic conditions may be due to biased selection of cultivars that perform well under chemical intensive conditions.

Elimination of pesticides and synthetic fertilizers has resulted in organic farms with different soil nutrient dynamics, soil microbial activity, and increased weed competition (Harris et al., 1994; Mäder et al., 2002; Pimentel et al., 2005). Therefore, it would be valuable to identify soybean cultivars that possess characteristics such as rapid and efficient nitrogen fixation (Kiers et al., 2007; Vollman and Menken, 2012), and high weed competitiveness (Place et al., 2011a).

Early season vigour has been identified as being one the most important characteristics contributing to weed competitiveness in annual grain crops (Lemerle et al., 1996; Bussan et al., 1997; Jannink et al., 2000; Zhao et al., 2006; Place et al., 2011a). Early season vigour is characterized as cultivars that gain rapid biomass and height early in the season. This is especially important for soybean, as the critical period for weed control is in the first 4-6 weeks after emergence (van Acker et al., 1993a). If cultivars can gain a competitive advantage over weeds early in the season, increased biomass production and final grain yield may reap the

benefits. Therefore, soybean cultivars that have increased biomass and height early in the season will be highly competitive with weeds and suffer lower yield loss due to weeds.

Past research has provided helpful definitions of competitive ability. Weed suppression is the ability for a plant to reduce the growth of a neighbouring competing plant (Goldberg and Landa, 1991). Crop tolerance on the other hand is a plant's ability to perform well despite interference from another plant's presence (Callaway, 1992). Rose et al. (1988) reported that as the days to maturity increased, weed growth decreased (ie. weed suppression). Vollman et al. (2010) reported that early maturing cultivars had greater weed tolerance ability than later maturing cultivars. McDonald (2003) also reported that early maturing field pea (*Pisum sativum* L.) genotypes suffered from smaller yield reductions than later maturing cultivars under the same weed pressure. It can be hypothesized that early maturing cultivars in the present study will suffer less yield loss due to weeds than later maturing cultivars due to the greater ability to tolerate weed presence.

It has been proposed that organic farmers need robust, flexible cultivars that can adapt to a wide range of environmental conditions. Soil nutrient status and weed populations can not be adjusted in season to suit the cultivar's needs (Lammerts van Beuren and Meyers, 2012). Under conventional breeding efforts, cultivars are bred to respond to favourable environments, and not bred to be robust under challenging environments (Vollman and Menken, 2012). Voldeng et al. (1997) reported that yield stability has not changed in cultivars released over the past 50 years under conventional management. Therefore, it is not expected that conventionally bred cultivars, such as the ones in the present study, will be identified with high stability and high yield under organic environments. However, identifying which cultivars

perform well in many different organic conditions would be valuable to organic farmers and researchers.

Cultivars characteristics and environmental conditions are the drivers for final grain yield. The present study uses Partial Least Squares Regression to assess the main factors that are controlling final grain yield for organic soybean production. Historically, physiological changes associated with increased photosynthetic rate, increased light interception, increased radiation use efficiency, and increased partitioning of biomass to seed have resulted in increased genetic yield advancement (Morrison et al., 1999; Koester et al., 2014). In organic systems, the ability for soybean cultivars to adequately fulfill these physiological requirements depends heavily on weed presence as they compete for limited resources (light, water, space, and nutrients). Therefore, it can be hypothesized the cultivar characteristics that have been associated with weed competitiveness in the past, early season height and early biomass accumulation, will have the greatest impact on final grain yield under organic conditions.

The objective of the present study was to evaluate the performance of 12 non-GM short-season soybean cultivars under organic and transition to organic management. Cultivar performance was assessed by measuring cultivar characteristics such as early and late biomass accumulation, early and late plant height, and final grain yield under weedy and weed-free conditions. In-season measurements allowed for investigative study to examine what parameters were controlling final grain yield under organic conditions. The present study also attempted to compare the relative competitiveness against weeds among cultivars through yield performance under organic conditions. This research contributes to a greater knowledge

of valuable traits and relative performance of soybean cultivars under organic conditions in southern Manitoba.

## **2. LITERATURE REVIEW**

### **2.1. Organic Agriculture: An overview**

Since the 1940s, the dominant form of agriculture practiced in developed countries around the world has been high input, industrialized farming (Troughton, 1985). While enabling the ability to achieve high yields, the continued adoption of high input industrialized farming, also categorized as 'conventional agriculture', has been repeatedly attributed to habitat and biodiversity loss, reduction in rural livelihood viability, herbicide resistant weeds, increased greenhouse gas (GHG) emissions, and soil degradation (Montgomery, 2007; Lobao and Stofferahn, 2008; Kruger et al., 2009; Asgedom and Kibreab, 2011; Tschardt et al., 2005). However, there have been multiple forms of alternative agricultural systems born out of the challenges that conventional agriculture has created over the past 70 years. Driven by farmers and consumers alike, one of the most widely adopted and successful alternatives is organic agriculture.

The Canadian General Standards Board (CGSB) (2015) defines organic agriculture as, "... a holistic system designed to optimize the productivity and fitness of diverse communities with the agro-ecosystem, including soil organisms, plants, livestock and people. The principal goal of organic production is to develop operations that are sustainable and harmonious with the environment" (CGSB, 2015). Organic systems operate according to production standards that prohibit the use synthetic pesticides, fertilizers, and veterinary drugs. Common features of organic farms are elimination of synthetic pesticides and fertilizers, longer and more complex

crop rotations, heavy reliance on cover crops, tight nutrient cycling, crop-livestock integration, and ecological approaches to pest control (Pimentel et al., 2005). Lynch (2009) provided a comprehensive scientific review on the environmental impacts of organic and conventional agriculture in Canada and the US. It was apparent that organic systems tended to have higher soil quality attributes, increased biodiversity, less off-farm nutrient losses, and lower GHG emissions. Results from a 22-year comparative experiment reported higher soil water percolation, lower energy requirements, and higher soil carbon (Pimentel et al., 2005). The Glenlea Long-term Rotation Study located near Winnipeg, Manitoba is Canada's longest organic rotation established in 1992. In 2010, Braman (2012) compared the microbial biomass and activity between organic, conventional, and restored grassland prairie systems. The forage-grain organic rotation had the highest microbial biomass carbon content compared to the conventional counterpart rotation, and performed the most similar to the grassland prairie system (Braman, 2012).

The Canadian organic industry has experienced tremendous growth in the past 10 years. In 2013, the Canadian Organic Trade Association (COTA) reported that the organic market in Canada was worth \$3.5 billion dollars (COTA, 2013). The organic market now accounts for 1.7% of the total food and beverage sales in Canada, a tripling since 2006 (COTA, 2013). Canadian organic exports were valued at \$458 million in 2013 (COTA, 2013). There are now 3 780 organic producers in Canada (COTA, 2016). In 2014, there were 903 948 hectares were under organic production, or 1.3% share of total agriculture land (COTA, 2016).

Organic systems are often criticized for lower yield potential, thus increasing land requirements to supply the global population with adequate food (Connor, 2013). Additionally,



the increased reliance on tillage for cover crop termination and weed control in organic production can lead to soil erosion. For example, a long-term crop rotation study found that 35-50% of land under organic systems was at high risk for serious erosion (Brandt et al., 2010). Lastly, phosphorus depletion is of particular concern on organic farms on the Canadian Prairies as there are few readily available forms of phosphorus available to organic farmers at the moment (Entz et al., 2001). In response to these challenges, research is continually carried out examining the potential of reducing tillage through cover crop no-till rotations and crop-livestock integration (Shirtliffe and Johnson, 2012; Cicek et al., 2014).

#### **2.1.1. Organic Production on the Prairies**

The Canadian Prairies are comprised of Manitoba, Saskatchewan, and Alberta. It is often referred to as the 'organic breadbasket of Canada', providing approximately 89% of organic wheat and oat, and 99% of protein crops. Across the Prairies, there are currently over 526 000 hectares under organic production, consistently led by Saskatchewan. Manitoba has approximately 34 000 hectares under organic production, and has about 134 organic producers in the province (COTA, 2016).

Organic pulses (ie. lentils, peas, etc.) and oilseeds (ie. flax, soybeans) account for approximately 24% of total organic field crop production on the Prairies (COTA, 2016). Within Manitoba, 18% of organic field crops are pulses and oilseeds. Grain legumes are an important phase in organic rotations, as they are able to supply their own nitrogen demands, provide income, and deliver an important protein source for livestock. Soybeans are a relatively new

grain legume crop for organic farmers in Manitoba, as only 119 hectares of soybeans were sown in 2014 (COTA, 2016). The principle grain legume grown on organic farms in Manitoba is field peas. In contrast to soybeans, field peas were grown on 512 hectares in 2014 (COTA, 2016). Field peas are mainly used as an organic protein feed source, and while the majority of organic soybeans grown in Ontario are destined for the food market, in Manitoba, organic soybeans are sold into the feed market or used for feed on farm as well (Laura Telford, personal comm., May 19, 2016). A high quality, reliable organic protein source is becoming increasingly important as organic livestock demand continues to grow in Canada and globally (soy2020, 2005; IFOAM, 2015). For example, between 2007 and 2013, Europe saw between 29 and 78% increase in organic livestock numbers (ie. Bovine, sheep, pigs, and poultry) and are the highest monetary contributor to the organic industry in the continent (IFOAM, 2015). In the United States, the top three commodities in organic sales were livestock products; milk (\$1.08 billion USD), eggs (\$420 million), and broiler chickens (\$372 million) (USDA, 2015a).

### **2.1.2. Environmental Characteristics of Organic Farms**

Canadian organic farmers are permitted to use non-organic non-GM untreated soybean seed; however, at the moment all soybean cultivars available to them have been bred under conventional conditions. These modern cultivars have been selected and bred in environments where the conditions do not accurately represent the environments under which they are to be grown organically. The consequence of using seed not bred under organic conditions has been

hypothesized to be sub-optimal performance in organic conditions, as the selection may be biased towards performing well under chemical intensive environments (Murphy et al., 2007).

The two principle management strategies that set organic and conventional production systems apart are sources and supply of soil fertility, and weed control. Therefore, the environment for both soil nutrients and weed control are very different under organic and conventional production. Nitrogen (N) use is focussed on in this report as it is the single most important determinant for yield and quality in organic systems. Phosphorus (P) is also of specific concern for organic farmers (Entz et al., 2001); however, organic farmers in Canada are not seeing yield reductions due to P deficiency currently (Martin et al., 2007). Furthermore, P bioavailability has been shown to be maintained over a long periods of time under organic management (Gallaher and Snapp, 2015).

#### ***2.1.2.1. Nitrogen Dynamics and Implications for Soybean***

Agronomic tactics organic farmers use to supply cash crops and forages with sufficient nutrients is through the use of complex crop rotations to increase soil microbial activity and mycorrhizal association to aid in nutrient mineralization (Snyder and Spaner, 2010). Soil microbes play a vital role in nitrogen and carbon cycling and nutrient mineralization for organic production systems as they serve as both the source and sink of plant nutrients (Dalal, 1998).

Organic farmers plant green manures, leguminous forages and apply animal manure before heavy feeder crops to supply nutrients to cash crops' needs. In a survey given to farmers in Canada, Nelson et al. (2010) found that 86% of organic producers use green manures and

66% of organic farmers use forages in their rotation. Over the course of a 22-year organic-conventional comparative study, Pimentel et al. (2005) found that adequate nitrogen levels were maintained using green manures or animal manures in rotation. In fact, nitrogen retention in the soil varied between organic animal, organic legume, and conventional based rotations (47%, 38%, and 17%, respectively) (Harris et al., 1994).

Crops and soils respond to legume-derived and inorganic N sources differently. Harris et al. (1994) found that while N levels between a legume-based cropping and fertilizer-based cropping system did not differ in contribution, N recovery for barley (*Hordeum vulgare* L.) was 49% where inorganic N had been used and 15% where a red clover cover crop preceded the barley. While more nitrogen was retained in the soil in the legume only system after harvest, no differences in losses were observed between systems (Harris et al., 1994). Additionally, the microbial community in the legume-based cropping system was more active than the conventional counterpart. Other studies have observed higher microbial mass, diversity, and activity in organic systems when compared to conventional (Bulluck et al., 2002; Mäder et al., 2002; Entz et al., 2004; Braman, 2012).

Organic farmers rely on microbial activity to increase nutrient availability to crops, and as such, nutrient availability is low in the beginning of the season when microbial activity is low (Mäder et al., 2002). Soybeans have the ability to biologically fix 50-60% of their own nitrogen from the atmosphere when it is able to enter into a symbiotic relationship with an effective strain of the bacterium *Bradyrhizobium japonicum* (Salvagiotti et al., 2008). The nodule infection and N<sub>2</sub>-fixing may not take place until 20-25 days after emergence (Rao and Reddy, 2010); during this time, soybeans suffer from a period of 'N hunger' unable to compete with

nutrient-scavenging ruderal weed species (Eaglesham et al., 1983; Place et al., 2011a).

Additionally, van Kessel and Hartley (2000) purport that conventional breeding efforts with maximum fertility levels may have indirectly selected for decreased nitrogen fixation. Due to the growth disadvantages soybeans are subject to during early growth, early season competitive ability against weeds is considered an important cultivar characteristic for weed competitiveness in soybean (Pester et al., 1999; Jannink et al., 2000).

#### ***2.1.2.2. Weed Ecology and Pressure, Implications for Soybean***

Weed control in organic systems requires an integrated approach. Due to the lack of herbicide use in their systems, organic farmers must combine different methods of control to manage weeds. Weed seed bank amounts have been observed to increase as farms transition from conventional to organic. On organic farms, Albrecht (2005) observed that in the first 3 years after conversion, the weed seed bank had increased from 4 050 to 17 320 total seed number m<sup>-2</sup>. Preventative strategies such as cleaning farm equipment, planting weed-free seeds, reducing weed seed rain, and composting manure have been used to reduce weed numbers on organic farms (Eghball and Lesoing 2000; Shirtliffe and Entz, 2005; Christoffoleti et al., 2007).

Diverse crop rotation, weed competitive species and cultivars, delayed seeding, and cover crops are examples of cultural weed control that are popular on organic farms (Nelson et al., 2010; Coulter et al., 2011a). Crop rotation diversity is an effective means of weed control by introducing varied environments in which weed species are forced to grow from year to year

(Blackshaw et al., 2007). Sjursen (2001) observed that after 3 years of annual cropping, annual dicot weed numbers increased from 7 200 to 17 600 seeds m<sup>-2</sup>, while the following three years of undisturbed grass-clover ley in the same 6-year rotation decreased seed number from 17 600 to 9 500 seeds m<sup>-2</sup>. Ominski et al. (1999) surveyed weed populations on commercial conventional farms, and found weed community differences among farms that included alfalfa (*Medicago sativa* L.) in their rotation and continuous annual cropping. The comparative study found that alfalfa inclusion provided more wild oat (*Avena fatua* L.), Canadian thistle (*Cirsium arvense* L.), and cleavers (*Galium aparine* L.) control than the cereal rotation, but inadequate control of dandelion (*Taraxacum officinale* L.) (Ominski et al., 1999).

Mechanical weed control is another popular method to attempt to reduce weed pressure on organic farms. The critical period of weed control (CPWC) in soybean is the first 4-6 weeks after emergence, the time in which the presence of weeds affects final yield the most (van Acker et al., 1993a). Pre-emergence harrowing, rotary hoe, and inter-row cultivation is common amongst organic farmers during this time (Coulter et al., 2011b). Soybeans are often damaged due to mechanical weed control methods; for example, Place et al. (2009a) found that four post-plant rotary hoe applications reduced soybean stands by 28%.

While it cannot be denied that many if not the majority of conventional farmers practice the aforementioned means of weed control in some capacity or another, organic farmers differ in that they rely more heavily on these practices for efficient and effective weed control. A failure to follow any or all of these practices often leads to crop failure or unprofitable yields. Cultivars grown in organic farms are subjected to environmental stress they may not have been

subjected to during the selection process.

## **2.2. Genetic traits and diversity valuable to organic production**

### **2.2.1. Nitrogen fixation efficiency**

Characteristics such as vigorous, deep root systems, ability to form mycorrhizal associations, and maintaining nutrient mineralization in the rhizosphere have been stated to be valuable in organic systems (Wolfe et al., 2008; Lammerts van Bueren et al., 2012). Murphy et al. (2007) found that cultivars directly selected under low nitrogen, organic production, resulted in yields ranging from 5 to 31% higher than wheat cultivars selected in adequate nitrogen environments. Recently, Wiebe (2015) reported greater N mobilization in organically bred wheat lines than conventional lines when grown in organic settings.

In legumes such as soybean, nitrogen fixation efficiency is observed as a valuable characteristic under organic systems, as it greatly contributes to overall yield performance (Vollman and Menken, 2012). Genetic diversity in nitrogen fixation among genotypes of soybean, lentil, field pea, and edible beans have been reported in the past (Herridge and Rose, 2000). Abi-Granem et al., (2011) tested five cultivars of lentil (*Lens culinaris* Medik.) with 13 to 15 available strains of *Rhizobium leguminosorum* bv. *Viciae* bacteria in growth chambers for 6 weeks. The authors found 'Eston' lentil cultivar produced the most nodules, and 'Riveland' produced the least. Furthermore, 'Eston' and 'Meritt' were highly compatible with all strains of *R. leguminosorum*, providing over 70% of plant N, and eight strains were compatible with 'Eston' (Abi-Granem et al., 2011). Above-ground biomass was significantly influenced by cultivar

as a main effect, and the researchers observed that above-ground biomass was positively correlated with below-ground biomass and size of nodules, but not correlated with the proportion of nitrogen fixed and supplied to the crop (Abi-Granem et al., 2011). Researchers in Spain reported genetic variation in nodule size and number among 158 field bean (*Phaseolus vulgaris* L.) genotypes grown hydroponically. Additionally, similar genotypes that exhibited efficient nodule and shoot development under controlled conditions also performed well in the field (Rodiño et al., 2011). Danso et al. (1987) demonstrated genetic variation in nitrogen fixation among three soybean cultivars. 'Amsoy-71' had the highest number of nodules formed, and 'Chippewa' had the least. 'Amsoy-71' was also able to fix the most amount of the nitrogen, with 'Chippewa' fixing the least (Danso et al., 1987). Similarly, Bello et al. (1980) found between 25% to 70% variability in kg N fixed ha<sup>-1</sup> among three soybean cultivars grown in two sites.

Nodulation speed has been shown to vary within cultivars as well. Chaverra and Graham (1992) tested 40 field bean accessions with three strains of *Rhizobium leguminosarum* bv. *phaseoli* for early nodulation. Cultivars 'RIZ23', 'RIZ108', 'N80068' and 'WI21-58' nodulated the fastest with all three strains, while 'Mantequilla Tropical', 'R1Z21' and '0051' were the slowest with all strains (Chaverra and Graham, 1992).

It has been proposed that older cultivars have an enhanced ability to discriminate between efficient and inefficient *Bradyrhizobium japonicum* strains present in the soil either through strain selectivity at the infection stage or through restriction of inferior strains post-infection (Kiers et al., 2007). The authors suggested that modern cultivars bred under high-nitrogen environments may have lost this trait.



Despite breeders' best efforts to increase nitrogen uptake and efficiency among legume grains, nitrogen fixation is easily disrupted by environmental stressors such as low temperature, drought stress, or high soil nitrate content (Vollman and Menken, 2012). However, research examining the molecular pathways influencing stress signals and identifying those genes has shown some promise for the future (Miransari et al., 2013). It may be valuable to consider the genotypic diversity of infection for optimal performance under organic conditions.

### **2.2.2. Weed Competitiveness**

Weeds compete with crops for a common pool of limited resources (water, light, space, and nutrients) that can reduce crop yield. Within cropping systems, there are two kinds of competition: intraspecific (between plants of the same species), and interspecific (between plants of different species (Asif et al., 2014). Intraspecific competition can be managed by adjusting seeding rates and row spacing. Interspecific competition involves the principle crop and weeds; weeds almost always have a negative effect on crops.

Goldberg and Landa (1991) identified two ways of comparing crop competitive abilities: competitive effect, defined as the ability to suppress competing weeds; and competitive response, defined as the ability to avoid being suppressed. Callaway (1992) built on the concept by defining the term of 'crop tolerance', describing the over-arching concept of high yield under weedy conditions and suppressing competing weeds (or competitive ability). However, Lemerle et al. (1996) suggested that crop tolerance and suppressive ability are two separate characteristics that may not be present in the same cultivar but are highly correlated with one

another. In this thesis, we will use the same terms and definitions as described by Lemerle et al. (1996), and the term competitive ability will encapsulate both weed tolerance and suppression. Multiple studies report cultivar characteristics such as rapid establishment (Bussan et al., 1997), vigorous early growth (Jannink et al., 2000), high biomass production (Vollman et al., 2010), weed biomass suppression (Burnside, 1972), tall plant height (Blackshaw, 1994), increased tillering (for cereals) (Mason et al., 2007), relative maturity (Monks and Oliver, 1988) and high yield in weedy conditions (Lemerle et al., 1996).

#### ***2.2.2.1. Early season vigour***

The ability for a crop to become autotrophic rapidly is advantageous against competing weeds, as it promotes root and shoot growth early in the season. Seedling development is especially important in locations like Manitoba where there are cooler spring temperatures, low nutrient availability, and a short growing season (Fatichin and Arima, 2013). Genotypic differences in early season vigour has been observed, and deemed to be important for crop competitiveness and optimal performance under organic conditions for soybean (Bussan et al., 1997), spring wheat (Wolfe et al., 2008), barley (Bertholdsson, 2005), and winter wheat (Wicks et al., 2004). Soybean cultivars must be able to germinate and develop rapidly under organic conditions, given that the competing weeds have a greater ability to scavenge for nutrients and moisture during this period (Eaglesham et al., 1983; Place et al., 2011a). It is especially important for soybeans to be competitive at early growth; weed interference within the first five weeks after emergence affects final yield the most (van Acker et al., 1993a). In cereals,

early season vigour is often observed through early season measurements in tillering ability, leaf width and architecture, and height (Wicks et al., 2004; Bertholdsson, 2005). Early vigour in soybeans is often measured using early season measurements such as plant biomass, leaf area, ground cover, and early height (Jannink et al., 2000; Place et al., 2011a; Fatichin and Arima, 2013).

#### **2.2.2.2. *Rapid establishment***

Rapid establishment is often associated with larger seed mass, as more energy is stored in the cotyledon enabling the seedling to develop rapidly (Burris et al., 1973). Vandamme et al. (2016) were able to connect larger seed size with more vigorous seedling growth under a range of soil nutrient supplies in soybean. Yan et al. (1995) demonstrated in field bean, larger seed mass correlated with more rapid root and shoot development early in the season. Wheat plants have been shown to have increased biomass production, yield, and suppress wild oat from larger seed sizes (Xue and Stougaard, 2006). Genotypic influence of seed size on rapid establishment was demonstrated by Place et al. (2011a), as early plant stand was strongly correlated with larger seeded soybean genotypes. By analyzing seed size effect on traits more closely, they found a 7% petiole length advantage for the largest seed class compared to the smallest seed class (Place et al., 2011b). It has been reported that larger seed size and rapid germination are inversely related (Edwards and Hartwig, 1971); however, other studies have reported no difference between seed size and germination efficacy or speed (Johnson and

Luedders, 1974; Place et al., 2011a). It may be advantageous for organic farmers to choose larger soybean seed size for increased competitive ability.

### **2.2.2.3. Vigorous juvenile growth**

The ability for a crop to gain a competitive advantage over the weeds in competition for resources is imperative for optimal productivity. Increasing rapid biomass accumulation at an early growth stage is one way a crop can suppress competition, and has been noted as an essential trait for cultivars grown under organic conditions (Pester et al., 1999; Hoad et al., 2012).

Benaragama et al. (2014) compared nine oat cultivars under weedy and weed-free conditions. The authors found that the cultivar 'SA0500479', 'SA050498' and 'Ronald' had the greatest seedling total leaf area which was strongly negatively correlated with wild oat biomass. Organic trials comparing 18 breeding lines in Sweden found that genotypes differed in early biomass by 35-50%, which was negatively correlated with weed biomass (Bertholdsson, 2005). Winter wheat cultivars with juvenile prostrate leaf architecture were observed to be positively correlated with increased weed density, which may be a valuable selection factor (Wicks et al., 2004).

Fatichin and Arima (2013) compared 27 soybean cultivars from six countries, and observed that 'Chamame', and 'Moyashimame' had the greatest early shoot dry weight across all genotypes. Large seed size, rapid cotyledon digestion, faster leaf expansion, and high photosynthetic rate were hypothesized to be the underlying mechanisms of early vigour in

‘Chamame’. It was suggested that cultivars with the largest leaf area are the best early growth performers in soybeans (Fatichin and Arima, 2013). Place et al. (2011a) compared the suppressive ability after seven weeks of growth between 27 soybean genotypes of varying intended end uses (soyfoods, forage, and commodity). The authors found that narrow-leaved natto genotypes were the poorest weed competitors at early growth which was hypothesized to be attributed to the smaller seed size, and shorter height, petioles, and petiolules compared to other cultivars (Place et al., 2011a).

#### **2.2.2.4. Juvenile height**

Height at early growth has been observed to differ among genotypes of cereal and legume species when grown in a community with weeds (Jannink et al., 2000; Bertholdsson, 2005; Hoad et al., 2012). Cultivar differences in early shoot and straw strength ranged from 12-44% in barley and 19-25% in wheat. Worthington et al. (2015) compared 53 winter wheat cultivars for the genotypic differences of height at various growth stages. Significant differences in early season height between genotypes were observed, and were strongly correlated with weed suppression. The authors suggested that selecting for tall cultivars earlier in the season (GS 29) should be given greater precedence over mature height for weed competitiveness (Worthington et al., 2015).

In soybean, Jannink et al. (2000) suggested a selection index for weed suppressive ability in which early soybean height was considered very important. The authors observed cultivars taller early in development grew faster than other cultivars and had a strong negative

correlation with weed biomass (Jannink et al., 2000). Genotypic variation has also been observed among wild soybean lines (Chen and Nelson, 2006). James et al. (1988) observed genotypic differences in soybean cultivars when grown under controlled settings, with 'Forest' being the tallest 40 days after planting, and 'Peking', the shortest. Rezvani et al. (2013) compared the performance of six soybean cultivars under weed pressure, and found that 'Sahar' and 'Hill' had rapid height development, and 'Sari' had the slowest. Place et al. (2011a) compared height at early growth (3 weeks after emergence) and found that 'N04-8906' had one of the best weed suppression abilities, and one of the tallest early season plant heights among cultivars tested. Soybean breeders selecting for weed competitiveness may want to make selections based on early season characteristics if the aim is to select for weed competitiveness.

#### **2.2.2.5. Cumulative biomass production**

Competitive ability encapsulates the ability for a crop to tolerate weed competition and simultaneously compete for resources. Maximum biomass production can be indicators for both competitive ability and tolerance (Wortmann, 1993; Vollman et al., 2010). Additionally, the amount of biomass produced by a cultivar is closely related to final yield (Beaver et al., 1985). Harris and Ritter (1987) reported that giant green foxtail (*Setaria viridis* var. major) reduced soybean biomass between 15-43% if left to grow with soybean up 16 weeks after emergence. Genotypic diversity in biomass accumulation in the presence of weeds has been observed in a variety of crops.

Blackshaw (1994) compared the competitive ability of winter wheat cultivars against downy brome (*Bromus tectorum* L.) using wheat biomass at maturity as an indicator. The author found that downy brome presence reduced winter wheat biomass across all cultivars; however, 'Norstar' and 'Redwin' retained the highest biomass across four downy brome densities. Lemerle et al. (1996) reported significant differences between cultivars in spring wheat biomass accumulation affected by weed interference. 'V743' accumulated the greatest biological yield over all other cultivars tested. Jacob et al. (2016) found that among 14 field pea cultivars, 'CDC Striker', 'CDC Dakota', and 'CDC Sage' produced the greatest shoot biomass regardless of whether they were grown under weedy or weed-free conditions. The authors hypothesized that strong competitive ability was related to large leaf area index associated with the cultivars.

As mentioned, the presence of weeds in the first 4-6 weeks of seeding strongly affects the final yield of soybeans (van Acker et al., 1993a). The ability for soybeans to assimilate sufficient carbon to translocate into yield components during this period is paramount (Egli, 2010). Cultivar responses to weed presence has been shown to affect carbon accumulation in soybeans in the first five weeks after emergence. Place et al., (2011a) observed significant differences in 2 of the 3 site years in biomass accumulation of 27 soybean cultivars in the presence of weeds. However, the authors did not detect a significant difference in biomass loss due to weeds among cultivars, suggesting there was no genotypic difference in a cultivar's tolerance to weed presence. However, in another study, Palmer amaranth (*Amaranthus palmeri* S. Wats.) was able to establish itself more successfully in the presence of 'Forrest' soybean cultivar as compared to 'Centennial', enabling 'Centennial' to accumulate more

biomass than 'Forrest' later in the season (Monks and Oliver, 1988). Konieczny and Shimamoto (1990) compared biomass production of three soybean cultivars in the presence of a natural weed community across varying lengths of time. All cultivars' biomass production was reduced in the presence of weeds, however, the cultivar 'Kitamusume' had the lowest biomass weight compared to other cultivars in the presence of weeds. Rezvani et al., (2013) reported that weed pressure reduced biomass production of soybean cultivars tested, however, the cultivar, 'Hill' produced the maximum biomass under weedy conditions, and 'Sari' produced the highest biological yield compared to cultivars under weed-free conditions.

In summary, a review of previous work has shown that cultivars vary in their ability to accumulate biomass in the presence of weeds, and this is an important trait to evaluate when comparing a cultivar's competitive ability under organic production.

#### **2.2.2.6. *Weed biomass production***

Weed biomass suppression is one of the most common indicators used to evaluate a cultivar's competitive abilities. This is intuitive; as while it is valuable for a cultivar to tolerate weed presence, suppressing weed growth is more valuable. Weed suppression results in easier harvestability and reduced weed-seed rain. Comparing weed biomass production among cultivars is also effective since weed suppression encapsulates multiple traits. The ability to suppress weeds among cultivars has been observed for multiple crop species.

Garrity et al. (1992) compared 24 upland rice cultivars against a natural weed community. Cultivars 'Salumikit', 'C84-21', and 'UPL R1-7' suppressed approximately 75% of



weed biomass. Mason et al. (2007) compared the performance of 27 spring wheat cultivars under organic management in Alberta. Significant cultivar effects were detected; 'Ruby', 'Preston', and 'Early Red Fife' resulted in the lowest weed biomass at maturity whereas the greatest weed biomass accumulated with cultivars 'Columbus', '5600HR', and 'Park'. Spies et al. (2011) reported that a forage pea cultivar, '40-10' suppressed, on average, three-fold more weed biomass than the other 10 cultivars tested in Saskatchewan.

When Bussan et al. (1997) compared 16 soybean genotypes with 12 weed species, 'Kato', 'Kasota', 'Dawson', 'Parker', 'Glenwood', and 'Dassel' were consistent competitors and suppressed the most weed biomass across all cultivars tested. 'Heifeng 25', 'Grande' and 'Norman' were the poorest competitors and suppressed weed biomass the least. Interestingly, Monks and Oliver (1988) observed that between 6 and 8 weeks after emergence, Palmer amaranth and common cocklebur (*Zanthum pensylvanicum* Wallr.) biomass increased in weed community under the soybean cultivars 'Forrest' and 'Centennial' but decreased only in the presence of 'Forrest' at 16 weeks. The authors reported that unlike 'Centennial', 'Forrest' continued to accumulate biomass and height, thus shading potential competition later in the season.

Measurements of weed biomass in natural communities are often highly variable due to weed density and species differences (Lemerle et al., 1996; Bussan et al., 1997; Jannink et al., 2000). High variability limits the ability to distinguish competitive ability between cultivars. For example, Lanning et al. (1997) compared the suppressive ability of wheat and barley, and subsequent cultivars of each. The authors found that a cultivar effect on weed biomass was apparent for wheat, but not with barley. Interestingly, no wheat cultivar suppressed as much

weed biomass as the least suppressive barley cultivar (Lanning et al., 1997). Jacob et al. (2016) compared 14 field pea cultivars' effect on weed biomass accumulation, and found no significant differences between cultivars. Bussan et al. (1997) reported that certain cultivars suppressed the most weed biomass in one test year, but did not in another. Additionally, soybean and weed biomass are cumbersome to measure due to large labour and time costs. Some researchers are suggesting that indirect selection (ie. selection in an environment different from the target environment) for certain characteristics in conventional breeding programs associated with weed suppressive ability such as juvenile, early vigour, and mature height may be a more practical approach to increase competitive ability of cultivars (Jannink et al., 2000; Place et al., 2011a).

#### ***2.2.2.7. Mature plant height***

Selecting cultivars for tall plant height at crop maturity is one of the oldest recognized cultivar traits for competitive ability, and continues to be relevant in modern breeding programs (Mumaw and Weber, 1957; Jacob et al., 2016). Taller plants have more of their leaves higher in the canopy therefore intercepting more light and limit sunlight to below-ground competition (Blackshaw, 1994; Christensen, 1995; Lanning et al., 1997; Hoad et al., 2012). Mature height can be a practical and powerful tool for breeders to select for when the goal is to increase competitive ability, as genotypic diversity of height has been well documented.

Blackshaw (1994) found that the winter wheat cultivar, 'Norstar' shaded more downy brome than 'Redwin', and hypothesized that it was due to 'Norstar' being 10 to 20 cm taller

than 'Redwin'. Zerner et al., (2008) examined the effect height had on the competitive ability of 13 spring wheat cultivars in community with the model weed, oat (*Avena sativa*). Weed tolerance was found to be greater in tall cultivars; in a drier growing season, short cultivars suffered 44% yield loss, compared to 27% yield loss in taller cultivars. The authors postulated yield loss occurred because shorter cultivars invested less in root growth than tall cultivars (Zerner et al., 2008). When conditions were favourable, taller wheat cultivars significantly suppressed oat seed production compared to shorter cultivars. Height has been shown to be a major factor contributing to weed competitiveness in field pea; as McDonald (2003) demonstrated that tall genotypes were more suppressive of annual ryegrass (*Lolium rigidum*) than shorter genotypes. Suppression resulted in taller genotypes retaining significantly higher yield than medium-height and short genotypes and lower ryegrass seed yield.

Genetic diversity in height has also been observed in multiple soybean studies when evaluating competitive ability. McWhorter and Hartwig (1972) observed differences in soybean height and subsequent competitive ability comparing six cultivars in competition with johnsongrass (*Sorghum halepense* L. Pers.) and common cocklebur (*Xanthium strumarium* L.). 'Lee' was the shortest cultivar and suffered 41% yield reduction due to weeds, and 'Hardee', the tallest cultivar, suffered 25% yield loss. Significant differences in mature height among genotypes were detected when Trezzi et al. (2013) compared seven soybean cultivars in competition with horseweed (*Conyza bonariensis*). 'CD225 RR' was significantly taller than all but one other cultivar, 'CD226 RR'. 'BMX Apolla RR' was the shortest cultivar tested. While no significant differences in horseweed biomass among cultivars was observed, 'CDC226 RR' had the lowest horseweed biomass present. However, it should be noted that this cultivar was

among the lowest yielding as well. The authors confirmed the importance of recognizing that tolerance and suppression are different characteristics for selection. Cultivars that are tall may not simultaneously tolerate weed interference to same to degree as shorter cultivars (Trezzi et al., 2013).

It is important to note that cultivars ‘compensate’ for shortness or ‘enhance’ tallness by increased branching (or tillering in cereals), increased leaf area index, and leaf angle (Blackshaw, 1994; Zerner et al., 2008; Place et al., 2011a; Hoad et al., 2012). Lastly, the height of the competing weeds is also a factor to consider; as it has been shown that tall cultivars can shade and suppress short weed species better than taller weed species (Blackshaw, 1994).

#### ***2.2.2.8. Relative Maturity Impacts***

Rapid growth and development early in the season has been hypothesized to be tightly connected with the relative maturity of soybean cultivars (Staniforth, 1962; Rose et al., 1984; Monks and Oliver, 1988; Place et al., 2011a), and spring wheat (Mason et al., 2007).

It is hypothesized that earlier maturing cultivars are associated with rapid growth earlier in the season, and thus have higher competitive ability (Monks and Oliver, 1988; Mason et al., 2007). However, other works postulate that long-season cultivars are superior in biomass production thus shading the competition and maintaining high yield (Rose et al., 1984; Place et al., 2011a). In some cases, a connection between maturity and weed suppressive ability had very minor bearing or was non-existent (McWhorter and Hartwig, 1972; James et al., 1988; McDonald, 2003). Weed suppressive ability at early growth integrates several traits together

and as such, the characteristics associated with the relative maturity of a cultivar are difficult to predict. Even so, the weed species emerging with the soybean at early growth matters. The specific weed species affects the relative competitiveness of the cultivar, regardless of the maturity group, when Bussan et al. (1997) compared 16 soybean genotypes across a range of maturity levels, and found that grass weed species reduced yields more than small-seeded broadleaf weeds regardless of relative maturity.

### **2.2.3. Yield**

Historical traditional soybean breeding efforts have resulted in consistent yield gains every year since the early 1900s. Voldeng et al. (1997) tested 41 short-season soybean cultivars (0 and 00 maturity groups) released over 58 years, and found that yield increased between 0.5 - 0.7% yr<sup>-1</sup>, solidifying the important role continued efforts in plant breeding are to yield improvement. Similar yield gains have been reported for hard red spring wheat in Canada (0.7% yr<sup>-1</sup>) from the early 1990s to 2013, global dry peas (0.9% yr<sup>-1</sup>) between 1961 and 2014, and global maize (1.6% yr<sup>-1</sup>) over a 20-year period (1988 to 2007) (Fischer and Edmeades, 2010; Thomas and Graf 2014; FAOSTAT, 2016). Cober and Morrison (2011) compared 20 short-season soybean cultivars released over 73 years, and reported that genetic yield gain ranged from 12.1 to 16.6 kg ha<sup>-1</sup> yr<sup>-1</sup>. However, soybean genetic yield gain under weedy conditions were reported between 14.2 kg ha<sup>-1</sup> yr<sup>-1</sup> (11% yield loss due to weeds) and 1.2 kg ha<sup>-1</sup> yr<sup>-1</sup> (80% yield loss due to weeds) (Cober and Morrison, 2011). Physiological changes associated with historical yields gains have been reported to be increased photosynthetic rate, light interception, radiation use

efficiency, and partitioning of biomass to seed (Morrison et al., 1999; Koester et al., 2014).

Similar physiological changes have been found to affect yield gains in cereals over time as well (Fischer and Edmeades, 2010).

Despite positive soybean yield gains, understanding the physiological and agronomic characteristics underlying those yield gains is still in its infancy (Koester et al., 2014).

Specifically, yield potential and gains under organic conditions are even less understood. Lower yields are often seen in organic production systems, for example, a 6-year study of 14 organic farms in the eastern section of the Northern Great Plains reported that hard red spring wheat, flax (*Linum usitatissimum* L.), oat, and field pea yielded 77%, 78%, 73%, and 67% of long-term average using conventional production systems (Entz et al., 2001). Pimentel et al. (2005) summarized a 22-year organic and conventional grain-based farming system trial at the Rodale Institute. It was found that organic corn and soybean yields were similar to conventional corn and soybean yields after a five-year period. However, it was noted that in some years, only soybean suffered negative impacts from weed competition (Pimentel et al., 2005). In other studies, season-long weed competition has been reported to reduce soybean yield anywhere from 14% to 99% depending on the density and the weed species in competition (van Acker et al., 1993b; Cowan et al., 1998; Trezzi et al., 2013). Qualities such as weed competitiveness, nutrient use efficiency, and yield stability have been identified as important agronomic qualities in organic systems, and some argue that selection of these parameters in breeding programs may increase the yield gains in organic systems (Lammerts van Beuren et al., 2002; Murphy et al., 2007; Kirk et al., 2012; Vollman and Menken, 2012).

### **2.3. How we can understand and evaluate yield stability**

Yield stability is commonly regarded as an important cultivar characteristic for organic production systems (Vollman and Menken et al., 2012). Yield stability is an important characteristic for all conventional systems as well, as conventional breeders are continually working towards selecting cultivars that respond reliably to external inputs such as artificial fertilizers and pesticides (Becker and Leon, 1988). However, it has been proposed that organic farmers especially need robust, flexible cultivars that can adapt to a wide range of environmental conditions, differing management schemes, and unfavourable environments (Lammerts van Bueren et al., 2012). In other words, environmental conditions can be altered to fit a cultivar's needs in conventional systems (ie., herbicides to eliminate weed competition), but organic cultivars need to adapt to organic environmental conditions. Wide and narrow adaptability have been observed in legumes such as lentil, where stable ranking in grain yield occurred under conventional and organic systems, and dissimilar cultivars performed optimally under the two systems (Vlachostergios and Roupakias, 2008).

Analysis of variance (ANOVA), the primary analysis approach used in many studies, is a valuable tool to compare the relative cultivar performance across multiple environments and detect general patterns. However, ANOVA is not sufficient to detect how individual cultivars responded to the varying environments. An alternative approach is the linear regression technique for stability, also known as the dynamic stability concept. This measure of yield stability was first proposed by Finlay and Wilkinson (1963) and later revised by Eberhart and Russel (1966). This type of stability analysis compares the relative performance of a cultivar

within the particular environment. This model has been widely adopted and applied to field and heirloom field beans (Park, 1987; Swegarden et al., 2016), cereals (Das et al., 2010; Ayalneh et al., 2013), and soybeans (Dashiell et al., 1994; Yue et al., 1997; Sneller et al., 1997; Zhe et al., 2010). Another popular stability measure is known as the static stability concept, and is calculated using a cultivar's coefficient of variation (CV) whereby the square root of the cultivar's variance among environments is divided by the grain mean yield (Becker and Leon, 1988). However, using the static stability model often results in selecting cultivars with low mean yield (Lin et al., 1986). For this reason, Becker and Leon (1988) recommended using the dynamic concept over static for yield studies.

#### **2.4. Using Partial Least Squares Regression Analysis for Significant Drivers on Yield**

Agricultural scientists are continually pondering and analyzing what environmental and genetic traits are propelling the final grain yield in conventional and organic systems. The most commonly accepted way to statistically analyze these relationships is through Principle Components Analysis (PCA; see Wold et al., 1987). However, in PCA, when there are a small number of observations, a high number of predictors, and multicollinearity among the predictors is present, 'over-fitting' of the data can occur (Sawatzky et al., 2015). When data are 'over-fitted' there may be many underlying factors that account for most of the response variation, and predictions from this model may be erroneous (Tobias, 1995). Partial least squares (PLS) is able to deal with high collinearity and extract significant factors contributing to the observations (Sawatzky et al., 2015).



PLS was developed in the 1960s by Herman Wold as an econometric technique; however, it is most commonly used by chemical engineers and chemometricians. Historically, PLS was also used to analyze data in industrial processes and spectroscopy (Tobias, 1995; Westad and Martens, 2000). More recently, PLS has been utilized in agricultural sciences; as Kumaragamage et al. (2012) analyzed the level of P-losses associated with the manure P fractions from four different manure sources. Large datasets such as vegetative health and spectral indices sampled from a large geographic area have been used to predict corn and peanut yield (Salazar, 2008; Elsayed et al., 2015). PLS can be a powerful statistical tool for analyzing cultivar performance in organic settings due to the ability to isolate and extract multiple collinear environmental and agronomic factors involved. However, to the author's knowledge there has been little to no utilization of PLS in cultivar performance evaluation field trials.

## **2.5. Non-GM Soybean cultivar development in Canada and the United States**

Organic farmers are prohibited from using GM soybean seed, therefore, non-GM soybean breeding programs will be discussed exclusively. Soybeans have been cultivated in North America since 1765 (Sleper and Shannon, 2003), and in Canada since 1881 (Shurtleff and Aoyagi, 2010). In the United States, organized soybean breeding began with the establishment of the US Regional Soybean Industrial Products Laboratory in 1936 in Urbana, Illinois, in partnership with other North Central agricultural experiment stations (Sleper and Shannon, 2003). In Canada, the first soybean cultivar was developed and registered by Charles Zavitz at

the Ontario Agricultural College in Guelph, Ontario in 1923. By 1976, Maple Arrow, the first early maturing, and cold tolerant cultivar was developed and registered. This cultivar enabled growers to expand acreage in Quebec and Manitoba. The majority of soybean cultivars in Canada were developed by the public sector until 1984, when private breeders developed 24 of the 35 cultivars described by the Ontario Ministry of Agriculture (Shurtleff and Aoyagi, 2010).

Public contributions to non-GM soybean breeding efforts in Canada are led by Istvan Rajcan at the University of Guelph, the Centre de Recherche sur les Grains inc. (CEROM), and Elroy Cober with Agriculture and Agri-Food Canada (AAFC). Soybean cultivars developed by Istvan Rajcan's lab and the majority of other soybean breeders in Canada are primarily grown in southern Ontario, where the highest proportion of Canadian non-GM acreage is sown. Cultivars developed by Elroy Cober at AAFC service areas with shorter seasons, for example, the Canadian Prairies and eastern Canada. Private industries involved in non-GM soybean cultivar development include Hyland Seeds, La Co-op Fédérée, Sevita International, Semence Prograin Inc., and Syngenta.

In the United States, interest in soybean breeding in the private sector in the 1970s was spurred by the Plant Variety Protection Act (PVP) which allowed for intellectual protection of crop cultivars (Sleper and Shannon, 2003). Beversdorf et al. (1995) reported that between 1922 and 1971, 171 cultivars were registered in Canada with almost 60% originating from US public (85 cultivars) and private (14 cultivars) programs. Sleper and Shannon (2003) reported that over 90% of soybean cultivars grown in the United States were developed by private programs. Currently, 94% of US soybeans acres are GM (USDA, 2015b). Canadian data on genetically modified soybean acreage is poor, however, the USDA estimates that 62% of Canadian soybean

acreage are GM (USDA, 2014). The lower proportion of GM soybeans grown in Canada is due to the highly successful Identity Preserved export program used to market non-GM soybeans to demanding countries (Shurtleff and Aoyagi, 2010). This data is relevant to organic farmers, as this limits their cultivar choices, and non-GM soybean breeders, as it limits their already narrow germplasm diversity (Gizlice et al., 1994). Germplasm diversity is further reduced consequentially due to the fact that 90% of cultivars are developed by private industry, whose germplasm is rarely shared because of intellectual property rights (Sleper and Shannon, 2003). Farmers wishing to grow non-GM soybean cultivars may need to depend on mainly public sectors for cultivar development in the future.

Currently, public sector soybean breeding efforts are spearheaded by public universities and government research initiatives in the United States and Canada (Miller-Gavin et al., 2010). However, some are concerned that too little effort is being applied to breeding non-GM soybeans given the economic benefits of GM breeding (Miller-Garvin et al., 2010). Due to the popularity of GM, Sleper and Shannon (2003) suggest that public breeders should focus on education of new plant breeders and enhancing germplasm diversity through recombinant DNA technology, cell fusion, and somaclonal variation. However, it is unclear whether certain certifying bodies would allow the use of cultivars developed through genetic engineering of any kind. Despite these challenges, responses from a 2010 non-GM soybean breeding survey in the United States state indicate increases in non-GM soybean breeding development, and a total of 61 cultivars were expected to be publically released from multiple breeders across seven states between 2013-2015 (Miller-Garvin et al., 2010).

## **2.6. Organic Crop Breeding in Canada, United States, and Europe**

### **2.6.1. Initiatives in Canada**

While organic plant breeding is certainly taking place on organic farms around the world, a focus on formal breeding programs from Canada, United States, and select countries Europe are supplied. Current organic breeding initiatives in Canada are mainly looking at cereals with a focus on weed competitiveness, high grain protein content and baking quality. Work has been and continues to be carried out in organic cereal breeding with funding from the Organic Science Cluster by Canadian researchers such as Jennifer Mitchell-Fetch and Stephen Fox at AAFC, Pierre Hucl at the University of Saskatchewan, and Dean Spaner at the University of Alberta (OACC, 2009; 2013). Out of this project, the first organically-developed oat cultivar in Canada was released, 'AAC Oravena' (OACC, 2013). Additionally, a nationwide Participatory Plant Breeding Program for organic production is an ongoing successful initiative involving oats, wheat, and potato with Martin Entz at the University of Manitoba, Benoit Bizimungu at AAFC, Maude Forte at Le Coop Agrobio du Quebec, and Lana Reid at AAFC, with funding from USC Canada, AAFC Growing Forward 2, and Organic Science Cluster (OACC, 2013). Unfortunately, no specific organic grain legume breeding initiatives are taking place in Canada at this moment. However, interest in organic grain legumes is growing, with interest from international markets and local organic livestock feed demands. Organic breeding trials were conducted by graduate student, Torin Boyle, under the supervision of Istvan Rajcan, specifically analyzing weed suppressive ability, nutrient use efficiency, and root morphology (Boyle et al., 2015).

### 2.6.2. Initiatives in Europe

The majority if not all cultivars currently available to organic farmers around the world are derived from conventional crop breeding programs (Wilbois et al., 2012). Some argue that this is sufficient; as breeders are able to select for highly heritable traits through indirect selection (Zhao et al., 2006). However, others argue that indirect selection is inadequate due to unknown cultivar characteristics that are not visually obvious to plant breeders such as root traits for nutrient uptake/efficiency, and plant-microbe-soil interactions apparent in organic systems (Messmer et al., 2012).

Organic crop breeding programs in Europe have gained traction in the public sector; Wageningen University in the Netherlands introduced an endowed chair specialized in Organic Plant Breeding in 2005, where the research team is working towards increasing the quality of organic propagation material with a focus on model crops cabbage, onion, wheat, and potato. Kassel University in Germany established a full-time chair for Organic Plant Breeding and Biodiversity in 2011 (Organic Research Centres Alliance, 2011). The Ecoprotein project started through the Knowledge Centre for Agriculture in Denmark, and is working towards supplying enhanced fababean cultivars to organic farmers to reduce organic protein import costs. A project initiated by the Organic Research Centre in the UK called Coordinating Organic Plant Breeding Activities for Diversity (COBRA) works towards supporting and developing organic plant breeding and seed production between 41 partners from 18 European countries (COBRA, 2016).

### **2.6.3. Initiatives in the United States**

Organic crop breeding initiatives in the public sector gained momentum through Sustainable Agriculture Research and Education program (SARE), federal Risk Management Agency (RMA), USDA Value Added Producer Grants program (VAPG), and the Organic Research and Education Initiative (OREI) funding (Lammerts van Bueren, 2012). In 2015, the National Institute of Food and Agriculture (NIFA) awarded \$21 million to organic research, three funding projects including advancing organic breeding and seed production (NIFA, 2015). Organic breeding efforts in public universities are becoming more common; Jim Myers holds the Baggett-Frazier Endowed Chair of Vegetable Breeding and Genetics at Oregon State University and Girish Kumar Panicker at Alcorn State University in Mississippi is working on melon cultivars for organic production (Shade, 2015). In 2009, Chris Reberg-Horton at North Carolina State University was awarded a \$1.2 million USDA grant to develop corn, soybean, peanut, and wheat cultivars for organic production (Robertson, 2012).

Organic farmers have started breeding their own vegetables cultivars due to coordination with the Organic Seed Alliance (OSA) and several grants, individual contributions, and seed and food company contracts. For example, eight organic farms collaborated to breed and release 'Abundant Bloomsdale', a slow-to-bolt, cold hardy, deep green spinach cultivar (OSA, 2016). Other organic vegetable breeding initiatives such as the Carrot Improvement for Organic Agriculture (CIOA), Northern Organic Vegetable Improvement Collaborative (NOVIC) and University of California Davis Student Collaborative Plant Breeding Education, work to join

researchers and farmers to address farmers' seed and plant breeding needs (CIOA, 2014; NOVIC, 2014).

Organic breeding efforts will probably continue to be dominated by the public sector, small seed companies and farmers. The continued demand for organic products will increase the demand for organic cultivars. In the meantime, organic cultivar trials of non-GM soybean cultivars are becoming more common across the United States and Canada. Public organizations such as Minnesota State University, University of Vermont, North Carolina State University, Iowa State University, Western Illinois University, Cornell State University, and SARE and Kansas Organic Producers Association are currently or in the past conducting organic soybean cultivar trials (Vogelsburg, 1994; Delate et al., 2003; Caldwell et al., 2011; Darby et al., 2012; Dale, 2014). In Canada, organic soybean cultivar trials have been conducted by provincial agricultural extension organizations and AAFC in Atlantic Canada, and cultivar trials were conducted through the as-mentioned graduate project at the University of Guelph (Hammermeister et al., 2007; Boyle et al., 2015). The present research is the first organic soybean yield trial to be done in Western Canada.

### **3. MATERIALS AND METHODS**

#### **3.1. Site Descriptions**

Field experiments were conducted over 10 site-years in 2014 and 2015. In 2014, experiments were located at the Organic Field Crops Laboratory on the Ian N. Morrison Research Farm in Carman MB, four organic farms located in Somerset, St. Pierre-Jolys, Swan Lake, Woodmore MB, and one organic transitional farm in Elie, MB. In 2015 experiments were established at the Organic Field Crops Laboratory on the Ian N. Morrison Research Farm in Carman MB, and the same organic farms located in Somerset, St. Pierre-Jolys, and Woodmore MB. The management, location and soil texture of each site is found in Table 1.

Weather data were obtained from weather monitoring stations located at the sites. If that was not possible, data from weather stations located in close proximity were obtained from Manitoba Agriculture, Food and Rural Development (MAFRD). Climate data (long-term average) was obtained from Environment Canada weather stations close to sites. Each experimental site varied in soil nutrient status, and previous crop which provided a wide diversity of growing conditions (Table 2).



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

Research Site	Site-year	Land Management ( <i>first organic year</i> )	Latitude (N)	Longitude (W)	Soil Subgroup	Soil Series ( <i>texture</i> )	Drainage
Carman	2014, 2015	Organic (2004)	49°29'52	98°02'12	Orthic Black	Hibsin ( <i>fine sandy loam</i> )	Well
Somerset	2014	Organic (2007)	49°19'40	98°43'39	Orthic Dark Grey	Dezwood ( <i>clay loam</i> )	Well
St.Pierre-Jolys	2014, 2015	Organic (2006)	49°25'47	96°57'44	Orthic Black	Red River ( <i>clay loam</i> )	Imperfect
Swan Lake	2014	Organic (2006)	49°29'00	98°47'46	Orthic Dark Grey Luvisol	Pembina ( <i>clay loam</i> )	Well
Woodmore	2014, 2015	Organic (2009)	49°07'18	96°53'54	Gleyed Rego Black	Lenswood ( <i>Loam sand</i> )	Imperfect
Elie	2014	Transition ( <i>2<sup>nd</sup> transition year</i> )	49°56'44	97°44'19	Orthic Black	Altamont ( <i>clay-silt loam</i> )	Imperfect
Somerset	2015	Organic (2007)	49°21'19	98°43'27	Dark Grey Luvisol	Nayler ( <i>loam</i> )	Well

**Table 2:** The soil nutrient status, organic matter content, pH, and crop history of experimental sites in 2014 and 2015

Site Location	Depth	N <sup>x</sup>	S <sup>y</sup>	P <sup>z</sup>	K	OM	pH	Previous Crop
	cm	--kg ha <sup>-1</sup> --		--ppm--		%		
Carman 2014	0-15	33.6	13.4	14.5	168	2.6	5.1	Spring wheat
	15-60	24.6	6.7	7	100	2.1	5.9	
Carman 2015	0-15	6.7	6.7	12	197	3.2	5.6	Spring wheat
	15-60	40.3	26.9				7.1	
Somerset 2014	0-15	30.2	13.5	7	391	5.4	7.5	Oats
	15-60	47.1	33.6				8.0	
Somerset 2015	0-15	35.8	11.2	20	404	5.6	6.1	Spring wheat
	15-60	67.3	26.9				6.4	
St. Pierre-Jolys 2014	0-15	19.1	26.9	8	420	5.8	7.9	Spring wheat
	15-60	36.9	349.7	2	237	3.5	8.1	
St. Pierre-Jolys 2015	0-15	16.8	67.2	10	146	3.8	7.9	Pea and oat green manure
	15-60	57.2	248.8				8.1	
Swan Lake 2014	0-15	48.2	35.8	46	4.8	4.5	7.1	Buckwheat
	15-60	60.5	87.4				7.2	
Woodmore 2014	0-15	21.2	29.1	5	77	2.2	7.9	Pea and oat forage
	15-60	60.5	53.8	2	46	1.1	8.2	
Woodmore 2015	0-15	13.4	11.2	4	62	2.2	7.9	Barley
	15-60	87.4	26.9				8.1	
Elie 2014	0-15	19.1	67.3	42	436	7.9	7.7	Spring wheat
	15-60	37.0	403.5				8.0	

<sup>x</sup>Nitrate-N, <sup>y</sup>Sulfate-S, <sup>z</sup>Olsen-P

### 3.2. Experimental Design and Treatments

This experiment compared 12 non-genetically modified (GM) soybean cultivars sourced from across Canada and North Dakota that varied in required crop heat units and relative maturity (Table 3). Company heat unit and relative maturity information was provided by seed companies. In 2014, seed stock used was sourced directly from the seed supplier listed. In 2015, seed stock used was saved from harvested material in 2014, and evenly blended for uniformity. The cultivars were chosen based on recommendations by the seed companies and where not genetically modified. The cultivars were also chosen to show a range of relative maturities to showcase maturity potential in Manitoba.

**Table 3.** Soybean cultivar, source, company heat units, and maturity ratings included in the study

Cultivar	Source	Company Heat Units	Relative Maturity
Tundra	Semences Prograin, Quebec	2350	000.5
SK0007	SK Foods, North Dakota	2375	000.7
OAC Prudence	Robert Weins, Manitoba	2450	00.7
Toma	Semences Prograin, Quebec	2500	00.7
OAC Petrel	SG Ceresco, Quebec	2520	00.5
DH 863	Sevita International, Ontario	2500	00.6
DH 401	Sevita International, Ontario	2550	00
Jari	Elite Le Coop, Quebec	2550	0.5
Auriga	Elite Le Coop, Quebec	2625	0.5
SVX14T0053	Sevita International, Ontario	2625	0
Savanna	Homestead Organics, Ontario	2650	0.4
Krios	Elite Le Coop, Quebec	2675	0

Cultivars were compared in a randomized complete block design with four replicates at all study sites. In Carman 2014, each experimental unit was 6 rows wide with 30cm row spacing and 5m long. Each experimental unit on satellite farms in 2014 was 4 rows wide with 30cm row spacing and 7m long. A 1m x 1m experimental sub-unit was kept weed-free to evaluate weed competitiveness. In Carman 2015, each experimental unit was 6 rows wide with 30cm row

spacing and 7m long. Each experimental unit on satellite farms in 2015 was 8 rows wide with 30cm row spacing and 7m long. The size and length was changed in 2015 to account for an additional biomass sampling. The weed-free experimental sub-unit spanned across the width of each experimental unit (6-rows in Carman, 8-rows at satellite farms) and 1m long. The expansion of the experimental sub-units was aimed at attempting to increase the ability to capture weedy versus weed-free yield differences. Border plots of OAC Prudence were established at the end of each replicate, and border rows of fall rye (var. Hazelet) were seeded in between each block and on either side of each experiment to minimize edge effects. Specific experimental unit size, experimental sub-unit size, and seeding date are provided in Table 4.

**Table 4.** Experimental unit size, sub-unit size, and seeding date used in the study at all sites

Site Location	Year	Experimental Unit Area (m <sup>2</sup> )	Weed-Free Sub-unit Area (m <sup>2</sup> )	Seeding Date
Carman	2014	9.2	1.0	May 23
Somerset	2014	8.4	1.0	May 27
St.Pierre-Jolys	2014	8.4	1.0	May 30
Swan Lake	2014	8.4	1.0	June 3
Woodmore	2014	8.4	1.0	May 28
Elie	2014	8.4	1.0	May 30
Carman	2015	12.8	1.8	May 21
Somerset	2015	16.8	2.4	May 27
St. Pierre-Jolys	2015	16.8	2.4	May 23
Woodmore	2015	16.8	2.4	May 26

### 3.3. Field Experiment Management

At all sites, the seedbed was prepared by using a tandem disc with diamond harrows if needed either immediately before seeding, or shortly before seeding depending on coordination with the farmers at the satellite farms. In Carman, experiments were seeded using a disk drill (Fabro Industries, Swift Current, SK). On all other organic farms, experimental units

were seeded using a custom made 4-row single disk drill equipped with a cone for seed distribution (University of Manitoba, Winnipeg, MB). Soybeans were seeded into moisture (approximately 3-5cm depth) at all sites at approximately 545, 600 seeds hectare<sup>-1</sup> (Place et al., 2009b). All experimental units were inoculated using Monsanto BioAg Cell-Tech C granular (*Bradyrhizobium japonicum*) inoculant at a rate of 7.9 kg ha<sup>-1</sup>. The rate of inoculant was between two to three times the recommended level. We wanted to ensure optimum nodulation where soybeans have never been grown previously. Weed control operations were carried out at pre-emergence in 2014 and Carman 2015. At Carman 2014 and 2015, a pre-emergence harrowing was carried out using a Lely tine harrow (Lely Agriculture, The Netherlands). On satellite farms, pre-emergence harrow was accomplished using a garden rake. In 2015, pre-emergence harrowing did not take place at satellite farms. Inter-row cultivation was implemented at the V3 (vegetative state at the third trifoliate stage) using a c-shank cultivator in Carman 2014 and at all other sites and years using a double blade wheel-hoe. Weed-free subplots were kept weed free through hand weeding.

### **3.4. Data collection**

Plant population density was evaluated when the soybean plants were at the V2 stage at all sites. Plant population values were calculated based on counts of 3 x 1 metre lengths per plot.

Early height measurements were taken when the third trifoliate had unfolded and elongated from the main stem, V3. Early plant height was taken at Swan Lake 2014 and

Somerset 2015 when the fourth trifoliate had unfolded and elongated from the main stem; therefore, plant heights for these sites were not included in combined analysis. Plant height was measured as the distance from the soil surface to the tip of the terminal bud. Some cultivars began flowering at the time of measurement, but this was not taken into account. Height at maturity was taken once the soybeans had reached the point at which pod-fill had begun at one of the four upper-most nodes on the stem (R5). Plant height was measured as the distance from the soil surface to the tip of the plant. Five measurements were taken per experimental unit, with plant height for each experimental unit being the average of the five measurements.

Pod height measurements were taken at the same time as height at maturity. Pod height was taken as the distance from the soil surface to the top of the pod's node where the pod was attached to the main stem. Pod height for each experimental unit was the average of the five measurements taken per plot.

Above-ground soybean biomass was assessed from samples taken once in 2014 at Carman, Somerset, Woodmore, and St. Pierre-Jolys. Samples were taken twice in 2015 at all sites except St. Pierre-Jolys (due to deer damage). The additional sample in 2015 was early season above-ground soybean biomass. This was sampled when the third trifoliate had unfolded and elongated from the main stem. Early above-ground biomass was sampled regardless of flowering time, and all cultivars were sampled at the same time. Soybean biomass samples were taken at R5 in 2014 and 2015. Late season samples were taken once the soybeans had reached the point at which pod-fill had begun at one of the four upper-most nodes on the stem (R5). It is at this point in the season where the maximum amount of biomass

has accumulation before leaves begin to abscise from the plant (Egli, 2010). One metre lengths from the centre two rows of each experimental unit were cut at ground level for each sample. Samples were then dried at 70°C for 48 hours after being collected. Dried biomass samples from each experimental unit were weighed to assess dry matter weight.

Above-ground weed biomass was taken to determine relative weed biomass accumulation between cultivars. Above-ground weed biomass was taken at the same time as soybean biomass. Soybean and weed biomass samples were sorted and separated in the field. Samples were dried at 70°C for 48 hours, and weighed to determine dry matter weight.

Plant maturity was defined as the date when 95% of the pods reached their mature colour (tan or brown) and all leaves have abscised from the plant. This date was recorded to the best of the observer's capabilities.

In 2014, all sites were harvested by hand in one metre lengths from four rows in the weedy and weed-free portion of the experimental units at maturity. In 2015, all sites except Carman 2015 and St. Pierre 2015 were harvested by hand in one metre lengths from eight rows in the weedy and weed-free portion of the experimental units at maturity. At Carman 2015, one metre lengths from six rows in the weedy weed-free portion were harvested. St. Pierre 2015 was not harvested (due to deer damage). Samples were dried on a forced ambient air drying bed before threshing. Threshing took place using a stationary Wintersteiger plot harvester (Wintersteiger, Austria). Further grain cleaning took place using a forced air grain separator. Weight per 100 seeds was obtained using a 'Old Mill Counter Model 850-3' (International Marketing and Design Corporation, San Antonio, Texas) seed counter and weighing the sub-

sample. Seed mass from weedy and weed-free experimental sub-units were measured in 2015. 'Grain yield' will be referred to as the weedy portion of the experimental unit harvested unless otherwise stated.

Yield loss due to weed competition was calculated to examine cultivar differences in the ratio of weedy yields and weed-free yields. Yield loss was calculated by subtracting the division of the weedy yield by the weed-free yield, and multiplying by 100 to result in a percentage value. Carman 2015, Woodmore 2015, and Somerset 2015 were the only sites evaluated using this calculation. The harvested area of 'weed-free' experimental sub-units in all other sites were quite small, experimental error and variability was very high.

$$\text{Yield Loss due to Weeds (\%)} = \left( 1 - \frac{\text{Weedy Grain Yield}}{\text{Weed-Free Grain Yield}} \right) \times 100$$

Grain Harvest Index (HI) was also calculated to assess how efficiently the different cultivars converted dry matter into grain. Grain weight and biomass was collected from weedy portion of the plots only.

$$HI = \frac{\text{Grain weight/unit area}}{\text{Biomass weight/unit area}}$$

In 2015 only, seed protein and oil content of each cultivar from weedy and weed-free experimental sub-unit using near-infrared transmittance. The samples were analyzed at the Agriculture and Agri-Food Canada Research Station in Morden, Manitoba using a Foss Infratec 1241 Grain Analyzer (Foss Industries, Hillerød, Denmark). Protein and oil content was not



analyzed for samples in 2014 due to insufficient required sample size. Refer to the appendix for seed quality data.

### **3.5. Data Analysis**

#### **3.5.1. Analysis of Variance**

Measures of soybean and weed biomass samples, plant height, pod height, grain yield, seed density per unit biomass, harvest index, seed size, protein content, and oil content of different cultivars were subjected to analysis of variance separately for each site year. Each data set was analyzed using PROC Mixed procedure with the Statistical Analysis Software program 9.4 (SAS Institute, 2013a), considering treatments as fixed effects and replications as random effects. Normality distribution assumptions were tested using Shapiro-Wilks with PROC Univariate procedure and first tested for homogeneity of variance using Bartlett's test. If data was not normally distributed, data was transformed using the log function. Differences among cultivars were tested using the protected Least Significant Difference (LSD) test and considered statistically significant at  $p < 0.05$ . Combined analysis of multiple site years was performed using PROC Mixed procedure with the Statistical Analysis Software program 9.4 (SAS Institute, 2013a).

#### **3.5.2. Stability Analysis**

Grain yield stability for each cultivar at every site-year was analyzed using the Finlay-Wilkinson regression procedure (Finlay and Wilkinson, 1963). The slopes of cultivar regression lines (the regression coefficient;  $b_i$ ) were calculated by plotting the cultivar mean yields at each site against site means yields. A regression line was then fit to each cultivar's performance data.

The slope of each regression line (the regression coefficient;  $b_i$ ) was then plotted against each cultivar mean yield across all 9 site-years. Linear regression responses of each cultivar are created by partitioning the genotype by environmental interaction. This was done using the PROC GLM procedure with the Statistical Analysis Software program 9.4 (SAS Institute, 2013a) considering the cultivar as the fixed effect and environment as a random effect.

The regression coefficient ( $b_i$ ) value describes the linear response of a cultivar across a range of environments, and the deviations from regression ( $S^2_d$ ) value describes the performance consistency (Eberhart and Russel, 1966). Cultivars with higher  $b_i$  values ( $>1.0$ ) indicate higher sensitivity to environmental changes and better performance in optimal environments, but worse than average performance in poor environments. Lower  $b$  values ( $<1.0$ ) describe low sensitivity to diverse environments, and better performance in worse environments, however, poor performance in good environments. When  $b_i$  is close to 1.0, it indicates that the genotype performs similarly to average across all environments. The model states that a desirable cultivar would have a high mean yield, a regression coefficient of 1.0 ( $b_i = 1.0$ ) and a deviation from the regression line as small as possible ( $S^2_d = 0$ ). Stability analysis was performed for the weedy grain yield data only.

### **3.5.3. Partial Least Squares Regression Analysis**

Quantitative relationships between grain yields and R5 soybean biomass (response variables), and predictor environmental variables were determined using partial least squares regression (PLSR) analysis using Proc PLS in SAS 9.4 (SAS Institute, 2013b). The data set

contained a small number of response variables (grain yield, and soybean R5 soybean biomass) and a large number of collinear predictive factors; therefore, PLS was utilized (Tobias, 1995). To determine which characteristics of cultivars and soil nutrient status of each site-year had the greatest influence in explaining the variability in grain yield and R5 soybean biomass, predictor variables (i.e., early and mature soybean height, soybean biomass, weed biomass, soil nutrient status (-N, -P, -K, -Cl, -Zn, -Cu, organic matter content, -pH), were initially included as predictor variables in the PLS model. Predictors contributing significantly ( $VIP > 0.8$ ) (Wold, 1995) to the variability in the grain yield and R5 soybean biomass were then selected for inclusion in the final model. The number of PLS factors were selected using a cross validation method in which predictive factors were taken out of the model if they were below a VIP of 0.8. Preliminary PLS analyses indicated that there were many predictor variables having a VIP value  $> 0.8$ . To refine the important factors, we defined variables having a VIP value  $> 1.2$  as critical factors (Liu et al., 2013). Parameter estimates for centred and scaled data represent the data such that the predictors and responses have a mean of 0 and a standard deviation of 1. Centering and scaling the data ensures that all predictors and responses are on equal footing relative to their variation in the data (SAS Institute, 2013b). Negative values correspond with a negative impact on the response variable, and the size of number reflects the magnitude in which the parameter contributed to the response variable's variability. When all parameter estimates (i.e. soybean height or biomass) are placed on equal footing, the proportion of explanation the parameter estimate has influenced the response variable (i.e. soybean grain yield) is reflected. For example, if soybean biomass at R5 has a largest positive number compared to other parameters, that parameter positively contributed the soybean grain yield variation the most.

Conversely, if weed presence has the largest negative numbers, that parameter negatively contributed to soybean grain yield variation. The parameter estimate in centred and scaled data allows for further interpretation of the data.

## **4. RESULTS AND DISCUSSION**

### **4.1. Environmental Conditions**

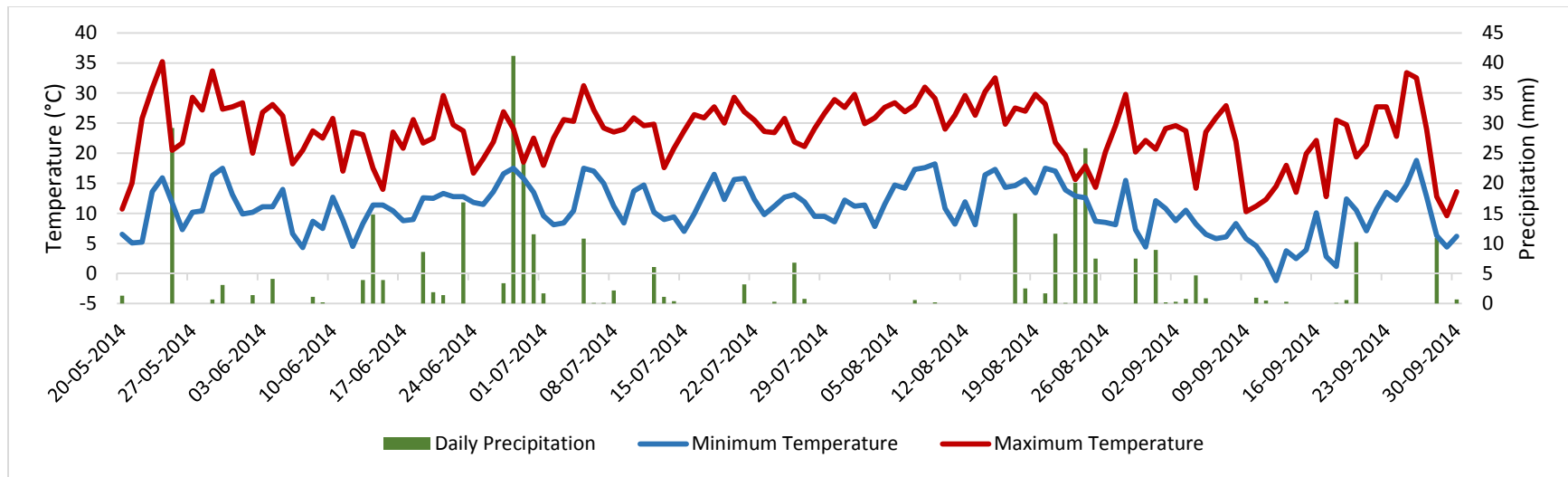
Average temperature during the growing season (May to September) at all sites ranged between 14.7 – 17.1°C (Table 5) (MAFRD, 2014; MAFRD, 2015) and closely matched long-term average temperatures (Environment Canada, 2015). Average growing season temperatures in 2015 were slightly warmer than 2014 by 0.5 – 1.4 °C.

Among all site years, growing season precipitation ranged between 289.7 – 706.2 mm between sites and years (Table 5) (MAFRD, 2014; MAFRD, 2015). With the exception of Somerset growing season, precipitation was greater in 2014 than 2015. Woodmore 2015 averaged 272.6 greater than Woodmore 2014 (Table 5).

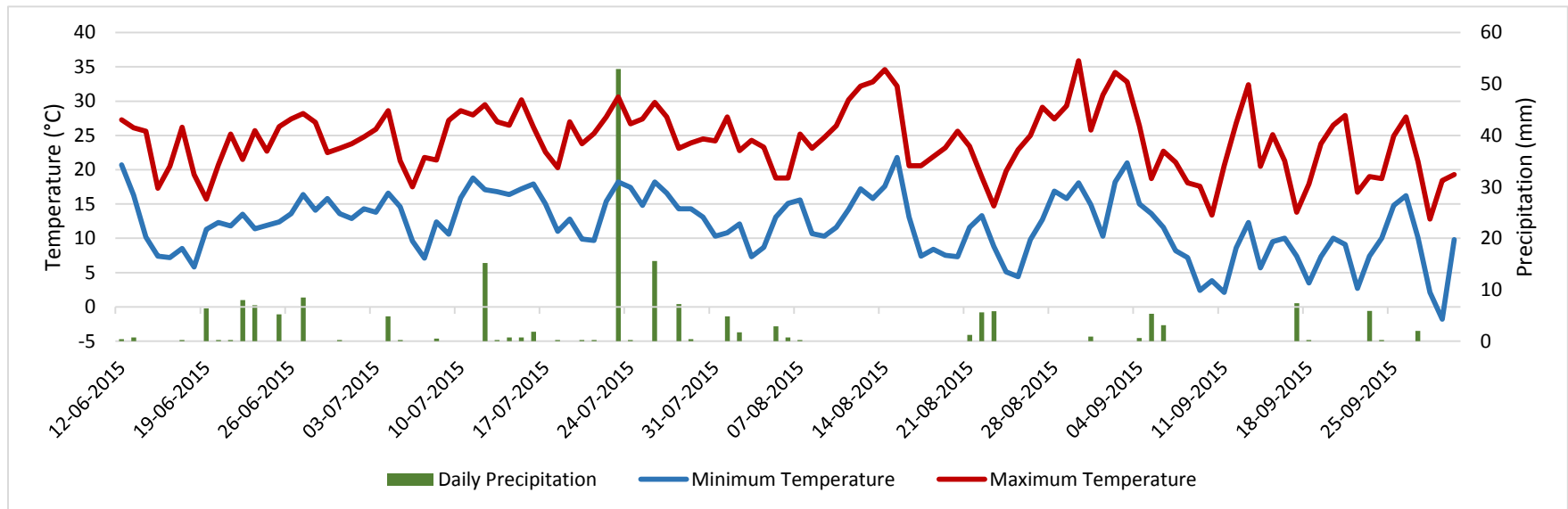
The distributed of growing season precipitation varied between years and sites. Swan Lake 2014 experienced heavy precipitation early in the season (Figure 1) that delayed timely weed management. Heavy precipitation after seeding immediately followed by high temperatures at Somerset 2015 (Figure 2) caused soil crusting. At all sites in 2014, there was very little to no precipitation during pod-fill (end of July and first three weeks of August), when soil moisture is required for efficient carbon translocation (Figures 1 and 3). This was not observed at many sites in 2015 (Figures 2 and 4).

**Table 5.** Mean monthly temperature and precipitation during the growing season (MAFRD 2014, 2015) and long-term averages (Environment Canada, 2015) at each experimental site.

Research Site	May	June	July	August	September	Growing Season
<b>Air Temperature (°C)</b>						
Carman 2014	11.3	16.6	18.2	18.7	13.1	15.6
Carman 2015	10.7	17.5	19.9	18.3	15.8	16.4
Long Term Average <sup>1</sup>	11.6	17.2	19.4	18.5	13.4	16.0
Somerset 2014	10.8	15.6	16.9	17.7	12.0	14.7
Somerset 2015	10.2	16.9	19.9	18.5	15.2	16.1
Long Term Average <sup>1</sup>	11.8	17	19.2	18.6	13.1	15.9
St. Pierre-Jolys 2014	11.8	17.8	18.8	19.3	14.0	16.4
St. Pierre-Jolys 2015	11.4	18.2	20.9	19.1	16.3	17.2
Long Term Average <sup>1</sup>	11.5	16.4	19.0	18.2	12.3	15.5
Swan Lake 2014	11.4	16.9	18.3	19.0	14.1	15.9
Long Term Average <sup>1</sup>	11.7	17.1	19.4	18.8	13.4	16.1
Woodmore 2014	11.9	17.8	19.4	19.6	14.3	16.6
Woodmore 2015	11.6	18.1	20.7	18.8	16.2	17.1
Long Term Average <sup>1</sup>	12.3	16.9	18.8	18.2	12.2	15.7
Elie 2014	11.4	17.0	18.6	19.1	13.3	15.9
Long Term Average <sup>1</sup>	11.9	17.1	19.8	18.9	13.1	16.2
<b>Precipitation (mm)</b>						
Carman 2014	31	117	48	122	47	364
Carman 2015	99	75	109	47	42	373
Long Term Average <sup>1</sup>	70	96	79	74	49	368
Somerset 2014	57	97	45	102	23	324
Somerset 2015	31	109	101	24	25	290
Long Term Average <sup>1</sup>	75	93	82	73	45	367
Swan Lake 2014	69	138	34	102	31	328
Long Term Average <sup>1</sup>	66	93	79	66	48	352
St. Pierre-Jolys 2014	66	157	68	92	56	440
St. Pierre-Jolys 2015	83	86	228	82	60	539
Long Term Average <sup>1</sup>	68	100	93	74	57	392
Woodmore 2014	59	194	57	76	48	434
Woodmore 2015	115	217	178	81	115	706
Long Term Average <sup>1</sup>	67	99	84	74	53	377
Elie 2014	36	147	27	91	40	341
Long Term Average <sup>1</sup>	60	98	76	68	56	358
<sup>1</sup> 30-year average						

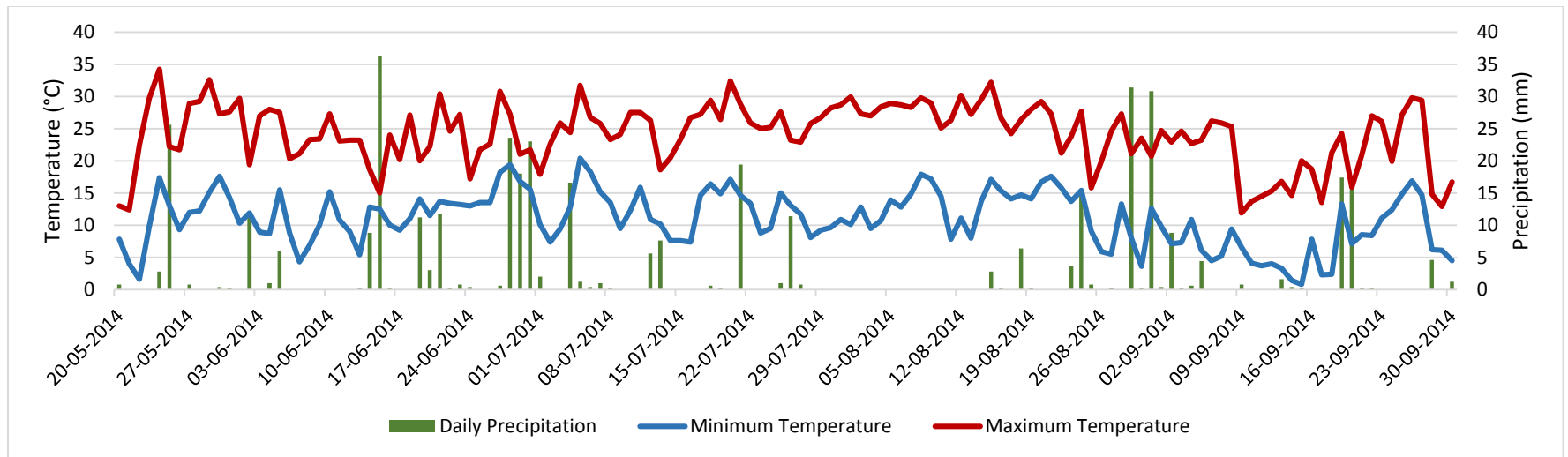


**Figure 1.** Daily temperature and precipitation accumulation for Swan Lake 2014 between the end of May and September.

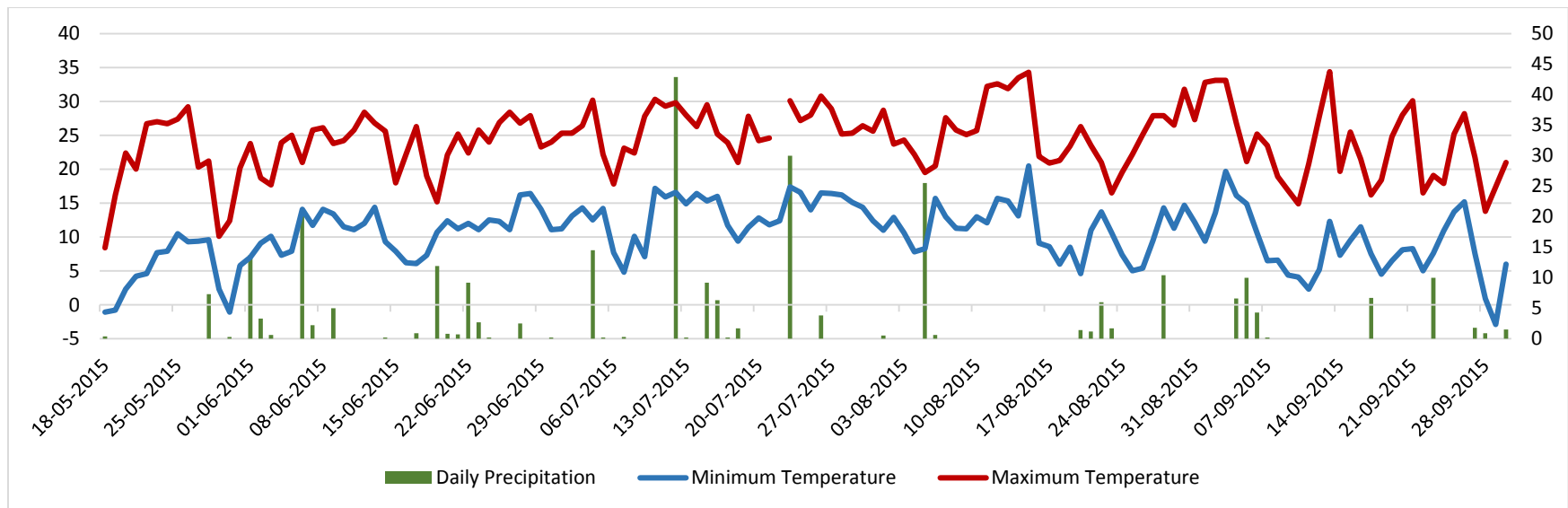


**Figure 2.** Daily temperature and precipitation accumulation for Somerset 2015 between the beginning of June and September





**Figure 3.** Daily temperature and precipitation accumulation for St. Pierre-Jolys 2014 between the end of May and September



**Figure 4.** Daily temperature and precipitation for Carman 2015 between the end of May and September.

## 4.2. Stand Density

Soybean stand densities were evaluated to compare the ability of different soybean cultivars to successfully establish under organic management conditions and to ensure consistent plant populations across the experimental locations. Significant differences amongst site years and cultivars were observed, in addition to a site-cultivar interaction (Table 6; Figure 5; appendices Table 14). Among sites, plant densities ranged from 25.4-47.2 plants m<sup>-2</sup>.

The differences between sites may be attributed to the different environmental characteristics between sites. For example, volunteer buckwheat (*Fagopyrum esculentum*) pressure was apparent at Swan Lake 2014, such that the soybeans were emerging in the presence of emerged buckwheat, resulting in low soybean populations (25.4 plants m<sup>-2</sup>). Buckwheat is recognized as being a highly competitive crop with rapid emergence in the spring, effectively shading potential plant competition. Buckwheat is also known to have allelopathic qualities. Kato-Noguchi et al. (2007) found the growth of four grass species seedlings' growth was inhibited when grown in an established community of buckwheat seedlings. Additionally, previously incorporated buckwheat residues have been shown to inhibit the growth of Powell amaranth (*Amaranthus powellii* L.) (Kumar et al., 2009). Low plant density at Carman in 2015 may be linked to dry soil. While the seed was planted into moisture on May 21 2015 in Carman, the site did not receive precipitation until seven days after planting (Figure 4). Carman 2015 also received pre-emergence Lely tine harrow weed management, which also may have contributed to lower plant stands. Place et al. (2009a) found that while pre-plant rotary hoe did reduced plant stands in soybean, there was no main effect on the final yield. Soybeans can

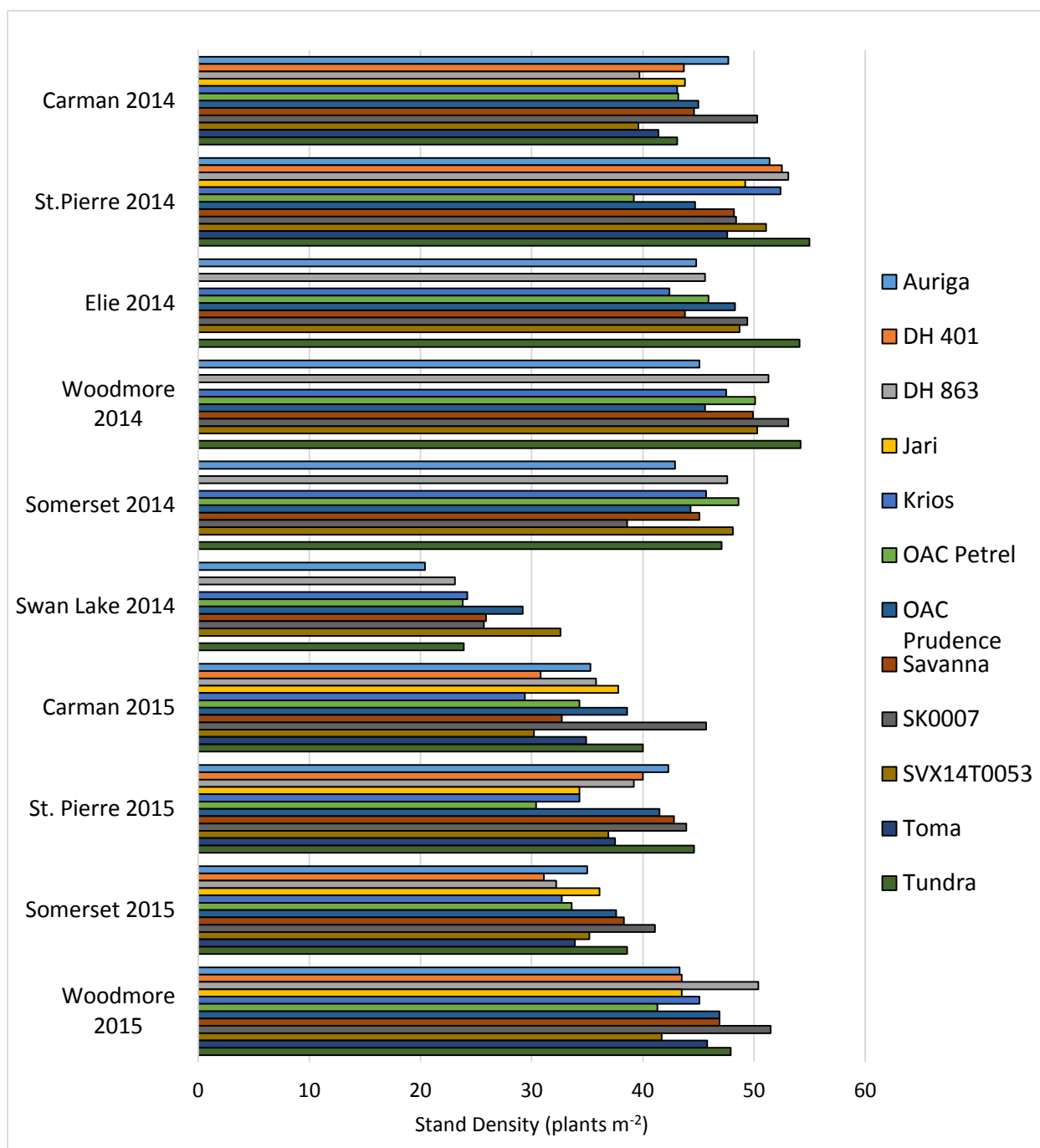
adapt to lower plant densities due to changes in stem morphology. Soybeans have the ability to increase seeds per plant by producing branches. Conversely, in higher densities, branching is reduced, thus reducing seeds per plant (Carpenter and Board, 1997).

With the exception of Swan Lake, soybean plant densities were within or above the recommended plant density of 30-37 plants m<sup>-2</sup> for full yield potential according to Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) (2009). However, organic farmers are advised to increase plant populations due to increased weed management tillage that may damage soybeans and higher seeding rates have been shown to increase weed competitiveness and yield potential in organic systems (Place et al., 2009a).

Plant population densities amongst cultivars ranged from 38.1 to 44.7 plants m<sup>-2</sup> (Table 6). However, a site-cultivar interaction indicated that the cultivars responded differently at the different sites. 'SK0007' exhibited the highest overall stand density, with a range of 25.7 to 53.1 plants m<sup>-2</sup>. However, 'SK0007' had low stand densities at sites such as Somerset 2014, Swan Lake 2014, and St. Pierre 2014. No indication of environmental differences between sites explains why 'SK0007' had low densities at these sites. 'Toma' had the lowest average stand densities which varied from 33.9 to 47.6 plants m<sup>-2</sup>. Past research has noted that smaller seeds imbibe more quickly whereas larger seeds experience germination delay, which may have reduced stand density (Place et al., 2011a). However, neither 'Toma' nor 'SK0007' had small seed mass compared to other cultivars (Table 6).

**Table 6.** Combined Analysis of Agronomic Parameters from Carman, St. Pierre Jolys, Woodmore, Elie, Swan Lake, Somerset 2014 and Carman, St. Pierre-Jolys, Woodmore, and Somerset 2015

	Soybean Stand Density	R1-R2 Soybean Biomass	R1-R2 Weed Biomass	R1-R2 Soybean Height	R5 Soybean Biomass	R5 Weed Biomass	Soybean Maturity Height	Soybean Pod Height	Soybean Grain Yield	Soybean Yield Loss Due to Weeds	Soybean Seed Mass	Soybean Harvest Index
	plant m <sup>-2</sup>	kg ha <sup>-1</sup>	kg ha <sup>-1</sup>	cm	kg ha <sup>-1</sup>	kg ha <sup>-1</sup>	cm	cm	kg ha <sup>-1</sup>	(%)	g/100 seeds	
<b>Site-year</b>												
<b>Carman 2014</b>	44 c	-	-	20 bc	3410 b	2043 b	66 b	14 c	2104 b	-	18 b	0.54 ab
<b>St. Pierre 2014</b>	49 a	-	-	20 c	3297 bc	1289 c	50 de	12 e	1944 c	-	19 a	0.48 bc
<b>Woodmore 2014</b>	50 a	-	-	21 b	3047 bc	1459 c	52 d	14 c	1637 d	-	17 c	0.49 ab
<b>Somerset 2014</b>	45 bc	-	-	22 a	2689 cd	1605 c	48 e	13 cd	907 e	-	15 d	-
<b>Elie 2014</b>	47 ab	-	-	-	-	-	53 d	13 cd	2212 b	-	17 c	-
<b>Swan Lake 2014</b>	25 f	-	-	-	-	-	51 de	18 a	369 f	-	15 d	-
<b>Carman 2015</b>	36 e	764	863 b	19 d	6481 a	2165 b	86 a	15 b	2681 a	20 a	17 bc	0.42 c
<b>St. Pierre 2015</b>	39 d	884	732 bc	18 d	-	-	-	-	-	-	-	-
<b>Woodmore 2015</b>	46 bc	752	637 c	17 e	3271 b	1392 c	64 b	15 b	1538 d	28 a	14 d	0.48 ab
<b>Somerset 2015</b>	36 e	838	2015 a	-	2363 d	2553 a	60 c	13 cd	1479 e	44 b	13 e	0.55 a
<b>Cultivar</b>												
<b>Auriga</b>	41 cde	721 cd	1158	20 cd	3139 bc	1635 cd	58 de	14 bcd	1621 ab	36	15 cd	0.54
<b>DH 401</b>	37 f	829 bc	1011	20 bc	3314 bc	1521 d	60 d	14 bcd	1384 b	28	17 a	0.52
<b>DH 863</b>	42 bc	817 bcd	1087	19 fg	3938 abc	1576 cd	71 b	14 cde	1631 ab	28	16 ab	0.49
<b>Jari</b>	38 ef	871 b	1305	20 cde	3871 abc	1655 bcd	79 a	16 a	1423 b	27	15 bcd	0.45
<b>Krios</b>	40 cdef	695 cd	1214	19 e	3333 abc	1789 abcd	65 c	14 def	1571 ab	32	15 d	0.49
<b>OAC Petrel</b>	39 def	763 bcd	1161	19 ef	3278 bc	1781 abcd	60 d	13 f	1497 b	36	15 d	0.49
<b>OAC Prudence</b>	42 abc	813 bcd	967	19 e	2891 c	2145 a	58 de	13 ef	1419 b	30	17 a	0.56
<b>Savanna</b>	42 bc	864 b	936	19 de	3611 abc	1637 cd	61 d	15 bc	1808 a	31	17 a	0.54
<b>SK0007</b>	45 a	1005 a	964	23 a	3407 abc	1971 abc	55 ef	15 ab	1455 b	32	17 a	0.44
<b>SVX14T0053</b>	41 cd	677 d	1097	17 g	3917 ab	1859 abcd	58 d	14 cdef	1566 b	34	17 a	0.5
<b>Toma</b>	37 f	841 bc	963	17 h	4470 a	1838 abcd	68 bc	14 bcdef	1587 ab	28	16 abc	0.46
<b>Tundra</b>	45 ab	863 ab	977	21 b	3124 bc	2085 ab	53 f	14 bcd	1467 b	37	17 a	0.5
<b>Source of Variation</b>												
	<b>P &gt; F</b>											
<b>Site</b>	<b>&lt;.0001</b>	0.2523	<b>&lt;.0001</b>	<b>&lt;.0001</b>	<b>&lt;.0001</b>	<b>&lt;.0001</b>	<b>&lt;.0001</b>	<b>&lt;.0001</b>	<b>&lt;.0001</b>	<b>0.0005</b>	<b>&lt;.0001</b>	<b>0.0007</b>
<b>Cultivar</b>	<b>&lt;.0001</b>	<b>0.001</b>	0.1379	<b>&lt;.0001</b>	<b>0.0210</b>	<b>0.0397</b>	<b>&lt;.0001</b>	<b>&lt;.0001</b>	<b>0.0005</b>	0.461	<b>&lt;.0001</b>	0.1288
<b>Site-Cultivar</b>	<b>0.0034</b>	<b>0.0098</b>	0.4692	0.8021	0.1946	0.078	<b>&lt;.0001</b>	<b>0.0028</b>	<b>0.0014</b>	<b>0.0012</b>	<b>&lt;.0001</b>	0.5743



**Figure 5.** Stand density values for 12 soybean cultivars for ten site-years.

### 4.3. Soybean Biomass Production at R1-R2 Growth Stage

Cultivar characteristics associated with weed competitiveness include rapid germination and seedling emergence, and accelerated, vigorous aboveground growth (Pester et al., 1999). Biomass production at the R1-R2 growth stage, a measure of this early season vigour, was significantly different among cultivars in the present study. Further, a significant interaction was observed in the present study (Table 6; Figure 6; see appendices Table 15).

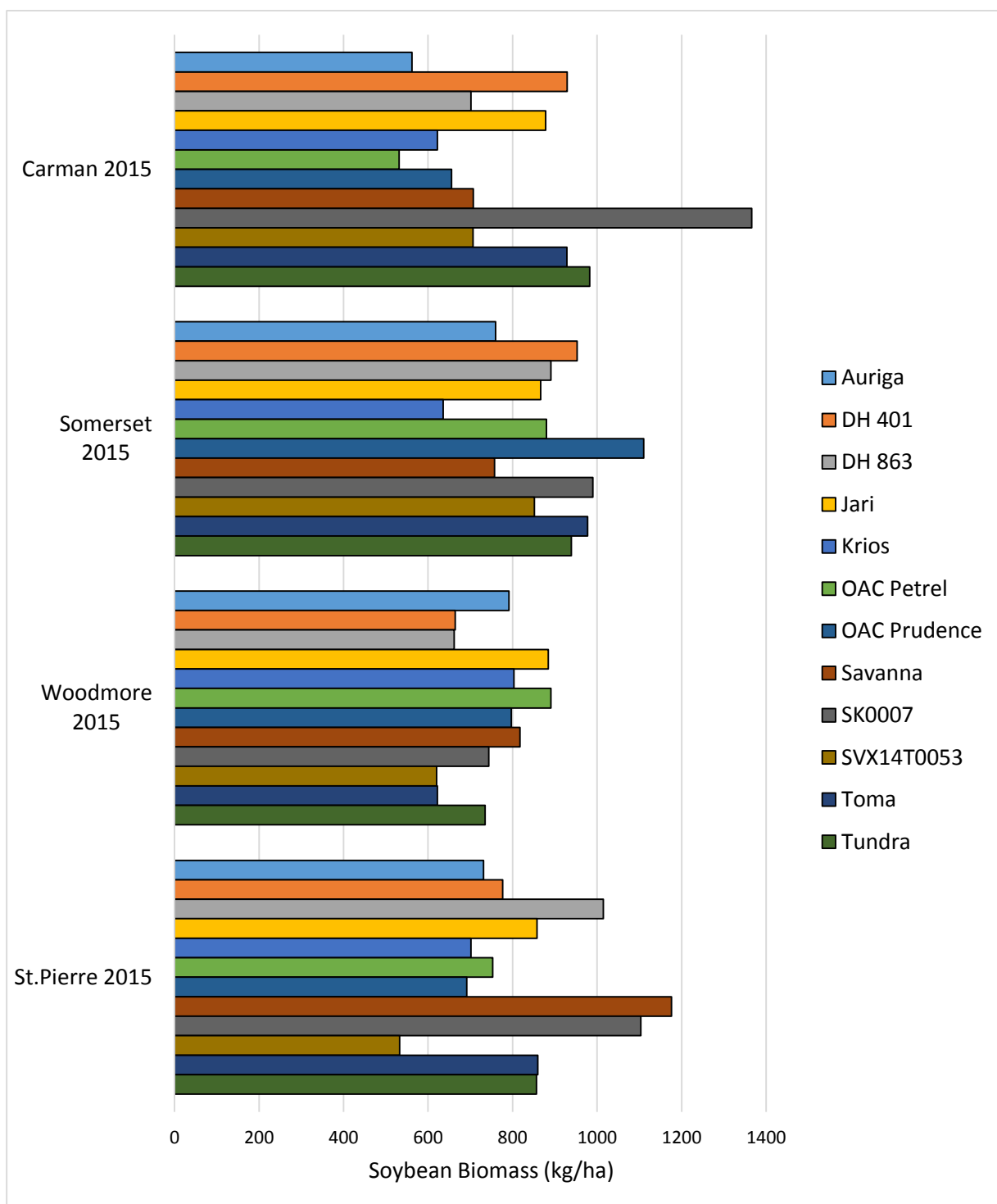
Early season biomass production ranged from 695 to 1005 kg ha<sup>-1</sup>. Cultivar performance was different at different sites. For example, 'SK0007' averaged the highest biomass production, but was not one of the highest biomass producers at Woodmore 2015 and St. Pierre 2015. Differences in early biomass production was also observed with 'OAC Prudence', which was the highest biomass producer at Somerset 2015, but had among the lowest biomass at Carman 2015. 'Savanna' accumulated high biomass only at St. Pierre 2015.

Previous research has also identified genetic differences among cultivars for early vegetative accumulation (Monks and Oliver, 1988; Fatichin and Arima, 2013). Fatichin and Arima (2013) examined 27 soybean cultivars and found that 'Chamame', an early-maturing cultivar, had the greatest shoot dry mass at 28 days after seeding and was associated with large seed size, high cotyledon digestion, faster leaf expansion, and high photosynthetic rate. 'SK0007' and 'Tundra' were the earliest maturing cultivars tested in the present study, which may have been responsible for higher early biomass accumulation.

Maturity level may influence weed competitiveness early in the season. Monks and Oliver (1988) found that 'Forrest', was approximately one half as competitive with weeds as the

later maturing 'Centennial' for the first 8 weeks after emergence. This may be why cultivars such as 'Savanna', 'Auriga', and 'Krios' did not accumulate high biomass at early growth.

In the present study, no obvious patterns between early and later maturing cultivars were observed, nor did one cultivar stand out as having a consistent advantage over other cultivars for early biomass production.



**Figure 6.** Soybean biomass at the R1-R2 development stage of 12 cultivars for four site-years



#### 4.4. Weed Biomass Production at R1-R2 Growth Stage

Significant differences in early season weed biomass production were observed among sites in 2015 (Table 6). However, no significant differences were observed between cultivars and no site-cultivar interactions were apparent. The greatest weed biomass production was observed in Somerset at 2015 kg ha<sup>-1</sup>, where weed biomass was approximately 250% of soybean biomass. Woodmore 2015 had the lowest weed biomass value at 637 kg ha<sup>-1</sup>, representing approximately 85% of soybean biomass accumulated. Similar studies assessing crop vs. weed biomass evaluated biomass at physiological maturity only (Bussan et al., 1997) or when early season measures were taken, only weed biomass was measured (Place et al., 2011a). Place et al. (2011a) observed redroot pigweed (*Amaranthus retroflexus* L.) biomass values in competition with soybean at 7 weeks after emergence ranged from 310 kg ha<sup>-1</sup> and 530 kg ha<sup>-1</sup>. The principle weed species in Somerset 2015 was wild mustard, *Sinapis arvensis*, while at Woodmore 2015 the principle weed species was wild oat, *Avena fatua*.

The absence of a site-cultivar interaction demonstrates that cultivars performed similar to each other despite large variation in weed pressure between sites. Staniforth (1962) compared relative weed competitiveness between four soybean cultivars that varied in maturity level. The authors found no significant differences in final weed yield between cultivars in the 'weedy' experimental units and concluded that no differences in cultivar competitiveness existed. Burnside (1972), on the other hand, observed significant differences between cultivars, as the cultivar 'Harosoy' suppressed weeds better than 'Hark', which was the

least suppressive. Genetic differences in soybean cultivars' weed suppressive ability was also observed by Rezvani et al. (2013).

It is important to consider that the above studies measured weed biomass differences at the end of the season. None of these studies measured weed biomass early in the season, as was the case in the present experiment. Weed community changes have been reported in relation to relative soybean competitiveness. For example, Monks and Oliver (1962) observed that the biomass of common cocklebur, Palmer amaranth, and tall morningglory had declined between 8 and 16 weeks when competing with 'Forrest' but increased when competing with 'Centennial'. It can be suggested that this is due to differing reproductive patterns of different weed species and relative weed biomass accumulation (Monks and Oliver, 1988). These observations highlight the need to assess the weed biomass earlier in the season when testing for genetic variation in weed competitiveness.

#### **4.5. Soybean Height at R1-R2**

The ability for soybeans to shade weeds, thereby interrupting weeds' access to light enables the crop to gain an advantage (Place et al., 2011a). Early height measurements were not collected in Elie 2014, Swan Lake 2014, and Somerset 2015 due to time constraints. At the sites where R1-R2 height was collected, significant differences were apparent among sites and between cultivars (Table 6). The lack of a site-cultivar interaction indicates that cultivars differences were stable across site-years and/or that site-year differences were stable across cultivars.

R1-R2 soybean height ranged from 17.2 cm to 21.6 cm. The site with the tallest plants was Somerset 2014, while the shortest plants were reported at Woodmore 2015. Among cultivars, 'SK0007' had an average R1-R2 height of 23.3 cm, greater height relative to other cultivars at all sites measured. Overall, 'Tundra' was the second tallest (Table 6). Interestingly, the two cultivars that exhibited the greatest R1-R2 height were two of the earliest maturing cultivars. Jannick et al. (2000) also observed that earlier maturing cultivars were taller earlier in the season, increasing weed competitiveness.

However, these trends in maturity differences do not agree with all previous studies. Several researchers found that later maturing cultivars were either more competitive with weeds or that maturity had no influence on weed competitiveness (Staniforth, 1962; Rose et al., 1984; Monks and Oliver, 1988; Place et al., 2011a). Few of these previous studies considered early season weed biomass and this may be one reason why results in the present study are different from the literature.

One explanation for why improved vigour was observed for early maturing soybean cultivars may be related to nitrogen. Soybean nitrate uptake increases until the full bloom stage, earlier maturing cultivars may be expected to uptake N earlier in the season (Harper, 1987). Therefore, if earlier maturing cultivars are able to acquire more than weeds earlier in the season, a competitive advantage belowground may be accomplished. Nitrate levels in spring may indeed be lower in organic compared with conventional production systems (Wolfe et al., 2008), and the implication is that cultivars able to scavenge for N better than other cultivars may be better equipped to achieve a competitive advantage.

#### 4.6. Soybean Biomass Production at R5

The vegetative phase of soybean extends to approximately the R5 stage (Purcell et al., 2002) and is the beginning of yield production since it provides the biomass required for pod formation and seed-fill. The ability for soybeans to accumulate required biomass is directly related to the photosynthetic capability of the leaves, environmental conditions, and proportion of solar radiation absorbed by the canopy (Egli, 2010). The presence of weeds, insects, and diseases affects the ability of the crop to accumulate maximum biomass either directly (e.g., shading plants) or indirectly (e.g., causing stress by reducing resource availability) (Egli, 2010).

Significant differences for soybean R5 biomass between sites and cultivars were observed in the present study; however, no site-cultivar interaction was observed (Table 6). Somerset 2015 resulted in the lowest R5 soybean biomass with 2363 kg ha<sup>-1</sup>, and Carman 2015 the highest at 6481 kg ha<sup>-1</sup>. Carman 2015 had accumulated almost three times as much biomass as the second highest biomass producing site, Carman 2014. All other sites' soybean biomass production ranged from 2363 to 3297 kg ha<sup>-1</sup>. Increased biomass production at Carman 2015 may be due to well-timed precipitation, low soil-N, weed species that were less competitive (small seeded-broadleaves) and adequate accumulated heat throughout the growing season (Figure 4).

Average cultivar biomass production ranged from 2891 to 4470 kg ha<sup>-1</sup>. 'Toma' produced the most biomass over all other cultivars, 10 137.2 kg ha<sup>-1</sup> at Carman 2015, almost 3000 kg ha<sup>-1</sup> more than the second highest biomass producer. Rezvani et al. (2013) observed

similar results, as 'Hill' accumulated approximately 4000 kg ha<sup>-1</sup> more biomass than the second highest biomass producer, and approximately 6000 kg ha<sup>-1</sup> more than the lowest biomass producer. Other cultivars such as 'SVX14T0053', 'Savanna', and 'Jari' were also top biomass producers. The absence of site-cultivar interaction suggests that cultivars didn't rank differently from one another across a variety of weed pressures, soil characteristics and environmental challenges. Interestingly, the top biomass producers in the present study were more commonly later-maturing cultivars, such as 'Toma'.

Final yield of soybean is directly dependant on the crop's ability to reach maximum vegetative mass from emergence to growth stage R5 (Egli, 2010). The crop's ability to reach maximum vegetative mass is also directly related to how much time the crop is able to commit to the vegetative growth phase before shifting to the reproductive phase (pod formation and fill) (Beaver et al., 1985). Egli (1994) found that the vegetative growth phase length in soybean increased in proportion to the total growth cycle, as soybeans in the MG 00 growth stage lasted 83 days, and soybeans in the MG V growth stage lasted 134 days. Zeiher et al. (1982) found that vegetative biomass was positively correlated with length of maturity. Differences in vegetative growth period between the latest maturing cultivar to the earliest ranged from 100 days to 66 days (Zeiher et al., 1982). The later maturing cultivar had increased biomass weight by 2 550 kg ha<sup>-1</sup>, but this was not closely related to final yield (Zeiher et al., 1982). Place et al. (2011a) notes that in the southern United States maturity group was the only genetic trait historically recognized to have a direct effect on weed competitiveness. Late maturing cultivars were specifically chosen to maintain ground cover and shade weeds (Place et al., 2011a). Organic farmers may therefore be inclined to choose later-maturing cultivars due to their ability to

increase biomass production and be competitive against weeds. For future research, it may prove valuable to compare the biomass accumulation rate and weight during different periods of the season, weed competitiveness and relative maturity in soybeans.

#### **4.7. Weed Biomass Production at R5**

Competitive ability in crops can be expressed in two ways. Crops can directly compete by reducing weed biomass production, or have the ability to tolerate competition and maintain high yields (Bussan et al., 1997). Therefore, weed biomass accumulation differences observed among soybean cultivars is an important indicator of relative weed competitiveness (James et al., 1988).

In the present study, weed biomass accumulation varied significantly between sites, as well as between cultivars (Table 6). Somerset 2015 had the highest weed biomass at 2 553 kg ha<sup>-1</sup>, followed by Carman 2015 at 2 165 kg ha<sup>-1</sup>. The site with the lowest weed biomass accumulation was St. Pierre 2014 with 1 289 kg ha<sup>-1</sup>.

There was no site-cultivar interaction for weed biomass. This indicates that the cultivars' relative suppressive ability did not change with the varied weed pressure and weed community characteristics experienced at the different sites. However, significant cultivar effects *per se* were observed. The cultivar with the highest weed biomass across sites was 'OAC Prudence' with 2 145 kg ha<sup>-1</sup>, the cultivar with the lowest weed biomass was 'DH 401' with 1521 kg ha<sup>-1</sup>. Vollman et al. (2010) detected relative weed competitiveness between cultivars as well,

but could not identify the agronomic characteristics of the cultivars that lead to their suppressive ability.

In the present study, the relationship between soybean and weed biomass accumulation at R5 did not follow a consistent inverse relationship when comparing different sites. For example, Somerset 2015 had the highest weed biomass production and lowest soybean biomass production, suggesting that weeds had the ability to suppress the soybean growth. However, Carman 2015 had the second highest weed biomass accumulation among sites as well as the highest soybean biomass accumulation. A possible explanation for these results is different weed species at each site. The principle weed species at Somerset 2015 were *Sinapsis arvensis* (wild mustard) and *Avena fatua* (wild oat) whereas the principle weed species present in Carman 2015 were *Amaranthus retroflexus* (redroot pigweed), *Cirsium arvense* (Canada thistle), and *Setaria lutescens* (yellow foxtail). Bussan et al. (1997) compared 16 soybean cultivars in the presence of 12 weed species and observed that broadleaved weed species produced less biomass than grass weed species when competing with soybean. Similar results were observed in the present study, where Somerset 2015 had a grass as the principle weed species and resulted in the highest weed biomass, and lowest soybean biomass. Conversely, Carman 2015, whose principle weed species was a small-seeded broadleaf (redroot pigweed), had the greatest soybean biomass in spite of having the second greatest mass of weeds. Soybeans in the present study may have been able to compete and tolerate redroot pigweed better than wild oat and wild mustard.

Seed yield and quality have been documented to differ in response to the abundance and particularly the relative abundance of certain weed species over others (Gibson et al.,

2008). Cowan et al. (1998) found that pigweed was more competitive than barnyardgrass when grown in competition with soybean. Vollman et al. (2010) examined the yield reduction due to undersown rapeseed (*Brassica napus*, L.), reduced soybean yield by 370 to 560 kg ha<sup>-1</sup> but when environmental conditions were favourable for soybean, yield increased in weed infested sub-plots by approximately 270 kg ha<sup>-1</sup>. Therefore, if conditions are more favourable for the soybean rather than the weed species, soybean has the ability to overcome weed pressure and even out-perform weed-free conditions (Vollman et al., 2010). This may have been the case in this experiment; Carman 2015 received more favourably timed precipitation to encourage early vigour and emergence (Figure 4), whereas in Somerset 2015 there were incidences of soil crusting during emergence due to an isolated rainfall event of 20.5mm 5 days after seeding (Figure 2). This may have given wild mustard a competitive advantage earlier in the season at Somerset 2015.

Staniforth (1962) observed soybean yield reductions due to weeds were more severe in plots where 32 to 64 kg ha<sup>-1</sup> N fertilizer was applied the previous year. Increased nitrogen in the soil gives weeds a competitive advantage over soybean early in the season. This may apply in the present experiment as Somerset 2015 had twice the amount of nitrate-N in the soil at the beginning of the season than Carman 2015 (Table 2). The relative competitiveness against certain weed species and soybeans early in the season may be valuable for future research in Manitoba.



#### 4.8. Soybean Height at Maturity

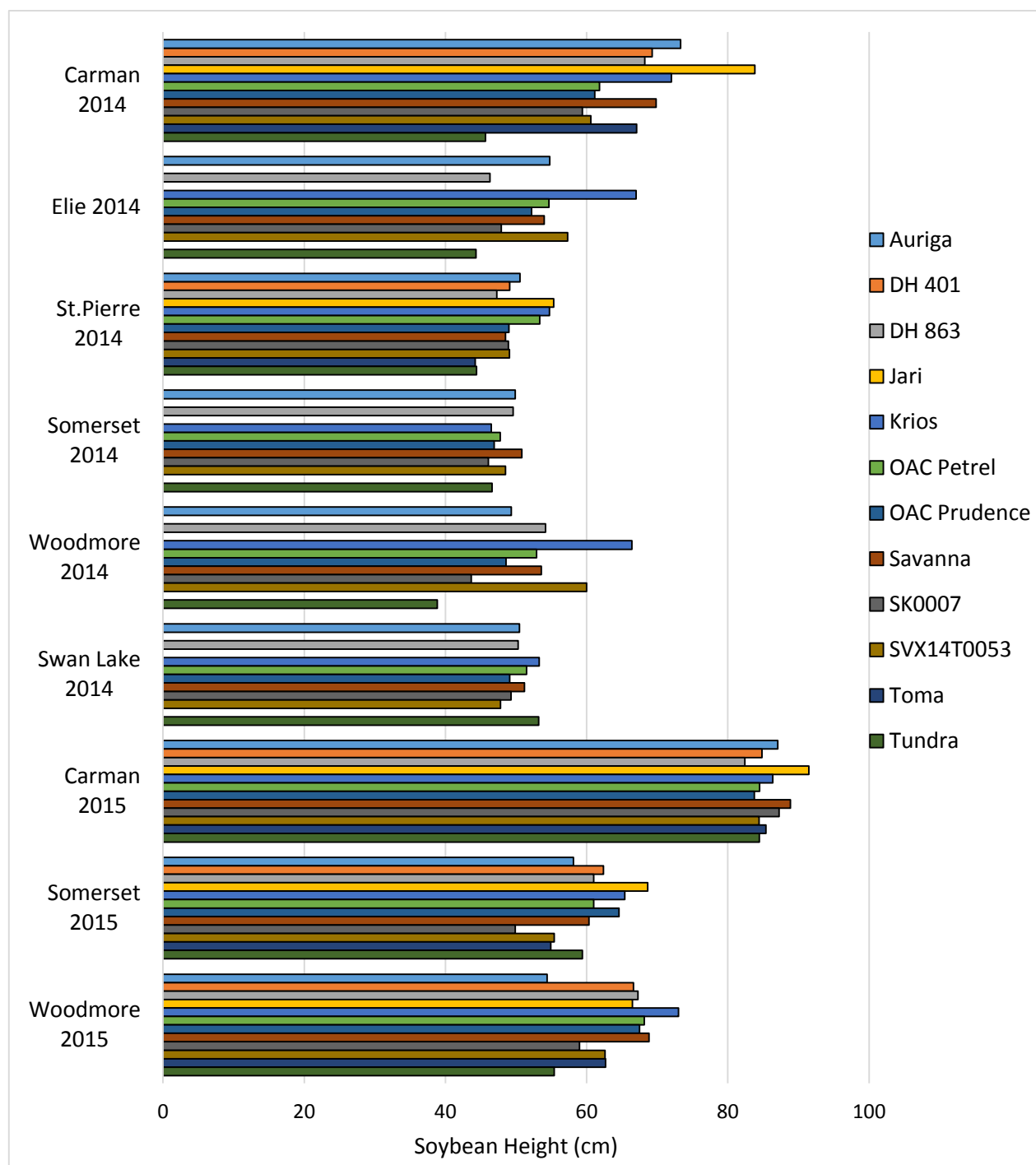
Soybean height measurements taken at maturity were significantly different between sites and cultivars (Table 6). Carman 2015 had the tallest average soybean height at 86 cm, and Somerset had the lowest average soybean height at 48 cm.

Averaged across all sites, cultivar heights ranged from 53 to 79 cm. The cultivar 'Jari' was the tallest cultivar, and Tundra was the shortest. A site-cultivar interaction was also observed, suggesting that the cultivars' heights were different relative to one another given different environmental conditions (Figure 7; see appendices Table 16). For example, 'Jari' was the tallest cultivar at the majority of sites where it was grown, however, it was not the tallest in Woodmore 2015. 'OAC Prudence' was often the tallest cultivar where 'Jari' was not sown; however, it was not the tallest in sites such as St. Pierre 2014, Somerset 2014, and Somerset 2015.

It is interesting that the height earlier in the season did not necessarily follow the same pattern later in the season. For example, 'SK0007' was the tallest cultivar early in the season; however, later in the season it was no longer among the tallest cultivars (Table 6). This suggests differences in vegetative growth between cultivars of differing maturities over the entire season. This concept is not well understood; continued research examining the development and growth patterns of choice cultivars with varying maturities would be useful for weed competitiveness at different points in the season.

Cultivar height is a widely accepted characteristic associated with weed competitiveness and optimal performance in organic systems for many crops (Jannink et al., 2000; Mason and

Spaner, 2006; Lammerts van Bueren et al., 2012). For soybean, early season height may be more important than height at maturity due to the higher influence from weed presence has on final soybean yield during the first 5 weeks after emergence (van Acker et al., 1993a). In many other soybean studies, juvenile height was often connected with increased weed suppressive ability or weed tolerance (Pester et al., 1999; Jannink et al., 2000; Place et al., 2011a). However, other soybean studies have reported no connection between any specific cultivar characteristic and competitive ability (Bussan et al., 1997).



**Figure 7.** Plant height at maturity for twelve soybean cultivars in 9 site-years.

#### 4.9. Pod Height

Soybean pod height is not directly associated with final yield performance and weed competitiveness. However, the height of the lowest pod is an important consideration for mechanical harvest efficiency. If pods are too low on the stalk, and too close to the soil, many combine harvesters are unable to capture the lowest pods with the cutterbar. In Kentucky, researchers have reported 0.4, 2 and 6.6% yield loss for cutterbar heights of 5, 10, and 15 cm, respectively (Grabau and Pfeiffer, 1990). Additionally, if farmers attempt to capture the lowest pod, stones and soil can be picked up, causing seed staining that reduces marketability and increasing potential combine damage. Many agronomic practices have been attempted to increase pod height from the soil through increasing plant population, different mulching techniques, and 'rolling' whereby a large barrel is 'rolled' during pre-plant or over juvenile soybeans to push stones into the soil and increase the space between the soil and the lowest pod (Martin and Wilcox, 1973; Cober et al., 2000; Iowa State University, 2011). Increased pod height is especially important in organic production systems, as soil is often intentionally thrown into the soybean row to cover weeds, making rolling obsolete and decreasing soil-pod distance.

Significant differences in average pod height were detected for all sites and cultivars; in addition, pod height was also influenced by a site-cultivar interaction (Table 6; Figure 8; see appendices Table 17). Height to lowest pod ranged from 12.1 – 18.2 cm, with Swan Lake 2014 having the highest pod heights, approximately 4 cm greater than at other sites. This observation was attributed to soybean and volunteer buckwheat simultaneously competing for

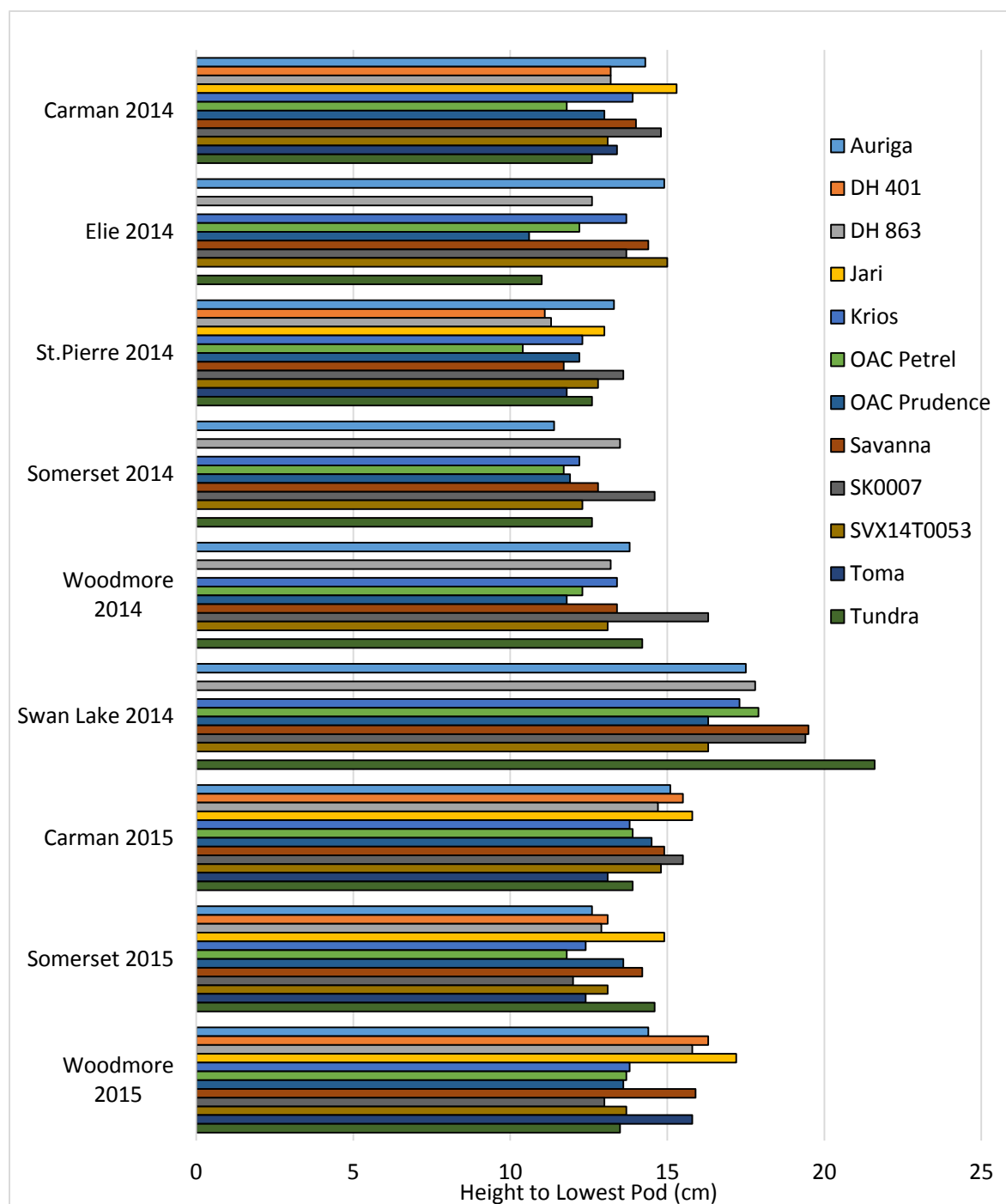
light resources resulting in soybean etiolation. Edwards and Purcell (2005) observed the general pattern that height to the lowest pod increased as soybean plant population increased. The same principle may apply here. The lowest height to the first pod was observed at St. Pierre 2014. St. Pierre 2014 had the least competition from weeds (Table 6).

A site-cultivar interaction was apparent for average pod height, cultivar pod heights ranged from 12.9-15.6 cm, respectively (Table 6). The cultivar with tallest pod height was 'Jari', which had the tallest pod height at all sites it was sown, with the exception of St. Pierre 2014, where 'SK0007' had the greatest pod height. However even at St. Pierre, 'Jari' was among the tallest. Past research has detected cultivar differences in soybean's etiolation ability (Konieczny and Shimamoto, 1990), and genetic differences in pod height (Beaver and Johnson, 1981). This may apply to the present study. For example, under low weed competition where etiolation may not have occurred, 'SK0007' had taller pod height than 'Jari' (Figure 8), whereas under weedy conditions (Swan Lake 2014), 'Jari' appeared to have better etiolation response.

Height to lowest pod is widely accepted as a heritable trait. Additionally, soybeans that are determinant (ie. cultivars tested in this study) tend to have higher pod heights when compared to indeterminant cultivars (Martin and Wilcox, 1973; Beaver and Johnson, 1981; Cober et al., 2000). However, the cultivars' pod height varied when grown under different conditions. For example, 'Tundra's' height to lowest pod was in the mid-range when compared to other cultivars but this was not consistent among sites (Table 6). At Swan Lake 2014, 'Tundra' achieved the highest height to lowest pod among all the cultivars which may have been attributable to the superior ability to extend stalk growth in the presence of intense resource competition, however, pod height cultivar effects were not significant at this site. Several

studies have suggested that soybeans can express phenotypic changes in response to light competition (Stoller and Woolley 1985; Jannink et al., 2000; Green-Tracewicz et al., 2012; Trezzi et al., 2013). Green-Tracewicz et al. (2012) observed a 25% height increase in the weedy treatment over the weed-free treatment as early as the first trifoliate (V1 stage). Trezzi et al. (2013) observed that cultivars responded differently to horseweed interference. Only one cultivar tested was taller when under horseweed competition when compared to without competition (Trezzi et al., 2013). Researchers in Hokkaido, Japan found that pod height tended to increase when weeds were allowed to grow along with soybeans for a longer duration in the season (Konieczny and Shimamoto, 1990). In the present study, overall cultivar pod height seemed to increase as weed pressure increased at certain sites.

Early season height measurements were taken later in the season than other sites at Swan Lake 2014. Therefore, Swan Lake 2014 was not included in the combined analysis. Soybean height measurements taken at the V4 stage at Swan Lake 2014 were different in height early and later in the season (Table 7). 'Tundra' and 'SK0007' were similarly among the tallest earlier in the season, increased pod height indicates etiolation earlier in the season setting the lowest pod height higher on the stem. Additionally, 'Tundra' was the tallest cultivar at the end of the season at Swan Lake 2014, the opposite result from all other sites in this experiment. A greater ability for 'Tundra' to elongate its stem under heavy weed pressure than other cultivars may explain this. Future research to better understand the roll of weeds on cultivar pod height are needed. One experimental approach could be to subject 'SK0007' and 'Tundra' to controlled light restriction to examine genotypic differences in stem elongation at early growth.



**Figure 8.** Height to lowest pod of 12 soybean cultivars in nine site-years.

**Table 7.** Plant height of soybean cultivars at V4 and maturity development stages, pod height at maturity at Swan Lake 2014.

<b>Cultivar</b>	<b>Height at V4*</b>	<b>Height at Maturity*</b>	<b>Pod Height</b>
	cm	cm	cm
<b>Auriga</b>	34bc	50	17
<b>DH 863</b>	34bc	50	18
<b>Krios</b>	34bc	53	17
<b>OAC Petrel</b>	33c	52	18
<b>OAC Prudence</b>	32c	49	16
<b>Savanna</b>	35abc	51	19
<b>SK0007</b>	38ab	49	19
<b>SVX14T0053</b>	31c	48	16
<b>Tundra</b>	39a	53	22
<b><i>P&gt;F</i></b>	<b>0.0171</b>	0.3127	0.0649

\* Height within column followed by the same letter are not significantly different at  $P < 0.05$  level.

#### 4.10. Yield Performance

Soybean grain yield was significantly affected by site, cultivar, and a site-cultivar interaction (Table 6; see appendices Table 18 and Figure 15). Swan Lake 2014 was the lowest yielding site with an average grain yield of 369 kg ha<sup>-1</sup>. Intense volunteer buckwheat pressure and wet conditions that delayed inter-row cultivation appear responsible for low yields at this site. Carman 2015 had the highest average grain yields at 2 681 kg ha<sup>-1</sup>. Carman 2015 resulted in the highest yield across all other sites for a combination of reasons. While soybeans tend to thrive on clay loam soils (Rao and Reddy, 2010), soybean can also perform very well on sandy loam soils given adequate moisture throughout the season. The environmental conditions in Carman 2015 were very favourable for soybean growth (Figure 4). Seasonal precipitation was adequate and well distributed throughout the season, especially in at the end of July and



beginning of August, when soybeans require adequate soil moisture for seed-filling functions (Egli, 2010). Optimal day and night temperatures vary widely for soybean; however, it is commonly agreed that optimal daily temperatures range above 20°C and below 30°C, and optimal night time temperatures should stay above 10°C (Dornbos and Mullen, 1991; Puteh et al., 2013). During the vegetative and reproductive stages in the season, Carman 2015 did not often fall below 20°C, or below 10°C during the night (Figure 4). An additional factor may be that residual soil nitrogen content was lower at Carman 2015 than other sites (Table 2); lower soil residual N has been connected with higher soybean yield and less weed competition (Staniforth, 1962). Finally, favourable conditions at Carman 2015 allowed for timely weed control practices that gave soybeans a competitive advantage over neighbouring weeds.

Lower yields at other sites can be attributed to a combination of different environmental stresses across sites. For example, a killing frost on September 12, 2014 in Somerset 2014 arrested soybean development for the majority of cultivars. Additionally, harvest was made difficult because seeds were unable to be threshed easily. Soybeans are usually 'safe' from being damaged due to frost if the plant has reached the 'R7' stage (when 50% of the leaves on the plant are yellow). If not, depending on the current development stage, soybeans can suffer up to approximately 80% yield reduction due to frost damage (Saliba et al., 1982). Somerset 2015 also suffered lower yields due to intense wild mustard and wild oat pressure.

A site-cultivar interaction was detected among the test sites and cultivars. Partitioning the sum of squares gives the opportunity to assess how much variation is associated with cultivars (genotypes), sites (environment), and the interaction between sites and cultivars

(Brandle and McVetty, 1981). Partitioning the total sum of squares (TSS) for seed yield in the present study indicated that most TSS were explained by the site effect (72.4% of TSS), while the site-cultivar interaction accounted for 8.1%, and the cultivar effect accounted for only 1.02% (Table 8). These observations reflect a much wider range of site main effects than cultivar main effects. Similar results have been observed in the past, where environment effects contributed the largest portion of total variation (Letta 2007, Das et al., 2010; Ayalneh et al., 2013). Complex external factors (abiotic and biotic) were likely due to the magnitude environment contributed to total variation.

Given that the site-cultivar interaction was very low compared to environment variation the decision was made to group ‘high’ yielding sites (sites that yielded 1900 kg ha<sup>-1</sup> and above; Carman 2014, Carman 2015, Elie 2014, and St. Pierre 2014) and ‘low’ yielding sites (sites that yielded lower than 1900 kg ha<sup>-1</sup>; Woodmore 2014, Somerset 2014, Swan Lake 2014, Woodmore 2015, and Somerset 2015) for separate analysis (van Deynze et al., 1992). It is difficult to assess the genetic potential of a particular cultivar when the relative ranking changes in different environments (Ayalneh et al., 2013).

**Table 8.** Analysis of variance for grain yield of 12 soybean cultivars grown in 9 sites in southern Manitoba

Source	<i>df</i>	Sum of Squares	Mean squares	Portion of total sum of squares (%)
Cultivar	11	4 905 811	445 983	1.0
Site	8	160 219 373	20 017 422	72.4
Site-Cultivar	76	17 877 566	235 231	8.1
Rep	3	45 286	150 795	
Residual	273	38 222 283	140 008	
Total		221 270 319		

#### 4.10.1. Low-Yielding Sites

No site-cultivar interaction was observed among the low-yielding sites (Table 9). One explanation could be that other factors such as weed pressure may have been limiting yield. However, site and cultivar effects were significant. 'Savanna' had the highest yield across all low-yielding sites with an average yield of 1231 kg ha<sup>-1</sup>. The cultivar with the lowest yields was 'OAC Prudence' with an average yield of 956 kg ha<sup>-1</sup>. Between the highest and lowest yields, there were no significant differences in yields between mid-range performing cultivars.

Cober and Morrison (2011) evaluated 20 old and new short season soybean cultivars released from 1934 to 2007 under weedy and weed-free conditions. Under weed-free conditions, the average rate of genetic improvement was 13.9 kg ha<sup>-1</sup> yr<sup>-1</sup>. However, under weedy conditions, genetic improvement averaged approximately 1.2 kg ha<sup>-1</sup> yr<sup>-1</sup>, and lower yield compared to weed-free conditions (Cober and Morrison, 2011). The Cober and Morrison (2011) paper may provide an explanation as to why there was no site-cultivar interaction. That is, under weed competition, cultivars were unable to function consistently at their highest genotypic potential.

Currently, research analyzing the genetic potential of cultivars in response to the environmental challenges is scarce. Frederick et al. (1991) compared genetic potential of old and new cultivars under water stress, and found no significant differences in yield between the cultivars, however, other studies consistently show newer cultivars outperforming older ones (Voldeng et al., 1997; Kumudini et al., 2001; De Bruin and Pederson, 2009). When cultivars are under high stress from weed pressure and/or moisture, the genetic potential is masked.

**Table 9.** Combined analysis of final grain yield of the lowest-yielding sites on organic farms in southern Manitoba.

Sites	Grain Yield	
	kg ha <sup>-1</sup>	
Woodmore 2014	1637	a*
Somerset 2014	907	c
Swan Lake 2014	369	d
Woodmore 2015	1537	a
Somerset 2015	1479	b
Cultivars		
Auriga	1016	de
DH 401	1141	ab
DH 863	1141	cd
Jari	1365	a
Krios	1025	de
OAC Petrel	1113	cde
OAC Prudence	956	e
Savanna	1231	bc
SK0007	1110	cde
SVX14T0053	1174	bcd
Toma	1471	a
Tundra	1053	de
Source of Variation		
Site	0.0005	
Cultivar	<.0001	
Site-Cultivar	0.1462	
*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance		

#### 4.10.2. High-Yielding Sites

Site and cultivar effects were significant when comparing the four highest yielding sites; Carman 2014, St. Pierre 2014, Elie 2014, and Carman 2015 (Table 10; Figure 9). Among cultivars, the highest yielding was 'Savanna' with 2425 kg ha<sup>-1</sup> and 'SK0007' yielded the lowest with 1914 kg ha<sup>-1</sup>. Additionally, the site-cultivar interaction was significant. While 'Savanna' had the highest yield overall, it was not the highest yielding cultivar at three of the four sites considered. Additionally, 'Auriga' was the highest yielding cultivar at St. Pierre 2014, and one of the top performers at Carman 2014, but amongst the lowest yielding cultivars at Carman 2015. No consistent patterns are apparent, as cultivars at one site outperformed other cultivars, yet did not yield as high at others.

It is important to note that while the sites mentioned were the 'high-yielding' sites in this experiment, the conditions were still under organic production, and the cultivars were subjected to environmental stresses unlike the environment they were selected under. Some researchers argue for cultivar testing and breeding program under the same environmental conditions as organic farmers (Murphy et al., 2005; Kandel et al., 2008; Lammerts van Bueren and Myers, 2012). However, Cober and Morrison (2015) argue that cultivars grown under conventional, high-yield environments express the maximum genetic potential compared low-yielding environments, making selection more accurate and useful. Differences in site-cultivar interaction observed in the present study comparing 'low-' and 'high-yielding' environments may be due to the minimal genetic expression of cultivars tested on organic farms. It is unclear what this means for organic breeding programs, continued research examining the

performance of organically-bred versus conventional-bred soybean cultivars under organic conditions would be valuable.

**Table 10.** Combined analysis of final grain yield of the highest-yielding sites on organic farms in southern Manitoba.

<b>Sites</b>		<b>Grain Yield</b>	
		kg ha <sup>-1</sup>	
<b>Carman 2014</b>	2104	b*	
<b>Elie 2014</b>	2212	b	
<b>St. Pierre 2014</b>	1944	c	
<b>Carman 2015</b>	2681	a	

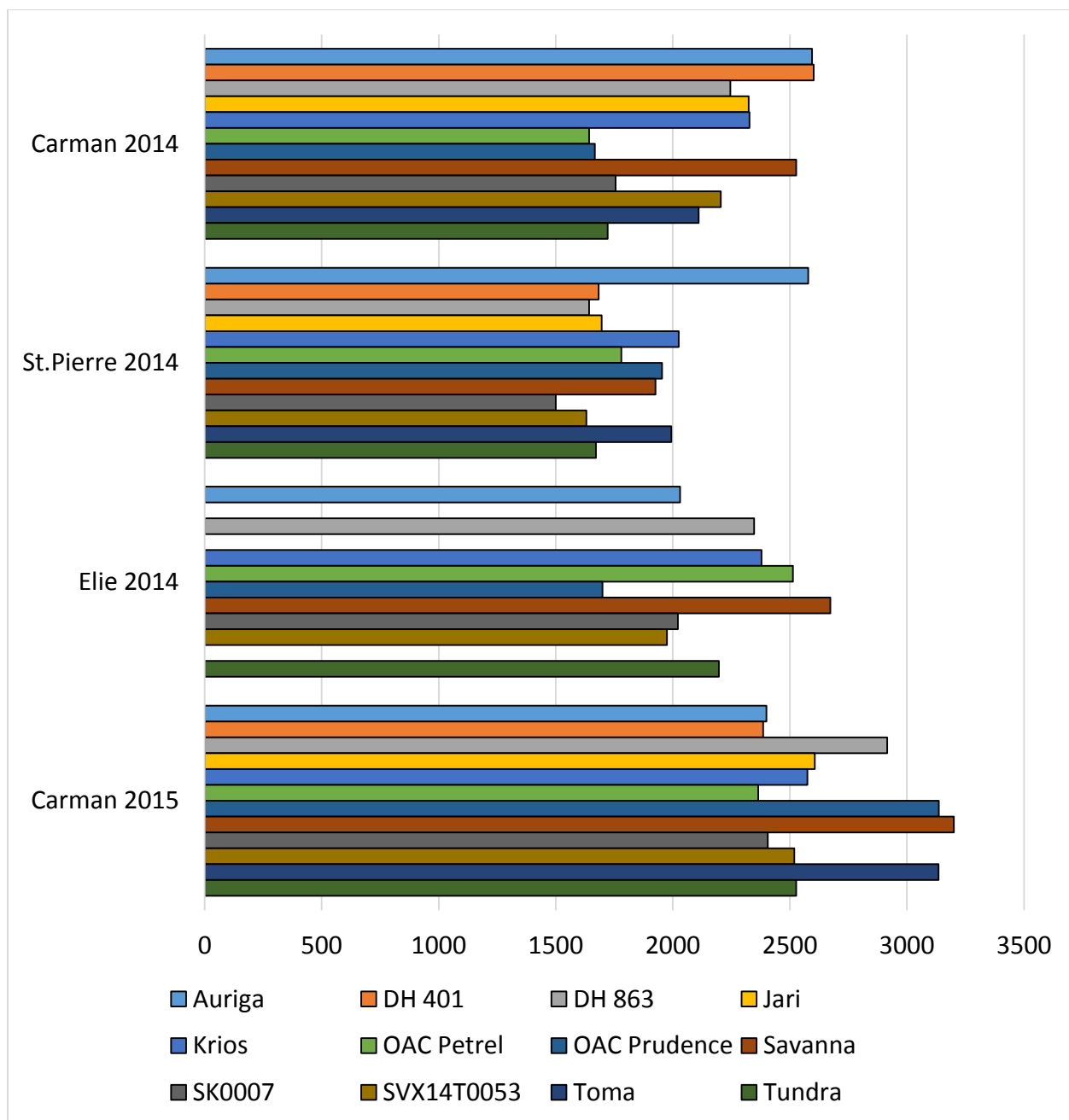
  

<b>Cultivars</b>		
<b>Auriga</b>	2426	ab
<b>DH 401</b>	2223	bcd
<b>DH 863</b>	2284	abcd
<b>Jari</b>	2209	bcd
<b>Krios</b>	2322	abc
<b>OAC Petrel</b>	2013	cd
<b>OAC Prudence</b>	2054	cd
<b>Savanna</b>	2575	a
<b>SK0007</b>	1913	d
<b>SVX14T0053</b>	2089	bcd
<b>Toma</b>	2413	abc
<b>Tundra</b>	2018	cd

<b>Source of Variation</b>	
<b>Site</b>	<b>0.0020</b>
<b>Cultivar</b>	<b>&lt;.0001</b>
<b>Site-Cultivar</b>	<b>0.0130</b>

\*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance



**Figure 9.** Grain yield of 12 soybean cultivars at four sites with the highest yields out of nine site-years.

#### 4.11. Yield Loss due to Weeds

Yield loss due to weed competition is commonly used to evaluate the critical weed control period and crop competitiveness for crops like soybean (van Acker et al., 1993a; Cowan et al., 1998; Vollman et al., 2010; Green-Tracewicz et al., 2012; Trezzi et al., 2013). Yield loss due to weed competition represents final grain yield that was grown with weed competition as a per cent of final grain yield grown under a weed-free environment. Yield loss due to weeds was calculated for Carman 2015, Woodmore 2015, and Somerset 2015 only.

When cultivar yield losses were averaged across sites, there was no main cultivar effect. This indicates that each cultivar's yield loss due to weeds was not significantly different from one another. The site effect was significant; however, Somerset 2015 had the highest yield loss due to weeds at 44.3%, whereas Carman 2015 and Woodmore 2015 did not differ significantly from each other at 20.3% and 28.4%, respectively (Table 6). It was not surprising that Somerset 2015 had the highest yield loss due to weeds as Somerset 2015 had the highest weed biomass ( $2\,553\text{ kg ha}^{-1}$ ) at the R5 development stage. The principle weed species present at Somerset 2015 were wild oats and wild mustard. It is possible that the environmental conditions favoured the weed species present enough that the soybeans could not compete well early in the season to overtake the weeds as it was discussed by Vollman et al. (2010). Cober and Morrison (2015) also identified weed competition as contributing to sub-optimal growing conditions that disable soybeans from expressing their genetic characteristics (Cober and Morrison, 2015).

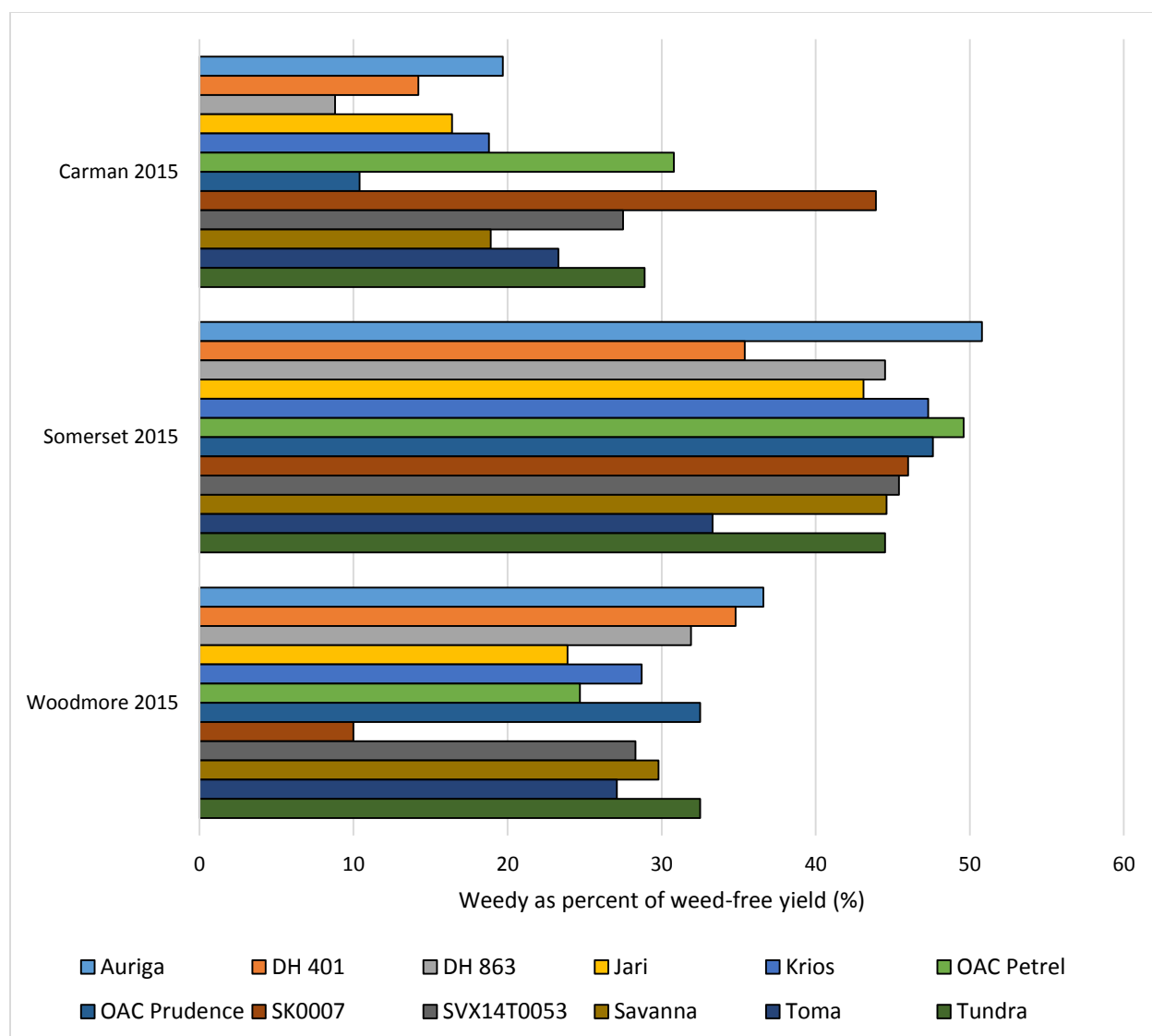
The significant site-cultivar interaction for yield loss due to weeds (Table 6; Figure 10; see appendices Table 19) was attributed to one cultivar ('SK0007') losing the least amount of



yield due to weeds at Woodmore 2015, while experiencing the highest yield reduction due to weeds at Carman 2015. Woodmore 2015 received almost double precipitation amount as compared to Carman 2015 (Table 5) and had less drainage potential (Table 1), suggesting that 'SK0007' may be more tolerant to wet conditions as compared to other cultivars.

No differences in yield loss among cultivar effects were observed when evaluating Somerset 2015 and Carman 2015 individually, however, cultivar effects were observed at Woodmore 2015 ( $P > 0.0378$ ). 'SK0007' was the only cultivar significantly different from all other cultivars. Average yield loss among cultivars and all sites observed ranged between 27.4 and 36.9% with an average of approximately 31.5%.

Yield loss due to weeds observed here was similar to other studies. Cowan et al. (1998) observed between 32 to 99% yield loss due to heavy pigweed competition, and Dielman et al. (1995) found that pigweed density of two plants  $m^{-2}$  emerging at the same time caused 12.3% soybean yield loss. Similarly, researchers in Brazil witnessed between 14 to 20% yield loss due to competition with horseweed (Trezzi et al., 2013), and when van Acker et al. (1993b) allowed weeds to compete with soybean until maturity, this resulted in 53 to 64% yield losses, as compared to weed-free soybeans. Comparative studies examining yield loss due to varying weed species would be valuable for organic farmers choosing where to grow soybeans on their farm.



**Figure 10.** Weedy as percent of weed-free yield of 12 soybean cultivars from three site-years.

#### 4.12. Seed Mass

Large seed mass in soybean has been associated with large embryos, large cotyledon leaf area, taller seedlings, and rapid emergence (Burris et al., 1973; Place et al., 2011b; Fatichin and Arima, 2013). Early seedling vigour is an important aspect of a cultivar's ability to tolerate

or suppress weeds (Jannink et al., 2000). Farmers interested in saving their own seed need cultivars with the ability to produce seeds with high mass under weed competition.

There was a significant difference in seed mass among all sites and cultivars (Table 6; Figure 11; see appendices Table 20). A significant interaction between cultivar seed mass and sites were also observed, indicating that the effect on cultivar seed masses varied with the site's characteristics. Soybeans grown at St. Pierre 2014 had the highest seed mass with an average of 19.4 g 100-seeds<sup>-1</sup>. Soybeans grown at Somerset 2015 had the lowest seed mass with an average seed mass of 13.5 g 100-seeds<sup>-1</sup>. Lastly, soybeans grown at Carman 2014 and 2015 also had some of the highest seed masses with 17.7 and 17.2 g 100-seeds<sup>-1</sup>, respectively.

Unfavourable environmental conditions have been shown to result in smaller seed size due to shortened seed-fill period and early maturity (Ashley and Ethridge, 1978; Frederick et al., 1991). The severity and duration of moisture stress varies the level of damage to final yield and seed size, as Brevedan and Egli (2003) showed that continued water stress early in the season and into seed-fill stage resulted in approximately 25-33% smaller seeds. The present study's data is not in agreement with past reports, as St. Pierre 2014 received no precipitation between July 27 2014 and August 15 2014, a critical time in the season for seed-fill, while Somerset 2015, while under heavy weed pressure, received adequate moisture (Figures 2 and 3).

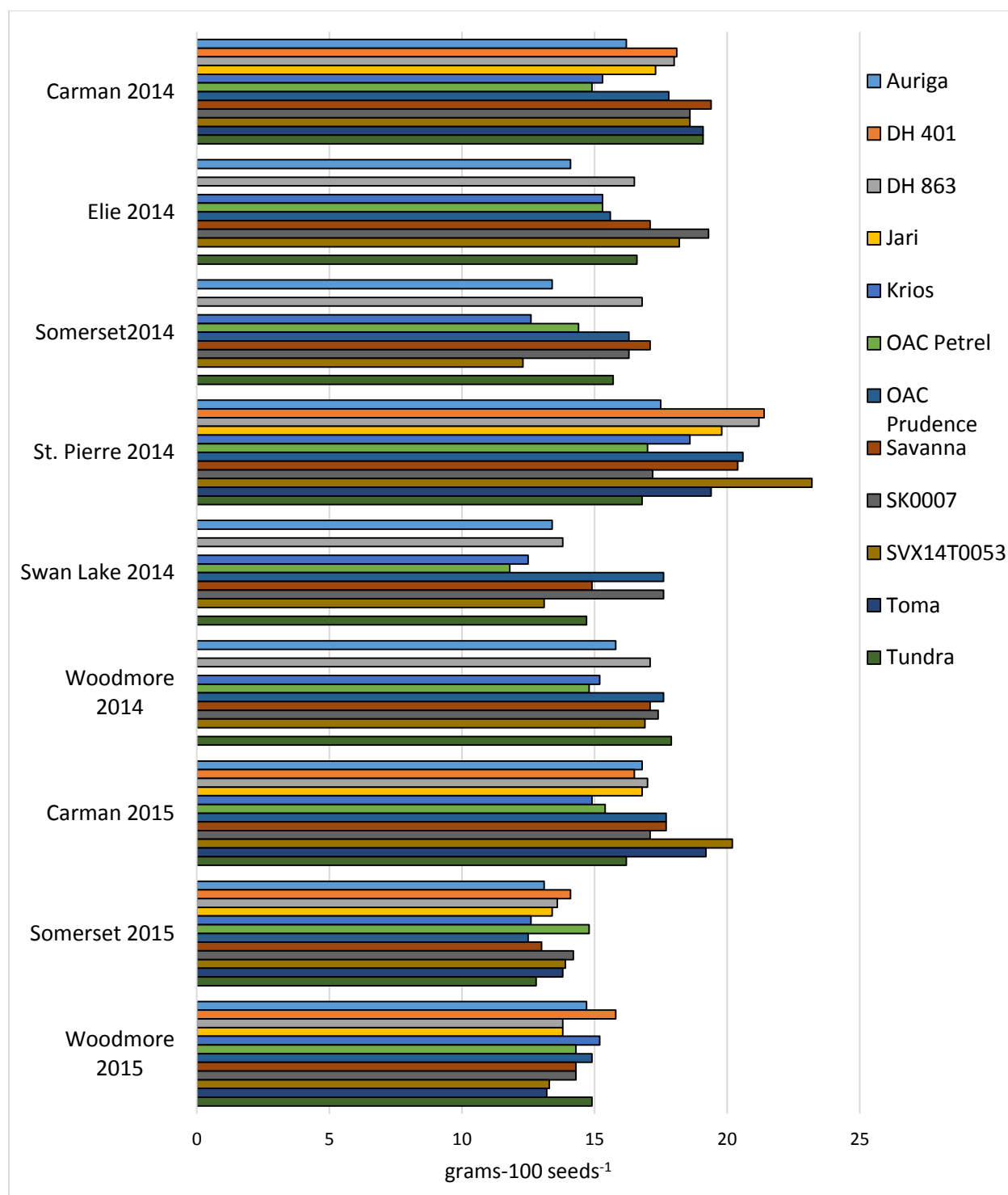
Severe weed competition may have resulted in lower moisture available to the soybean to achieve optimum soybean seed size in sites such as Somerset 2015, but this is still unclear. The influence of weed community and seed mass is still not well known, or bears little influence (Gibson et al., 2008; Vollman et al., 2010). Cober and Morrison (2011) found that weed

interference with soybeans results in inconsistent seed sizes across a range of old and new short-season soybean cultivars. More research examining the relationship between seed size and weed community would be valuable to the organic community as many farmers save their own seed.

Cultivar effects were identified, and ranged from 14.7 to 16.8 g 100-seeds<sup>-1</sup> with 'SK0007' being the largest, and 'Krios' with the smallest seed mass. 'DH 401', 'DH 863', 'OAC Prudence', 'Savanna', 'Toma', and 'Tundra' were also among the highest average seed mass, and not significantly different from 'SK0007'.

The 100-seed weight across cultivars was similar to or greater than values reported by other researchers, Gibson et al. (2008) measured 100-seed weight from natural weed infested soybean experimental units, which averaged approximately 12.8 g 100-seeds<sup>-1</sup>. Vollman et al. (2010) observed average 100-seed weights ranged from 15.6 and 17.1 g 100-seeds<sup>-1</sup>, and found no significant differences between weed infested seed mass and weed-free seed mass.

The interaction between sites and cultivars indicate that cultivars responded differently to the different sites in terms of acquiring seed mass throughout the season; however, no specific pattern was observed. It is important to note that while large seed mass is an important consideration for organic production systems, if farmers are interested in saving their own seed, the ability for the cultivar to amass large seed size while under environment stresses (such as weed competition and moisture stress) is as critical as understanding the benefits of large seed size.



**Figure 11.** Seed mass values of 12 soybean cultivars from 9 site-years

#### 4.13. Harvest Index

Harvest index (HI) is often used as an indicator of the efficiency of partitioning vegetative mass into reproductive sinks for final yield (Donald, 1968). HI is a very popular measure to examine the relative efficiency of source and sink partitioning; however, this is made difficult for soybeans due to the abscission of leaves and petioles during seed fill (Egli, 2010). To accurately measure 'actual' HI, 'biological yield' was sampled at the R5 stage and compared to the final seed yield, adjusted to a common moisture concentration (Schapaugh and Wilcox, 1980). Buzzell and Buttery (1977) put forth the practice of using the mature plant, seed and pod weight as the total vegetative mass, rather than biological vegetative mass, known as 'apparent' harvest index. However, this measurement may favour earlier maturing soybeans as vegetative growth stops earlier in the season and yield may not change (Egli, 2010). Schapaugh and Wilcox (1980) confirmed that using mature plant weight is an acceptable way to compare the relative performance of soybean with varying maturities over biological yield; however, apparent harvest index on average, increased harvest indices over 'actual' harvest index by 23 to 39%. Due to two distinct methods of measuring the efficiency index, seed yield and biological yield was referred to as harvest index, and seed yield and mature plant weight was referred to as apparent harvest index (Schapaugh and Wilcox, 1980). In this experiment, harvest index was measured comparing the seed yield to biological yield, and therefore, will be referred to as harvest index.

Among sites, harvest index ranged from 0.42 to 0.55 (Table 6). There were significant differences among sites, with Somerset 2015 having the highest HI and Carman 2015 with the

lowest HI. High HI suggests an increase in the ability for the soybean plant to transfer more carbon stored in the vegetative state (source) into seeds (sink) (Hay, 1995). Efficient partitioning is an important contributor to final soybean yield (Koester et al., 2014). Soybeans in Somerset 2015 seem to be much more efficient than other sites at partitioning vegetative and reproductive growth stages, especially higher than Carman 2015. The HI reported in this experiment is similar to apparent harvest index but on average higher than other reported harvest indices in literature.

On average, HI in soybean ranges between 0.35 and 0.60 (Egli, 2010). Similar values are reported for apparent HI. Cregan and Yaklich (1986) found that amongst a range of cultivar release dates and maturities, HI ranged from 0.49 and 0.58, and found that HI was highly variable across genotypes.

Koester et al. (2014) reported that historical gains in conversion efficiency have been connected to increased biomass production; however, in the present study, higher efficiency was associated with Somerset 2015 which had the lowest soybean biomass accumulation (Table 6). Additionally, the effect of weed interference on HI in soybeans is not well understood, and possibly may have little to no effect on partition efficiency. There was a significant negative correlation between HI and per cent yield loss due to weeds ( $corr(X,Y) = -.28013, P > 0.0016$ ), meaning that as per cent yield loss decreases, HI also decreases. This is not in agreement with Konieczny and Shimamoto (1990) who found that there was no pattern associated with HI and the duration of weed interference. The contradictory results stress the need for further research observing the effect of weed interference loss in partitioning efficiency.

There were no significant differences in HI between cultivars, which ranged from .46 to .56. No significant correlation was observed between HI and cultivar crop heat units ( $corr(X,Y) = 0.06067, P > 0.5015$ ). Johnson and Major (1979) measured the harvest indices of soybean cultivars varying in maturity at different planting dates. Harvest indices ranged from 0.29 to 0.41.

Interestingly, a negative significant relationship between HI and yield was observed ( $corr(X,Y) = -.28998, P > 0.0010$ ). Past reports have stated that the relative soybean maturity length may have an effect on HI, as HI tends to be inversely related to increased yield and maturity group (Buzzell and Buttery 1977; Schapaugh and Wilcox, 1980). How HI is impacted by organic conditions under which soybeans are grown is relatively unknown. It may be helpful to a conduct study focussing on differences in partitioning efficiency of cultivars under organic conditions.

#### **4.14. Stability Analysis of Cultivars under Organic Production**

Yield stability is often an important consideration in plant breeding programs; however, cultivars that are bred under conventional production may exhibit adaption to a narrow range of environmental conditions, since weed presence and soil nutritional deficiencies can more easily be corrected (Vollman and Menken, 2012). The present experiment provided the opportunity to consider cultivar stability analysis. This is because the observed yield genotype x environment interaction (Table 6) indicates that the cultivars responded differently to the range of environmental conditions experienced during this research.



Relative stability among cultivars was calculated using the Finlay-Wilkinson (1963) method. The  $b_i$  values were calculated by plotting cultivar mean yield at each site by the site mean yield (Figure 12). The slope of each regression line for separate cultivar was calculate to find  $b_i$ . The  $b_i$  value represents how sensitive a cultivar is to environmental change. Cultivars with higher  $b_i$  values ( $>1.0$ ) indicate higher sensitivity to environmental changes and better performance in optimal environments, but worse than average performance in poor environments. Cultivars with  $b_i$  values below 1.0 are thought to have low sensitivity to diverse environments, better performance in worse environments but poor performance in favourable environments. Cultivars with  $b_i$  close to 1.0 are said to perform similar to average compared to all other cultivars across all environments. Deviations from the regression  $S^2_d$  represents how far each cultivar data point deviates from the regression line. Cultivars with low  $S^2_d$  indicates data points closely follow the regression lines, indicating predictable, consistent performance. Desirable cultivars possess a  $b_i$  close to 1.0 and a low  $S^2_d$  value.

Analysis of variance between cultivars, sites, and cultivar regression lines were also calculated (Table 11). Cultivar regression lines were significantly different from each other, suggesting that cultivars' yield performance differed from one another.

Calculated environmental regression coefficients ( $b_i$ ) ranged from 0.788 ('SK0007') to 1.212 ('Savanna') (Table 12; Figure 13). Therefore, grain yield for 'SK0007' changed the least across the nine site-years, and 'Savanna' grain yield was the most varied across multiple site-years.

‘Savanna’, ‘Toma’, and ‘DH 863’ had the highest  $b_i$  values, 1.212, 1.129, and 1.135, respectively. This indicates that these cultivars were sensitive to environmental change and may not have been the top performers in unfavourable environments. For example, in environments with heavy weed pressure such as Somerset 2015 (Table 6), ‘Savanna’ and ‘Toma’ were not among the top yield performers, however, they responded very well to high-yield environments like Carman 2015 where the two cultivars accumulated the highest biomass and yielded the highest (Table 6). However,  $S^2_d$  values (‘Savanna’  $S^2_d = 0.098$ , ‘Toma’  $S^2_d = .161$ ) indicate that ‘Savanna’s’ yield performance was more consistent than ‘Toma’s’.

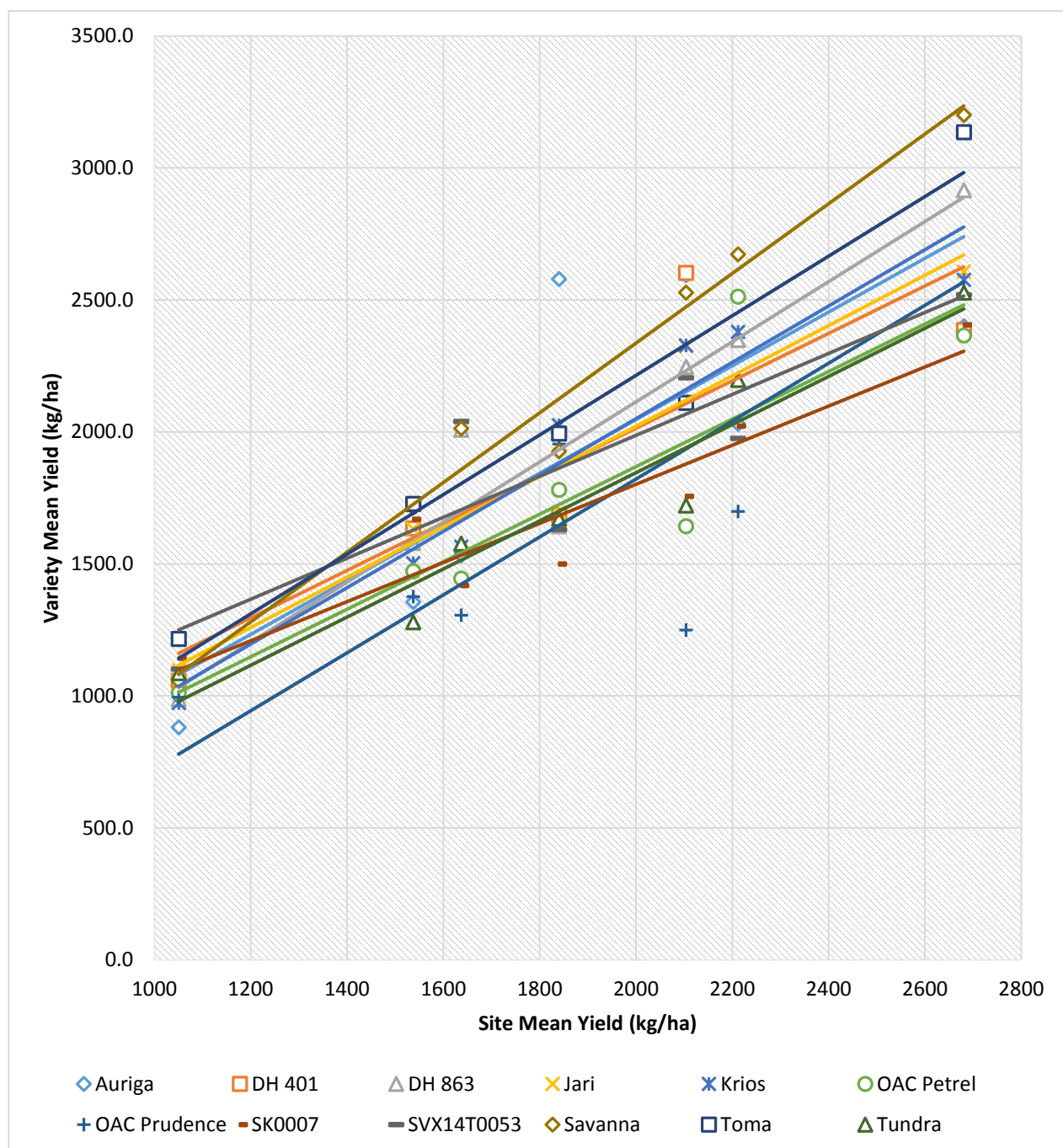
The cultivars with the lowest  $b_i$  values were ‘Tundra’, ‘SK0007’, and ‘OAC Petrel’ ( $b_i = 0.884, .788, .792$ , respectively). The low  $b_i$  values mean that the cultivars were less sensitive to change across the range of conditions encountered in the present study. The implication is that these cultivars were more stable and that they may perform better than other cultivars in unfavourable environments. However, ‘Tundra’, ‘SK0007’, and ‘OAC Petrel’ did not yield as much as other cultivars under favourable conditions. ‘Savanna’, ‘Toma’, and ‘DH 863’ responded positively to more favourable environments, but ‘Tundra’, ‘SK0007’, and ‘OAC Petrel’ did not.

The  $b_i$  values observed in the present study are consistent with other analyses. Dashiell et al. (1994) compared 18 soybean lines in five locations in Nigeria and found that  $b_i$  values ranged from 0.67 to 1.34. Similarly,  $b_i$  values ranged from .80 to 1.17 when five field bean cultivars at 36 environments were evaluated in Ontario (Park, 1987).

Visual assessment of the dynamic concept of stability was conducted by examining the relationship between cultivar means and regression coefficients (Figure 13). Results of the

present study identified no cultivars in the bottom right quadrant, meaning that there are no cultivars that exhibited high yield stability and high yield simultaneously. However, 'Krios', 'Auriga', 'SVX14T0053', 'Jari', and 'DH 401' yielded near or above the cultivar average, had a regression coefficient of near 1.0, and did not deviate from the regression line very much. This is important to note because these cultivars showed relatively high yield potential under organic conditions and are simultaneously neither sensitive nor insensitive to environmental changes.

Dynamic stability assessment shows that under a variety of environments, cultivars respond different from each other. The present research illustrated that high yields are attainable organic production (Figure 12). Additionally, while 'Savanna' and 'Toma' were the most sensitive to environmental changes, when grown in heavy weed presence, they did not yield so low as to be significantly different from the highest yielding cultivars. Breeders may be in a better position to choose a high yielding, high  $b_i$  value cultivars such as 'Savanna' or 'Toma', rather than the lower yielding cultivars, 'Tundra', 'SK0007', or 'OAC Petrel' to place themselves in the best position for satisfactory production.



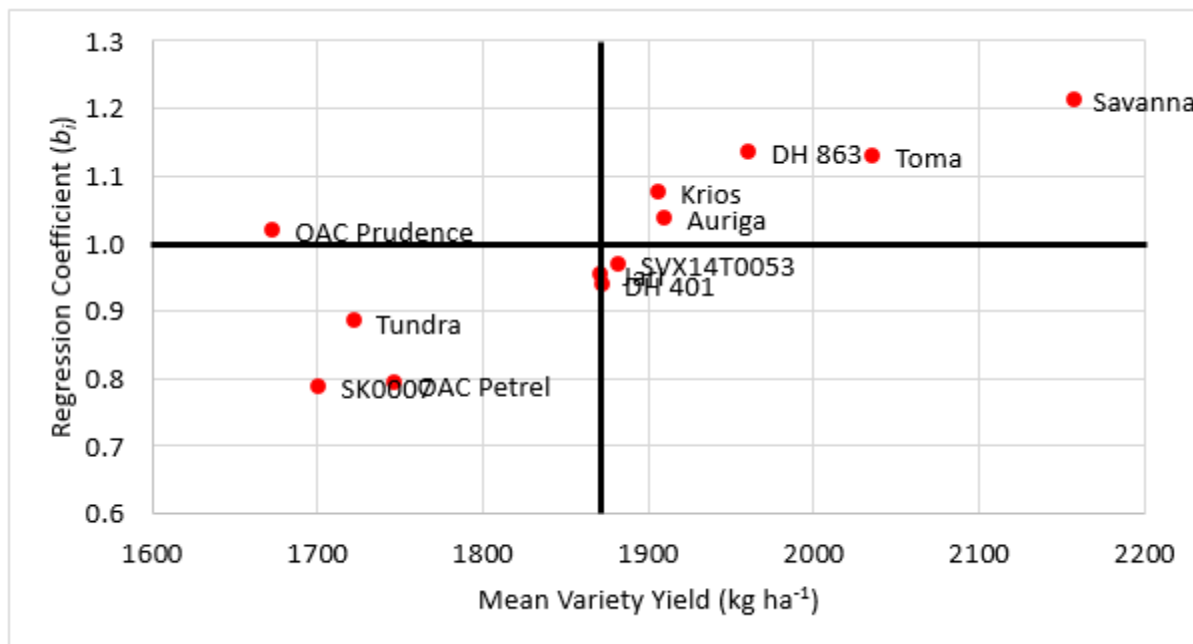
**Figure 12.** The regression lines of 12 soybean cultivars from 9 site years.

**Table 11.** Analysis variance of 12 cultivars across 9 site-years, 9 site-year yield means, linear trends for each site-year, and cultivar deviation from regression lines.

Source	df	Type 1 Sum of Squares	Mean Square	F Value	P > F
Cultivar mean difference	11	11 014 502.4	1 001 318.4	7.78	<0.0001
Site mean difference	8	160 393 528.7	2 0049 191.1	155.71	<.0001
Differences in regression lines for each site	11	2 913 692.8	264 881.2	2.06	0.0044

**Table 12.** Stability parameters of soybean yield from 12 cultivars from 9 site-years.

Cultivar	Yield kg ha <sup>-1</sup>	Regression coefficient $b_i$	Deviations from regression $S^2_d$
Auriga	1910	1.038	0.098
DH 401	1872	0.939	0.161
DH 863	1961	1.135	0.098
Jari	1871	0.953	0.161
Krios	1906	1.075	0.098
OAC Petrel	1747	0.792	0.099
OAC Prudence	1673	1.019	0.099
Savanna	2158	1.212	0.098
SK0007	1701	0.788	0.098
SVX14T0053	1882	0.969	0.098
Toma	2036	1.129	0.161
Tundra	1722	0.884	0.098



**Figure 13.** The yield stability for 12 soybean cultivars. Genotype regression coefficients ( $b_i$ ) are plotted against their cultivar's grand mean yield. The  $b$  value describes the linear response of a cultivar across changing environments. The vertical solid line is the cultivar's grand mean yield. The horizontal solid line represents a regression coefficient of average stability ( $b_i = 1.0$ ).

#### **4.15. Partial least squares regression analysis for soybean cultivar evaluation under organic management**

Partial least squares regression (PLS) analysis was conducted for final soybean grain yield in an effort to identify factors controlling yield of cultivars tested under the different conditions in the study. All variables that were considered to potentially have an impact on final grain yield were included in the model [(early and mature soybean height, soybean biomass, weed biomass, soil nutrient status (-N, -P, -K, -Cl, -Zn, -Cu, organic matter content, -pH)] at sites where variables were present (Carman 2014, St. Pierre 2014, Woodmore 2014, Carman 2015, Somerset 2015, and Woodmore 2015).

Important variables were selected using a cross validation method in which variables were taken out of the model if they were below Wold's VIP of 0.8. Preliminary PLS analyses indicated that there were many variables having a VIP value > 0.8. To refine the important factors, we define variables having a VIP value > 1.2 as critical factors (Liu et al., 2013). Additionally, the centred and scaled data (Table 13) for each significant variable allows for further interpretation of the data. Negative values correspond with a negative impact on the response variable (ie. Grain yield or soybean biomass at R5), and the size of number reflects the magnitude in which the variable contributed to the response variable.

Seven variables; Carman 2015, Somerset 2015, weed interference, soybean biomass at R5, soybean height at R1, mature soybean height, and soil-N were considered significant contributors (Figure 14). Weed interference, Somerset 2015, soybean height at R1 and soil-N were considered significant negative contributors to final grain yield. All seven variables explained 79% of the variability in final grain yield. This level of explanatory variability (79%) is

high compared to other PLS studies. For example, Kumaragamage et al. (2012) found that ten manure phosphorus fractions explained 56% of the variation in the 0- to 30-minute dissolved reactive phosphorus soil losses. Salazar et al. (2008) used PLS to explain approximately 71% of corn yield variation with various vegetative health indices collected through satellite data over 23 years in Kansas.

Variables that did not contribute significantly to the variability in grain yield included cultivars. Therefore, the specific genetic potential of the cultivars tested did not influence the final yield enough to account for variability. This is important for organic farm management decisions, as cultivar choice did not impact final yield.

#### **4.15.1. Site Influence**

Carman 2015 had the highest yield among all sites, and yielded approximately 20% higher than the next highest yielding site (Elie). Conversely, Somerset 2015 had a negative, less significant effect on final grain yield. This is possibly due to the low yielding nature of Somerset 2015.

Carman 2015 experienced lower nitrogen levels which may have given the soybeans a competitive advantage (Table 2), well-timed precipitation during pod formation and seed fill (end of July into beginning of August) during the season (Figure 4), and effective weed control which resulted in very high yields (Table 6). On the other hand, lower yields were observed at Somerset 2015 due to very heavy weed pressure (Table 6).



#### **4.15.2. Soybean Biomass at R5 and Mature Soybean Height**

It is logical that soybean biomass at R5 would contribute a large, positive contribution towards final yield variation (Table 13) because it is understood that the amount of biomass produced by the soybean becomes the basis for final yield (Egli, 2010). Beaver et al. (1985) found that biomass produced by a soybean cultivar was very closely related to yield.

A combination of light competition through shading and biomass accumulation were likely reasons mature soybean height positively contributed to final grain yield variation (Table 13). Other studies examining weed competitiveness have noted that taller cultivars correlated with better weed suppression. The findings in the present study are not in agreement with past studies reporting that early season soybean height was a more important characteristic than mature soybeans height when selecting for weed competitiveness. Jannink et al. (2000) and Place et al. (2011a) did not recommend to breeders to select for tall cultivars. It should also be noted that cultivars that were tall when mature were not necessarily the tallest early in the season (Table 6). This is valuable information as breeders who may be selecting breeding lines for organic production with taller early plant height may not develop cultivars with the highest weed suppressive ability.

#### **4.15.3. Soybean Height at R1**

Soybean height at R1 was considered to be an important negative contributor to grain yield variability (Table 13). The present study is not agreement with Jannink et al. (2000) who stated that early soybean height was highly genetically correlated with weed suppressive

ability. Two cultivars, 'SK0007' and 'Tundra', were the tallest at R1 in this study, however, produced the lowest final yield overall. This may be why early height negatively affected final yield. Although past work has not seen a significant yield difference between late and early maturing soybean cultivars (Egli, 1993; Edwards and Purcell, 2005), the earlier maturing cultivars (ie. 'Tundra' and 'SK0007') were lower yielding than later maturing soybeans (ie. 'Savanna' and 'Toma'). Separate PLS analysis was carried out for soybean biomass at R5 (Figure 15; Table 20, refer to appendix). Results of the biomass analysis showed similar patterns related to maturity. Examining relative weed competitiveness between early and late maturing soybeans and mechanisms associated with final yield under organic management may be valuable; in the past late maturity was regarded as a characteristic associated with weed competitiveness (Place et al., 2011a).

#### **4.15.4. Soil-N Influence**

PLS analysis showed that soil-N was an important, negative contributor to grain yield variation. Soil-N levels have been shown to influence crop-weed competition (Blackshaw et al., 2004; Wells et al., 2013). Nodulating, N<sub>2</sub>-fixing crops may benefit from low soil-N by achieving a competitive advantage over non-nodulating weeds.

As soil-N increased, increased relative competitiveness of weeds on soybean lowered final grain yields. However, we were not able to observe a significant correlation between weed biomass at R5 and nitrogen ( $corr(X,Y) = -.04246$ ). There was no significant relationship between weed biomass at R1 and nitrate-N either ( $corr(X,Y) = .42347$ ). Sicklegod (*Senna obtusifolia*) has

been shown to increase its reproductive abilities by increasing nutrient availability (Tungate et al., 2002). Blackshaw et al. (2004) found that weed community competitiveness increased against spring wheat as nitrogen fertilizer applications increased. This could explain the negative relationship between soil-N and yield in the present study ( $\text{corr}(X,Y) = -.54403$ ,  $P > F < .0001$ ).

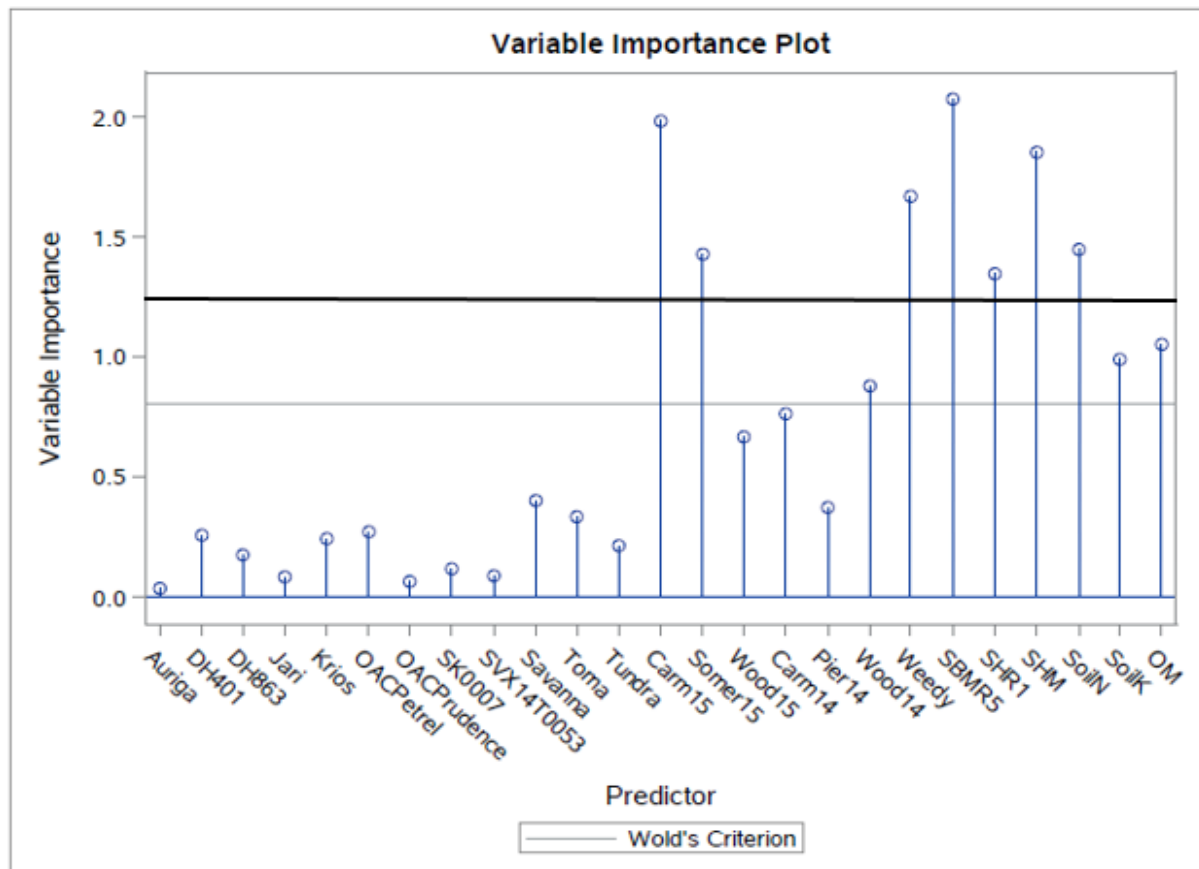
Soybeans may have been unable to compete with resource scavenging weeds during early growth before N<sub>2</sub>-fixing bacterial infection. The wide range of weed species in the present study makes it difficult to see clear relationships between weed competitiveness and soil-N status. Response to higher nitrogen content varies across species, additionally and soybean response to different weed species varies (Bussan et al., 1997; Cowan et al., 1998; Tungate et al., 2002). It would be advantageous for organic farmers to plant soybean crops in low N environments. Results of the present study illustrate the importance to continue research on soil-N dynamics and weed-crop community within legume crop rotations in organic management systems.

#### **4.15.5. Concluding Remarks**

Results from the PLS regression analysis indicate that the major positive agronomic contributors towards final grain yield were weed interference, soybean biomass at R5, and mature soybean height, confirming the importance of choosing vigorous, tall cultivars for organic production. Negative contributors were also identified, such as increased presence soil-N, which may help farmers and agronomists when designing rotations and preparing their land

for soybean production. The current analysis illustrates that site selection is more important than cultivar selection. Organic farmers and agronomists are advised to plant soybeans in low nitrate-N soils. However, if soybeans are sown in high nitrate-N soils, well-timed, effective weed control is required. It should be noted that PLS analysis was carried out on six of the 10 sites evaluated in the present study due to missing data from the omitted sites. If all 10 sites were included in the model, increased subtleties from those environments may have been captured.

The use of PLS regression is not often used to analyze the variation in final grain yield for cultivar evaluation. PLS is traditionally used as a chemometric and spectral reflectance technique, however, use in agricultural studies is growing and shows future promise (Salazar et al., 2008; Williams et al., 2008).



**Figure 14.** The partial least squares (PLS) regression variable importance in the projection (VIP) plot for final grain yield. The black line denotes the variable importance value of 1.25. Any parameter  $>1.25$  is considered a significant contributor the model. Carm15, Carman 2015; Somer15, Somerset 2015; Wood15, Woodmore 2015; Carm14, Carman 2014; Pier14. St. Pierre 2014, Wood14, Woodmore 2014; Weedy, weed interference; SBMR5, soybean biomass at R5; SHR1, soybean height at R1; SHM, soybean height at maturity; SoilN, inorganic soil nitrogen test status taken in the spring at each site, SoilK, soil potassium test status taken in the spring at each site; OM, organic matter level status taken in the spring at each site.

**Table 13.** Partial least squares (PLS) regression parameter estimates of significant factors for final grain yield in Carman 2014, Carman 2015, St. Pierre 2014, Somerset 2015, Woodmore 2014, and Woodmore 2015.

<b>Significant Variable</b>	<b>Estimate for Final Yield, Centred and Scaled Data</b>
Intercept*	0.0
Carman 2015	0.24
Somerset 2015	-0.076
Weed Interference	-0.28
Soybean Biomass at R5	0.21
Soybean Height at R1	-0.06
Mature Soybean Height	0.24
Soil-N Status	-0.11

## 5. GENERAL DISCUSSION

### **Does direct selection under low-yield capacity environments stifle genetic potential?**

There is an ongoing debate as to whether specific organic breeding programs are required to enhance the overall productivity of organic production systems (Murphy et al., 2007; Pswarayi et al., 2014). Currently, multiple institution and government agencies have invested in direct selection; as funding for organic crop breeding programs has increased in the Canada, the United States, and Europe (Lammerts van Bueren and Myers, 2012). However, Cober and Morrison (2015) argue that the magnitude of the genetic potential of a cultivar is larger in high-yield capacity environments (ie. conventional) than low-yield potential environments (ie. weedy conditions such as organic). The authors argue that if plant breeders choose to conduct selections under low-yield capacity environments, they may be trading off genetic progress. In an earlier paper, Cober and Morrison (2011) illustrated that genetic progress among 20 cultivars released from 1934 to 2007 differed from 13.9 kg ha<sup>-1</sup> yr<sup>-1</sup> under weed-free conditions to 1.2 kg ha<sup>-1</sup> yr<sup>-1</sup> under weedy conditions. This is an interesting concept, because if this is the case, then organic breeding programs may in fact be *stifling* the genetic progress of new, organically bred, cultivars.

The present research supports this hypothesis, as a cultivar x environment interaction was apparent in 'high yielding' environments but not in 'low yielding' environments. Cultivars grown in the 'low capacity' environments may have been unable to express their true genetic abilities due to stresses such as weed pressure, poorly timed precipitation, or low soil fertility. Additionally, all cultivar yields increased as environment mean yield increased. However, if

Cober and Morrison's (2015) hypothesis is true, then one would expect there to be no cultivar x environment interactions across all sites and no significant cultivar effects at individual environments but this was not the case. Significant cultivar effects were apparent at St. Pierre 2014, and Carman 2015. Other studies have reported cultivar yield differences under weedy conditions in field pea and soybean (Bussan et al., 1997; McDonald, 2003; Rezvani et al., 2013). Additionally, multiple studies have observed differential performance when comparing cultivars under organic and conventional management (Murphy et al., 2007). Cultivar x environment interactions in the higher yielding sites and genotypic differences point to the idea that there may be a 'stress threshold' for genotypic expression of characteristics contributing to yield.

Harris and Ritter (1987) found that soybean would tolerate up to 1 weedy grass species/7.5 cm of crop row without significantly reducing soybean yield. Other research indicates that the degree to which weeds reduce yield is dependent on environmental conditions such as soil moisture (Cowan et al., 1998). Ryan et al. (2009) analyzed 27 years of data from the Rodale Institutes Farming Systems Trial, the longest running organic-conventional comparison study in North America. While mean weed biomass was 4.5-6.3 times greater in the organic systems, soybean yield was only 8% lower than in the conventional system. Additionally, yield loss per unit weed biomass was less in the organic than the conventional system. The authors concluded that crops grown organically seem to have the ability to tolerate more weed competition (Ryan et al., 2009). Weed densities or biomass were not reported by Cober and Morrison (2015) or earlier works of Cober and Morrison (2011), therefore speculation about weed density and biomass influence cannot be made.



One argument in favour of direct selection under organic conditions is that organic production systems rely heavily on microbial activity for nutrient availability and productivity (Messmer et al., 2012; Lammerts van Bueren and Myers, 2012). Lammerts van Bueren et al. (2002) describes the importance for cultivars to have adequate root architecture and interacting with beneficial micro-organisms are important genetically variable characteristics in organic systems. Unfortunately, indirect selection for these qualities is difficult in conventional systems due to the cost and destructive nature of root examination, different microbial activities and adequate nutrients readily available in the rhizosphere (Place et al., 2011a; Messmer et al., 2012). Lack of readily available phosphorus in the rhizosphere has been shown to induce higher mycorrhizal infection in flax (Entz et al., 2004), and induce root architecture adaption in soybean (Pan et al., 2008). Genotypic difference in nodule infection speed and efficiency has also been observed in soybean (Chaverra and Graham, 1992; Rodiño et al., 2011). It should be noted while Cober and Morrison (2011) compared genetic progress between weedy and weed-free environments, the soil nutrient status was standardized between weedy and weed-free plots. It would be valuable to compare genetic progress of cultivars on bred and selected organically managed farms.

The Cober and Morrison (2015) paper is valuable, as it attempts to explain why organic breeding programs and organic variety trials may not observe yield differences between cultivars. Organic breeding programs may attempt to establish a certain 'weed density threshold' to allow the soybeans to adequately express cultivar characteristics.

## **Is there a place for organic crop breeding?**

The present research was conducted on organic farmers' fields in southern Manitoba, and crop management within the trials was carried out to simulate similar management (such as weed control) on an organic farm. Therefore, the information born out of the present study is relevant and should be valuable to organic farmers. However, the final yield of each soybean cultivar is dependent on multiple interacting genetic traits and environmental conditions. The main challenge for the present study and for other weed competition studies is uniformity of species and density in natural weed communities. Results from the present study may not be relevant to an organic farmer who has different weed species and densities on their farm.

Due to the unique and diverse needs on organic farms, organizations and education institutions have teamed with organic farmers to create participatory plant breeding (PPB) programs (Desclaux et al., 2008). In these programs, farmers, who have education passed down through generations and on-farm observational experience make selections either selections on their own farms, or visit other organic farms and participate in rating cultivars (Kandel et al., 2008; Kirk et al., 2012). These programs have the potential to increase the stability of a food system by increasing the diversity of genetics grown in the world. Additionally, PPB programs have the potential to empower farmers through gaining knowledge of the breeding process, one of the beneficial results of a PPB program carried out in Syria, as documented by Desclaux et al. (2012).

A PPB program is already in place in Canada for wheat, oats, and potatoes, however, the participants may also benefit from a soybean component due the lack of short-season non-GM

soybean cultivars currently available. This research would benefit a potential organic PPB program as it provides information about candidate parental lines.

### **Should we incorporate Partial Least Squares Regression Analysis in cultivar evaluation?**

In the present study, the statistical tool PLS was utilized to examine the influence multiple variables had on soybean yield. Agricultural scientists may desire to include PLS in their statistical procedures, as it has been shown to be well suited to complex environmental characteristics that are commonly highly collinear (see appendices Table 21) (Williams et al., 2008). Additionally, PLS has the ability to indicate if the response variables negatively or positively contribute to the dependant variable's data. While principle component analysis deals with multicollinearity very well, principle component analysis is unable to indicate positive or negative effects on the dependant variable in question.

For example, the ability to positively or negatively connect soil-N to final grain yield was valuable and catalyzed discussion surrounding the influence soil-N had on soybeans' final performance. More research should be done examining the role of residual soil-N on final soybean performance in organic systems, as yield represents the cumulative effect of agronomic characteristics which were beyond the scope of this study.

As mentioned, PLS is not widely used among the agricultural science community, especially varietal evaluation studies, although it may prove to be a valuable tool. Agronomic sciences share similar concerns to quantitative near-infrared studies. In 2000, Westad and Martens stated that there was still hesitation to use PLS in quantitative near-infrared studies,

due to a lack of established statistical theory for significance testing in that discipline. Currently, PLS analysis is one of the most commonly used statistical analyses for spectroscopy and NIR studies (Mevik and Wehrans, 2007). This provides hope that the PLS regression tool can gain popularity in agricultural science studies.

### **Environmental Conditions had Greater Influence on Performance than Cultivar Choice**

Cultivar selection is an important consideration for organic soybean production, however, the present research revealed that the environmental conditions under which the cultivars were grown made a greater impact on final performance than cultivar choice.

This is important to note; as farmers and agronomists need to consider the environment under which the soybeans will be grown as much as cultivar selection. Due to soybean's inability to compete well with weeds early in the season, the present study showed that planting soybeans in a low Soil-N environment and being equipped to execute a rigorous weed control management plan is essential to a successful soybean crop.

### **Research Limitation and Future Research Directions**

The present study attempted to evaluate cultivars' performance based on aboveground genetic diversity useful to organic conditions such as height and biomass. However, below ground interactions with soil microbial communities, weed roots systems, phosphorus foraging ability, allelopathic qualities, and nitrogen fixation ability were not examined. Organic farmers rely on microbial communities to immobilize and mineralize nutrients to control proper crop requirements and reduce nutrient losses (Snyder and Spaner, 2010). Belowground genetic diversity has been observed in ability to fix nitrogen efficiently, and make productive

associations with certain bacterium in various legume field crops (Danso et al., 1987; Herridge and Rose, 2000; Abi-Granem et al., 2011).

Weed-crop interactions belowground have potential to provide insight that may develop varieties that are tolerant. Gal (2014) reported that in the presence of aboveground weeds, soybean root biomass and nodulation was reduced. Rose et al. (1984) found that in greenhouse experiments, soybean root exudates were able to inhibit the growth of velvetleaf plants by 15%, the presence of soybean dry matter in soil prevented germination of velvetleaf by 46%, and foxtail millet germination by 82% (Rose et al., 1984). Further research examining the weed-crop interactions between soybean and weed roots would be valuable.

Enhancing root architecture to scavenge for phosphorus may be of particular interest for organic farmers, as productivity may be enhanced. The root architecture of crops is of specific interest as it relates to phosphorus foraging; phosphorus must be acquired by roots in close proximity as it is not soluble in water (Lynch, 2007). Root adaptation such as greater root biomass, longer, denser root hairs, high amounts of adventitious roots, smaller root diameter, shallower basal roots, and higher dispersed lateral roots may contribute to higher P efficiency and access (Bonser et al., 1996; Miller et al., 2003; Lynch 2007; Pan et al., 2008).

The soybean roots' impact on the rhizosphere has also been linked to increased phosphorus uptake and efficiency. Qualities such as carboxylate acid root exudation result in phosphate mobilisation from bound forms (Richardson et al., 2011). Secreted acid phosphatases into the rhizosphere have also been considered a very important component to increase phosphorus nutrition to the crop (Li et al., 2004). Organic farmers rely heavily on

mycorrhizal associations to increase nutrient availability, and associations have been shown to be higher in organic farming systems than conventional due to lower phosphorus levels (Entz et al., 2004). Breeding for specific traits such as these would be extremely helpful to organic and conventional farmers, as input costs can be reduced if crops are bred to perform well in for low-input environments.

## 6. CONCLUSIONS

The objective of this study was to evaluate 12 non-GM soybean cultivars for suitability to organic and transition to organic conditions in southern Manitoba. The findings of this study highlight the importance of certain soybean cultivar characteristics that may be valuable to organic farming systems. Although the objective of this study was not to compare cultivar's weed competitiveness, weeds greatly influenced soybean performance. Environmental conditions impacts final performance to a greater degree than cultivar choice. The study found significant differences among soybean cultivars' relative performances.

The first hypothesis was that soybean cultivars with increased biomass and height early in the season would be highly competitive with weeds and suffer less yield loss. Combining the data across all site years, two cultivars with the greatest early season height and biomass were 'SK0007' and 'Tundra'. The cultivars were amongst the lowest yielding, and were amongst the cultivars whose yields suffered the most due to weeds (although not significantly). This is not in agreement with other soybean studies examining weed competitiveness, where the most vigorous cultivars early in the season were the most competitive (Jannink et al., 2000; Place et al., 2011a). Both 'SK0007' and 'Tundra' were amongst the earliest maturing varieties, and their vegetative growth may have slowed earlier in the season compared to the other varieties due to earlier onset of reproductive development. However, Egli (1993) reports that short-season and longer-season soybean cultivars have equal yield potential. The mechanism driving lower yield may ultimately be lower competitive ability. Therefore, this study rejects the hypothesis

that cultivars with increased biomass accumulation and height early in the season will be highly competitive with weeds and experience lower yield loss due to weeds.

The second hypothesis was that early maturing soybean cultivars will suffer less yield loss due to weed competition than later maturing cultivars due to the higher ability to tolerate weed pressure. Across all sites, the values for percent yield loss due to weeds showed no cultivar effect, however, the earliest maturing varieties were usually among the lowest yielding at many sites. At the same sites, the latest maturing varieties were among the top performers.

Some sites presented very heavy weed pressure against the test cultivars. But yield loss due to weeds at these stressful sites was not different between early and later maturing cultivars. Therefore, results of this study reject the hypothesis that early maturing soybean cultivars will suffer less yield loss due to weeds than later maturing cultivars due to the higher ability to tolerate weed pressure.

The present study hypothesized that cultivars bred under conventional conditions will not results in high and stable yield under organic conditions due to the added challenges met by the cultivars across many environments. Cultivars that expressed high stability ( $b_i < 1$ ) were also amongst the lowest yielding across all sites tested. Cultivars that expressed low stability ( $b_i > 1$ ) were amongst the highest yielding across all sites. However, there was no cultivar that exhibited high stability and high and stable yields under organic management, and ultimately the present study lends support to the hypothesis that cultivars bred under conventional environments will not produce high yields and high stability under organic conditions. Swegarden et al. (2016) found that heirloom dry bean cultivars were able to achieve 'high'



yields (as compared to one another) and high stability on organic farms. However, these cultivars were not bred specifically for organic conditions. It may be valuable to test already organically bred cultivars in other crops under the same conditions to observe if this is possible.

The last hypothesized outcome was that the cultivar characteristics associated with weed competitiveness in the past (ie. early season height and early biomass accumulation) will have the greatest impact on final grain yield under organic conditions. The PLS analysis results indicated that soybean height at R1 and at maturity, soybean biomass at R5, weed interference, and soil-N explained the majority of the variation in grain yield. Increases in soybean height at maturity and soybean biomass at R5 were positively associated with increased final grain yield. However, but interestingly, soybean height at R1 was negatively associated with final grain yield, and soybean biomass at R1 was not considered to significantly contribute to grain yield variation. Therefore, the results of the present study indicate that height at maturity may be more important to select for as opposed to early soybean height if the goal environment is organic. Relative branching was not measured in this study. Future studies should consider branching because increasing height and branching may be valuable in organic systems, as soybean biomass at R5 heavily impacted final grain yield. Additionally, branching may increase light interception and increase competition for sunlight against weeds.

The final performance of the cultivars tested in the present study is a culmination of a variety of environmental elements and cultivars' reaction to those environments through their genetic diversity. The present study had the benefit of partnering with organic farmers to submit the tested cultivars to multiple and varied conditions. There were diverse responses from cultivars in different organic conditions, as final grain yield exhibited a site-cultivar

interaction. We observed certain cultivars that performed very well under organic conditions such as 'Savanna' and 'Toma', and as such had certain characteristics increasing increased height at maturity and increased biomass accumulation that were significantly higher than other cultivars. However, 'Savanna' and 'Toma' mature much later than the average Manitoba farmers requires for their farm. It would be valuable to attempt to cross 'Savanna' and a shorter season variety in order to select for high yield capacity under organic conditions and proper maturity.

Finally, the environment in which cultivars were grown influenced final performance more than cultivar choice. In general, organic farmers and agronomists should take an integrated approach that considers soil-N, weed pressure and cultivar selection together.

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## APPENDICES

**Table 14.** Stand density of 12 soybean cultivar across 10 site-years.

	Carman 2014*	St.Pierre 2014	Elie 2014	Woodmore 2014	Somerset 2014	Swan Lake 2014	Carman 2015	St. Pierre 2015	Somerset 2015	Woodmore 2015
Cultivar	plant m <sup>-2</sup>									
Auriga	48	51 ab	45	45	43	20	35 bcde	42 a	35	43
DH 401	44	52 ab	-	-	-	-	31 de	40 ab	31	43
DH 863	40	53 ab	47	51	48	23	36 bcde	39 ab	32	50
Jari	44	49 abc	-	-	-	-	38 bcd	34 bc	36	43
Krios	43	52 ab	42	48	46	24	29 e	34 bc	36	45
OAC Petrel	43	39 cd	46	50	49	24	34 bcde	30 c	33	41
OAC Prudence	45	45 cd	48	45	44	29	38 bc	41 ab	38	47
Savanna	44	48 bc	49	50	45	26	33 cde	43 a	38	47
SK0007	50	48 abc	49	53	39	26	46 a	44 a	41	51
SVX14T0053	39	51 abc	49	50	48	33	30 e	40 abc	35	42
Toma	41	48 bc	-	-	-	-	35 bcde	38 abc	34	46
Tundra	43	55 a	54	54	47	24	40 ab	44 a	39	48
Coeff. Variation (%)	11	11	11	11	11	27	18	17	18	12
<i>P &gt; F</i>	0.1203	<b>0.0024</b>	0.054	0.325	0.0947	0.356	<b>0.0024</b>	<b>0.0176</b>	0.6851	0.1151
*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance										

**Table 15.** Soybean biomass production at R1-R2 development stage from 12 soybean cultivars at 4 site years

	Carman 2015*	St. Pierre 2015	Somerset 2015		Woodmore 2015
Cultivar	kg ha <sup>-1</sup>				
Auriga	561	760	731	de	792
DH 401	929	953	776	cde	664
DH 863	701	890	1015	abc	662
Jari	878	867	857	bcd	884
Krios	622	635	702	de	803
OAC Petrel	531	880	753	cde	890
OAC Prudence	655	1110	692	de	797
Savanna	707	757	1176	a	818
SK0007	1366	990	1103	ab	744
SVX14T0053	706	852	533	e	620
Toma	929	977	860	bcd	622
Tundra	982	939	856	bcd	735
Coeff. Variation (%)	38	31	29		22
<i>P &gt; F</i>	0.0546	0.4846	<b>0.0013</b>		0.2124
*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance					

**Table 16.** Soybean height at maturity development stage of 12 soybean cultivars at 9 site years

	Carman 2014*		St.Pierre 2014		Elie 2014		Woodmore 2014		Somerset 2014		Swan Lake 2014		Carman 2015		Somerset 2015		Woodmore 2015	
Cultivar	cm																	
Auriga	73	ab	51	55	bc	49	cd	50	50	87	58	bc	54	e				
DH 401	69	ab	49	-	-	-	-	-	-	85	62	abc	67	ab				
DH 863	68	b	47	46	cd	54	c	50	50	82	61	abc	67	ab				
Jari	84	a	55	-	-	-	-	-	-	91	69	a	66	abc				
Krios	72	ab	55	67	a	66	a	47	53	86	65	ab	73	a				
OAC Petrel	62	b	53	55	bc	53	cd	48	51	84	61	abc	68	ab				
OAC Prudence	61	b	49	52	bcd	49	d	47	49	84	65	ab	67	ab				
Savanna	70	ab	48	54	bc	54	cd	51	51	89	60	bc	69	ab				
SK0007	59	bc	49	48	cde	44	e	46	49	87	50	d	59	cde				
SVX14T0053	61	bc	49	57	b	60	b	49	48	84	55	cd	63	bcd				
Toma	67	b	44	-	-	-	-	-	-	85	55	cd	63	bcd				
Tundra	46	c	44	44	e	39	e	47	53	84	59	bc	55	de				
Coeff. Variation (%)	20		14	15		17		9	8	7	12		11					
P > F	0.0047		0.1117	0.0054		<.0001		0.6759	0.3127	0.7731	0.0046		0.0003					
*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance																		

\*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance

**Table 17.** Pod height of 12 soybean cultivars at 9 site years

	Carman 2014*	St.Pierre 2014	Elie 2014	Woodmore 2014	Somerset 2014	Swan Lake 2014	Carman 2015	Somerset 2015	Woodmore 2015			
Cultivar	cm											
Auriga	14	13	15	14	bc	11	c	17	15	12	14	bcde
DH 401	13	11	-	-	-	-		-	15	13	16	ab
DH 863	13	11	12	13	bc	13	ab	18	15	13	16	abcd
Jari	15	13	-	-	-	-		-	16	15	17	a
Krios	14	12	14	13	bc	12	bc	17	14	12	14	cde
OAC Petrel	12	10	12	13	cd	12	c	18	14	12	14	cde
OAC Prudence	13	12	11	11	d	12	bc	16	14	14	14	de
Savanna	14	12	14	13	bc	13	abc	19	15	14	16	abc
SK0007	15	13	14	16	a	15	a	16	15	12	13	e
SVX14T0053	13	13	15	13	bc	12	bc	16	15	13	14	cde
Toma	13	12	-	-	-	-		-	13	12	16	abcd
Tundra	13	12	11	14	b	13	bc	22	14	15	13	e
Coeff. Variation (%)	13	13	17	11		11		15	11	12	14	
P > F	0.2468	0.0799	0.056	<.0001		0.035		0.0649	0.5365	0.0535	0.0058	
*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance												

\*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance



**Table 18.** Final grain yield of 12 soybean cultivars at 9 site-years

	Carman 2014*	St.Pierre 2014	Elie 2014	Woodmore 2014	Somerset 2014	Swan Lake 2014	Carman 2015	Somerset 2015	Woodmore 2015			
Cultivar	kg ha-1											
Auriga	2594	2578	a	2031	1533	1005	311	2400	c	880	1355	cd
DH 401	2602	1683	bc	-	-	-	-	2386	c	1058	1435	abcd
DH 863	2246	1643	bc	2348	2008	851	279	2915	abc	987	1579	abcd
Jari	2324	1696	bc	-	-	-	-	2607	abc	1097	1632	abc
Krios	2328	2025	b	2379	1565	775	310	2575	abc	973	1502	abcd
OAC Petrel	1642	1780	bc	2513	1445	1141	496	2365	c	1013	1472	abcd
OAC Prudence	1667	1954	bc	1699	1306	824	280	3136	ab	995	1376	bcd
Savanna	2528	1926	bc	2673	1867	1110	410	3200	a	1056	1713	a
SK0007	1756	1500	c	2022	1418	778	545	2405	c	1142	1669	ab
SVX14T0053	2205	1631	bc	1975	2013	729	317	2519	bc	1101	1707	a
Toma	2110	1994	bc	-	-	-	-	3135	ab	1215	1727	a
Tundra	1721	1672	bc	2197	1577	947	375	2527	bc	1087	1279	d
Coeff. Variation (%)	32	24		19	24	32	61	19		17	16	
P > F	0.1338	0.0131		0.0907	0.072	0.2922	0.4651	0.0425		0.5445	0.0402	
*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance												

\*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance

**Table 19.** Yield loss due to weeds of 12 soybean cultivars at 3 site years

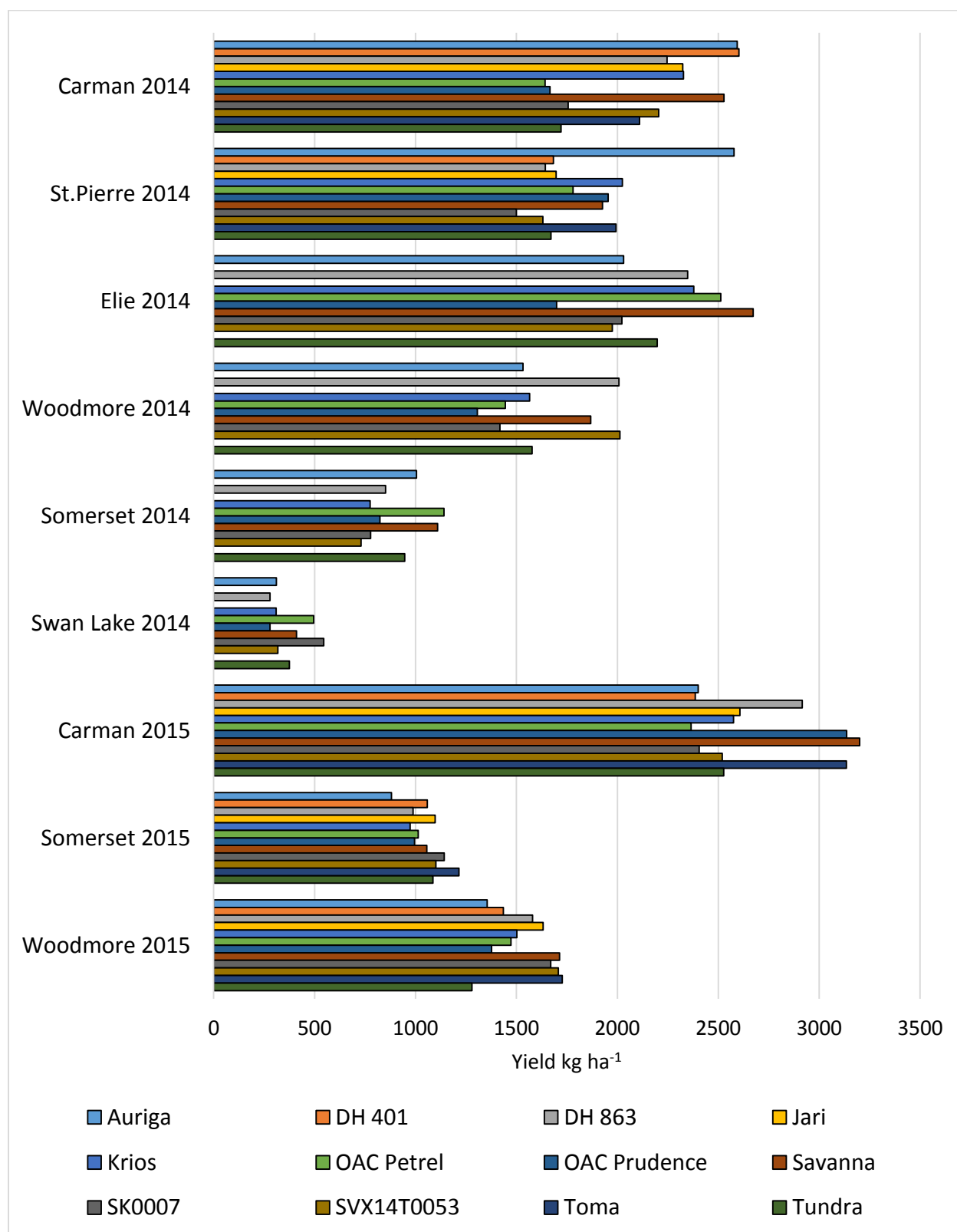
	<b>Carman</b>	<b>Somerset</b>	<b>Woodmore</b>	
	<b>2015*</b>	<b>2015</b>	<b>2015</b>	
<b>Cultivar</b>	<b>kg ha<sup>-1</sup></b>			
<b>Auriga</b>	20	51	36	a
<b>DH 401</b>	14	35	35	a
<b>DH 863</b>	9	44	32	a
<b>Jari</b>	16	43	24	a
<b>Krios</b>	19	47	29	a
<b>OAC Petrel</b>	31	50	25	a
<b>OAC Prudence</b>	10	48	32	a
<b>Savanna</b>	19	45	30	a
<b>SK0007</b>	44	46	10	b
<b>SVX14T0053</b>	28	45	28	a
<b>Toma</b>	23	33	27	a
<b>Tundra</b>	29	44	32	a
<b>Coeff. Variation (%)</b>	22	20	16	
<b><i>P</i> &gt; <i>F</i></b>	0.6086	0.3818	<b>0.0378</b>	

\* Means within a column followed by the same letter are not significantly different at the 0.05 level of significance

**Table 20.** Seed mass of 12 cultivars across 9 site-years

	Carman 2014*		St.Pierre 2014		Elie 2014		Woodmore 2014		Somerset 2014		Swan Lake 2014		Carman 2015		Somerset 2015		Woodmore 2015	
Cultivar	g-100 seeds <sup>-1</sup>																	
Auriga	16	d	17	h	14	f	16	a	13	d	13	cd	17	cde	13		15	
DH 401	18	bc	21	b	-		-		-		-		16	cde	14		16	
DH 863	18	bc	21	bc	16	cde	17	a	17	a	14	bc	17	cd	14		14	
Jari	17	c	20	ef	-		-		-		-		17	cd	13		14	
Krios	15	e	19	g	15	ef	15	bc	13	de	12	de	15	f	13		15	
OAC Petrel	15	e	17	hi	15	def	15	c	14	c	12	e	15	ef	15		14	
OAC Prudence	18	c	20	cd	15	de	18	a	16	ab	18	a	18	c	12		15	
Savanna	19	a	17	cd	17	bc	17	a	17	a	15	b	18	bc	13		14	
SK0007	18	ab	17	hi	19	a	17	a	16	ab	18	a	17	cd	14		14	
SVX14T0053	18	ab	23	a	18	ab	17	a	12	e	13	cd	20	a	14		13	
Toma	19	a	19	f	-		-		-		-		19	ab	14		13	
Tundra	19	a	17	i	17	cd	18	a	16	b	17	a	16	def	13		15	
Coeff. Variation (%)	9		10		10		8		12		15		10		9		9	
P > F	<.0001		<.0001		<.0001		<.0001		<.0001		<.0001		<.0001		0.1262		0.1695	
*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance																		

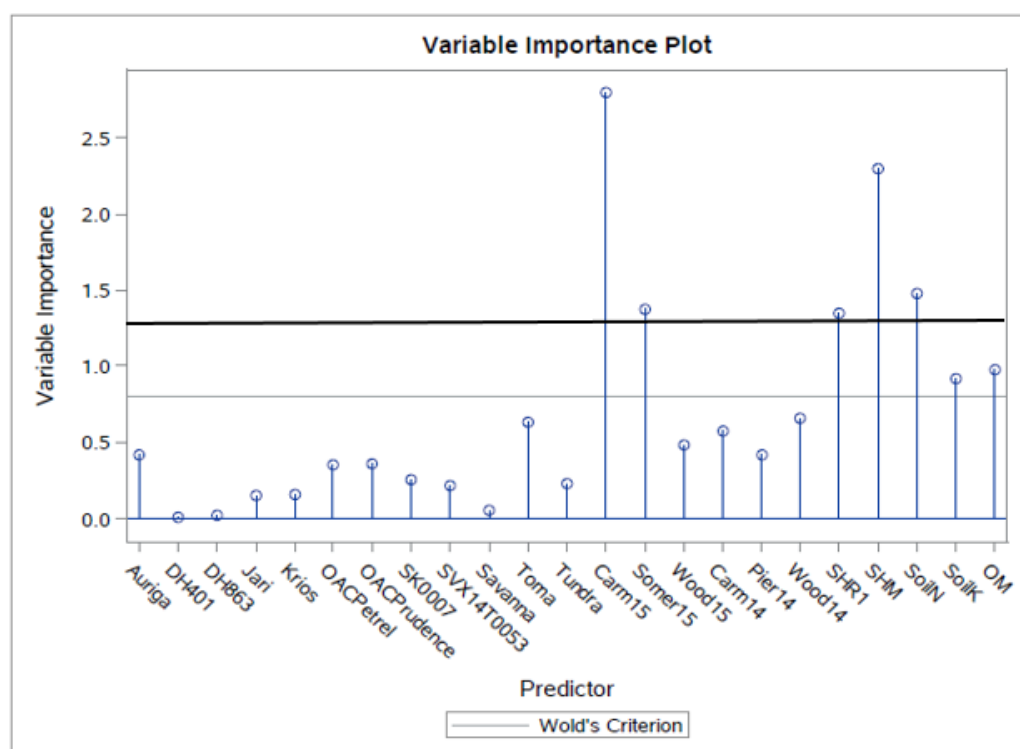
\*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance



**Figure 15.** Yield performance of 12 soybean cultivars from 9 site years.

**Table 21.** Correlation Matrix of 12 soybean cultivars from Carman 2014, St. Pierre 2014, Woodmore 2014, Carman 2015, Somerset 2015, and Woodmore 2015

	Yield	Weed Presence	Soybean Biomass at R5	Weed Biomass at R5	Soybean Height at R1	Soybean Height at Maturity	Harvest Index	Seed Mass	Soil Nitrate	Soil Phosphorus	Soil Potassium	Soil Sulfur	Soil Zinc	Soil Copper	Organic Matter	pH
Yield	1	-0.31325 <.0001	0.45909 <.0001	-0.06058 0.1898	-0.28493 <.0001	0.45422 <.0001	-0.08104 0.0793	0.07186 0.1198	-0.33421 <.0001	-0.05098 0.2701	-0.17937 <.0001	-0.08888 0.0542	-0.16143 0.0004	0.04186 0.3652	-0.20959 <.0001	-0.29002 <.0001
Weed Presence	-0.31325 <.0001	1	-0.00272 0.9531	0.00923 0.8418	-0.00701 0.8796	0.00215 0.9629	0.0048 0.9174	-0.00092 0.984	-0.04101 0.375	-0.00417 0.9282	-0.00225 0.9612	0.00282 0.9514	-0.00674 0.8842	0.00138 0.9763	-0.00145 0.975	0.00454 0.9219
Soybean Biomass at R5	0.45909 <.0001	-0.00272 0.9531	1	-0.19724 <.0001	-0.28586 <.0001	0.55986 <.0001	-0.61154 <.0001	0.08405 0.0687	-0.34999 <.0001	0.02534 0.5837	-0.12199 0.0081	-0.1209 0.0087	-0.05711 0.2165	-0.03357 0.4678	-0.14577 0.0015	-0.20981 <.0001
Weed Biomass at R5	-0.06058 0.1898	0.00923 0.8418	-0.19724 <.0001	1	0.35753 <.0001	0.17838 0.0001	0.25043 <.0001	0.04954 0.2838	0.10744 0.0198	0.46247 <.0001	0.27279 <.0001	-0.23404 <.0001	0.3087 <.0001	-0.18109 <.0001	0.25863 <.0001	-0.3514 <.0001
Soybean Height at R1	-0.28493 <.0001	-0.00701 0.8796	-0.28586 <.0001	0.35753 <.0001	1	-0.10067 0.0291	0.11373 0.0136	-0.07702 0.0954	0.38558 <.0001	0.77102 <.0001	0.67715 <.0001	-0.1555 0.0007	0.62785 <.0001	-0.13524 0.0033	0.66273 <.0001	-0.36104 <.0001
Soybean Height at Maturity	0.45422 <.0001	0.00215 0.9629	0.55986 <.0001	0.17838 0.0001	-0.10067 0.0291	1	-0.18604 <.0001	-0.12655 0.006	-0.09172 0.0469	0.27272 <.0001	-0.13491 0.0034	-0.45109 <.0001	-0.01871 0.6858	-0.35187 <.0001	-0.14293 0.0019	-0.47482 <.0001
Harvest Index	-0.08104 0.0793	0.0048 0.9174	-0.61154 <.0001	0.25043 <.0001	0.11373 0.0136	-0.18604 <.0001	1	0.05474 0.2362	0.13939 0.0025	0.0428 0.3545	0.11442 0.0131	0.08914 0.0535	-0.02962 0.5218	0.09143 0.0476	0.12025 0.0091	-0.02082 0.6525
Seed Mass	0.07186 0.1198	-0.00092 0.984	0.08405 0.0687	0.04954 0.2838	-0.07702 0.0954	-0.12655 0.006	0.05474 0.2362	1	0.01221 0.7918	0.01055 0.8195	0.07827 0.0901	0.12055 0.0089	-0.14108 0.0022	0.1568 0.0006	0.08001 0.0831	-0.07814 0.0906
Soil Nitrate	-0.33421 <.0001	-0.04101 0.375	-0.34999 <.0001	0.10744 0.0198	0.38558 <.0001	-0.09172 0.0469	0.13939 0.0025	0.01221 0.7918	1	0.33029 <.0001	0.29786 <.0001	-0.06322 0.1713	-0.17661 0.0001	-0.21582 <.0001	0.39236 <.0001	0.03802 0.4108
Soil Phosphorus	-0.05098 0.2701	-0.00417 0.9282	0.02534 0.5837	0.46247 <.0001	0.77102 <.0001	0.27272 <.0001	0.0428 0.3545	0.01055 0.8195	0.33029 <.0001	1	0.71527 <.0001	-0.33145 <.0001	0.5709 <.0001	-0.21799 <.0001	0.69253 <.0001	-0.72952 <.0001
Soil Potassium	-0.17937 <.0001	-0.00225 0.9612	-0.12199 0.0081	0.27279 <.0001	0.67715 <.0001	-0.13491 0.0034	0.11442 0.0131	0.07827 0.0901	0.29786 <.0001	0.71527 <.0001	1	0.41137 <.0001	0.30841 <.0001	0.4605 <.0001	0.99269 <.0001	-0.26642 <.0001
Soil Sulfur	-0.08888 0.0542	0.00282 0.9514	-0.1209 0.0087	-0.23404 <.0001	-0.1555 0.0007	-0.45109 <.0001	0.08914 0.0535	0.12055 0.0089	-0.06322 0.1713	-0.33145 <.0001	0.41137 <.0001	1	-0.42424 <.0001	0.95268 <.0001	0.42971 <.0001	0.50104 <.0001
Soil Zinc	-0.16143 0.0004	-0.00674 0.8842	-0.05711 0.2165	0.3087 <.0001	0.62785 <.0001	-0.01871 0.6858	-0.02962 0.5218	-0.14108 0.0022	-0.17661 0.0001	0.5709 <.0001	0.30841 <.0001	-0.42424 <.0001	1	-0.37821 <.0001	0.23612 <.0001	-0.28001 <.0001
Soil Copper	0.04186 0.3652	0.00138 0.9763	-0.03357 0.4678	-0.18109 <.0001	-0.13524 0.0033	-0.35187 <.0001	0.09143 0.0476	0.1568 0.0006	-0.21582 <.0001	-0.21799 <.0001	0.4605 <.0001	0.95268 <.0001	-0.37821 <.0001	1	0.45157 <.0001	0.24719 <.0001
Organic Matter	-0.20959 <.0001	-0.00145 0.975	-0.14577 0.0015	0.25863 <.0001	0.66273 <.0001	-0.14293 0.0019	0.12025 0.0091	0.08001 0.0831	0.39236 <.0001	0.69253 <.0001	0.99269 <.0001	0.42971 <.0001	0.23612 <.0001	0.45157 <.0001	1	-0.2132 <.0001
pH	-0.29002 <.0001	0.00454 0.9219	-0.20981 <.0001	-0.3514 <.0001	-0.36104 <.0001	-0.47482 <.0001	-0.02082 0.6525	-0.07814 0.0906	0.03802 0.4108	-0.72952 <.0001	-0.26642 <.0001	0.50104 <.0001	-0.28001 <.0001	0.24719 <.0001	-0.2132 <.0001	1



**Figure 16.** The partial least squares (PLS) regression variable importance in the projection (VIP) plot for soybean biomass at R5. The black line denotes the variable importance value of 1.25. Any parameter <1.25 is considered a significant contributor the model. Carm15, Carman 2015; Somer15, Somerset 2015; Wood15, Woodmore 2015; Carm14, Carman 2014; Pier14, St. Pierre 2014; Wood14, Woodmore 2014; SHR1, soybean height at R1; SHM, soybean height at maturity; SoilN, inorganic soil nitrogen test status taken in the spring at each site; SoilK, soil potassium test status taken in the spring at each site; OM, organic matter level status taken in the spring at each site.

**Table 22.** Partial least squares (PLS) regression parameter estimates of significant factors for soybean biomass at R5 in Carman 2014, Carman 2015, St. Pierre 2014, Somerset 2015, Woodmore 2014, and Woodmore 2015.

Significant Variable	Estimate for Final Yield, Centred and Scaled Data
Intercept*	0.0
Carman 2015	0.35
Somerset 15	-0.076
Soybean Height at R1	0.083
Mature Soybean Height	0.28
Soil-N Status	-0.12

**Table 23.** Combined analysis of protein and oil values from 12 soybean cultivars in 3 site years under organic management

	<b>Protein Content*</b>		<b>Oil Content</b>	
	<b>(%)</b>		<b>(%)</b>	
<b>Site-year</b>	-		-	
<b>Carman 2015</b>	44	a	19	b
<b>Woodmore 2015</b>	42	b	20	a
<b>Somerset 2015</b>	44	a	18	c
<b>Cultivar</b>				
<b>Auriga</b>	41	h	20	bc
<b>DH 401</b>	46	a	17	e
<b>DH 863</b>	46	a	17	f
<b>Jari</b>	46	a	18	e
<b>Krios</b>	45	b	18	e
<b>OAC Petrel</b>	43	d	20	c
<b>OAC Prudence</b>	43	de	19	cd
<b>Savanna</b>	42	ef	20	b
<b>SK0007</b>	43	c	19	d
<b>SVX14T0053</b>	44	c	19	e
<b>Toma</b>	42	fg	21	a
<b>Tundra</b>	41	gh	19	e
<b>Source of Variation</b>	----- $P > F$ -----			
<b>Site</b>	<b>0.0006</b>		<b>0.0002</b>	
<b>Cultivar</b>	<b>&lt;.0001</b>		<b>&lt;.0001</b>	
<b>Site-Cultivar</b>	<b>&lt;.0001</b>		<b>&lt;.0001</b>	

\*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance

**Table 24.** Protein content values for 12 soybean cultivars from 3 site years under organic management

Cultivar	Carman 2015**		Somerset 2015*	Woodmore 2015*
	-----%-----			
	Weedy	Weed-Free	Average	Average
Auriga	40 k	41 jk	41 ef	40 e
DH 401	48 a	48 ab	46 ab	44 ab
DH 863	48 ab	47 ab	47 a	44 ab
Jari	48 a	47 bc	47 ab	45 a
Krios	46 d	46 c	46 bc	43 b
OAC Petrel	44 e	44 ef	43 d	41 cde
OAC Prudence	43 fgh	43 gh	42 de	42 bc
Savanna	43 gh	42 hi	42 ef	41 cd
SK0007	43 fgh	42 ghi	43 d	44 a
SVX14T0053	45 d	45 d	45 c	42 cd
Toma	43 fg	42 hi	41 f	41 cde
Tundra	41 ij	40 k	42 def	40 de
<b>Weedy/Weed-Free</b>				
<b>Weedy Average</b>	44.3a		43.7b	42.1b
<b>Weed-Free Average</b>	43.9b		44.1a	42.6a
<b>Source of Variation</b>	----- P>F-----			
Cult	<.0001		<.0001	<.0001
Weedy/Weed-Free	0.0005		0.041	<.0001
Interaction	0.019		0.7942	0.0736

\*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance

\*\*Means within both weedy and weed-free columns followed by the same letter are not significantly different at 0.05 level of significance



**Table 25.** Oil content values from 12 soybean cultivars in 3 site years under organic management

Cultivar	Carman 2015**		Somerset 2015*	Woodmore 2015*
	-----%-----			
	Weedy	Weed-Free	Average	Average
Auriga	21 bc	20 cd	19 c	21 ab
DH 401	16 o	17 n	17 ef	19 d
DH 863	17 mn	17 mn	16 f	19 d
Jari	18 lm	18 jk	19 de	19 cd
Krios	18 kl	17 mn	17 de	19 cd
OAC Petrel	20 gh	19 fgh	19 bc	20 bc
OAC Prudence	20 ef	20 def	19 bc	19 bcd
Savanna	20 cde	20 cde	20 b	21 ab
SK0007	20 fg	20 defg	19 c	18 d
SVX14T0053	19 hi	19 hi	18 d	19 d
Toma	21 ab	21 a	21 a	22 a
Tundra	19 ij	19 ghi	18 d	19 d
<b>Weedy/Weed-Free</b>				
<b>Weedy Average</b>	19		18	19
<b>Weed-Free Average</b>	19		18	19
<b>Source of Variation</b>	----- P>F-----			
Cult	<b>&lt;.0001</b>		<b>&lt;.0001</b>	<b>0.0002</b>
Weedy/Weed-Free	0.0685		1	0.8915
Interaction	<b>0.0101</b>		1	0.2571

\*Means within a column followed by the same letter are not significantly different at the 0.05 level of significance

\*\*Means within both weedy and weed-free columns followed by the same letter are not significantly different at 0.05 level of significance