STUBBLE MANAGEMENT EFFECTS ON MICROCLIMATE AND PERFORMANCE OF CANOLA ACROSS DIFFERENT CLIMATIC REGIONS IN WESTERN CANADA

BY

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Abstract

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In the Canadian Prairies the climate is semi-arid, which causes moisture to be a limiting factor in canola production. Previous research in the most arid region of the Canadian Prairies has shown alteration of the microclimate using wheat stubble cut tall the previous year can create more favorable microclimatic conditions for canola development. There were three main objectives of this research. The first was to determine if stubble cut short or tall created microclimatic differences in air temperature close to the ground. The second was to determine if these stubble treatments created significant benefits for canola performance. The hypothesis was that tall stubble would reduce evaporative soil moisture loss and improve canola emergence with a subsequent positive effect on yield. If the tall stubble treatment improved the surface soil moisture levels, this could also increase disease pressure on the crop. Therefore, a third objective was to determine whether stubble treatment had a significant impact on canola disease pressure.

In 2011, four field sites were established; one location in Manitoba at Swan Lake, two in Saskatchewan at Indian Head and Swift Current and one site in Grimshaw, Alberta. In 2012 there was an expansion of the experiment to include additional locations at Kenton MB, Falher and Lethbridge AB. At each site, large replicated plots of tall stubble cut at 50 cm height were compared to large replicated plots of short stubble cut at 20 cm tall and a stripper header

treatment (present at five of the eleven site years) in which only the heads of the wheat were removed causing the stubble to be longer than 50 cm.

The microclimatic conditions that were measured in each treatment included growing degree hours (GDH) accumulated during the 10 days prior to the second leaf stage of canola development. Microclimatic conditions included air temperature measured in the stubble profile at 50, 20, 5 cm above and 5 cm below the soil surface, snow catch, soil moisture and evapotranspiration. There were significant differences in GDH at 5 cm below the soil surface compared to the other three heights, but no differences in growing degree days between the three levels above the soil surface. Between the tall and short stubble treatments there were no significant differences in accumulated GDH between the four stubble heights. This indicated that stubble height variation did not create significant differences in the air temperature profile near the ground surface. The results of the snow catch accumulation in 2011 and 2012 were consistent with previous data showing tall stubble creates a wind barrier that increased snow catch compared to short stubble. However, the impact of snowmelt on spring soil moisture was masked by heavy spring precipitation in both 2011 and 2012. The evapotranspiration rates were highly variable during the 2011 and 2012 growing seasons but overall were independent of stubble height.

Canola performance was evaluated using % seeds emerged, plant population density per m^{-2}, canola biomass, yield, harvest index and disease pressure from Blackleg and Sclerotinia. The canola emergence and plant populations showed no significant treatment effect from the three stubble treatments. Over the 11 site years there was only one site in 2011 that had a significant difference between treatments in canola biomass production and overall yield. The harvest index and disease pressure from Blackleg and Sclerotinia showed no significant differences created by the stubble heights. The one location (Grimshaw 2011) with significantly higher biomass and yield in the tall compared to the short stubble was coming out of a three year drought cycle. This indicates that tall stubble can have a measurable benefit to canola performance when spring conditions are dry. However, additional data is needed to better quantify where and how often tall stubble would provide a measurable benefit. If drought stress is apparent at harvest, then implementing tall stubble to trap more snow and reduce evaporative demand could potentially create greater moisture reserves in the spring.

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Chapter 1 Introduction

1.1 Background

The global population recently reached 7 billion people, increasing pressure to produce more food, fuel and fiber. Canada is fortunate to have a large agricultural land base and relatively small population making the nation an exporter of many different crops. An important crop in Canada is canola *(Brassica napus* L.. In 2011 it contributed 15.4 billion dollars to the Canadian economy with the majority grown and processed in Western Canada (Canola Council of Canada, 2011c). Canola demand is increasing because of the status of canola oil as a healthy diet choice, low in saturated and trans fats and high in linoleic acid which is a source of vitamin E (Canola Council of Canada, 2011d). Canola is also a potential source of biodiesel which reduces CO_2 emissions when blended with diesel fuel (Canola Council of Canada, 2011a). Growing market demand increases the price of canola which creates incentive for producers to grow more of this crop. However, there are significant limitations to further canola production in Western Canada. The climate of the Canadian Prairies is semi-arid, therefore, soil moisture is often a limiting factor in canola production. If simple changes in management could affect even small changes in the microclimate for canola growth the following year, this could result in an increase in the overall yield and production of the crop.

A potential strategy to reduce the moisture limitation normally experienced on the Prairies is to utilize the previous season crop stubble to alter the microclimate for the current season's crop to retain more of the overwinter snowfall on the field and reduce evaporative losses. Previous research (Cutforth and McConkey 1997, Cutforth et al. 2002, Cutforth et al. 2006) in one of the most arid region of the Canadian Prairies near Swift Current, Saskatchewan indicated that the alteration of the early season microclimate by leaving tall stubble from the previous year can possibly create more favorable conditions for early emergence in several different crops. The research was conducted on wheat (*Triticum* spp.) in 1997, pulse crops in 2002 and canola in 2007. It was reported that tall stubble reduced wind speed and evapotranspiration compared to shorter stubble, improving the water use efficiency of the various crops that were studied (Cutforth and McConkey 1997, Cutforth et al. 2002, Cutforth et al. 2006). Cutforth et al. (2011) found the benefits to crop yield with tall stubble compared to cultivated stubble was the tall stubble reduced stresses on the crop during emergence (ex. wind damage) and improved water use efficiency in the crop while reducing moisture lost through evaporation. The early emergence benefits are believed to translate into higher yields. Earlier research by Aase and Siddoway (1980) on the planting of winter wheat into spring grain stubble showed taller stubble allowed for more snow to collect on the soil surface. In addition, a reduction of the microclimate temperature above the soil surface of the tall stubble and a greater wind speed reduction in the tall stubble contributed to lower evaporation. Based on this previous research, it appeared that there would be potential for a relatively simple and inexpensive crop management technique to improve canola production.

1.2 Climate and Environmental Alterations from Stubble

Wheat stubble left after the fall harvest of an annual crop creates the opportunity to trap increasing amounts of snowfall on the field in proportion to the length of the stubble. Studies in the northern USA place snowfall at 20% of the mean annual precipitation on the Northern Great Plains (Willis et al., 1969; Siddoway, 1970; Aase, and Siddoway, 1980). Steppuhn (1994) showed the amount of snow collected within the standing stubble is directly related to the stubble height. If more snow is caught in the stubble there will be the potential for more snowmelt to infiltrate into the soil which is an added benefit to crops in dry areas (Campbell et al., 1992). If there is not enough moisture in the soil after the crop has emerged the crop can be harmed due to water stress, at later stages of its development (Willis et al., 1961). Aase and Siddoway (1980) asserted snow could provide a moisture reserve to the soil during the spring melt if there is some type of barrier on the soil surface to trap the snow such as standing stubble. If there is no barrier then snow accumulates in low elevation points on a field, ditches and other barriers like fences or barns. Aase and Siddoway (1980) compared snow accumulation for winter wheat planted into a bare treatment and stubble treatments 19 cm or 35 cm in height in Sidney, Montana USA. Their results showed a 3.6 times greater accumulation of snow on the tall (35 cm) treatments compared with the bare soil plots. The extra accumulation of snow led to a water gain of 1 to 3 cm in the stubble treatments. At the end of the growing season, the bare soils had a decrease of soil moisture compared to the spring moisture level but the two wheat stubble treatments showed slightly more moisture at the end of the growing season than in the spring (Aase and Siddoway, 1980). Thus, standing stubble catches more snow than bare soils, creating the potential for higher soil moisture levels following the spring melt. However, the amount of water infiltrating into the soil during the spring melt is also dependent on favorable soil conditions for infiltration (Campbell et al. 1986, 1992, Steppuhn, 1994, Cutforth and McConkey 1997).

Gauer et al. (1982) compared soil water levels under zero tillage with and without residues removed and conventional tillage and found higher soil moisture in the zero tillage plots, especially in the early part of the growing season when the majority of soil moisture loss was lost from evaporation in the bare plots. They also reported that in the early part of the growing season, the stubble covered soil (under zero-tillage) had lower maximum soil temperatures, than the conventional tillage and zero-tilled plot with no stubble on the surface but no difference between the minimum temperatures recorded (Gauer et al., 1982). Overall the average weekly temperature in the early season was between 0.5 to 2°C lower in the zero-tillage with stubble on the surface (Gauer et al., 1982).

Cutforth et al. (2006) measured soil temperatures 5 cm below the surface and found they were cooler under tall stubble treatments than the cultivated bare soil plots. Cutforth and McConkey (1997) also reported significant differences, between the cultivated, short and tall stubble treatments in wind speed and solar radiation, before the 3-5 leaf stage. Although air temperature showed no significant difference at 15 cm and 1 meter height above the stubble treatments, the tall stubble tended to have lower temperatures (Cutforth and McConkey 1997). Cooler temperatures within tall stubble create conditions in the spring that would lower evaporation allowing for a larger moisture reserve within the soil for the canola to uptake after seeding of the crop (Aase, and Siddoway, 1980; Cutforth and McConkey, 1997).

Tall stubble also functions as a windbreak. Cutforth et al. (2006) documented average daily wind speed in tall stubble (30 cm) was reduced by 77% at 15 cm above the soil surface, 14% at 100 cm above the ground and 7% at 200 cm above the ground compared with cultivated stubble. These results are very similar to the study by Cutforth and McConkey (1997) where tall stubble reduced wind speed by 70% at 15 cm and 10% at 100 cm. For pulse crops that were seeded into tall spring wheat stubble, the wind speed was reduced 70% at the 15 cm height and 8% at 100 cm height compared to cultivated stubble (Cutforth et al., 2002). Reduced wind speeds protect small emerging plants from damage as a result of strong wind gusts and particles being transported in the air (Aase and Siddoway, 1980).

The barrier created by standing stubble reduces evaporative demand on plants. The greater the amount of wind on a crop in water deficient area, the larger the demand of evapotranspiration on the crop which increases moisture stress (Cutforth et al., 2006). A crop planted within taller stubble, will experience lower evaporative demand because the standing stubble barrier can reduce wind speed near the surface, lower soil water loss through evapotranspiration and maintain soil water levels for plant use for a greater length of time when moisture is limited (Rosenberg, 1976). Standing stubble creates a thicker boundary layer above the ground surface which lowers the amount of heat being transferred from the soil (Gauer et al., 1982). Indirect evidence of warmer soil conditions with barriers such as standing stubble comes from Frank et al. (1976), who showed the growth rate of agricultural crops increased when they were growing near or in a non-competitive barrier.

Standing stubble also affects the amount of sunlight reaching the soil surface. It has been shown that tall stubble (30 cm) reduces solar radiation at 7.5 cm above ground compared to short stubble (15 cm) (Cutforth et al, 2006). The shading effect of the stubble reduces sunlight reaching the surface. Tall stubble (30 cm) was able to reduce the incoming solar radiation by 21% before the flowering stage of the canola plant, as the plant developed there was a further 38% reduction of solar radiation after flowering when compared with canola on a bare surface (Cutforth et al., 2006).

Shading from the stubble seems to affect the crop throughout the growing season. Other microclimate factors such as soil temperature are most pronounced when the crop is emerging. During the bolting stage, the canola reaches the height of the standing stubble. At this stage of development, microclimate alterations created by tall stubble would be reduced within the crop canopy because canola on any type of stubble would have reached a similar height and size.

The growing season normally extends from May to August with precipitation generally heaviest during June and July. After seeding, canola emerges, usually in May then grows rapidly through June and early July. The highest growing season temperatures generally occur near the end of July then decline by the harvest. This rapid increase in leaf surface area, along with increasing temperatures normally creates a moisture deficit at some point during the growing season depending on the amount of spring soil moisture and the local level of precipitation (Bullock et al., 2010). Canola also prefers cooler conditions and is at risk of heat stress during later stages of development (Angadi et al., 2000). Approximately one third of energy used during evapotranspiration is consumed during the transfer of latent heat from the soil surface (Hagen and Skidmore 1974, Grace and Quick 1988, Cutforth and McConkey 1997). Transpiration of water through plant leaves requires large amounts of solar energy, thus a well-watered canola crop can lower the plant surface temperature through evaporative cooling (Rosenburg, 1976).

Cutforth et al. (2006) estimated consumptive water use (CWU) using soil water at harvest minus soil water at seeding plus precipitation during the growing season. Water use efficiency (WUE) was calculated by dividing CWU by grain yield. They had several treatments of tall and short stubble during the 2001-2002 drought in Western Canada. The microclimate alterations from tall stubble were insufficient to overcome the extreme drought stress and provided no benefit to the canola. Cutforth and McConkey (1997) conducted a similar experiment on spring wheat on tall stubble (43 cm), short stubble (15 cm) and bare soil. The precipitation during the growing season which ran from 1992-1995 was average to above average. They found that evapotranspiration was not affected by the tall and short stubble heights but WUE was significantly greater in plots with tall stubble (43 cm) than plots with the short stubble (15 cm) and bare soil. Cutforth and McConkey (1997) also noted lower temperatures in the tall stubble.

1.3 Physical Processes and Stubble Effects

Although zero-till has been used since ancient history, during the 20th century there was a shift towards intensive tillage. In the 1970s it was realized that excessive tilling was not sustainable, and there was a shift from intensive tillage back to zero-till or conservation tillage (Triplett and Dick, 2008). Reduced tillage management has been widely adopted across many regions of Western Canada to reduce soil erosion, improve the soil structure, and increase soil organic matter, all of which provides potential for increased crop productivity and improved water use efficiency (Triplett and Dick, 2008). On the Canadian Prairies, the two major issues of soil erosion and moisture stress can cause reduction of cereal productivity. Reduced tillage management is able to address both limitations (Cutforth and McConkey, 1997).

Bruce et al. (2005) conducted a stubble retention experiment at different locations in southeastern Australia comparing canola development (emergence, growth and yield) between stubble left on the soil surface compared with bare soil. At one site, a comparison of canola emergence and yield was made between plots that had bare soil (which had stubble burned before seeding) and different amounts of spread wheat stubble on the soil surface. The spread stubble was wheat stubble left lying in piles on the soil surface and ranged from 2 to 10 t ha^{-1}. The growth and development of canola in the spread stubble was greatly reduced with higher amounts of stubble lying on the surface compared to bare treatments (Bruce et al. 2005). Overall emergence was reduced 25% and growth was reduced by 33% with spread stubble of 5 t ha^{-1} or more. Canola on spread stubble that was less than 4 t ha^{-1} generally had no significant difference in canola emergence, growth and yield compared to the bare soil (Bruce et al. 2005). Canola on spread stubble had smaller plant weight, fewer leaves and the longest length of hypocotyl arc (Bruce et al. 2005). The delays in early canola development on spread stubble were decreased as the canola reached the flowering stage but there was some evident reduction of canola seed at harvest (Bruce et al. 2005). The overall average of the bare and spread stubble showed the spread stubble had a 23% reduction of canola seed yield (Bruce et al. 2005). The significant reduction in canola yields from the standing stubble could have resulted from a variety of reasons such as reduction of sunlight, cooler temperatures near the soil surface or toxicity from the decomposing stubble (Bruce et al. 2005, Hocking and Stapper, 2001). In an additional study, Bruce et al. (2006) found that both spread stubble and a plastic cover reduced individual canola root lengths by 43% compared with the bare soil treatments. These results show that conditions which delay or reduce emergence during early canola development can negatively affect the canola crop throughout the growing season. It also shows possible draw backs to having stubble spread on the soil surface instead of being left in a standing position.

1.4 Biological Effects of Standing Stubble

Stubble management affects not only the microclimate for emerging canola but also the biological components of the field such as disease risk. The three requirements for a crop to become infected with a disease are a susceptible host, the presence of the disease vector and favorable environmental conditions. Altering the microclimate under a canola canopy, due to the stubble treatment, tends to create moister soil conditions, which can result in higher humidity under the canola canopy and an increased risk of disease outbreak. Two important diseases that affect canola in western Canada are Sclerotinia *(S. sclerotiorum* Lib. De Bray*)* and Blackleg *(Leptosphaeria maculans* Sowerby*)*, both of which can cause significant yield reduction.

1.4.1 Sclerotinia

Sclerotinia is difficult to control once a field is infected and fungicides are expensive for the farmer to apply (Bom and Boland, 2000). The Government of Saskatchewan sclerotinia stem rot forecast lists five factors that are critical in determining sclerotinia risk in canola: (1) number of years and crop rotations since canola was last planted on that field; (2) occurrence of sclerotinia in the last infected crop; (3) crop density; (4) presence of apothecia and ascospore release during the canola flowering stage; (5) heavy rainfall before and during the canola flowering stage (Government of Saskatchewan, 2009b).

The sclerotia produced by the disease are capable of surviving the winter within the soil. At the early blossom stage of the canola crop there can be small mushrooms called apothecia sprouting on the soil surface which release tiny ascospores (Canola Council of Canada 2011b). The ascospores, because of their size, are transported by the wind over large distances. When the spores land on petals of the canola crop, they use the petal tissue as a food source (Canola Council of Canada 2011b). As the canola plant matures the petals fall off the leaves and under moist conditions stick and collect on leafs and stems of the canola plant from where they can infect the plant with sclerotinia (Canola Council of Canada 2011b). One to two weeks after petals drop from the canola plant, the impact of sclerotinia starts to become apparent in the field (Canola Council of Canada, 2011b). The infected canola plant becomes white and the stem dries out becoming very brittle to the touch. This causes lodging of the canola crop and shattering of the pod when the crop is either swathed or during harvest causing a reduction in canola yield.

The Canola Council of Canada (2011b) states the standard yield loss on a field infected by sclerotinia is approximately one-half of the percentage of infected plants observed in a field. The council also states that even though the disease is highly variable, it is estimated to be economically in the producer's best interest to apply a fungicide if the percentage of crop affected by sclerotinia is more than 15%.

1.4.2 Blackleg

Blackleg can significantly damage canola and decrease yields. The source of the blackleg is the fungus called *Leptosphaeria maculans* (Guo et al., 2005). The blackleg fungus overwinters on infected canola stubble. This is slow to breakdown and can cause disease outbreaks three to five years later (Government of Alberta, 1997). The Blackleg fungus can affect any part of the canola plant and at any stage from seedling to podding (Government of Saskatchewan, 2009a). The disease generally is found on the stem of the canola plant, along several inches of stem length with a black or grey appearance (Canola Council of Canada 2011b). The infection dries the base of the plant causing it to ripen earlier and causing the plant to lodge easier (Government of Saskatchewan 2009a). The yield of a crop infected with blackleg declines because the early ripening causes the pods and seeds to shatter during swathing or harvesting.

Despite an increase in producers switching to no-tillage which increases the amount of residue on the soil surface, blackleg disease pressure has not increased (Government of Saskatchewan 2009a). It has been shown in experiments done in Carman, Manitoba, that crop rotations with non-host crops can reduce blackleg pressure in a canola field (Guo et al. 2005). If non-host crops such as cereals, grasses or pulse crops are included within a crop rotation this reduces blackleg incidence within canola (Guo et al., 2005).

1.4.3 Canola Yield

Microclimate alterations using stubble management have been shown to increase yields of canola in the Swift Current region of Canada (Cutforth et al., 2011). Further, there was a linear relationship between canola yield and stubble height such that the greater the stubble height in the semi arid prairies the higher the yield (Cutforth et al., 2011). The maximum height at which stubble was found to create this linear relationship between stubble height and yield was 45 cm. At the larger stubble heights created by stripper headers, it was not known if the additional stubble would have a yield benefit or create conditions which disadvantage the crop (Cutforth et al., 2011).

1.5 Hypothesis and Objectives

The literature overall has generally reported that tall stubble provides better microclimate conditions for canola emergence by increasing soil moisture levels and reducing both evaporative demand and seedling damage via lower wind speed. However, most of these data originate from the most arid region of the Northern Great Plains, where soil moisture deficit is frequently a significant problem. The potential benefits sound promising but require testing across a wider range of climatic conditions and on large field size plots to better understand whether the benefits extend across the broad range of conditions experienced on the prairies.

The hypothesis is that taller standing stubble will enhance canola performance the following year by altering the microclimate favorably. More specifically, tall stubble or stripper header stubble will enhance the germination of canola as well as create additional moisture reserves within the soil and cooler canopy conditions that will enhance canola growth and yield. An additional hypothesis is that tall stubble alteration of the microclimate under canola will increase the risk of disease pressure, specifically from Sclerotinia and Blackleg as a result of the moister conditions.

The overall objective of this project is to determine if the favorable impact of tall stubble on the following canola crop reported near Swift Current can be duplicated across the range of growing season weather conditions in the canola growing region of Western Canada. The results will help determine if taller stubble is able to alter the microclimate to create significant variation in canola response variables such as emergence, biomass production and yield in different climatic regions.

Ultimately, the goal is to determine if the practice of leaving tall stubble can increase canola yields and generate higher production without additional inputs of pesticides and fertilizers. This would benefit both producers and the environment, in particular the surface water and groundwater in proximity to agricultural land.

1.5.1 Scope of the Study

This project evaluated cereal stubble height management across the prairie region to determine the effects of higher stubble on the microclimate and yield of the following canola crop across the broad range of climatic conditions found in Western Canada. All sites had two types of treatments, short stubble, which is around 20 cm in height and tall stubble, that is 50 cm in height. At several sites, stripper header stubble, which results in only the heads of the preceding crop being cut during harvest leaving the entire stock of plant intact, was also evaluated. One treatment of conventional fall tillage was also evaluated.

During the 2011 growing season, there were four locations; Swan Lake, Manitoba, Indian Head Saskatchewan, Swift Current Saskatchewan and Grimshaw Alberta. During the 2012 growing season, three additional sites were added at Kenton Manitoba, Falher and Lethbridge Alberta. The Indian Head and Swift Current sites were located at Agriculture and Agri-Food Canada Research stations, while Swan Lake and Grimshaw were located on producers' fields. Kenton consisted of two separate fields located on producer land. The Falher site and the Lethbridge site were both located on producer land. These sites provided a range of climatic conditions across which the canola performance from emergence to final harvest was monitored and compared with the microclimate alteration caused by the stubble treatments.

Several different types of data were collected at each site including air temperature using specially designed iButton stations which measured air temperature 50, 20, 5 cm above the soil surface and soil temperature 5 cm below the surface, soil moisture levels in the spring and fall, crop emergence, biomass, yield, Sclerotinia incidence, Blackleg incidence and snow catch. Impact assessment focused on two critical stages of the growing season (1) seeding to the 2 to 4 leaf stage and (2) canola maturity to harvest.

The thesis contains two main data chapters and a concluding synthesis. The first of these chapters highlights the microclimate alternations across the various stubble treatments in terms of snow catch, the spring moisture in the soil profile after the spring melt, air temperature profile prior to the 2^{nd} leaf stage, overall evapotranspiration and the macro level of precipitation and temperature over the growing season. The second data chapter focuses on the biological response of the canola to the stubble treatments and microclimate alterations including canola emergence, the disease pressure in all treatments, the amount of biomass and yield per treatment and the harvest index.

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Chapter 2 Microclimate alterations from the Stubble Treatments

2.1 Abstract

The climate of the Canadian Prairies is semi-arid, thus moisture is a limiting factor in canola production. Previous research in one of the most arid regions of the Canadian Prairies indicates that the alteration of the early season microclimate using tall wheat stubble from the previous year can create more favorable microclimatic conditions for the canola. The objective of this research was to test this approach over a broad range of climatic conditions across western Canada to determine climatic alterations created by different stubble treatments. In 2011 four field sites were established; one location in Manitoba at Swan Lake, two in Saskatchewan at Indian Head and Swift Current and one site in Grimshaw, Alberta. In 2012 there was an expansion of the experiment to include additional locations at Kenton MB, Falher and Lethbridge AB. At each site, large replicated plots of tall stubble cut at 50 cm height were compared to large replicated plots of short stubble cut at 20 cm tall and a stripper header treatment (present at five of the eleven site years) where only the head of the wheat was removed. The snow catch, soil moisture and evapotranspiration of the stubble treatments were estimated. Within each stubble treatment, two iButton towers monitored air temperature at 50, 20, 5 cm above and 5 cm below the soil. There were no significant differences between the Growing Degree Hours in the tall and short stubble treatments. There generally was significantly lower heat unit accumulation 5 cm below the soil surface compared to the other three heights which had no significant variation between each other. The results of the snow catch accumulation in 2011 and 2012 were consistent with previous data showing tall stubble creates a wind barrier that increases snow catch compared to short stubble. However, the impact on spring

soil moisture was masked by heavy precipitation early in the growing season during the months of May and June in both 2011 and 2012. The Swift Current location in 2012 showed a significant treatment effect in the stripper header treatment which was likely an artifact of damage to the stubble over the winter. The evapotranspiration rates were highly variable during the 2011 and 2012 growing seasons but overall were independent of stubble height.

2.2 Introduction

In Western Canada, the area seeded to canola has increased significantly from 6,403,198 acres in 1986 (Statistics Canada 1986) to 12,388,717 acres in 2006 (Statistics Canada 2007). Canola is normally grown in a 2 to 4 year rotation with other crops and commonly it is grown the year following wheat or another cereal. Previous studies from Cutforth and McConkey (1997), Cutforth et al. (2002) and Cutforth et al. (2006) have evaluated the benefits of leaving the wheat stubble from the previous year in the field and the microclimate alterations created in crops grown in the following growing season. Standing stubble is a common occurrence in conservation agriculture which utilizes minimal or no tillage and can have several benefits such as reduced erosion, improved soil organic matter content and increased soil water moisture reserves. The tall stubble also alters the microclimate near the soil surface and within the emerging crop itself which affects soil moisture as well as the surface temperature of both the soil and the air (Cutforth et al. 2011). This impacts the early season performance of the crop that is planted into the stubble. Stubble height management is basically a mechanical management alternative that can potentially increase yields the following year and generate more income from greater amounts of canola produced without adding any additional pesticides or fertilizers. Thus, any benefits that accrue from this simple stubble management modification would add directly to producer canola production revenue.

On the Canadian Prairies, moisture demand normally outstrips the available crop water supply (Bullock et al. 2010). The majority of research on stubble height alteration of the microclimate has been conducted in the most arid regions of the Canadian Prairies and suggests that additional soil moisture by snow catch from taller stubble could result in a net benefit to the canola crop (Cutforth et al. 2011). Under extreme moisture stress, Cutforth et al. (2006) found the microclimate alterations that were created by various stubble heights were unable to completely overcome the extreme moisture deficits. It is not known whether taller stubble will have a beneficial impact on the microclimate in less arid regions of the prairies, nor if the microclimate alterations will benefit the canola seeded into the stubble.

The study focused on microclimate alterations in different climatic zones created by different stubble heights. It is hypothesized that the taller stubble length and stripper header stubble length can reduce the amount of solar radiation reaching the ground which can reduce evaporation and maintain larger moisture reserves in the soil. In comparison to shorter stubble, the additional barrier created by the tall stubble was expected to alter the air temperature close to the ground surface, reduce wind speed and lower evaporation from the soil surface. By placing these stations in different canola growing regions the variation created by the tall and short could be compared across different climate regions.

The objective of this project was to evaluate the impact of stubble height management on the microclimate next to the soil surface at a range of growing locations across Western Canada. The microclimate parameters specifically of interest were snow catch, soil moisture, evapotranspiration and surface air temperature. Replicated large-scale plots were monitored to determine if there were significant differences between the treatments at each site. The results will help determine if tall stubble, which can be beneficial in arid regions, can provide similar benefits in other climatic regions.

2.3 Materials and Methods

2.3.1 Study Sites

The study sites were located in Swan Lake (2011, 2012) MB, Kenton (2012) MB, Indian Head (2011, 2012) SK, Swift Current (2011, 2012) SK, Lethbridge (2012) AB, Falher (2012) AB and Grimshaw (2011, 2012) AB. The stubble from the preceding wheat crop was either sculpted in the fall or early spring ahead of canola seeding to create replicates of short 20 cm stubble and tall 50 cm stubble at all of the locations (Table 2.1). In addition to the short and tall stubble treatments, there was also a stripper header stubble treatment at the Swift Current, Lethbridge and Grimshaw sites. The stripper header removes just the head of the standing cereal crop leaving most of the entire length of the stem intact following harvest. The Grimshaw site also included a conventional tillage treatment that was unique to the Grimshaw site only.

Table 2.1 Study site locations and dates of management operations.

	Sculpting Date	Seeding Date	Spring Moisture[z] Sample Date	Swathing Date	Fall Moisture[z] Sample Date
Swan Lake 2011[y]	Fall-2010	07-19	07-28	N/A	10-21
Indian Head 2011	Fall-2010	05-17	06-10	08-18	08-26
Swift Current 2011	Spring-2011	06-02	06-06	08-13	08-26
Grimshaw 2011[x]	Spring-2011	05-24	06-01	10-01	10-14
Swan Lake 2012	Fall-2011	05-15	05-15	08-25	08-22
Kenton 2012[w]	Fall-2011	05-13	05-15	08-15	09-04
Indian Head 2012	Fall-2011	05-17	06-01	08-28	08-28
Swift Current 2012	Fall-2011	05-14	05-11	08-25	08-28
Lethbridge 2012[v]	Spring-2012	05-12	05-14	09-16	N/A
Falher 2012	Spring-2012	05-16	05-19	09-15	10-14
Grimshaw 2012[x]	Spring-2012	05-28	05-09	09-27*	09-28

[z]Moisture samples from 0-15, 30-45, 60-75, 90-105 and 105-120 cm unless otherwise noted.

[y]Seeding significantly delayed by excessive spring moisture. Canola did not mature. No harvest.

[x]Moisture samples from 0-15 and 30-45 cm only.

[w]Moisture samples from 0-15, 15-30, 30-60, 60-90 and 90-120 cm in fall. No 90-120 in spring.

[v]Moisture samples not taken in the fall.

*Exact date of canola swathing unknown and assumed swathing to be near the time of fall moisture sample dates.

Table 2.2 Study site locations soil types and environmental data.

	EcoZone	EcoRegion	EcoDistrict	Soil Series	% of District	Soil Texture
Swan Lake	Prairie	Manitoba Upland	Pembina Hills	Altamont[x]	20	Clay Loam
				Dezwood[y]	18	Loam
				Firdale[y]	11	Loam
Kenton	Prairie	Aspin Parkland	Hamiota	Taggart[y]	28	Clay
				Harding[y]	20	Clay
				Janick[z]	10	Clay Loam
Indian Head	Prairie	Aspin Parkland	Kipling Plain	Oxbow[w]	87	Loam
Swift Current	Prairie	Mixed Grassland	Swift Current Plateau	Hillwash	48	Undifferentiated
				Alluvium Chenozemic[y]	23	Loam
Lethbridge	Prairie	Mixed Grassland	Lethbridge	Lethbridge[z]	90	Loam
Falher	Boreal Plain	Western Boreal	Falher	Bareburn[w]	60	Clay Loam
				Calais[y]	30	Clay
Grimshaw	Boreal Plain	Peace lowlands	Grimshaw	Whitelaw[w]	50	Clay Loam
				Albright[w]	35	Clay Loam

[w]Well Drained Till

[x]Poorly Drained Lacustrine Soil

[y]Moderately Drained Lacustrine Soil

[z]Well Drained Lacustrine Soil

2.3.2 Meteorological Data

All study sites had weather stations set up on or near the site to record the macroclimate. At Swan Lake, both a Campbell Scientific weather station (Campbell Scientific, Logan, UT) and a Watchdog weather station (Spectrium Technologies, Plainfiled, IL) were installed adjacent to the site in 2011 and recorded air temperature, humidity, wind speed, solar radiation and rainfall during the growing season. At Indian Head and Swift Current, meteorological data was recorded from Environment Canada weather stations located on site that monitored air temperature, humidity, wind speed, solar radiation and rainfall during the 2011 and 2012 growing seasons. At Grimshaw 2011, the closest Environment Canada weather station was the Peace River Airport approximately 20 km away, which was the only weather data available for this site.

At Swan Lake 2012, the Campbell Scientific weather station was set up adjacent to the site along with a Decagon weather station (Decagon Devices, Inc., Pullman, WA). At the Grimshaw 2012, Lethbridge, Kenton and Falher sites Decagon weather stations were installed to record relative humidity, temperature, solar radiation, wind speed, wind direction and precipitation.

2.3.3 Snow Catch and Accumulation

Snow catch was monitored only at the sites where the stubble was sculpted in the fall to determine the potential snow melt recharge created by the tall and short stubble treatments. These sites included Swan Lake and Indian Head in both 2011 and 2012. Swift Current was sculpted in the fall of 2011 but lack of snow that winter precluded any snow measurements. The 2011 measurements were taken on April 4th at Swan Lake and April 11th at Indian Head. In 2012, the Swan Lake samples were taken on March11th and Indian Head on March12th.

Snow density and snow depth were measured in each treatment replicate to determine snow water equivalent. Snow depth was determined by pushing a wooden meter stick vertically into the snowpack down to the ground surface and recording the depth to the nearest centimeter (cm). The snow depth measurements were taken at 15 random locations across each treatment replicate in 2011 and at 20 random locations in 2012. If the snow was very dense, a mallet was used to hammer the meter stick down to the ground surface. In some areas, there were large snow drifts which required numerous attempts to reach the ground surface.

Snow density measurements were taken approximately 25 m from each end of each treatment in spring 2011 (2 per treatment). During spring 2012, snow cores were taken at 3 random locations in each treatment. Snow density was measured by inserting a 1.2 meter by 3.8 cm clear plastic tube vertically into the snowpack down to the ground surface. A mallet was used to drive the tube down to the ground surface if the snow was hard. Once the tube was fully inserted to the soil surface, the depth of the snow in the tube was recorded. A hole was dug adjacent to the sample tube and a shovel was slid under the lower end of the tub to prevent the snow from falling out. The snow that was captured within the tube was placed into a zip lock bag and sealed. The following day the snow had melted into a liquid which as weighted. The volume of the snow core was divided by the weight of the melted snow to determine the snow water equivalent for each treatment. The mean snow water density for each replicate was multiplied by the mean snow depth for the same replicate to determine each replicate's snow water equivalent.

2.3.4 Soil Moisture Measurements

It was intended to have soil moisture measurements from the soil profile at each treatment replicate at every site at the time of seeding and at the time of swathing to calculate a water balance and estimate evapotranspiration. Weather conditions and the logistics of site locations spanning 1500 km across western Canada presented challenges in achieving this goal, so it was only partially successful (Table 2.1). Additionally, at the fall-sculpted sites, soil samples were taken to determine the moisture levels in the various treatments at the end of the snow melt.

A Dutch auger and meter stick were utilized to extract soil samples at the depths 0-15, 30-45, 60-75, 90-105 and 105-120 cm. There were either 3 or 4 samples taken from every treatment replicate at the time of sampling. The samples were sealed and taken to the laboratory where a subsample was taken for wet weight measurement. Each subsample was dried in an oven at 105°C for at least 24 hours, and then weighed to determine the oven-dry weight and the gravimetric soil moisture content.

Soil bulk density samples were taken at each site. Either 3 or 4 bulk density samples were taken for each treatment replicate at the same depths as the gravimetric samples. During the 2011 season, bulk density samples were taken with an Iwan flat-bottomed auger and using a meter stick to determine the depth increment of each sample. The volume of the soil extracted was calculated from the diameter of the auger and depth increment. A subsample of soil from the auger was taken to the laboratory where it was dried in an oven at 105°C for at least 24 hours, then weighed to determine the oven-dry weight and the bulk density of the sample. In the 2012 season, most of the bulk density samples were taken using a Giddings soil probe rather than the Iwan flat-bottomed auger.

Each gravimetric soil moisture determination was multiplied by the soil bulk density for the same soil layer to determine the volumetric moisture content of each depth range. This was converted to cm of moisture for each depth increment, and the cm moisture for all depths at a sample location were added to determine total moisture content in the soil profile. The profile water contents from all samples in each replicate were averaged to determine cm total moisture in the soil profile by treatment replicate.

2.3.5 Evapotranspiration

Evapotranspiration (ET) was estimated using a water balance approach. The spring total soil water (θvs) in each treatment replicate was added to the total amount of precipitation (Pgs) that fell during the growing season at that site and the fall volumetric moisture content (θvf) for the treatment replicate was then subtracted. The calculation for each treatment replicate is shown below.

$$ET = (\theta vs + Pgs) - \theta vf$$

This equation assumes that no rainfall is lost via runoff or deep drainage and it also assumes that net groundwater recharge or discharge into the soil profile is zero. The growing season weather was not ideal for meeting these conditions, so there is certainly a risk of error with this method. At several sites, there were also difficulties acquiring the spring or fall moisture samples within a time frame that was representative of when the canola was utilizing soil moisture. For that reason, a number of the sites were not utilized for growing season ET calculation. The sites which were considered suitable for evaluating growing season ET included Indian Head 2011, Swift Current 2011, Swan Lake 2012, Kenton 2012, Indian Head 2012 and Swift Current 2012.

2.3.6 I-Button Station Programming and Construction

The device used to measure air and soil temperature near the surface was the Thermochron iButton (Dallas Maxim, *San Jose, CA*). The device has been used previously in scientific research because of its accuracy (Abatzoglou et al. 2011, Hubbart et al. 2005). The sensor is an integrated circuit that logs temperature as well as the date and time of each reading with an accuracy of +/- 0.5° C (Dallas Maxim 2012). The model DS1922L Thermochron iButton can hold a total of 8192 8-bit readings over time intervals ranging from 1 second to 273 hours. In this study, during 2011, the iButtons were programmed to record air temperature every 15 minutes (900 seconds). This was more data than was required and in 2012 the iButtons were programmed for hourly air temperature readings.

Towers were constructed to hold iButton sensors at four different heights: 5 cm below the soil surface and, 5 cm, 20 cm and 50 cm above the soil surface. The towers were constructed from 3.8 cm ABS pipe cut to 90 cm in length then split lengthwise into two semi-circular shields. The top 60 cm were spray-painted white to reduce radiative heat transfer. After the white paint was applied, a yellow stripe was painted 30 cm from the bottom on the inside of the ABS pipe to mark the depth to which each tower was inserted into the soil. This was to ensure that all of the stations at all of the various study locations and treatments would be installed at the correct depth. An iButton holder was constructed from a strip of 1.3 cm birch wood. Each holder was about 70 cm long. The holes for the iButtons were placed at intervals of 10 cm, 20 cm, 35 cm and 65 cm along the birch wood. The wood was later fastened to the inside of a semi-circular ABS pipe section. A black line was drawn 15cm from the lower end of the birch wood and lined up with the yellow stripe on the pipe section to ensure the buttons were held in place at the correct depth and height. Holes 1.6 cm in diameter were drilled in the center of the birch wood at each measured height and then the wood strip was attached with machine screws and wing nuts. The wing nut was an important part of the design because in 2011 the iButton data needed to be retrieved twice during the growing season and the wing nut design allowed for easy removal of the iButton holder to retrieve the data and return it to its exact spot without removing the tower from the ground. During the 2012 season, the hourly data collection allowed the iButtons to remain in place in the field until after the crop bolted at which time all of the data was downloaded at one time. The final step of the iButton tower construction was to fill the back of the wooden hole between the birch wood and the pipe with insulating foam to prevent warming of the iButton as a result of heat absorption by the pipe. The iButton sensors were then pushed into the holes that had been drilled in the wood prior to the towers being deployed in the field.

Each station was labeled to identify its location on its specific treatment. Every iButton sold from the manufacturer had its own code engraved on the stainless steel surface of the device. The identification number was recorded, as well as its position on the station and the treatment and site to which the device was deployed. This was done to ensure the date from each iButton could be quickly assigned to the correct site, treatment and height.

There were two iButton towers deployed in each treatment on either end of the plot. For the statistical analysis only the data from the tall and short stubble treatments were used. Comparisons were made between the iButton sensor readings from a tower in a short stubble treatment to the closest tower in a tall stubble treatment. There were three comparisons done for each site. The layout and design of each study site varied therefore the distance between iButton stations in adjacent tall and short treatments were different. The variation in plot size and orientation did not lend itself to a comparison of average values of iButton temperatures on the same treatment. The iButton stations in closest proximity between a tall and short treatment was used for growing degree hours (GDH) accumulation and statistical analysis. The time period of 10 days prior to the 2^{nd} leaf stage was used to standardize the comparisons at all sites. The rationale was that this is the critical early growth period for canola and the stage when differences in surface air temperature would be significant to the early development of the crop. The hourly air temperatures for exactly 10 days were used to calculate GDH which were accumulated for each iButton at each height in each treatment (Table 2.2). The calculation of growing degree hour is shown below.

$$GDH = \sum T_h - T_b$$

The GDH was calculated by taking the recorded air temperature at a specific height of the air temperature profile (T_h) and subtracting it from a base temperature (T_b) of 0˚. In 2011, T_h was calculated from four instantaneous measurements taken within the hour. In 2012, T_h was an instantaneous measurement at the top of the hour.

Table 2.3 iButton GDD comparisons at each site

Location	iButton Towers Compared	Distance Between Stations (m)	GDH Accumulation Period
Swan Lake 2011	A1 (short) B1 (tall), E1 (short) F1 (tall), G1 (short) H1 (tall)	20-24	22/07/2011-31/07/2011
Indian Head 2011	A2 (short) B2 (tall), C2 (short) D2 (Tall), E2 (short) F2 (tall)	49-52	04/06/2011-13/06/2011
Swift Current 2011	D1 (short) C2 (tall), G2 (short) H1 (tall), J2 (short) K1 (tall)	20	22/06/2011-01/07/2011
Grimshaw 2011	G1 (short) J1 (tall), G2 (short) J2 (tall), F2 (short) I1 (tall), F1 (short) I2 (tall)	20	10/06/2011-19/06/2011
Swan Lake 2012	A2 (short) B2 (tall), C1 (short) D1 (tall), E1 (short) F1 (tall), G2 (short) H2 (tall)	11-15	27/05/2012-05/06/2012
Kenton 2012	B2 (short) C2 (tall), H1 (short) E1 (tall), J1 (short) I1 (tall), J2 (short) I2 (tall)	19	01/06/2012-10/06/2012
Indian Head 2012	A2 (short), B1 (tall), B2 (tall) C1 (short), C2 (short) D1 (tall), G2 (short) F1 (tall)	30	27/06/2012-06/07/2012
Swift Current 2012	B1 (short) D1 (tall), G1 (short) E1 (tall), L1 (short) J1 (tall)	20	27/05/2012-05/06/2012
Lethbridge 2012	E1 (short) F1 (tall), E2 (short) F2 (tall), H1 (short) I1 (tall), H2 (short) I2 (tall)	21	25/05/2012-04/06/2012
Falher 2012	C1 (short) H1 (tall), C2 (short) H2 (tall), E1 (short) J1(tall), E2 (short) J2 (tall)	20	29/05/2012-07/06/2012
Grimshaw 2012	C1 (short) D1 (tall), C2 (short) D1 (tall), E1 (short) D2 (tall)	19	12/06/2012-21/06/2012

2.3.7 Statistical Analysis

Prior to statistical treatment, response variable data collected from the stubble management project temperature profile results were expressed as the accumulated GDH values for each height at each site. The accumulated GDH values were taken from stations closet apart in the tall and short stubble treatments at each site. The layout of the sites varied, so some treatments were dropped from the analysis to create a balanced RCBD. The response variables were modeled using a four-way ANOVA with the fixed effects treatment, site, height and year. Replication nested within site and year was considered the random effect. To meet the assumption of Gaussian distribution of residuals, GDH data were log transformed. Following transformation, outliers were removed using Lund's test (Lund 1975). ANOVA was conducted using the mixed procedure in SAS. Heterogeneity of variances were corrected when necessary via the repeated statement using AIC (Akaike Information Criteria) as a measure for the most correct model. Following ANOVA, means were separated using the pdmix800 macro (Saxton, 1998) using the Scheffe test.

The response variables snow melt water equivalent, spring soil moisture and evapotranspiration were analyzed as described above with minor exceptions. The fixed effects were treatment, site and year if necessary. Replication was considered random. The ANOVA was conducted using a two-way factorial model on spring soil moisture data and a three-way ANOVA including year on the remaining response variables. All else was as described above.

2.4 Results and Discussion

2.4.1 Growing Season Weather Conditions

During 2011, precipitation was above average (based on the 30 year long term average from Environment Canada, 2013) at three of the four locations (Table 2.3). During the growing season, it was generally wet during spring and early summer which delayed seeding at Swan Lake and Swift Current. At all four of the 2011 sites, the month of May had higher than average precipitation and three of the four sites had higher than average June precipitation (Figures 2.1 to 2.4). The precipitation was below average in July at Swan Lake, Indian Head and Swift Current with Grimshaw showing above average July precipitation. In August 2011, all four sites experienced below average precipitation. The monthly temperature trend was the opposite to the precipitation pattern with below average values early in the season and slightly above average later in the year at all but the Grimshaw location, which was warmer than average in May and below average from June through August (Table 2.3).

In 2012, precipitation levels were lower than the previous year but still above normal at four of the seven locations (Table 2.3). Generally, the precipitation pattern in 2012 was similar to 2011 with wetter conditions earlier in the growing season followed by a more gradual reduction in precipitation to below average levels (Figures 2.5 to 2.11). However, the timing varied between sites. Swift Current, Lethbridge and Falher all had above average precipitation during May, and June and below average precipitation during July and August (with the exception of Falher in the month of July). At Indian Head and Kenton there was above average precipitation in May and July and below average precipitation in June and August. At Swan Lake and Grimshaw the entire growing season had below average precipitation. The growing season was generally warmer in 2012 than in 2011, especially in the Peace River region (Table 2.4). However, the pattern was variable over the remaining five locations with a mix of slightly above and below average temperatures at different times of the year.

Table 2.4. May through August Precipitation at the study sites.

Site	Long-Term Mean[z]	2011 Total Precipitation	2011 % of Mean	2012 Total Precipitation	2012 % of Mean
Swan Lake	273.5	222.8	81.5%	177.0	64.7%
Kenton[y]	245.8	-	-	228.6	93.0%
Indian Head	250.3	291.0	116.3%	285.4	114.0%
Swift Current	218.6	272.6	124.7%	230.7	105.5%
Lethbridge[y]	161.8	-	-	200.2	123.8%
Falher[x]	182.9	-	-	251.8	137.7%
Grimshaw[w]	228.3	351.9	154.1%	225.8	98.9%

[z] Long term means are from 1971-2000 data at Pilot Mound, Brandon, Indian Head, Swift Current, Lethbridge, Peace River and Peace River, respectively (Environment Canada, 2013)
[y] Precipitation was measured from May 15 to August 31. Long-term mean precipitation for May was divided by 2.
[x] Precipitation was measured from May 15 to August 15. Long-term mean precipitation for May and Aug was divided by 2.
[w] In 2011, the Grimshaw precipitation was measured at Peace River, approximately 20 km away.

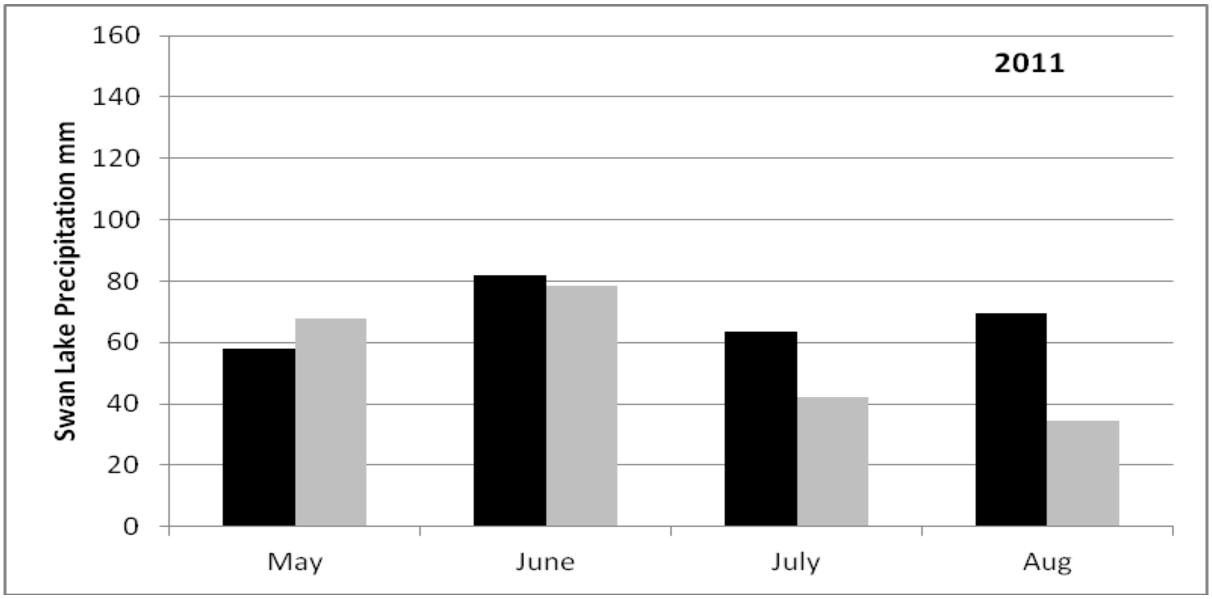

Figure 2.1. Swan Lake site monthly precipitation for 2011 (light grey bar). Long term average precipitation at Pilot Mound (black bar, Environment Canada 2013).

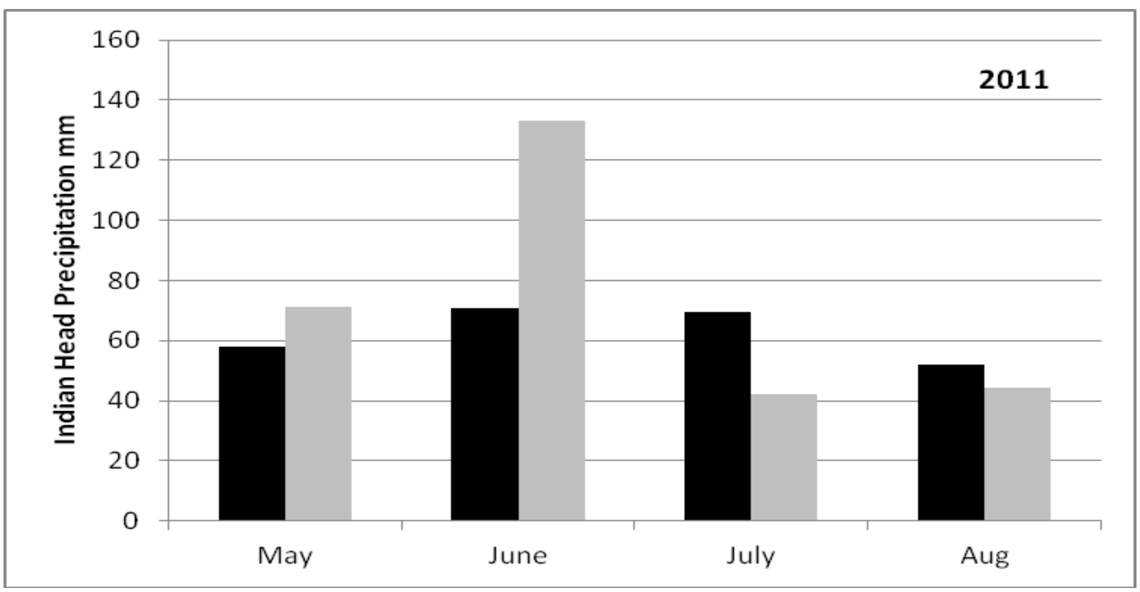

Figure 2.2. Indian Head monthly precipitation for 2011 (light grey bar). Long term average precipitation at Indian Head (black bar, Environment Canada 2013).

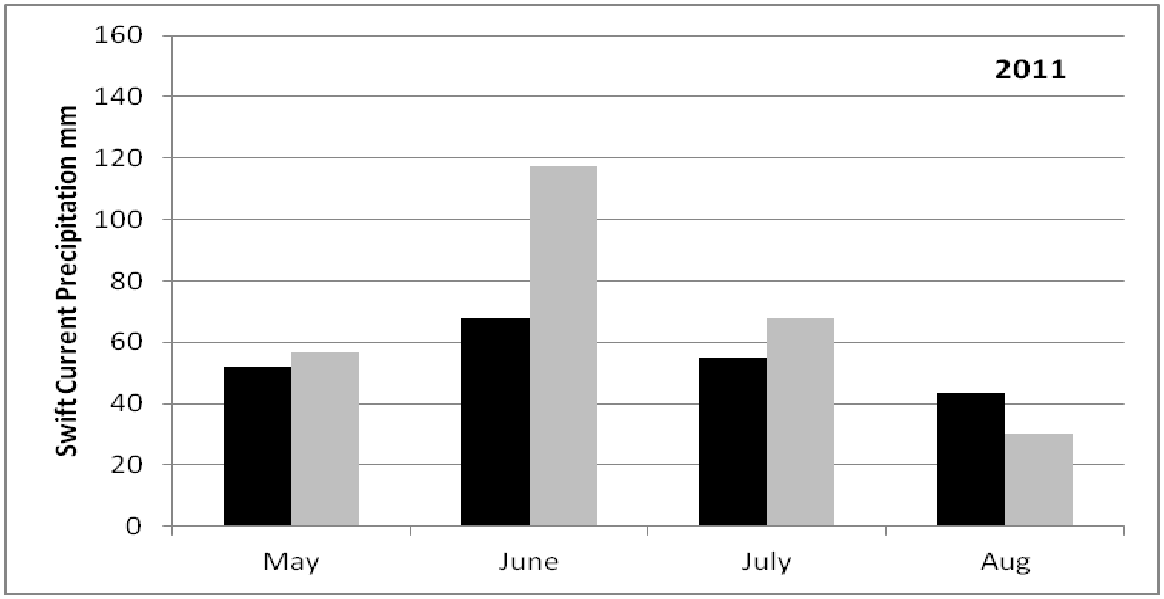

Figure 2.3. Swift Current monthly precipitation for 2011 (light grey bar). Long term average precipitation at Swift Current (black bar, Environment Canada 2013).

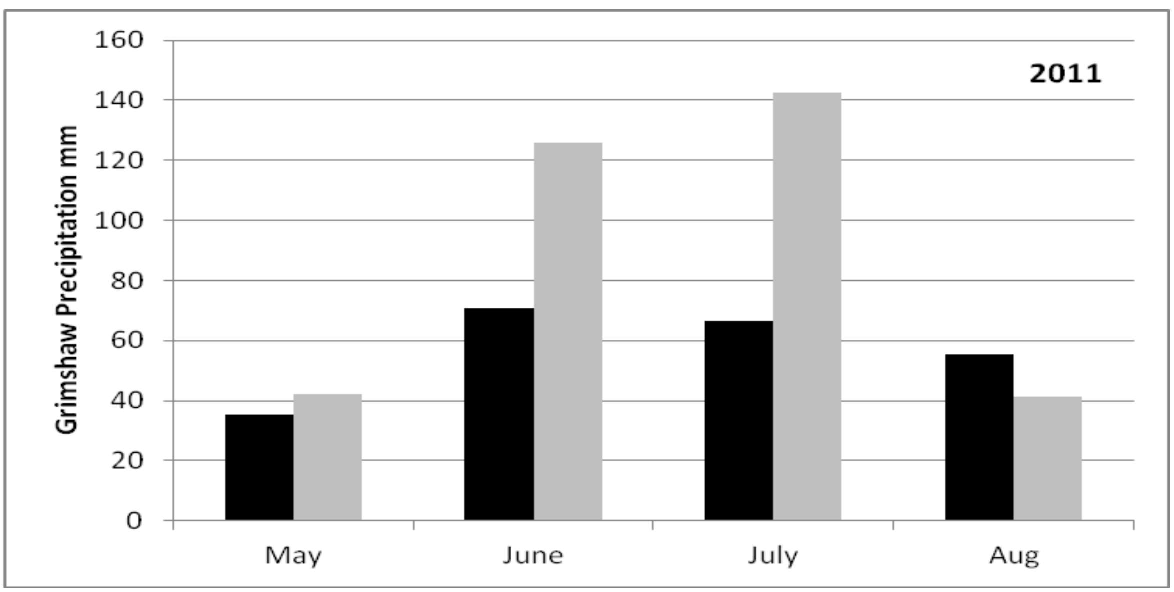

Figure 2.4 Grimshaw monthly precipitation for 2011 as measured at Peace River approximately 20 km away (light grey bar). Long term average precipitation at Peace River (black bar, Environment Canada 2013).

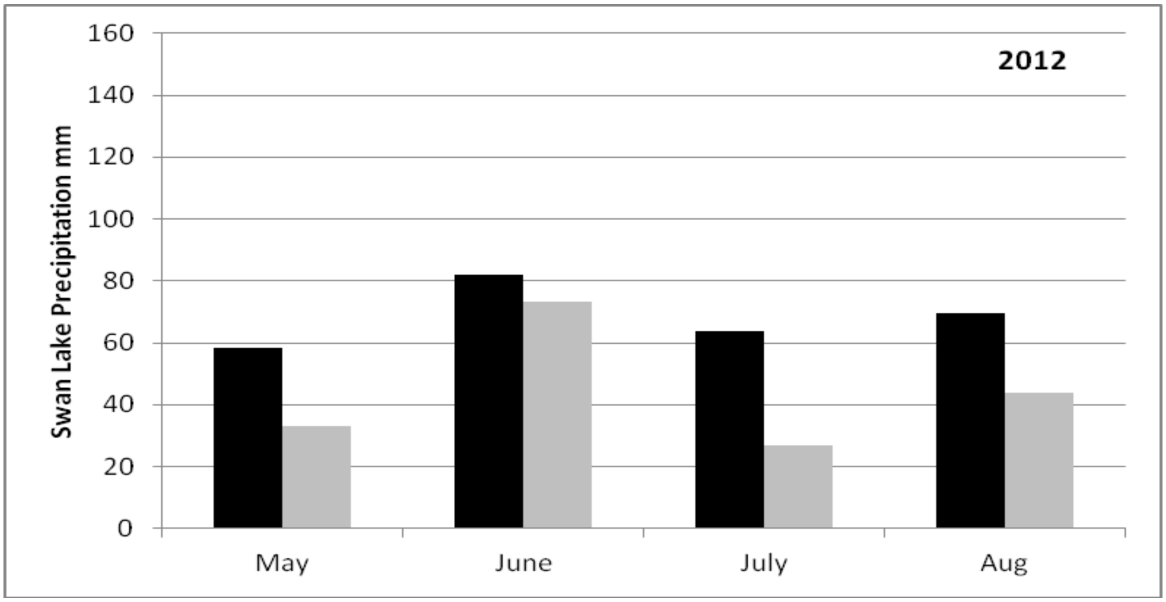

Figure 2.5. Swan Lake on site monthly precipitation for 2012 (light grey bar). Long term average precipitation at Pilot Mound (black bar, Environment Canada 2013).

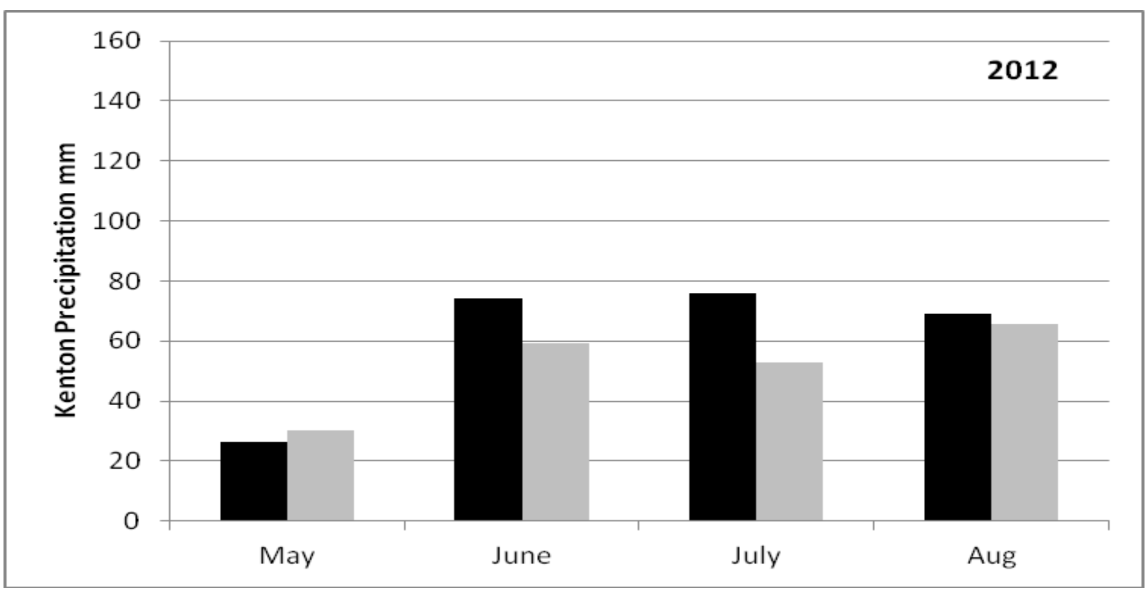

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Figure 2.6. Kenton on site monthly precipitation for 2012 (light grey bar). Long term average precipitation at Brandon (black bar, Environment Canada 2013). May normal has been divided by 2 for comparison because precipitation monitoring commenced on May 15

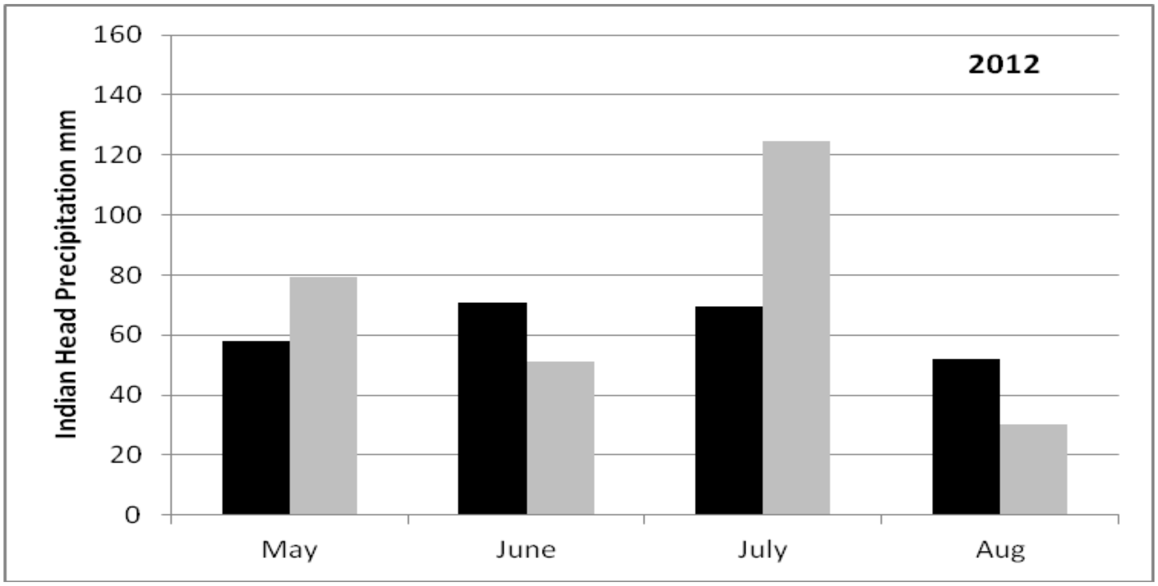

Figure 2.7. Indian Head monthly precipitation for 2012 (light grey bar). Long term average precipitation at Indian Head (black bar, Environment Canada 2013).

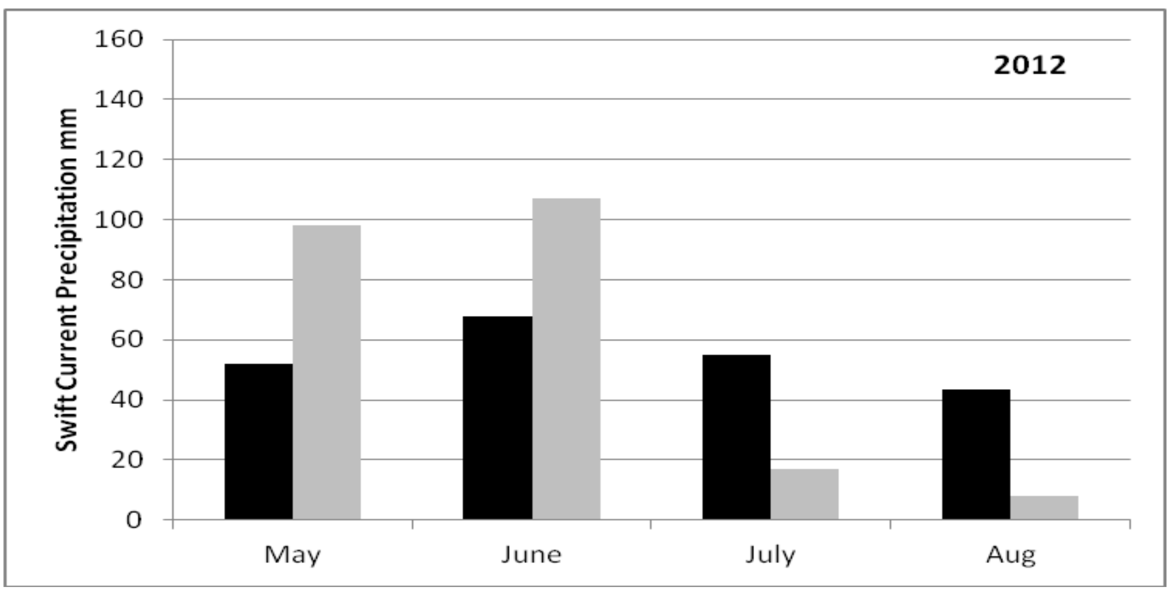

Figure 2.8. Swift Current monthly precipitation for 2012 (light grey bar). Long term average precipitation at Swift Current (black bar, Environment Canada 2013).

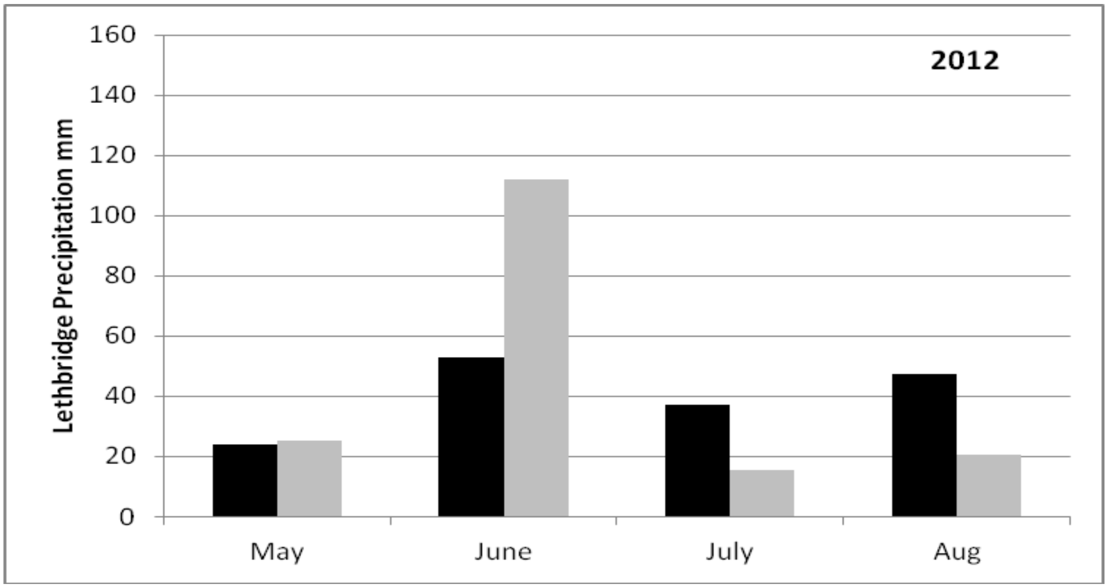

Figure 2.9. Lethbridge site monthly precipitation for 2012 (light grey bar). Long term average precipitation at Lethbridge (black bar, Environment Canada 2013). May normal has been divided for 2 for comparison because precipitation monitoring commenced on May 15.

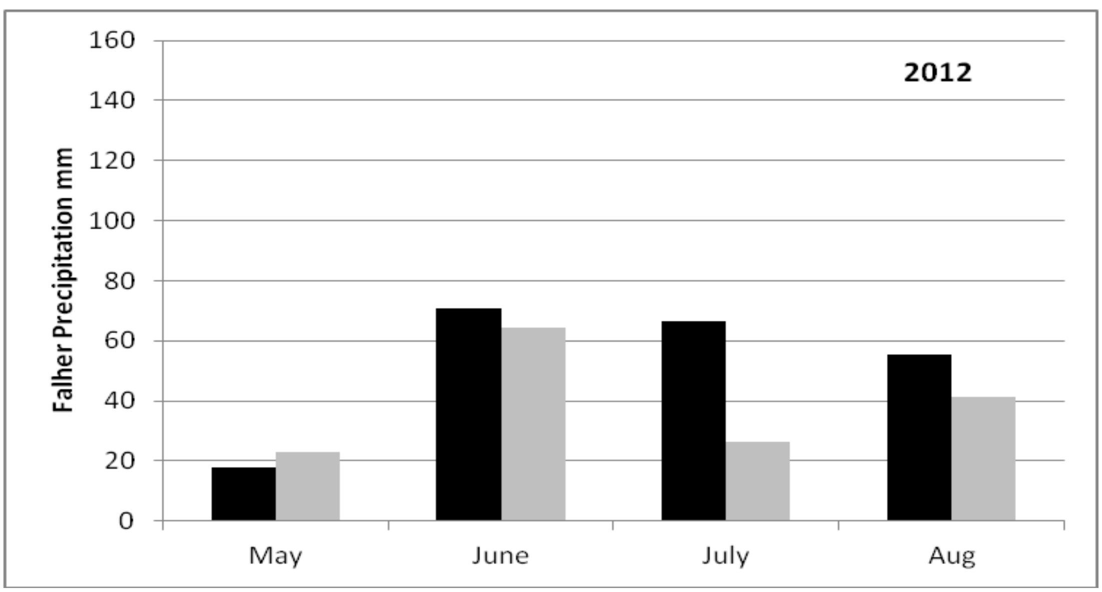

Figure 2.10. Falher site monthly precipitation for 2012(light grey bar). Long term average precipitation at Peace River (black bar, Environment Canada 2013). (Monthly total recorded on site with a Decagon station). May and August normals have been divided by 2 for comparison because precipitation monitoring commenced on May 15 and ended August 15.

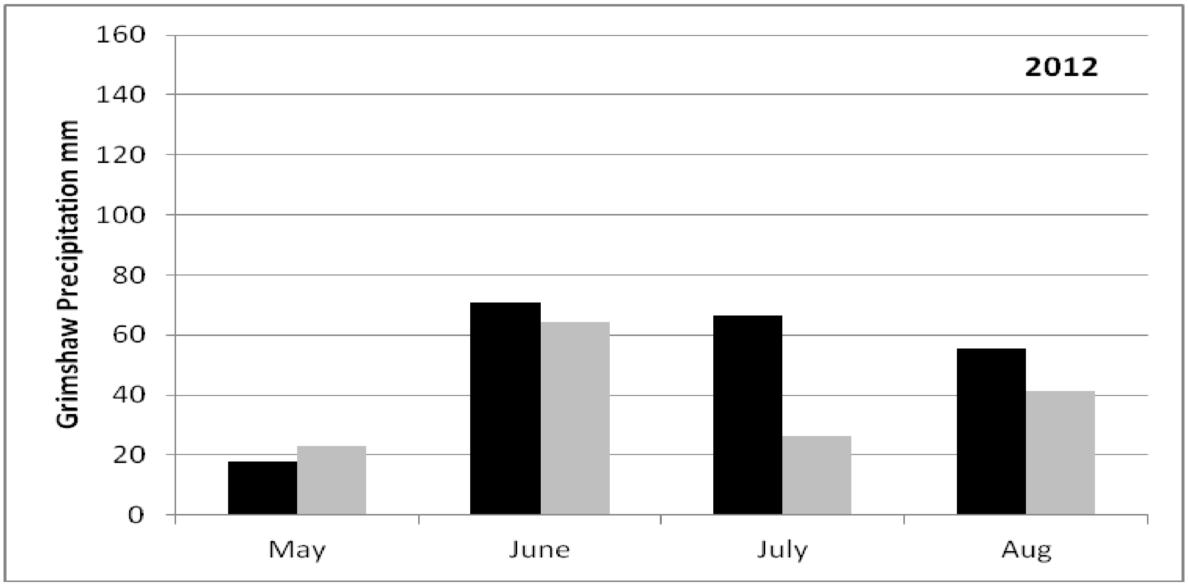

Figure 2.11. Grimshaw site monthly precipitation for 2012 (light grey bar). Long term average precipitation at Peace River (black bar, Environment Canada 2013). May normal has been divided by 2 for comparison because precipitation monitoring commenced on May 15.

The Canadian Prairies are semi-arid and moisture stress can have significant effects on crop yield. In addition, canola is known as a cool season crop with yield decreases as a result of heat stress (Angadi et al. 2000; Brandt and McGregor 1997; Morrison 1993). During the 2011 and 2012 growing seasons, the general trend in the weather pattern was above average precipitation early in the growing season followed by a sudden shift to below average precipitation. Higher than average precipitation early in the growing season likely masked any potential benefits of a larger moisture reserve that the tall stubble could produce from higher snow catch during winter.

Table 2.5. Monthly growing season temperatures at the study sites.

Site	Month	Long-Term Mean[z]	2011 Monthly Temperature	2011 Deviation from Mean	2012 Monthly Temperature	2012 Deviation from Mean
Swan Lake	May	11.3	9.6	-1.7	10.9	-0.4
	June	15.8	15.9	0.1	17.6	1.8
	July	18.7	19.0	0.3	21.4	2.7
	August	17.9	18.3	0.4	18.5	0.6
Kenton[y]	May	10.8	-	-	11.3	0.5
	June	16.7	-	-	17.2	0.5
	July	21.0	-	-	20.9	-0.1
	August	18.5	-	-	18.1	-0.4
Indian Head	May	11.4	9.5	-1.9	9.9	-1.5
	June	16.1	15.1	-1.0	16.5	0.4
	July	18.4	18.8	0.4	19.2	0.8
	August	17.5	17.8	0.3	17.1	-0.4
Swift Current	May	11.1	9.5	-1.6	9.4	-1.7
	June	15.6	14.3	-1.3	15.5	-0.1
	July	18.1	18.2	0.1	20.0	1.9
	August	17.9	18.2	0.3	19.0	1.1
Lethbridge[y]	May	11.4	-	-	10.7	-0.7
	June	15.6	-	-	14.8	-0.8
	July	18.2	-	-	18.4	0.2
	August	17.7	-	-	17.2	-0.5
Falher[x]	May	10.2	-	-	11.5	1.3
	June	14.2	-	-	15.1	0.9
	July	16.0	-	-	17.8	1.8
	August	14.7	-	-	15.9	1.2
Grimshaw[w]	May	10.2	11.9	1.7	11.4	1.2
	June	14.2	13.5	-0.7	15.0	0.8
	July	16	15	-1.0	18.5	2.5
	August	14.7	14.5	-0.2	16.3	1.6

[z] Long term means are from 1971-2000 data at Pilot Mound, Brandon, Indian Head, Swift Current, Lethbridge, Peace River and Peace River, respectively (Environment Canada, 2013)
[y] Temperature was measured from May 15 to August 31.
[x] Temperature was measured from May 15 to August 15.
[w] In 2011, the Grimshaw temperature was measured at Peace River, approximately 20 km away

In general, monthly precipitation as a percent of normal was higher when monthly temperature deviation from normal was lower and vice versa. A combination of warmth and drier weather in the latter part of the growing season put increased moisture stress on the canola crop, which would be expected to impact yield negatively. This pattern was not as clearly evident at the Grimshaw 2011 location where June and July had above average precipitation and below average temperatures with a reversal in the month of August. This would have limited the moisture stress at this location. During 2012, this wet early season followed by a drier period was apparent but generally not as extreme as that in 2011.

2.4.2 Snow Catch and Accumulation

The snow pack was measured at Swan Lake and Indian Head in both 2011 and 2012 because the wheat stubble was sculpted into tall and short treatments in the fall prior to the growing season. This was also done at Swift Current 2012 but the snow melted before measurements of the snow pack could be taken. At Kenton the cereal stubble was also sculpted in the fall of 2011 but due to time constraints on the project snow pack data was not recorded. At Indian Head the tall stubble was cut 50 cm and the short stubble was 20 cm, but at Swan Lake the stubble treatments were shorter with the tall stubble 35 cm and the short stubble 15 cm.

As expected, the tall stubble generally caught significantly more snow than the short stubble at both sites except for Swan Lake 2012 (Figure 2.12). In 2012, snow fall was limited but the tall stubble still collected more snow than the short stubble. There was virtually no snow remaining in the short stubble at Indian Head in 2012 because of very mild temperatures by the time of sampling in March. The Swan Lake 2012 location had cooler weather during the winter, so more snow was retained in the short stubble by the time of sampling in March. Overall, the tall stubble treatments consistently had a higher snow water equivalent in the late winter at both locations. In 2011, there were larger amounts of snow caught at Indian Head compared to Swan Lake. In 2012, there was no statistical difference in snow catch between sites.

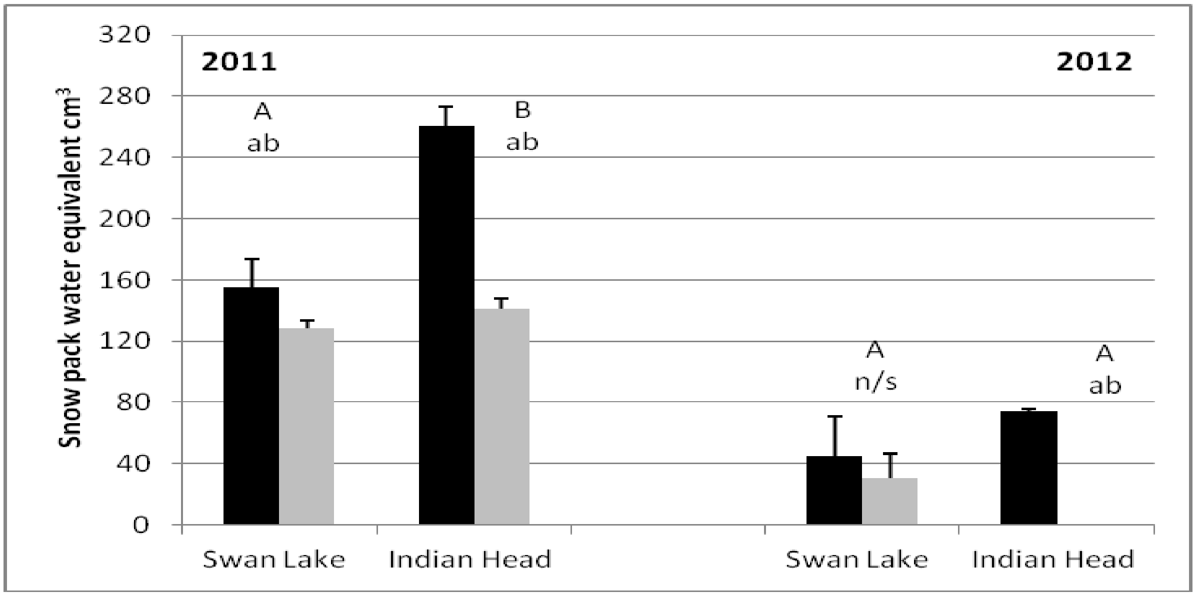

Figure 2.12 Snow water equivalent, calculated as mean snow density and mean snow depth per treatment at Swan Lake and Indian Head in 2011 and 2012 (black bar-tall stubble, light grey bar-short stubble). Capital letters indicate significant differences between sites and small letters indicate significant differences between treatments by site, both at p=0.05.

These results are consistent with previously published work on barriers and snow catch (Aase and Siddoway, 1980), which found that tall stubble cut to 35 cm, caught 3.6 times as much snow compared to a bare soil. The greater the stubble height, the more snow trapped (Cutforth and McConkey 1997; Steppuhn 1994). Wheat stubble on the soil surface acts like a wind barrier and catches snow within the stubble row. Without the stubble on the soil surface the snow would have accumulated in low spots or other topographical locations like ditches and along fences (Aase and Siddoway, 1980).

2.4.3 Spring Soil Moisture

Two 2011 sites and three 2012 sites with stubble treatments sculpted the previous fall provided an opportunity to determine if there were significant effects on the amount of spring soil moisture following snow melt. During the spring of 2011, there were heavy rains early in the season which eliminated any differences in soil moisture as a result of snow melt and infiltration from the different stubble treatments.

In 2012, a comparison of spring soil moisture after snow melt showed a significant site effect but treatment was only significant at Swift Current where the stripper header stubble had significantly higher spring moisture compared to the tall stubble. The short stubble was not statistically different compared to the tall and stripper header treatments in a spring moisture profile (mm) of water per 120 cm of soil (Figure 2.13).

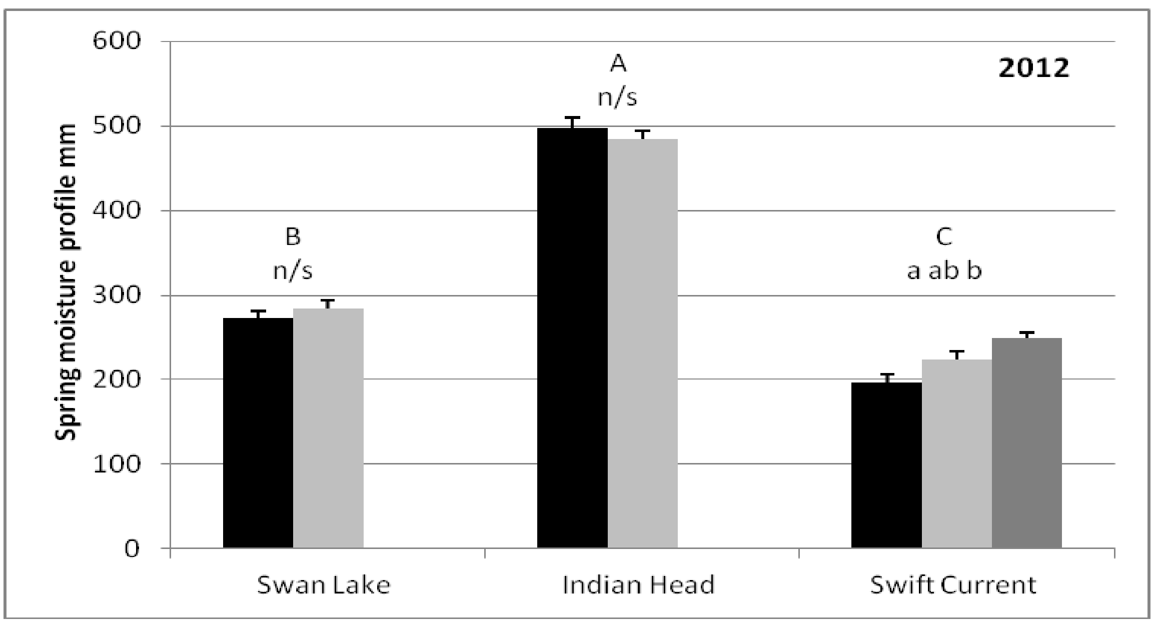

Figure 2.13 Spring soil moisture (mm) per 120 cm soil depth (black bar-tall stubble, light grey bar-short stubble, dark grey bar-stripper header stubble). Capital letters indicate significant differences between sites and small letters indicate significant differences between treatments, both at p=0.05.

Spring soil moisture after snow melt at Swan Lake, Indian Head and Swift Current in 2012 was significantly different (Figure 2.13). Generally, on an east-west transect across the southern Canadian Prairies, the climate becomes increasingly arid in a westward direction from Winnipeg towards the foothills of the Rocky Mountains. In 2012, Swift Current, which is located in the most arid region, had the lowest spring moisture reserves as would be expected. However, Swan Lake had lower soil moisture levels than Indian Head, more because of spring rainfall than snow melt. Swan Lake site had almost 30 mm less than the long term average precipitation for May (Figure 2.5). There was over 25 mm of extra May rainfall in Indian Head compared to the long term average (Figure 2.7). The additional rainfall not only gave Indian Head the highest spring soil moisture levels of the 3 sites but also reduced any measurable variation of spring soil moisture in the tall and short stubble treatments that may have occurred as a result of differences in the amount of spring snow melt between these treatments (Figure 2.12). The variation in spring soil moisture across the 3 sites was a function of the variation in fall precipitation, snow melt, spring rainfall and texture. A wide variation in spring soil moisture conditions between locations in western Canada is a normal occurrence for a region of this size.

At Swan Lake and Indian Head in 2012, the spring rainfall was sufficient to mask any differences in soil moisture between tall and short stubble (Figure 2.13). The significant treatment effect at Swift Current location was unexpected because the tall stubble treatment had significantly lower soil moisture (195 mm) than the stripper header stubble (240 mm). The short stubble was intermediate (240 mm) and not significantly different than either the tall or the stripper header stubble. The tall and stripper header stubble at Swift Current 2012 were heavily lodged by snow and wind over the winter and were in very poor condition when inspected in mid-March. Most of the tall and stripper header stubble was laying on the soil surface instead of standing upright. Most of the snow in Swift Current had melted by March 2012; however, it is entirely possible that the short stubble caught more snow because it remained upright compared to the tall and stripper header stubble. The stripper header stubble was the longest and created a thicker layer of biomass on the soil surface when it lodged in comparison to the tall stubble. It is possible that the heavier stripper header stubble laying on the ground reduced evaporation more than in either the short stubble or the lodged tall stubble. Thus, the stripper header stubble was more effective in limiting the evaporative losses of the heavy rainfall in May (Figure 2.8) than either the short or tall stubble.

Despite the majority of locations having limited differences in soil moisture between treatments, the effectiveness of tall stubble to trap snow was clearly demonstrated and it can be a useful way to increase soil moisture reserves (Frank et al. 1976). However, it is important for tall stubble to remain intact. All three sites were under zero-till management which allows for larger amounts of water to infiltrate into the soil (Campbell et al. 1992). The greater the moisture that can infiltrate into the soil during the spring melt, the larger the moisture reserves that the crop can have available at the start of the growing season. The higher than normal spring rainfall in both 2011 and 2012 eliminated any significant benefit of higher snow catch on spring soil moisture.

2.4.4 Evapotranspiration

There was no significant site effect on evapotranspiration (ET) during 2011. The ET was significantly lower in the tall than the short stubble treatments in a combined analysis including all 3 sites, however when treatments at each location were analyzed within location there were no significant differences between treatments (Figure 2.14).

In the 2012 growing season, there were no significant treatment effects at any of the four sites where ET was estimated. There also was no overall significant difference between the tall and short stubble treatments. The Swan Lake ET levels were significantly higher than those at the Kenton location (Figure 2.14).

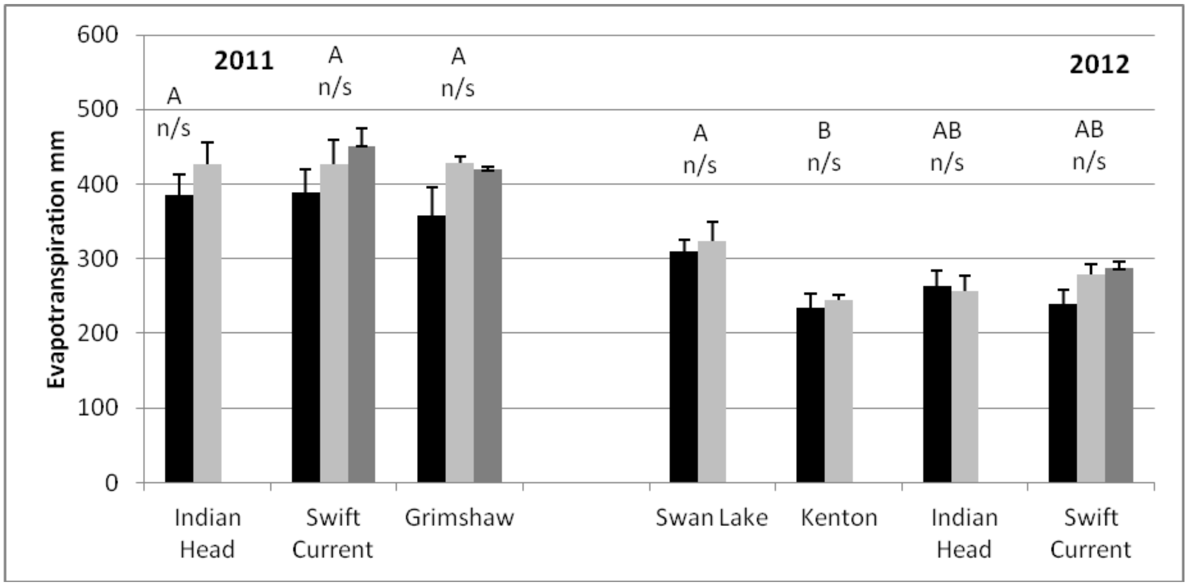

Figure 2.14 Growing season evapotranspiration estimated from spring soil moisture plus precipitation minus fall soil moisture (black bar-tall stubble, light grey bar-short stubble, dark grey bar-stripper header stubble). Capital letters indicate significant differences between sites at p=0.05. There were no significant treatment effects at individual sites.

The lack of stubble height treatment effect on ET is supported by previous research (Cutforth et al. 2002; Cutforth and McConkey 1997) which found ET was not influenced by stubble height. The ET levels were lower in 2012 than in 2011, so there was a more limited opportunity for tall stubble to exert an impact on the ET level. However, it is possible that the extremely wet spring weather in 2011 generated runoff or deep drainage from the fields. The ET estimation was done by using a water balance and assuming that runoff and deep drainage were negligible. Therefore, any losses such as these would erroneously increase the ET estimate. It is possible that these losses occurred in 2011 and that the growing season ET values are inflated as a result.

At Swift Current 2012, the stubble was heavily damaged in the tall and stripper header treatments. The majority of the site had to be reseeded. The stubble damage likely reduced the impact of the tall and stripper header treatments. Also the 2012 growing season was extremely stressful on the canola crop. The Swift Current site is located in the one of the most arid locations in the prairies and has low average rainfall. This area is most likely to benefit from additional moisture, although Cutforth et al. (2006) reported that in a severely water stressed year; stubble treatments were insufficient to make up the entire moisture deficit created in the extreme growing season. At Swan Lake 2012, the tall stubble was only 35 cm in height and short stubble was only 15 cm. The smaller size of the tall stubble was perhaps insufficient to slow ET and overall moisture reserves in the tall stubble compared to the short stubble.

Aase and Siddoway (1980) compared soil moisture at the end of the growing season in areas that were either tall stubble or bare soil. The bare soil treatments had 2 to 3 cm less moisture in the soil profile compared to the standing stubble in the fall compared to the spring. The treatments which had standing stubble on the surface had greater amounts of moisture in the soil profile than during the spring. The implication is that the tall stubble reduced ET and prevented the soil moisture levels from declining to the same extent as the bare soil. These results are more similar to the 2011 results of this study.

ET was highly variable from year to year. In years with high precipitation and low temperatures early in the season followed by limited moisture and high temperatures later on, tall stubble appears to reduce overall growing season ET, as was demonstrated under the 2011 climate conditions. If precipitation is more evenly distributed, then ET may be independent of the stubble height as demonstrated under the 2012 climate conditions. Both scenarios are supported by results from previous research (Cutforth et al. 2006; Cutforth and McConkey 1997).

2.4.5 iButton microclimate Results

The tall and short stubble remained more intact and upright than the stripper header treatments. Due to the stubble being more intact in the tall and short heights it was hypothesized that the difference between the tall and short stubble treatments would be the most significant in terms of temperature variation at the four different heights that were tested. However, over the 11 site years there were no significant differences between the accumulated GDH between tall and short stubble at each site. Even when the sites were grouped according to locations where the stubble was intact versus sites where it was damaged, the differences in accumulated GDH were not significant.

A site by height comparison for the 50, 20, 5 and -5 cm heights showed some limited significant differences in accumulated GDH between the stubble heights (Appendix 5.1). The Swan Lake 2011, Kenton 2012, Indian Head 2011 & 2012, Swift Current 2011 & 2012, Falher 2012 and Grimshaw 2012 sites (Figures 2.15 through 2.18, 2.20, and 2.21) all had significantly lower accumulation of GDH 5 cm below the soil surface compared to the above ground measurements. Swan Lake 2012, Lethbridge 2012 and Grimshaw 2011 did not show this effect (Figure 2.15, 2.21 & 2.19). The small number of replications and high variability among the towers analyzed resulted statistical power was low which can explain why Swan Lake 2012, Lethbridge 2012 and Grimshaw 2011 had no difference in GDH below the soil surface. There was no significant difference between GDH accumulations at any heights above the ground surface at any location.

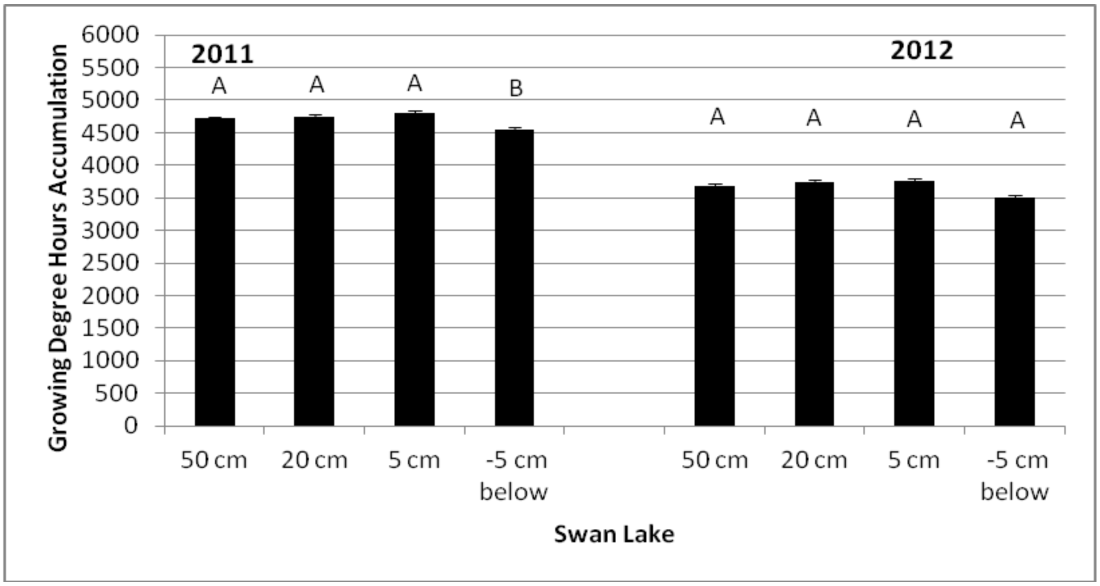

Figure 2.15 Growing Degree Hour accumulations at Swan Lake 10 days prior to second leaf stage of canola development during the 2011 & 2012 growing seasons.

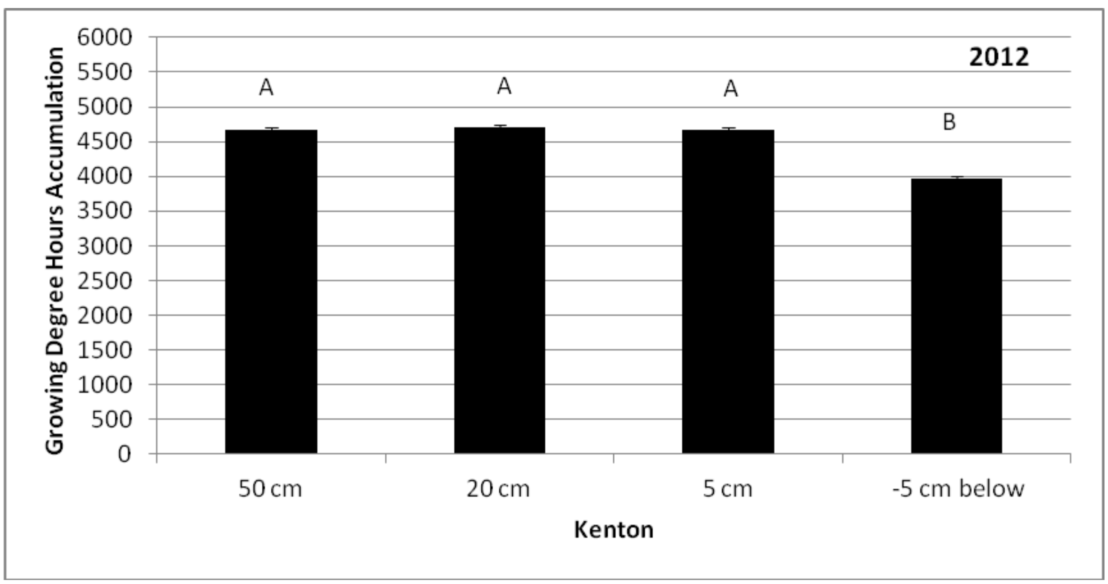

Figure 2.16 Growing Degree Hours accumulation at Kenton 10 days prior to the second leaf stage of canola development during the 2012 growing season.

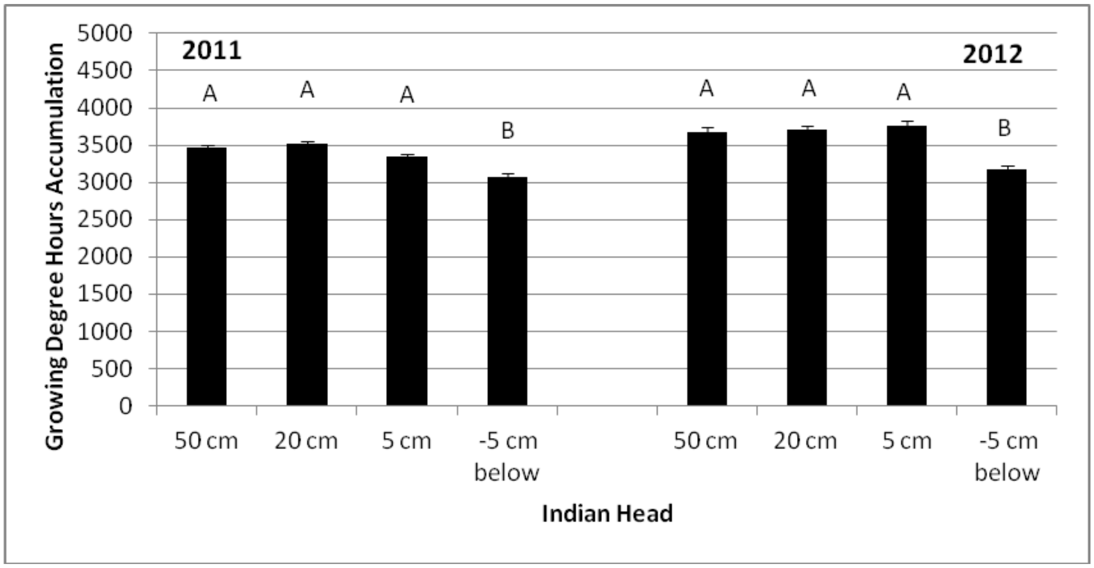

Figure 2.17 Growing Degree Hour accumulation at Indian Head 10 days prior to the second leaf stage of canola development during the 2011 & 2012 growing seasons.

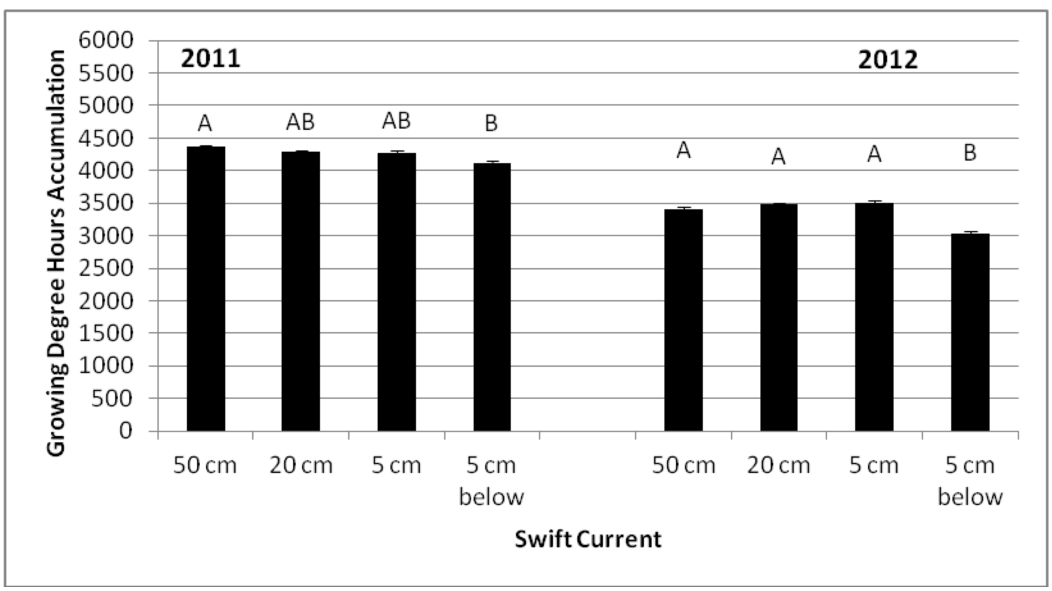

Figure 2.18 Growing Degree Hour accumulation at Swift Current 10 days prior to the second leaf stage of canola development during the 2011 & 2012 growing seasons.

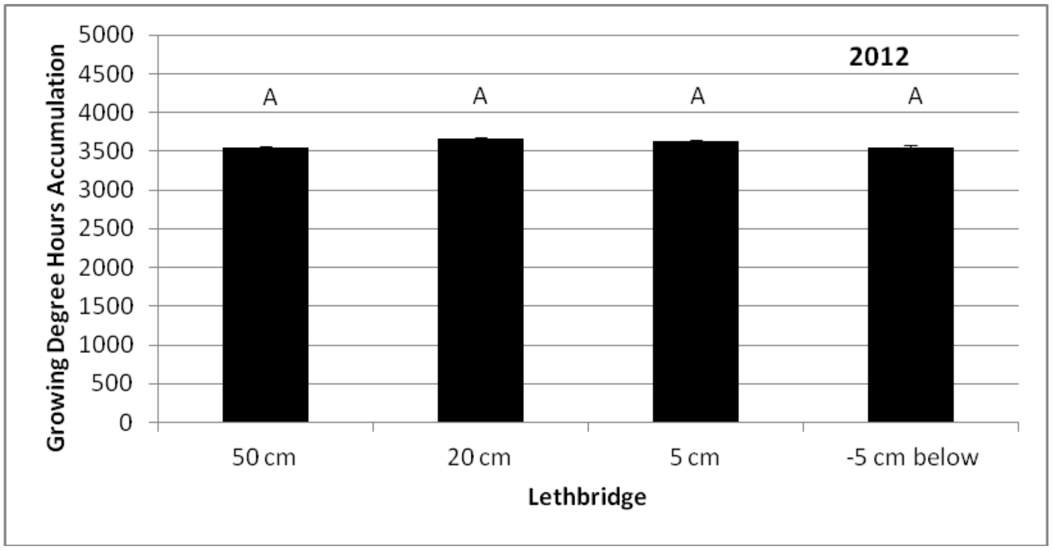

Figure 2.19 Growing Degree Hour accumulation at Lethbridge 10 days prior to the second leaf stage of canola development during the 2012 growing season.

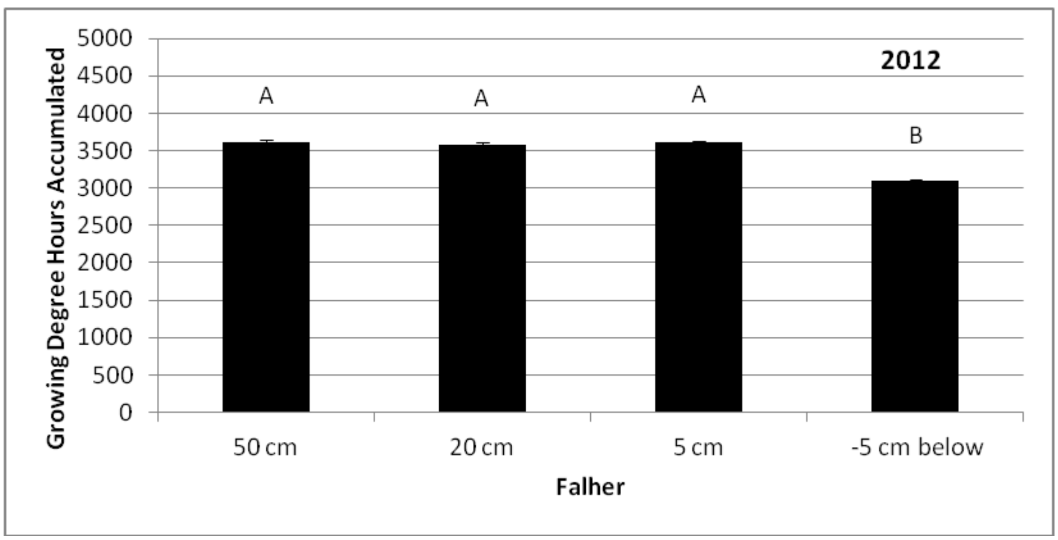

Figure 2.20 Growing Degree Hour accumulation at Falher 10 days prior to the second leaf stage of canola development during the 2012 growing season.

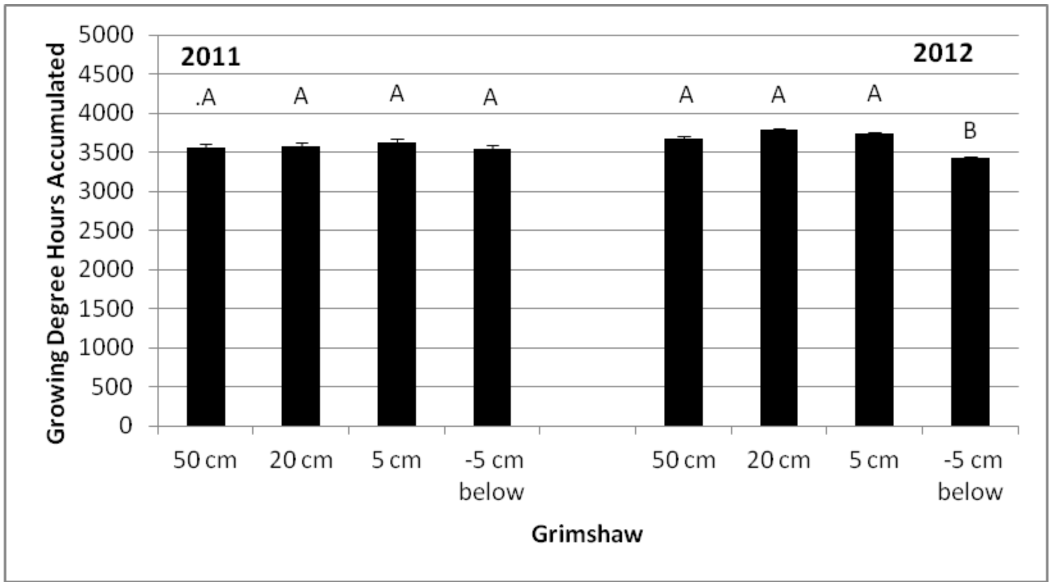

Figure 2.21 Growing Degree Hour accumulation at Grimshaw 10 days prior to the second leaf stage of development during the 2011 & 2012 growing seasons.

There was reduced accumulated GDH below the soil surface compared to the air temperature above. However, the lack of variation in accumulated GDH between the 5, 20 and 50 cm heights above the stubble indicates that the stubble did not alter the air temperature in a significant way despite previous literature (Cutforth et al. 2006) indicating a reduction of air temperatures in tall stubble. There lack of significant differences in GDH between sites with intact stubble and damaged stubble indicates that the condition of the stubble did not affect the air temperature significantly, at least in the 10 days prior to the 2nd leaf stage of canola development.

It should be noted that the iButton stations were an original design and not previously tested for this type of research. However, the consistent significant variations 5 cm below the soil surface indicates that the iButton stations were detecting temperature differences consistently between sites, thus the lack of air temperature variation above the surface was not a result of faulty sensor performance. Each site was located in a different geographic area and the iButton stations were able to record the variation in the temperatures. Swan Lake 2011 (Fig. 2.1) had the greatest GDH accumulation because late seeding delayed the 2^{nd} leaf stage of development until July.

2.5 Conclusion

Overall the tall stubble was able to generally catch significantly higher amounts of snow than the short stubble during the winter months. This was found consistently at the locations (Swan Lake 2011, Indian Head 2011 & 2012) which were sculpted in the fall and measured prior to snow melt during both the 2011 and 2012 growing seasons. However, the spring soil moisture levels were not significantly different between treatments at the same locations. The GDH accumulated over a 10 day period prior to 2^{nd} leaf stage of development did not show any significant differences between the tall and short treatments nor significant differences between the 5, 20 and 50 cm stubble heights. The only significant difference was lower accumulated GDH at 5 cm below the soil surface at all sites except Swan Lake 2012, Lethbridge 2012 and Grimshaw 2011.

In 2011 and 2012, growing season precipitation showed a consistent trend of above average precipitation during the early part of the growing season (May and June), then a decrease in precipitation which was sharp in the 2011 but more gradual in 2012. The temperature followed a more varied pattern but was generally inverse to the monthly precipitation (when there was above average precipitation the temperature was below average and vice versa). The above average precipitation reduced the ability of tall stubble treatment to increase soil moisture during the early part of the growing season. The significant difference in spring moisture between the stripper header stubble and tall stubble treatments at Swift Current may have been an artifact of the overwinter damage to the stubble. The above average precipitation and cooler temperatures during the early part of the growing season and then subsequent reduction in precipitation and increase in temperature during the later part of the season did not affect the evapotranspiration estimated at multiple locations in 2011 and 2012. This is consistent with previous research in the Swift Current area and indicates that it is also applicable over a range of different climatic regions.

These results show that the stubble height was not able to alter the microclimatic around the canola crop in any significant way at that particular stage of canola development. The tall stubble treatment does have the potential to impact the moisture conditions for canola the following year; however the differences are masked with high spring precipitation. Thus, the benefit from increased moisture will occur more frequently in the arid regions of Western Canada and less frequently in the more humid regions.

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Chapter 3 Impacts of Stubble Height Management on Canola Performance

3.1 Abstract

In the Canadian Prairies the climate is predominately semi-arid near the Rocky Mountains and gradually becomes sub-humid towards the eastern Canadian Prairies. In this climate, moisture is a limiting factor for canola production. Previous research in the most arid region of the Canadian Prairies has shown alteration of the microclimate using tall wheat stubble from the previous year can create more favorable microclimatic conditions for canola (*Brassica napus)*. The objective of this research was to determine if climatic alterations created by different stubble treatments caused significant benefits for canola emergence which would positively affect the yield without increasing disease pressure on the crop. In 2011, there were four field sites established: one location in Manitoba at Swan Lake, two in Saskatchewan at Indian Head and Swift Current and one site in Grimshaw, Alberta. In 2012 there was an expansion of the experiment to include additional locations at Kenton, MB, Falher, AB and Lethbridge, AB. At each site, large replicated plots of tall stubble cut at 50 cm height were compared to large replicated plots of short stubble cut at 20 cm tall and a stripper header treatment (present at five of the eleven site years) in which only the head of the wheat was removed. Canola % emergence, plant population per m^{-2}, canola biomass, yield, harvest index and disease pressure from Blackleg *(Leptosphaeria maculans)* and Sclerotinia *(S. sclerotiorum)* were recorded to determine the effects of using standing stubble to alter the microclimate of the canola field. Canola emergence and plant populations showed no significant treatment effect from the three stubble treatments. Over the 11 site years there was only one site in 2011 that had a significant difference between treatments in total canola biomass production and seed yield. The harvest index and disease pressure from

Blackleg and Sclerotinia showed no significant differences created by the contrasting stubble heights.

3.2 Introduction

Variation in the height of stubble after the harvest of annual cereals has measurable effects on the microclimate next to the ground surface the following spring (Cutforth et al. 2006; Caprio et al. 1985). Since only 40-70% of canola seeds that are planted in the soil emerge it is important to maximize the number of seeds successfully emerging due to the high cost of seed (Blackshaw, 2013). Management of stubble height, therefore, is a relatively inexpensive crop management technique that can have a potentially beneficial impact on seed germination and seedling emergence of the following crop (Cutforth et al. 2006; Caprio et al. 1985). It has potential to increase spring soil water levels as a result of higher snow catch, and reduced evaporation through its impact on ground surface wind speed and incident solar radiation. In arid climates, these modifications can increase water-use efficiency and potentially increase yields (Cutforth et al. 2006; Cutforth and McConkey, 1997; Aase and Siddoway, 1980). This previous research, conducted in a very arid region of the Northern Great Plains near Swift Current, Saskatchewan has demonstrated that tall stubble created favorable conditions for canola emergence. Generally on the Canadian Prairies, moisture demand by agricultural crops is greater than the available water resources (Bullock et al. 2010). However, this technique has not been evaluated in less arid locations in the prairie region.

The purpose of this study was to assess the impacts of stubble height management on the performance of canola across a wide range of climatic conditions. The overall goal was to determine if stubble height management is a reliable method to increase canola production across the broad range of climatic conditions that exist on the Canadian Prairies.

It was hypothesized that the greatest benefit of tall stubble on the canola would be from the time of seeding to the bolting stage of the plant. This time period is critical for canola establishment. Larger spring soil moisture reserves at the time of planting, can potentially improve emergence in the early growing season. It was also hypothesized, however, that the higher soil moisture and lower evaporation under tall stubble could increase risk of disease which could reduce any early season benefits the tall stubble provides. Much of the work done on stubble management impacts on canola has been conducted in the Swift Current region where disease pressure is traditionally quite low. Disease monitoring in canola across different climatic regions will better determine the potential disease risk associated with altering the microclimate with stubble height management. Large field-size replications of the plots were monitored all season with data being retrieved during the 2nd leaf stage to bolting and several weeks after the petals dropped off the plant. Overall the results will help determine if the benefits of tall stubble found in arid climates are also evident in other canola growing regions.

3.3 Methodology - Material and Methods

3.3.1 Study Site Overview

The project was conducted at sites across the prairie region (Figure 3.1) during two annual cycles. Field sites established in the fall 2010 and spring 2011 were used for canola performance evaluation during the 2011 growing season. Sites established in the fall 2011 and spring 2012 were used for canola performance evaluation during the 2012 growing season. There were four sites evaluated during the 2011 growing season, including Swan Lake, MB, Indian Head, SK, Swift Current, SK and Grimshaw, AB. The Indian Head and Swift Current sites were located at Agriculture and Agri-Food Canada Research Centers, while Swan Lake and Grimshaw were located on fields belonging to producer collaborators. In 2012, an additional three sites were added to the project along with the four above. The additional sites were located in Kenton, MB, Falher, AB and Lethbridge, AB. All of these sites utilized land from producer collaborators.

Since the study sites were separated by large distances, there were very different weather conditions across locations during the growing season period, which was expected and an important aspect of the study. As a result, the dates of key measurements at each study location were variable (Tables 3.1, 3.2). Due to the large distance between the sites, it was necessary that local field crews at each site were available to ensure timely field operations.

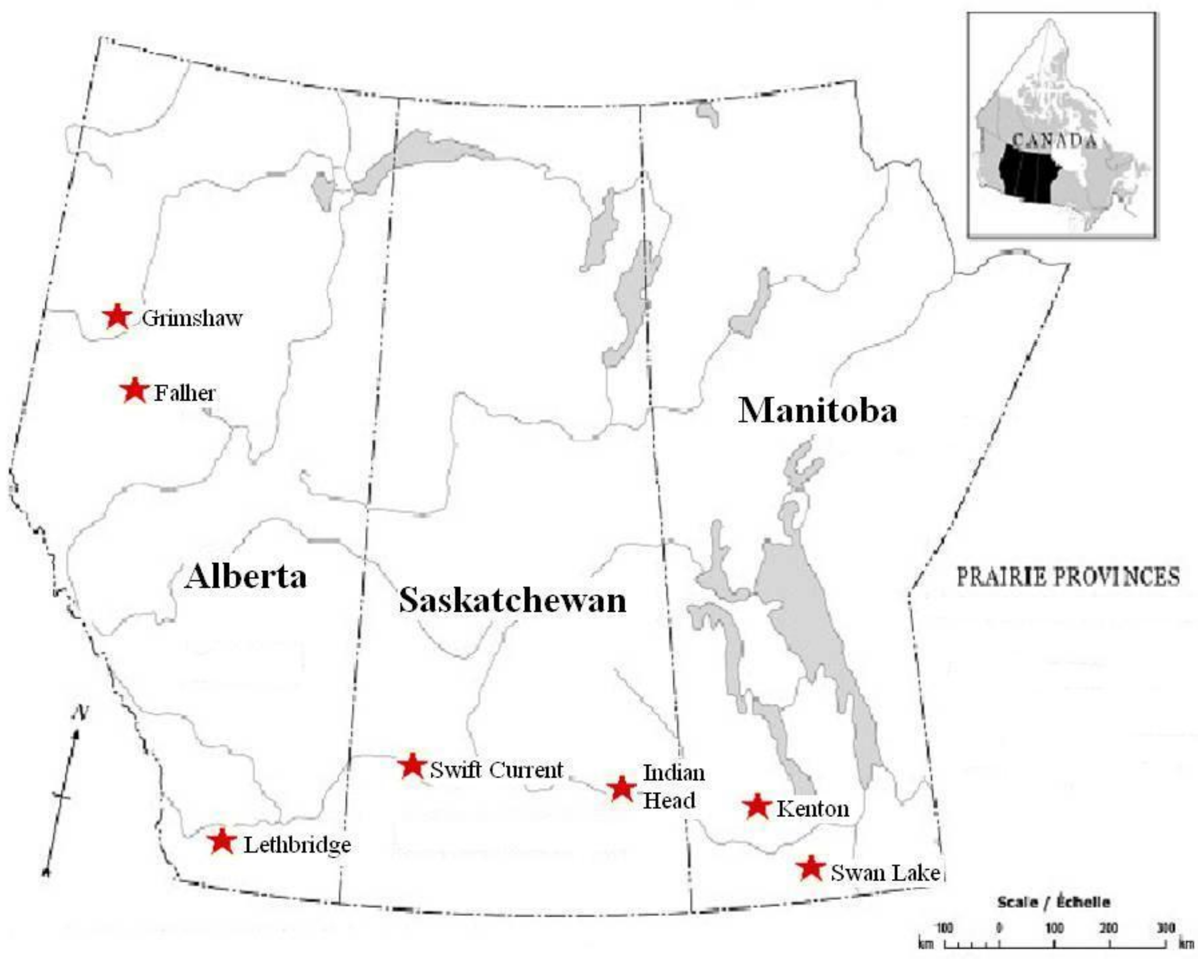

Figure 3.1 Canola performance evaluation sites in 2012. In 2011, the Kenton, Falher and Lethbridge sites were not yet established.

3.3.2 Stubble Height Treatments

The stubble height treatments at each site varied according to the equipment and logistics at each location. The common treatments at all sites were cereal stubble cut at approximately 20 cm height (short) and cereal stubble cut at approximately 50 cm height (tall). At some locations, a stripper header (stripper) was available which was not measured specifically but was greater than 50 cm. This implement basically strips the grain off the heads of cereal plants and leaves most of the stubble standing. This treatment was evaluated at those locations where a stripper header was available.

In some cases, the stubble treatments were implemented in the fall during or following the cereal harvest. In other cases, the stubble was cut tall or with a stripper header during the cereal harvest, and then sculpted in the spring to create the treatments. Each site varied in size and shape but they all had at least three replicates each of tall and short stubble.

3.3.3 Site Layouts

The treatments at each study site varied in size and layout (Figs. 3.2 to 3.13) however all locations had plot sizes that were large enough to create microclimatic differences between treatments. Plots were removed from Swan Lake 2011, Swift Current 2012, Falher 2012 and Grimshaw 2012 to create a randomized complete block design. The main agronomic information for each site is listed in Tables 3.2 and 3.3. It was decided at the beginning of the project that standardizing the canola variety at each location would be logistically very difficult. In addition, the most common and suitable canola varieties vary for different regions of western Canada, and it would be difficult to find one variety that would suit the wide range of locations for the study.

Table 3.1 Summary of data collection dates at the study sites.

	Time of Sculpting	Date of Seeding	Number of Replications	Stripper Header Treatment	Total Plot Size (m)	Date of Biomass Collection
2011 Sites						
Swan Lake	Fall (2010)	Jul 19	3	No	150 X 204[z]	Oct 12-13
Indian Head	Fall (2010)	May 17	3	No	300 X 311	Aug 17
Swift Current	Spring (2011)	Jun 2	3	Yes	180 X 120[z]	Aug 25
Grimshaw	Spring (2011)	May 24	3	Yes	60 X 690	Sep 7
2012 Sites						
Swan Lake	Fall (2011)	May 15	4	No	51 X 102	Aug 10
Kenton	Fall (2011)	May 13	4	No	n/a[x]	Aug 15
Indian Head	Fall (2011)	May 17	4	No	220 X 210	Aug 24
Swift Current	Fall (2011)	May 14	3	Yes	n/a[x]	Aug 13
Lethbridge	Spring (2012)	May 12	3	Yes	100 X 189	Aug 2
Falher	Spring (2012)	May 16	4	No	30 X 679[y]	Aug 22
Grimshaw	Spring (2012)	May 28	3	Yes	469 X 82[z]	Aug 20

x-Kenton and Swift Current 2012were none continues plots scattered over a large area (see Figures 3.7 & 3.9).
y-Falher total size includes two large exclusion areas and plots removed from analysis (see Figure3.11)
z-Swan Lake 2011, Swift Current 2011 and Grimshaw 2012 total area includes plots which were removed from analysis (see Figure 3.2, 3.4 & 3.12)

Table 3.2 Summary of the agronomic information for all sites during the 2011 growing season

	Seeding Rate (kg/ha)	Row Spacing (cm)	Canola Variety	Chemical Applications and Dates[Z]	N, P_2O_5, S Rates Kg/Ha	Date of Biomass Collection
2011 Sites						
Swan Lake	5.6	25.4	Nexera[v]	Glyphosate	56, 28,33	Oct 12-13
Indian Head	5.9	30.5	Invigor[W]	June.14th Liberty 150SN, Select Oct.4th Centurion,Prepass XC,A and B	123,34,17	Aug 17
Swift Current	8.7	30.5	RoundUp Ready[X]	May.5th RoundUP Transorb, June.30th RoundUP Weathermax	87, 46, 27	Aug 25
Grimshaw	6.8	30.5	RoundUp Ready[Y]	June.11th Glyphosate w/t Bioboost, June.27th Glyphosate	82, 80, 16	Sep 7

V- Nexera by DowAgroSciences®™
W- INVIGOR® Liberty Link L150", Viterra™
X- RoundUp Ready, RR#9595", Proven Seed®
Y- RoundUp Ready, BY#6040 RR
Z- All chemical applications done to recommended manufacturer rates all, dates of application listed if not listed exact date is unknown. For additional site history see Appendix 5

Table 3.3 Summary of the agronomic information for all sites during the 2012 growing season.

	Seeding Rate (kg/ha)	Row Spacing (cm)	Canola Variety	Chemical Applications and Dates[Z]	N, P_2O_5, S Rates Kg/Ha	Date of Biomass Collection
2012 Sites						
Swan Lake	5.3	25.4	Nexera[X]	Glyphosate	101, 34, 28	Aug 10
Kenton	5.6	25.4	Invigor[W]	June.20th Liberty Herbicide	84, 28, 0	Aug 15
Indian Head	5.9	30.5	Invigor[Y]	May.17th Vantage + Max 2, Liberty 150SN Centurion and Amigo	123, 33, 17	Aug 24
Swift Current	8.0	30.5	RoundUp Ready[V]	June.25th RoundUp WeatherMax	106, 35, 8	Aug 13
Lethbridge	5.3	19.1	Liberty Link[Y]	Liberty Link, Herbicide	100, 36, 9	Aug 2
Falher	4.5	30.5	Liberty Link[Y]	Liberty Link, Glyphosate	135, 37, 17	Aug 22
Grimshaw	5.6	30.5	RoundUp Ready[U]	May.16th,June.20th, July.6th Glyphosate	72, 13, 19	Aug 20

U- RoundUp Ready, BY#6130 RR
V- RoundUp Ready, VR #9535 Q
W- INVIGOR® Liberty Link L130", Viterra™
X- Nexera by DowAgroSciences®™
Y- INVIGOR® Liberty Link L150", Viterra™
Z- All chemical applications done to recommended manufacturer rates all, dates of application listed if not listed exact date is unknown. For additional site history see Appendix 5.2

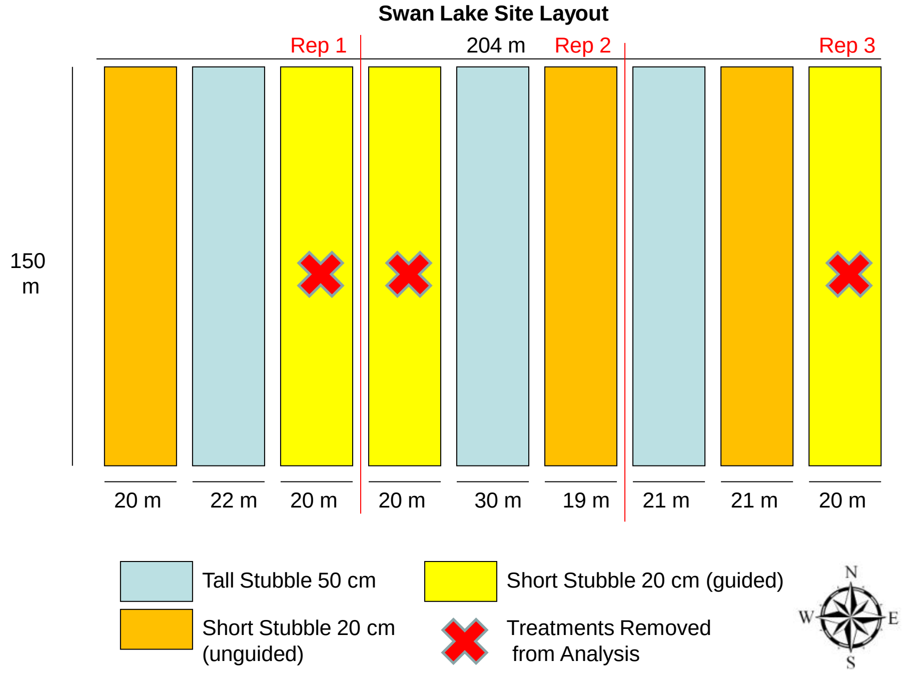

Figure 3.2. Swan Lake site layout in 2011. The short-guided treatments were not used in the analysis.

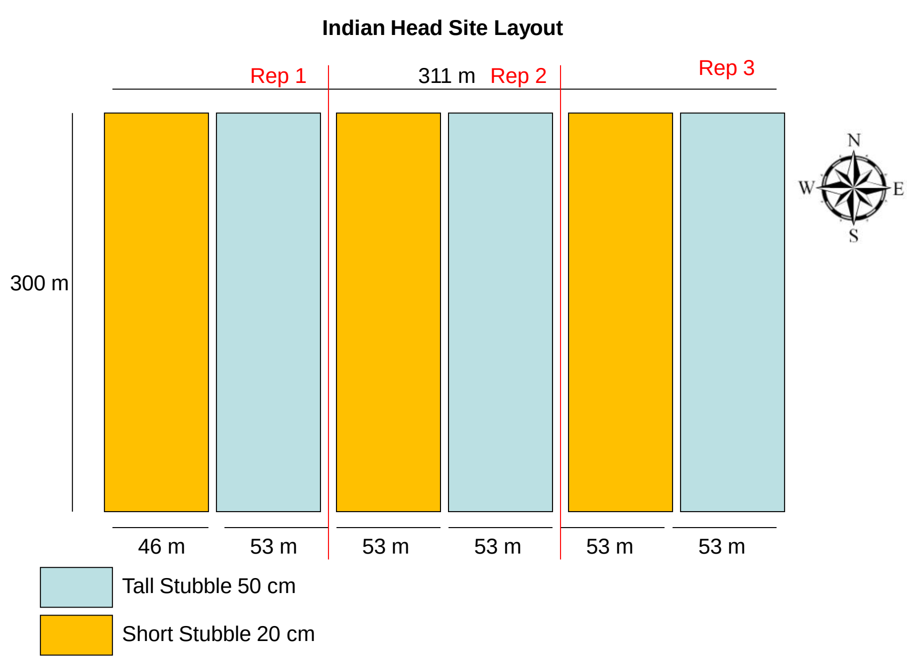

Figure 3.3 Indian Head site layout in 2011.

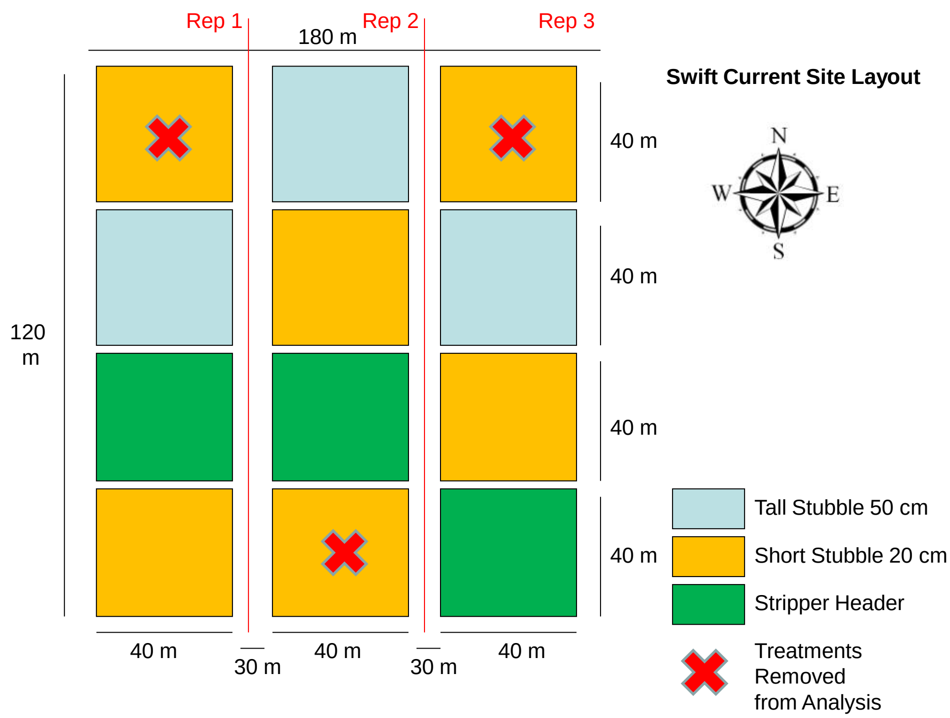

Figure 3.4 Swift Current site layout in 2011. The three replicates (one from each block) removed from statistical analysis are indicated.

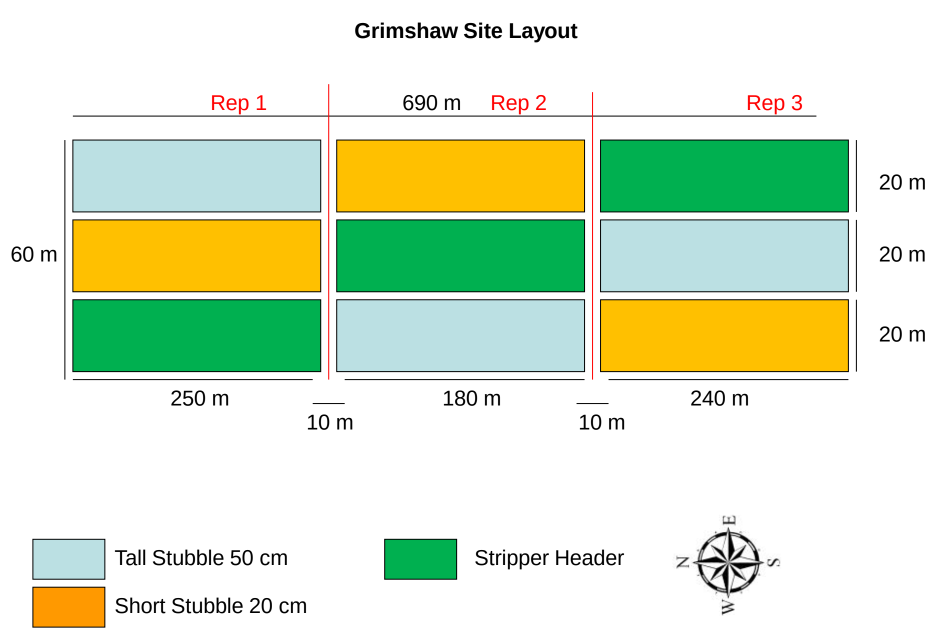

Figure 3.5 Grimshaw site layout in 2011.

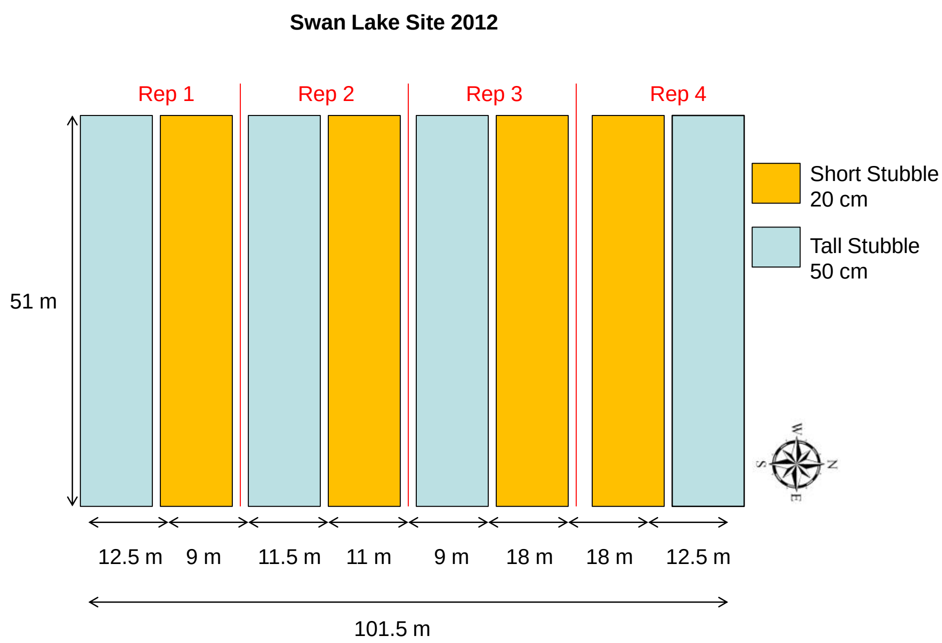

Figure 3.6 Swan Lake site layout in 2012.

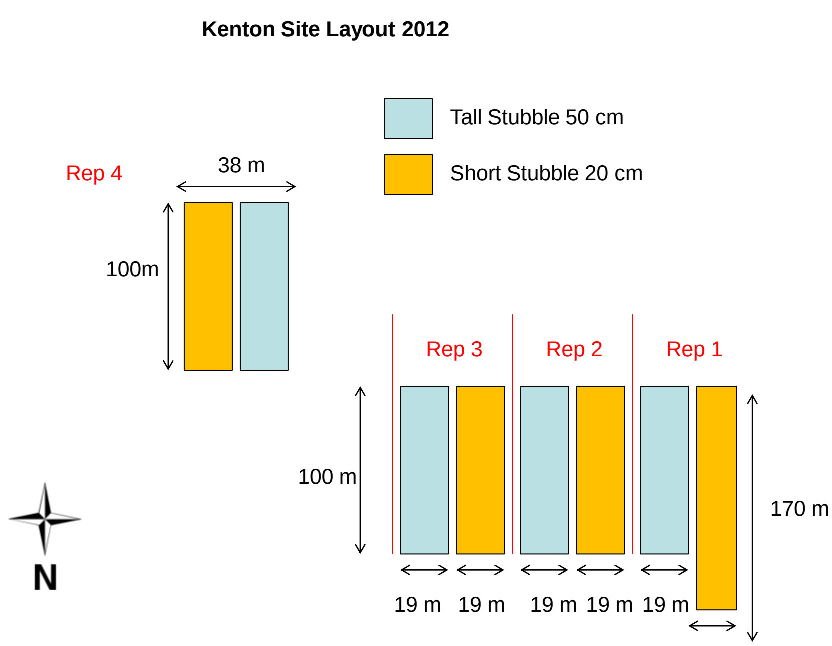

Figure 3.7 Kenton site layout in 2012.

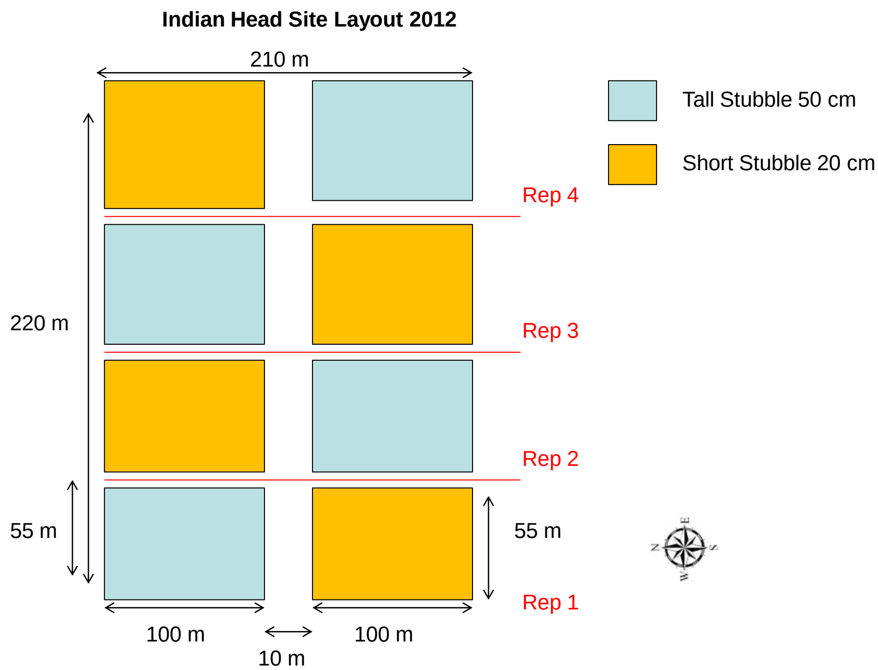

Figure 3.8 Indian Head site layout in 2012.

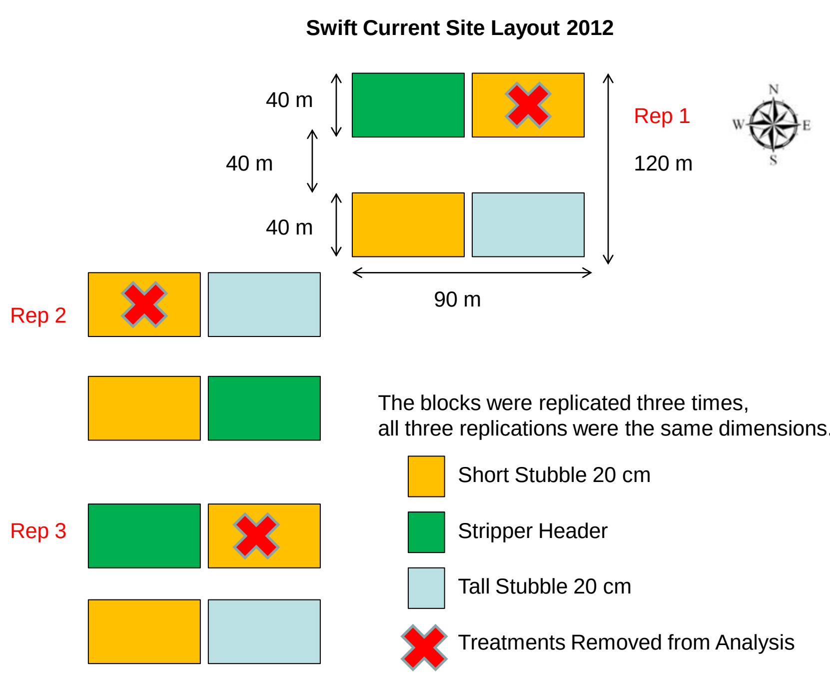

Figure 3.9 Swift Current site layout in 2012.

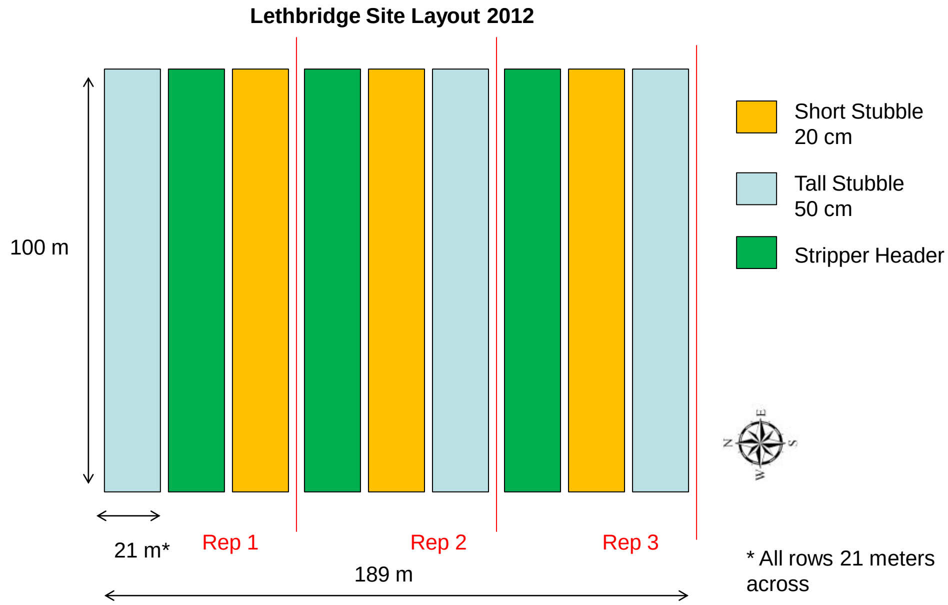

Figure 3.10 Lethbridge site layout in 2012.

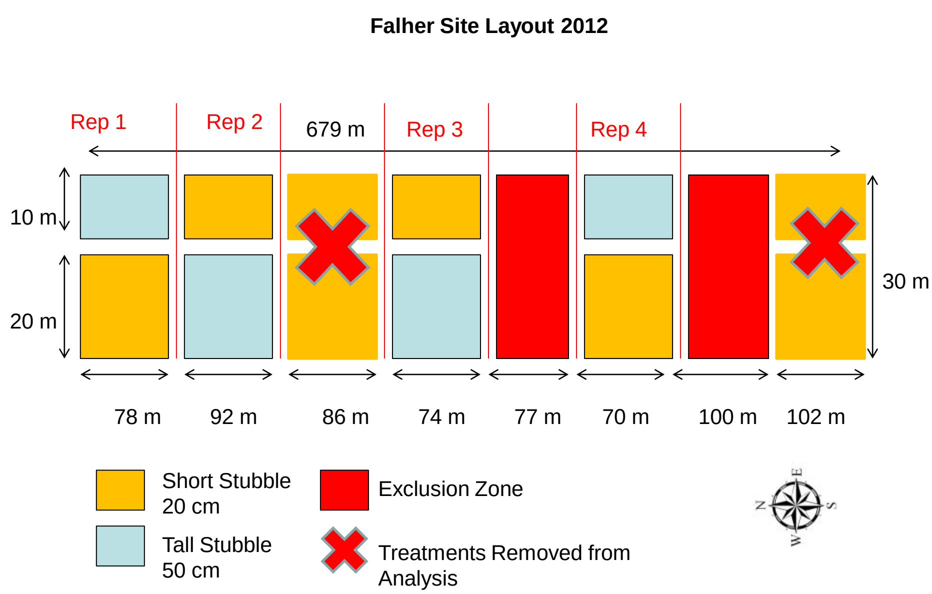

Figure 3.11 Falher site layout in 2012.

Figure 3.12 Grimshaw site layout in 2012.

3.3.4 Canola Performance Measurements

3.3.4.1 Canola Emergence Determination

In each replicate of each treatment at all sites, there were twenty-four 1 m row sections randomly established at the Rosette stage (second leaf stage) of development. The second leaf stage was the time period used to determine if there was any significant treatment effects on canola emergence. The method of Harker et al. (2012) was utilized. Canola development 2 to 3 weeks after emergence was assumed to represent the established canola that would most likely reach maturity.

At every 1 m row section, a meter stick was placed along the canola row and two pin flags were placed on either end to ensure that only plants in the one meter row were being counted. All canola plants that were within this section were counted. Any canola plants still at the cotyledon stage were counted separately. The average total plant count from the 24 measurements in each treatment was considered to be the number of plants emerged per meter of row in each replicate.

During the 2012 growing season, seed samples were collected from 6 of the 7 seven sites (Falher did not have any extra seeds). A sample of 250 seeds was counted from each treatment using Assess 2.0 image analysis software (APSnet, 2013). The seeds were weighed and the total weight was multiplied by 4 to determine the thousand kernel weight (TKW) of each seed sample. The TKW, the seeding rate and the row spacing were used to calculate the number of seeds planted in a 1 m row length. The total plants emerged in a 1 meter row length divided by the number of seeds planted per 1 m row length provided the germination rate of each 1 meter row length. The mean of the twenty-four 1 meter samples was considered the germination rate for each replicate.

3.3.4.2 Biomass, Yield and Harvest Index Determination

Biomass sampling took place generally about two weeks after most of the petals had dropped off the canola plant. This timing helped ensure the crop still had the pods intact and facilitated disease scouting at the same time. The plants from the twenty-four 1 meter row lengths in each replicate were clipped and bagged. The canola samples were cut with a blade one inch from the soil surface. The number of plants was recorded and they were then placed into a cotton bag and labeled for processing. In 2011, the samples were taken from the same spots as the emergence samples for 3 of the 4 sites. In 2012, and at Grimshaw 2011, samples were taken from twenty-four randomly-selected locations across each replicate. All samples were collected in cotton bags to prevent the canola seeds from being lost in the biomass weighting and threshing process. The bags of canola were oven dried at 35˚C for a minimum of one week. In 2012 due to space constraints, the Swift Current samples were air dried outside from Aug.13th until they were processed on Sep 17-18th. The dried samples were weighed to determine total dry biomass. The samples were then threshed in stationary combines to determine grain yield. In 2011, all samples were threshed between Sep 10 and Nov 18. In 2012, all samples were threshed between Aug 24 and Oct 1. The weight of the seed was divided by the total weight of the dry biomass to determine harvest index.

3.3.4.3 Disease Level Determination

All disease counts were taken at the same time as biomass sampling in both 2011 and 2012. The canola crop was still green in color at this stage. Blackleg and Sclerotinia would be very prominent because both diseases cause canola plants to ripen prematurely, unevenly and increase the risk of lodging and pod shatter.

Sclerotinia incidence was determined during both the 2011 and 2012 growing seasons. Sclerotinia causes grey brown blemishes on the green stem of the canola. Depending on the intensity of the disease, the entire stem of the canola could be hollow causing the canola to lodge. During biomass collection, the total number of plants per 1 meter row was recorded and any plants affected by sclerotinia were also counted. The number of plants infected with sclerotinia was divided by total plants count to determine the percentage. The average of the twenty-four 1 meter rows was considered the percentage of sclerotinia infection for each replicate.

Blackleg scouting was conducted during both 2011 and 2012. Blackleg affects the base of the canola stem. The inside of the stems on healthy canola plants have a white center. If Blackleg was affecting the plant, small black dots were apparent on the white tissue on the inside of the stem. Blackleg on the base of the canola stem weakens the plant causing the crop to lodge.

During biomass collection the stem of the canola plant was visually inspected to determine if blackleg was present in each plant. The total number of plants infected with Blackleg in each 1 meter row section was divided by the total number of plants to determine the percentage. The average of the twenty-four 1 meter rows was considered the percentage of Blackleg infection for each replicate.

3.3.5 Statistical Analysis

The response variables percent canola emergence, plant population per m^2, biomass, yield, harvest index and disease pressure (Blackleg and Sclerotinia) were analyzed as described in section 2.3.7 with minor exceptions. The fixed effects were treatment, site and year if necessary. Replication was considered random. The ANOVA was conducted using a two-way factorial model on percent canola emergence and Blackleg disease pressure and a three-way ANOVA including year on the remaining response variables. All else was as described in section 2.3.7.

3.4 Results and Discussion

3.4.1 Canola Emergence

When the canola emergence was analyzed there was a significant difference between the tall and short stubble as an overall comparison across all locations. However there were no significant differences in canola emergence between the short, tall and stripper header stubble treatments at any of the individual sites (Figure 3.13, 3.14). Also there were no significant differences between locations, with the exception that the Indian Head site had significantly greater emergence than Swan Lake. This indicates canola emergence was very similar across highly variable climatic zones and across a range of different seeding and management regimes. Stubble management did not have a significant effect on canola emergence when comparing the tall, short and stripper header stubble treatments.

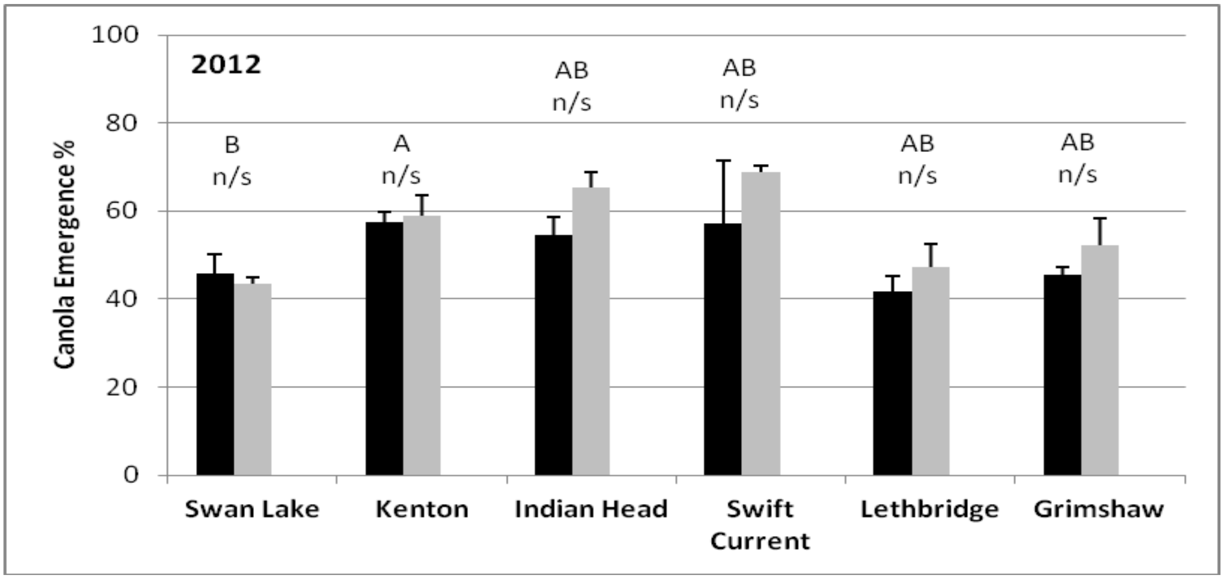

Figure 3.13 The percentage of canola seeds that emerged in short and tall stubble at the 2nd leaf stage at 6 locations in 2012. The black bar represents tall stubble, light grey bar represents short stubble. The capital letters indicate significant differences between sites. Based on Scheffe's test there were no significant differences between treatments by site.

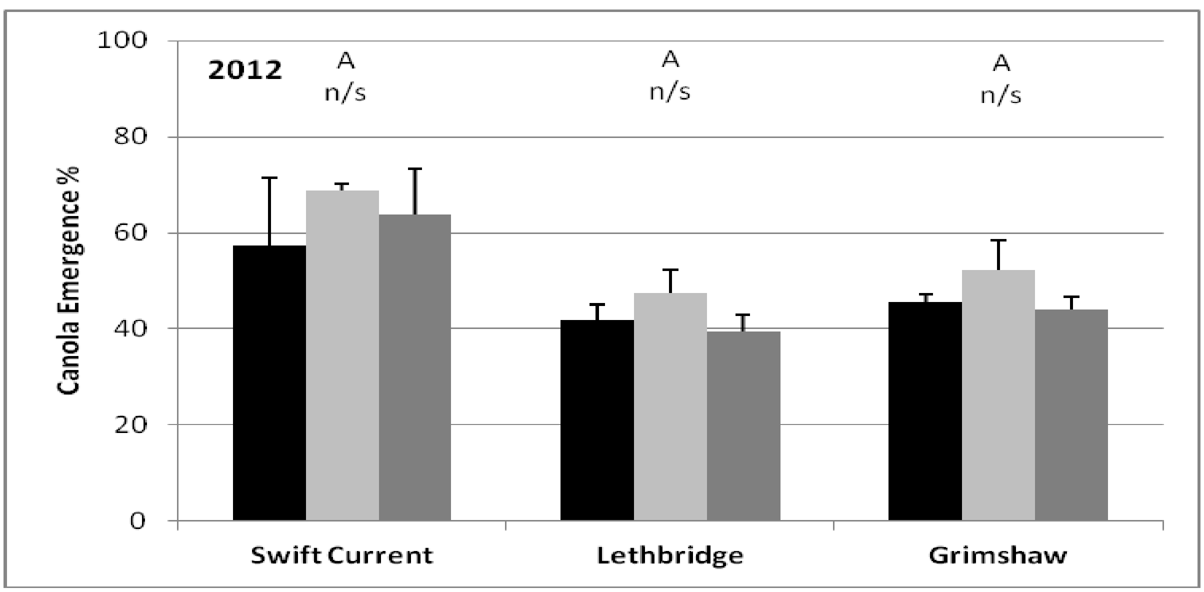

Figure 3.14 The percentage of canola seeds that emerged at the 2nd leaf stage at sites with stripper header treatments. The black bar represents tall stubble, light grey bar represents short stubble and dark grey bar is the stripper header stubble treatments. The capital letters indicate

significant differences between sites. There were no significant differences between treatments by site.

Visual observations in the spring showed that the stubble at Swan Lake, Indian Head and Kenton was intact but at Swift Current much of the tall and stripper header stubble was lodged and had fallen over during snow fall events. In addition, both the Lethbridge and Grimshaw sites had significant damage to tall and stripper header stubble treatments with most of the stubble laying in piles on the surface. In Lethbridge, strong spring winds caused the stubble to lodge. At Swift Current and Grimshaw the greatest amount of damage to stubble happened during seeding. At both locations there was precipitation events at seeding, the tall and stripper header stubble reduced evaporation which caused the ground to be very wet. The seeding machinery got caught in the seeder and was dragged or torn apart during seeding. The stubble looked more like dry mulch on the soil surface.

Bruce et al. (2005a) studied the impacts of wheat stubble on canola in New South Wales Australia and found that more stubble laying on the soil surface reduced both seedling emergence and canola establishment. Canola emergence in areas with stubble on the soil was reduced by 25% (Bruce et al. 2005a). This reduction in emergence led to overall slower development of the canola. Another study of the physical and biological growth suppression caused by the stubble (Bruce et al. 2005b) showed that emerging canola plants displayed a physiological response to the standing stubble. The decrease in emergence was linked to the canola seedlings having to elongate the hypocotyl further to emerge through the standing stubble. This elongation decreased the tissue on the plants surface weakening the cotyledon and leaving it vulnerable to mechanical disturbances on the field (Bruce et al 2005b; Ganade and Westoby, 1999). Bruce et al. (2005b) noted that cotyledons have energy reserves for the plants future development. Since this is used for greater elongation of the hypocotyl, they hypothesized that this further reduced plant growth. Although hypocotyl length was not studied in this project, it provides a plausible explanation for why the overall trend of average emergence was 7% greater in the short stubble than the tall stubble across the six sites.

Overall canola emergence in this study was similar to that reported elsewhere (Harker et al. 2012; Harker et al. 2008). Most agronomic recommendations for canola are targeting plant populations of 80 to 180 plants m^2 (Angadi et al. 2003). However, research done by Angadi et al. (2003) showed canola had the ability to compensate for low plant populations to some degree by creating more seeds on the branches of the canola plant. There is an increased risk of heat stress with lower plant densities which can decrease seedling vigor and cause more rapid aging of the canola plants (Gusta et al 2003). Canola is well-adapted to the lower temperatures of the Canadian Prairies, therefore, above average heat increases stress on the plant (Morrison 1993; Brandt and McGregor 1997). In this study, canola plant populations fell within the range of 39 to 157 plants m^2 (Table 3.4). At this level, canola has the capacity to compensate for the impact of excess precipitation and other climatic variation.

Table 3.4 The range in canola plant populations during this study.

		Plants m^{-2}							
		Max	Min		Max	Min		Max	Min
Indian Head 2011	Tall	111	91	Short	111	88		-	-
Swift Current 2011	Tall	70	62	Short	81	62	Stripper	72	68
Grimshaw 2011	Tall	45	39	Short	63	44	Stripper	57	45
Swan Lake 2012	Tall	61	47	Short	58	51		-	-
Indian Head 2012	Tall	74	51	Short	86	69		-	-
Kenton 2012	Tall	62	51	Short	73	51		-	-
Swift Current 2012	Tall	157	73	Short	122	93	Stripper	130	81
Grimshaw 2012	Tall	59	51	Short	78	53	Stripper	59	50
Lethbridge 2012	Tall	55	44	Short	65	46	Stripper	53	41

The canola plant population at the second leaf stage was analyzed to determine any differences in plant populations between the three treatments. In 2011, there was no significant difference between the tall, short and stripper header treatments at all three locations (Figure 3.15). The number of plants per square-meter was nearly identical in each treatment. In 2011, the Indian Head location had a significantly higher canola population compared to Swift Current which was significantly higher than Grimshaw (Figure 3.15). The 2012 season showed similar results with no significant difference in the canola plant population among treatments. The Swift Current location had the highest canola population among all the locations. The Indian Head location had significantly higher canola populations than the Swan Lake location but all other four locations had no significant differences in canola plant population (Figure 3.15). At the 2011 and 2012 sites with stripper header treatments, there were no significant treatment differences but in 2011 Swift Current had a significantly larger plant population than Grimshaw and in 2012 Swift Current plant population was higher than both Grimshaw and Lethbridge 2012 (Figure 3.16).

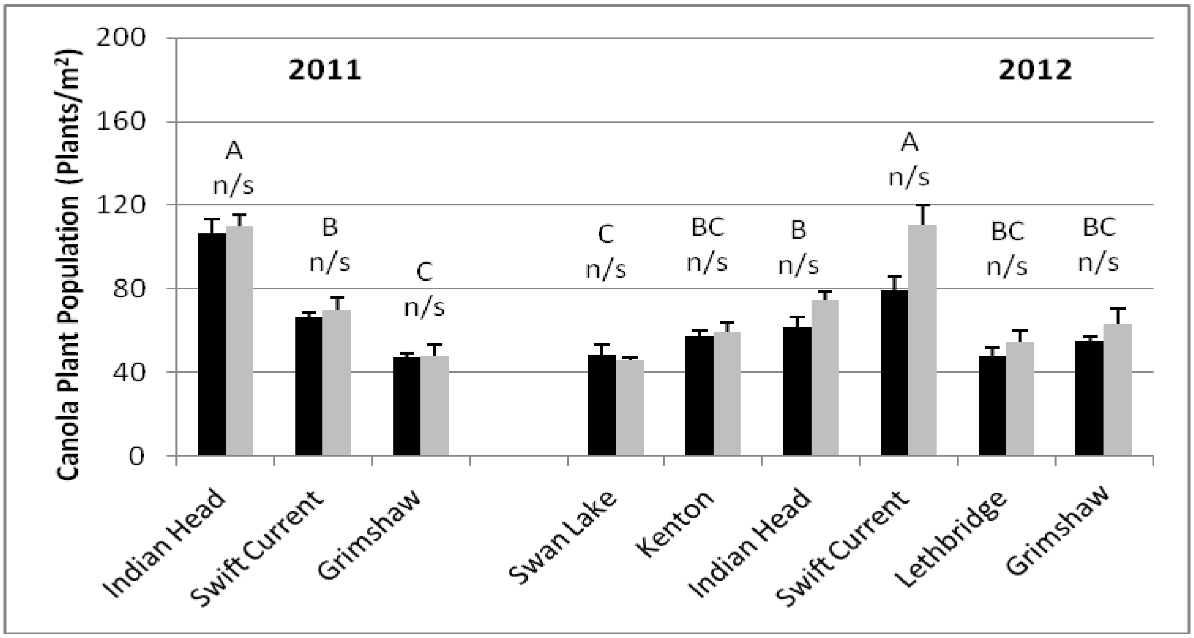

Figure 3.15 The canola plant population per meter squared. The black bar represents tall stubble, light grey bar represents short stubble. The capital letters indicate significant differences between sites. The small letters represent significant differences between treatments by site.

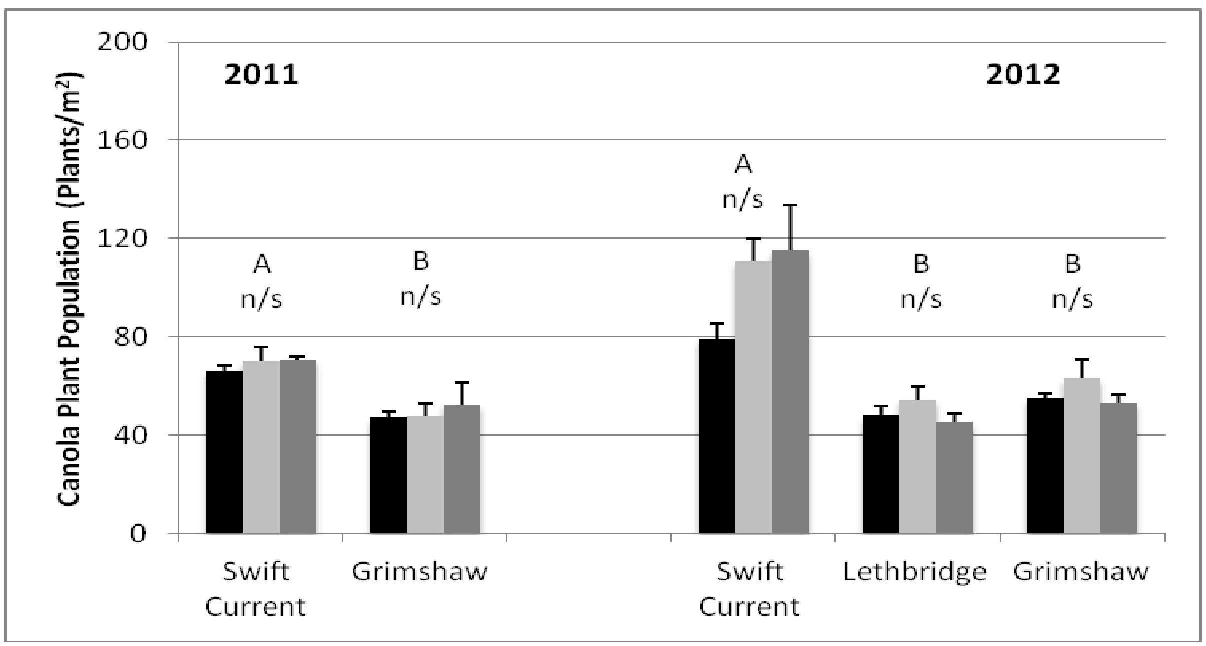

Figure 3.16 The canola plant population per meter squared with stripper header treatments. The black bar represents tall stubble, light grey bar represents short stubble and dark grey bar is the stripper header stubble treatments. The capital letters indicate significant differences between sites. The small letters represent significant differences between treatments by site.

3.4.2 Canola Production

3.4.2.1 Biomass

There was large variation in amount of biomass collected among treatments, sites and years (Figures 3.17, 3.18). In 2011, biomass ranged from 2,100 to 10, 000 kg ha^{-1}. Swan Lake 2011 was not seeded until July and had the lowest biomass that year. Grimshaw 2011 had excellent growing conditions and the highest biomass levels in 2011. In 2012, biomass production ranged from under 2,000 to 8,100 kg ha^{-1}. Indian Head 2012 recorded the highest biomass levels in 2012 and in a reversal from the previous year, the Grimshaw 2012 location had the lowest biomass levels.

The tall, short and stripper stubble treatments had no significant impact on canola biomass except at the Grimshaw 2011 site where the biomass in the tall stubble was significantly larger than the short and the stripper stubble treatments (Figure 3.18). Over the 11 site-years, stubble height treatment created a significant difference in canola biomass only at one site year.

However, there were significant differences in canola biomass production among site-years. In 2011, the Grimshaw site had statistically higher biomass production than Indian Head or Swan Lake (Figure 3.17). Canola biomass production at Swift Current and Indian Head was statistically higher than at the Swan Lake site. In 2012, Indian Head canola biomass production was statistically higher than at all the other 2012 locations (Figure 3.17). Canola biomass production at Falher 2012 was higher than at Lethbridge 2012 and Swan Lake 2012. Swift Current 2012, Lethbridge 2102, Kenton 2012 and Swan Lake 2012 biomass production was statistically higher than Grimshaw 2012.

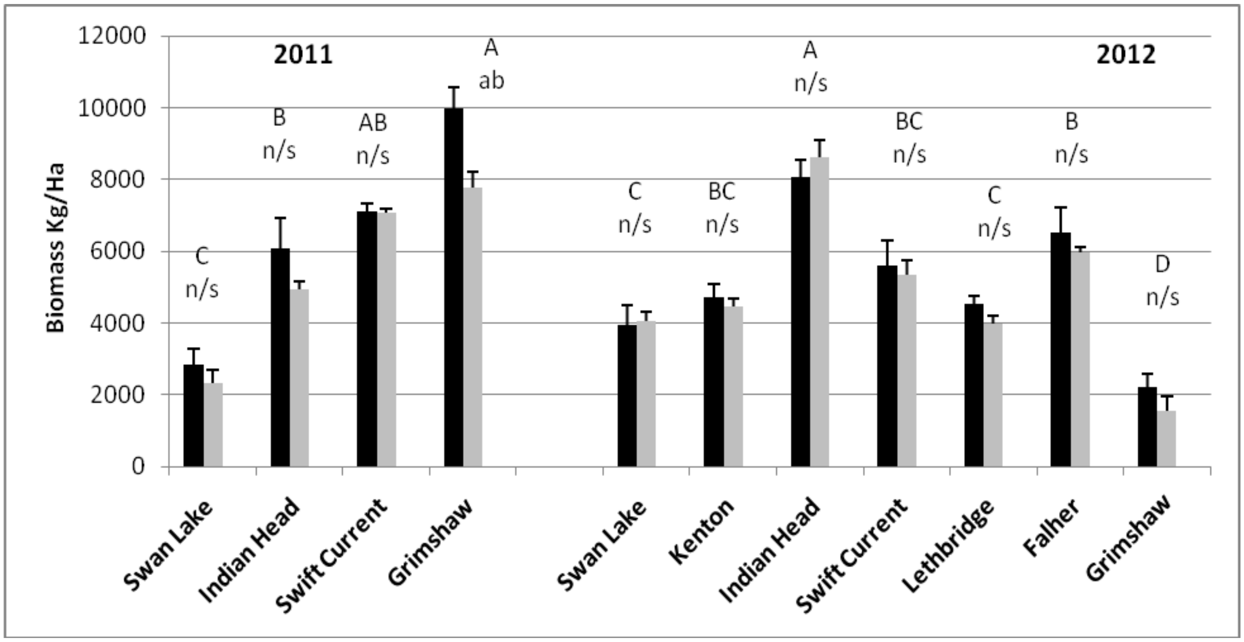

Figure 3.17 Canola biomass production by tall and short stubble treatment and site (black bar-tall stubble and light grey bar-short stubble).

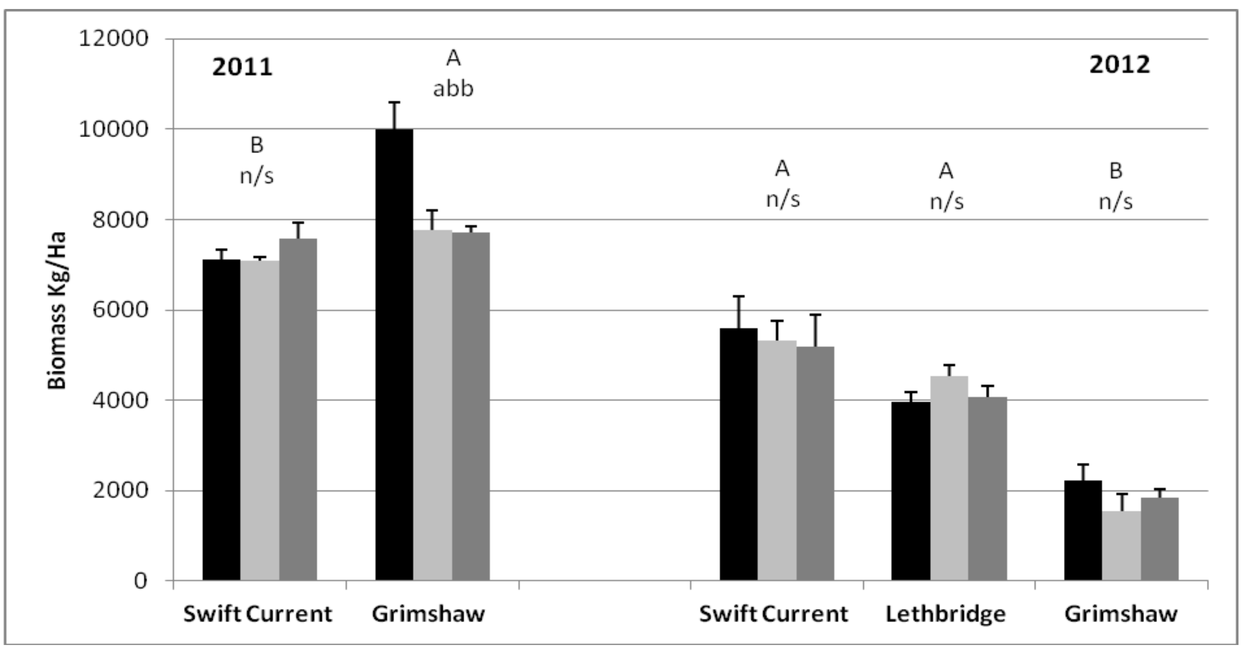

Figure 3.18 Canola biomass production by tall, short and stripper treatment and site (black bar-tall stubble, light grey bar-short stubble and dark grey bar-stripper header stubble).

3.4.2.2 Canola Yield

Overall there were limited differences between the tall and short stubble treatments. The Grimshaw 2011 site had significantly higher yield in the tall stubble compared to the short and stripper stubble treatments (Figures 3.19, 3.20). There were no other significant treatment effects in 2011 or 2012.

There was no statistical difference in canola yield among sites in 2011 (Figure 3.19). The canola seeded in July at Swan Lake 2011 did not mature, so no canola seed was harvested. In 2012, there was a significant site effect on canola yield observed. The Falher 2012 yield was statistically higher than all other sites in 2012, except Indian Head 2012, which in turn was higher than all the remaining sites except Kenton. Kenton 2012 had statistically higher yields than Swift Current 2012, Lethbridge 2012 and Grimshaw 2012 (Figure 3.19). At Lethbridge 2012, it is possible that the time of biomass collection, which was earlier than desirable as a result of logistics, contributed to the low yield. At Swift Current 2012, the wet seeding conditions were a problem and Grimshaw went from being the highest yielding location in 2011 to one of the lowest yielding locations in 2012, as a result of unfavorable temperature and precipitation in the latter year. The highest yielding locations Indian Head and Falher achieved yields three times as large as the lowest three sites.

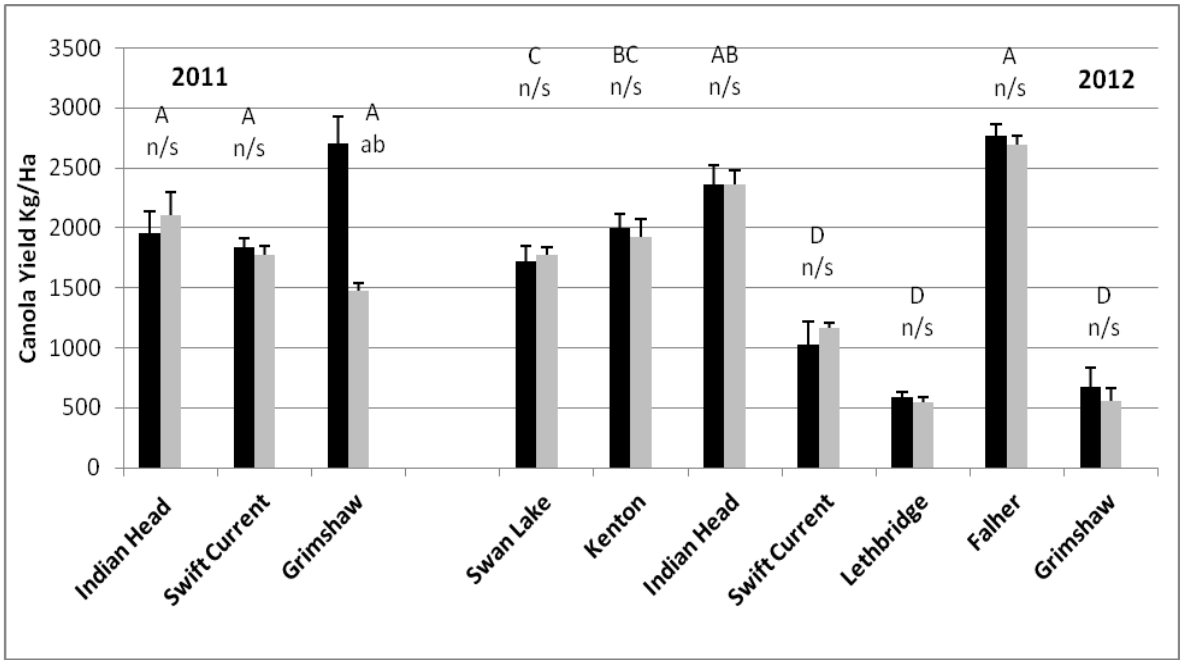

Figure 3.19 Canola yield by tall and short stubble treatment and site (black bar-tall stubble and light grey bar-short stubble).

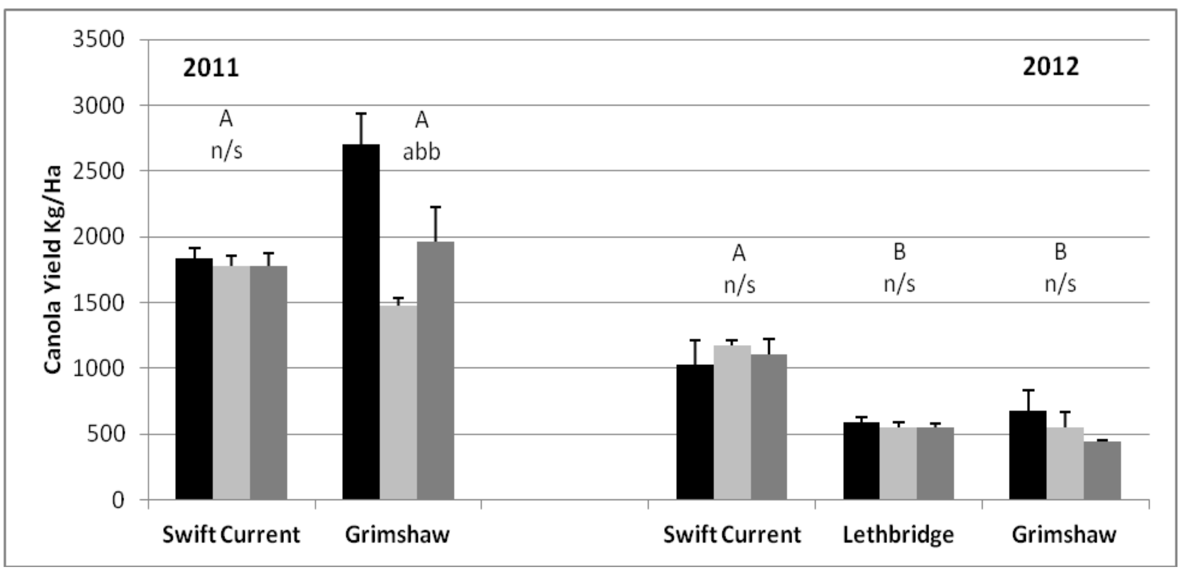

Figure 3.20 Canola yield by tall, short and stripper treatment and site (black bar-tall stubble, light grey bar-short stubble and dark grey bar-stripper header stubble).

3.4.2.3 Harvest Index

There were no significant stubble treatment effects on harvest index (HI) at any of the sites (Figures 3.21, 3.22). At Indian Head 2011, the difference between the tall and short stubble HI seemed large but the results showed that it was not significant. The tall stubble HI was 0.30 while the short stubble was 0.21. The average HI for Indian Head was 0.25. The results may reflect either a small sample size or wide variation in HI within the samples that were collected.

In 2011, there was no significant difference in HI between sites but in 2012 there was a significant site effect (Figure 3.21). The HI at Falher 2012 was statistically higher than at all other sites, except Kenton 2012, which in turn was statistically higher than all the remaining sites except for Indian Head 2012. Lethbridge 2012 and Grimshaw 2012 had the lowest HI of all sites in both years.

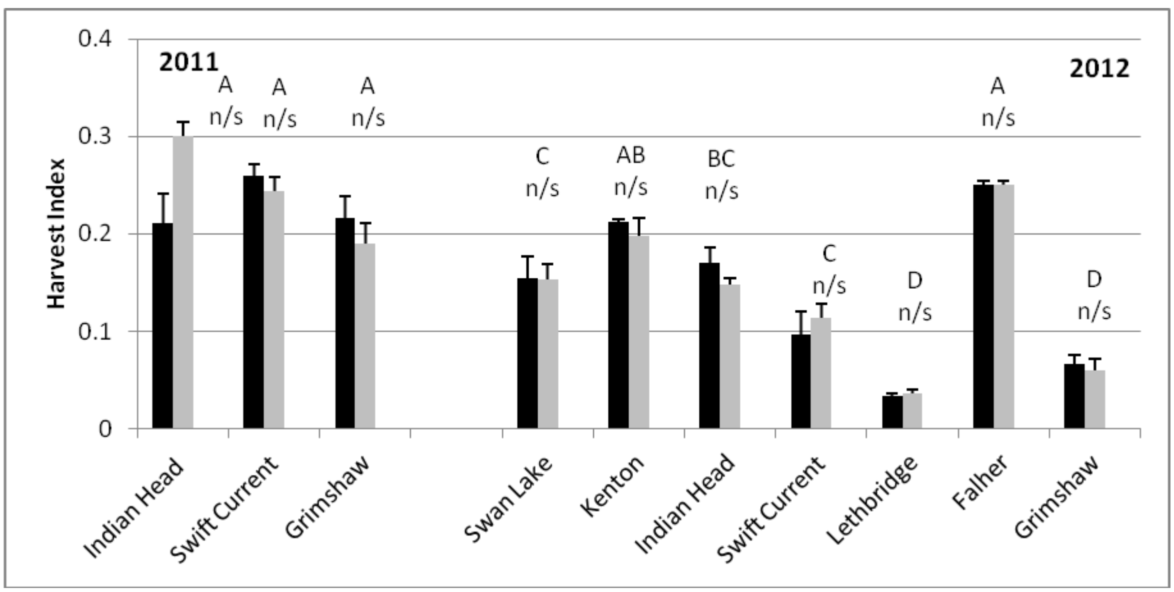

Figure 3.21 Harvest index by tall and short stubble treatment and site (black bar-tall stubble and light grey bar-short stubble).

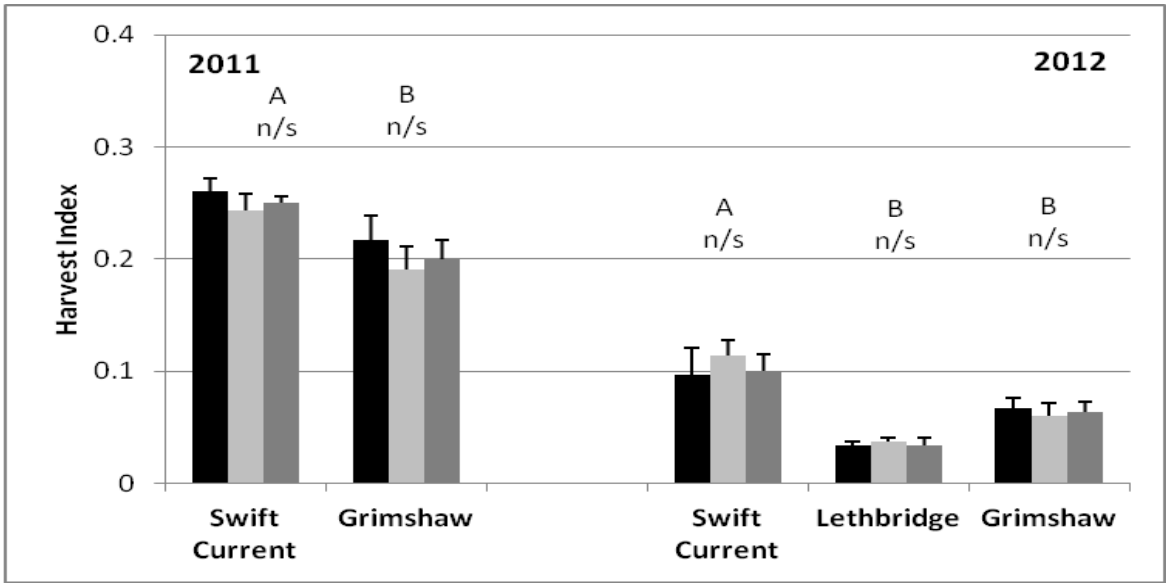

Figure 3.22 Harvest index by tall, short and stripper treatment and site (black bar-tall stubble, light grey bar-short stubble and dark grey bar-stripper header stubble).

3.4.2.4 Canola Production

The low biomass production at Swan Lake 2011 was due to a very wet spring. Heavy rainfall prevented field access. These problems were amplified by the site being located at the bottom of a ridge which slowed the drying of the field. Seeding was delayed until July 19 in 2011 compared to the more normal seeding time in mid-May. When the biomass samples were collected on Oct.13, 2011 the crop had not reached maturity as the pods were just starting to develop and no yield was recorded.

The higher biomass production at Grimshaw 2011 did not translate into higher canola yield at this site. Although not statistically significant, the HI was sufficiently higher at Indian Head 2011 and Swift Current 2011 compared to Grimshaw 2011 and eliminated differences in yield between the tall and short treatments. When the stripper header treatments were included, canola at the Swift Current 2011 site had significantly greater harvest index than Grimshaw 2011. The advantage of higher canola biomass levels at Grimshaw 2011 was lost as a result of its slightly lower HI.

At Grimshaw 2011, the higher canola yield in the tall stubble treatment is consistent with results from Cutforth et al. (2006, 2011). In the latter study, conducted near Swift Current, Saskatchewan from 2001-2003, the three growing seasons were in the top 5 hottest and driest years on record. The overall yields were greater in the treatments which had the highest stubble by an average of 17% Cutforth et al. (2011). They found that yield response was positive and linear with the height of stubble. In this regard, the stripper stubble treatment in Grimshaw 2011 was not consistent with the results of Cutforth et al. (2011) even though the stripper stubble was greater than 50 cm in length. Based on the results from Cutforth et al. (2011), the Grimshaw 2011 stripper header stubble should have produced even greater yields than the tall stubble. In 2011, the Peace River region, where the Grimshaw 2011 site was located, was coming out of a drought cycle. Thus, the conditions were similar to those where Cutforth et al. (2006, 2011) had shown that tall stubble (45 cm) created a beneficial effect on canola yield. The tall stubble benefit at Grimshaw 2011 was not a result of increased snow catch because the stubble was not sculpted until the spring. Although there was no significant difference in ET among the stubble treatments in Grimshaw 2011 over the growing season (Fig. 2.14), it is possible that during the spring, the tall stubble reduced ET sufficiently to provide more moisture to the canola during the critical early growth phase. This is not certain because ET was not estimated during this time period. However, with the Grimshaw 2011 site coming out of a 3-year drought period, it is certainly possible that some additional moisture in the spring as a result of reduced evaporative demand could provide sufficient advantage to create higher amounts of biomass and yield in the tall stubble treatment. At Grimshaw 2011, the tall stubble was intact; however, the stripper stubble was damaged during seeding which caused some of it to pile on the soil surface. The poor condition of the stripper stubble eliminated any potential benefit that could have occurred through reduced evaporation and higher water use efficiency. Bruce et al. (2005a) found that stubble spread on the soil reduced yield of the canola by decreasing plant density. The spread stubble forced the canola hypocotyls to elongate and diverted energy resources to growth and away from development at an early stage this likely reduced the number of leaves on the canola plant lowering the overall biomass produced (Bruce et al. 2005b; Hocking and Stapper 2001).

In 2012, the ranking for biomass production was different from the ranking for yields. The two locations that resulted in the highest canola biomass production, Indian Head 2012 and Falher 2012, were also the two highest yield locations. However, even though Swift Current 2012 and Lethbridge 2012 had significantly higher biomass than the Grimshaw 2012 location, the yield for those three sites showed no statistical difference.

There were other factors that influenced yield at each site. In Lethbridge 2012, the biomass was collected on Aug.12th but the site was not harvested until Sept.15th 2012. However, since the yield results were based on canola seed within the biomass samples, it is possible that some of the canola seed might not have been fully developed when the biomass samples were collected. The biomass samples were placed in cotton bags to prevent loss of seeds, but in the process of cutting the canola some pods could have shattered. The loss of seeds to disease and during handling could have reduced the reported yields and harvest index at some locations more than other but would not have affected the biomass determination.

At Swift Current 2012, large areas of the research plots had to be reseeded several weeks later. The seeder had plugged due to the canola being lodged from the previous winter and the ground being wet at time of seeding. This caused damage to large parts of the stubble and reduced the area that could be sampled for biomass and yield analysis and the areas that were reseeded were not included in this analysis.

The large site by site variation in canola biomass and yield was expected because of the different climate, soil and topographic conditions at each location which influenced the development, growth and final harvest of the canola crop. The lowest yielding sites in 2012 suffered from low precipitation over July and August (less than 20 mm of rain) which caused moisture stress.

However, there was a lack of consistency int the variation of canola biomass and canola yield between sites. Angadi et al. (2003) compared canola yields achieved from plant populations at a range of plant densities from 5, 10, 20, 40 to 80 plants m^{-2}. Low plant density only affected the yield at 20 plants m^{-2} or lower as the crop became more vulnerable to extreme weather, environmental conditions and disease (Angadi et al. 2003). When the population was reduced from 80 m^{-2} to 40 m^{-2} there was no effect on canola biomass or yield. Angadi et al. (2003) stated the canola plant has large plasticity. Table 3.4 shows the plants per square meter ranged from 39 to 157 plants m^{-2}, which is within the range with no impacts on yield as identified by Angadi et al. (2003). Their research was conducted in the most arid regions of the Canadian Prairies, however, this study had sites located across a range of prairie climatic zones indicating the plasticity of canola is unchanged by climate and the crop is able to compensate for lower plant densities through the variety of weather conditions typically experienced in western Canada.

The HI influenced the yield ranking between sites in 2012. In general, the sites with highest HI also had the highest canola yields. In fact, yield was more strongly influenced by HI than biomass. The low yields in Swift Current 2012, Lethbridge2012 and Grimshaw 2012 were related to low HI. At all three sites, there was water stress as a result of precipitation well below monthly averages. The plants harvested at Swift Current 2012 and Grimshaw 2012 were noticeably small and thin. The Lethbridge 2012 site samples had to be taken a month before the producer harvested the plot and the early cutting may have led to some seeds not being fully mature.

There was one exception to the yield and HI relationship. The Swan Lake 2012 and Kenton 2012 sites had no statistical difference in yield but the Kenton site had a statistically higher HI compared to Swan Lake. Thus, higher yields do not always occur with a high harvest index. The environmental conditions likely caused variation in canola development between the different locations the canola was grown. Angadi et al. (2003) found similar results in their study which showed very consistent harvest index across different plant densities. Only when the canola experienced extreme stress were there significantly lower HI values. Angadi et al. (2003) further stated that canola populations had no effect on the harvest index but the growing season conditions played a greater role in potentially altering the harvest index. The fact that harvest index was not different between the tall, short and stripper header treatments at any locations during 2011 and 2012 indicates that the microclimate alterations during the early part of the season did not have a lasting impact on the canola over the entire growing season.

The tall stubble treatment increased the yield of canola at 1 out of 11 site-years. In general, there was little or no impact of a tall stubble treatment on most of the performance measurements. Thus, the positive impact of tall stubble (45 cm) on canola yield reported at the Swift Current Research facility (Cutforth et al. 2006, 2011) had a measurable benefit to canola less than 10% of the time across the range of conditions encountered in western Canada during this study.

3.4.3 Disease Pressure

3.4.3.1 Blackleg

In 2011, there was no blackleg discovered at any of the sites. In 2012, only low amounts of Blackleg were found at just the four sites shown in Figure 3.23. Blackleg incidence, as a percentage of plants, ranged between 0.1 and 0.65%. There was no significant difference in disease pressure among stubble treatments or among sites.

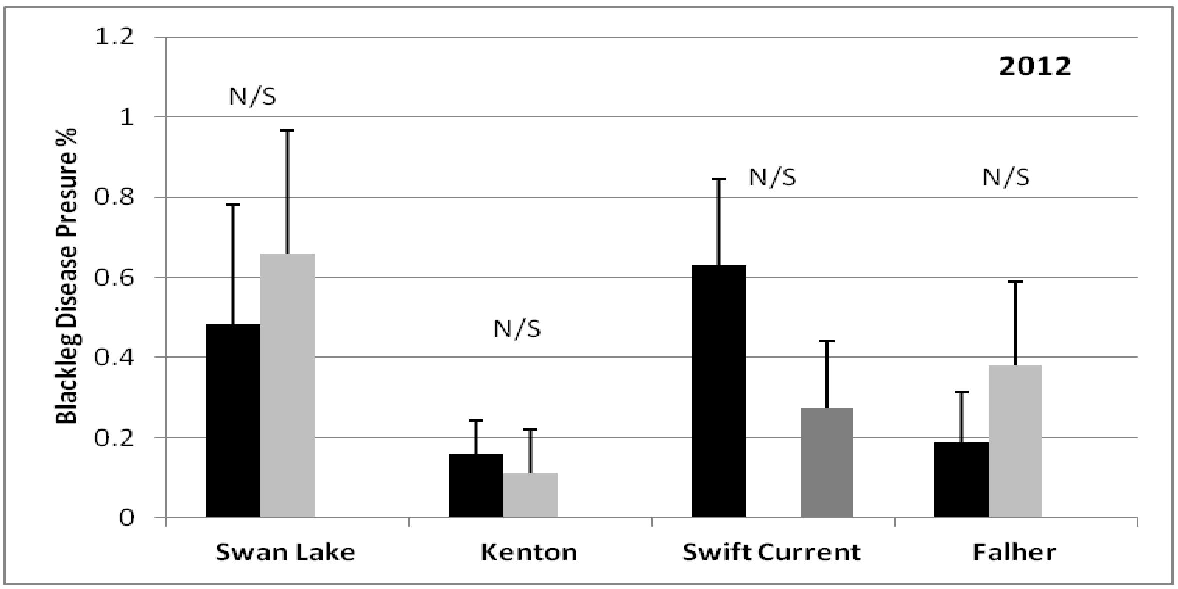

Figure 3.23 Blackleg disease pressure in 2012 (black bar-tall stubble, light grey bar-short stubble and grey bar-stripper header stubble).

3.4.3.2 Sclerotinia

In 2011, Sclerotinia was found only at Grimshaw. There was no significant difference in the disease pressure among treatments (Figures 3.24, 3.25). In 2012, Sclerotinia was found at six sites at various intensities (Figure 3.24, 3.25). Despite the wide range of sclerotinia incidence, there was no significant treatment effect between the tall, short and stripper stubble. However, there were significant site differences in sclerotinia incidence. Indian Head 2012 had the highest incidence of sclerotinia, statistically more than any of the other sites (Figure 3.24). Kenton had the next highest sclerotinia incidence which was statistically higher than Swan Lake and Falher. The locations in 2012 which had the stripper header treatment showed no significant site variation (Figure 3.25).

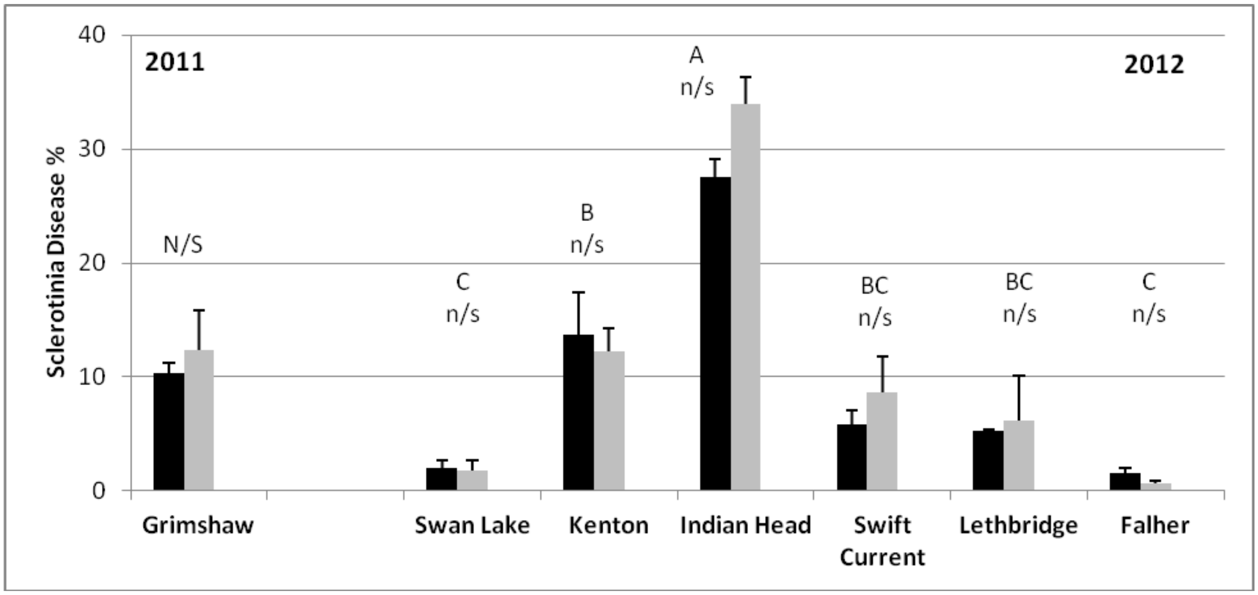

Figure 3.24 Sclerotinia incidence during 2011 and 2012 (black bar-tall stubble and light grey bar-short stubble).

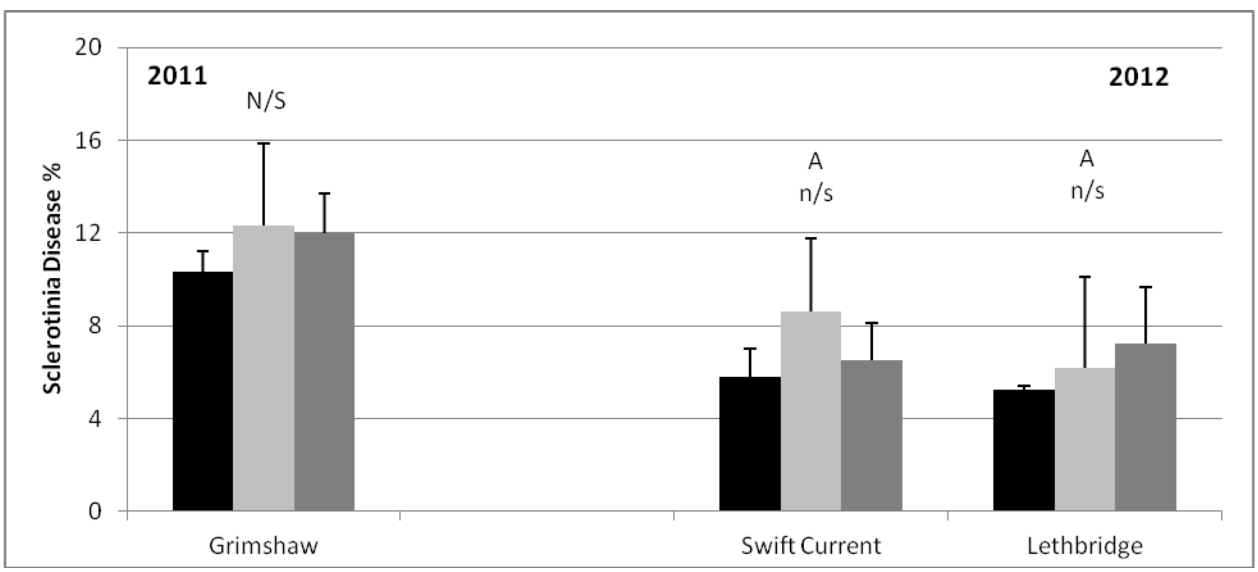

Figure 3.25 Sclerotinia incidence with stripper header treatment during 2011 and 2012 (black bar-tall stubble, light grey bar-short stubble and dark grey bar-stripper header stubble).

3.4.3.3 Disease Pressure

Sclerotinia and blackleg disease incidence varied between the 2011 and 2012 growing seasons. In 2011 there was no blackleg found at any sites and only one site had sclerotinia despite extensive disease scouting. Weather strongly influences both blackleg and sclerotinia outbreaks and during the 2011 growing season weather was not conducive for disease development across much of western Canada. In general, warm and wet growing season are favorable for both blackleg and sclerotinia (Canola Council of Canada, 2011). The 2011 growing season was characterized by very wet (in some locations record wet) spring conditions which turned into very dry conditions starting in late June to late July through to the end of the crop year across almost all of the prairies. The dry growing season created unfavorable conditions for both blackleg and sclerotinia to affect the canola crop in most areas.

The Grimshaw 2011 site was the only site where any disease was found. The area had experienced 3 years of drought. During the 2011 growing season, precipitation was slightly above average in April and May but during June and July there was twice as much rainfall compared to the long term average. August and September experienced a more average level of rainfall (Figure 2.4). At this location, the excess moisture contributed to the presence of sclerotinia but there was no statistical difference in sclerotinia incidence between treatments. Thus, the microclimate alterations created by the standing stubble did not influence the level of sclerotinia. The presence of the disease was related to the growing season weather.

In 2012, there was more Blackleg detected at the study sites. Overall the blackleg incidence numbers were extremely low with the maximum level of incidence only 0.65%. There was no difference in blackleg disease pressure between treatments and no statistical difference in blackleg incidence between sites. One of the main management practices that can reduce the impacts of blackleg incidence on a canola field is crop rotation (Guo et al. 2005). The 4 year site history obtained from each site shows the majority of sites were practicing a two year rotation of non-host crops (Appendix 5.2). Only the Grimshaw site had canola at the same location both years but the dry conditions in 2012 created conditions unfavorable to blackleg development and limited the extent of the disease.

In 2012 the sclerotinia disease incidence was more severe than in 2011. Six of the seven sites had sclerotinia at intensities that ranged from 1-33% of plants infected. The sites with the highest levels of disease were Indian Head and Kenton. These sites had the greatest amount of precipitation in July with 125 mm and 52 mm for Indian Head and Kenton, respectively. All other 2012 sites had July rainfall levels below 30 mm. Swan Lake, despite being located in a region that is generally humid and warm had a July precipitation total that was much lower than the Kenton and Indian Head locations. Swift Current and Lethbridge are located in more arid regions where the level of crop disease and July precipitation would be expected to be lower. Grimshaw, the only site with disease in 2011, had a dry growing season in 2012, especially in the month of July (Figure 2.11) which resulted in no disease being detected. Swan Lake, Swift Current, Falher and Lethbridge all experienced above average precipitation during May and June then a sharp decrease in precipitation over July and August, similar to the 2011 conditions. The lack of precipitation later in the 2012 growing season appears to have been a significant factor that reduced sclerotinia pressure at these sites.

An interesting note is that the Kenton 2012 and Indian Head 2012 sites had statistically similar yield and harvest index but Indian Head 2012 had the statistically greatest amount of sclerotinia followed by Kenton 2012. The overall climatic conditions at both sites appear to have increased occurrence of sclerotinia disease but did not heavily affect the overall canola performance at both sites. Based on our results the benefit of the additional moisture on the growth and yield of the canola overshadowed the impact of higher sclerotinia incidence. Since there was no significant effect of stubble height at any of the sites, these treatments neither promoted nor limited incidence of either blackleg or sclerotinia.

3.5 Conclusion

Overall there were no significant differences in both canola emergence and number of canola plants between the three stubble treatments (tall, short and stripper header). This indicates that despite previous literature indicating the benefits of tall stubble in the most arid region of the Canadian Prairies, the emergence benefits were not evident at any of the 11 site years. Any microclimatic alterations created by the stubble heights were overshadowed by the growing season climatic conditions. Additionally, the physiology of the canola plant compensated for lower plant populations. Previous research had shown that reducing canola population to as low as 40 plants m^{-2} had no impact on yield (Angadi et al. 2003). However both Angdi et al 2000 and Gusta et al. 2000 highlighted risks of heat stress on the canola plant at the flowering stage of development. The number of plant populations in this study ranged from 39 to 157 m^{-2} all above the 20 plant threshold. Biomass and yield showed a significant increase in tall stubble at one location over the 2011 and 2012 growing seasons. The harvest index showed no significant treatment effects at any of the sites. The site which experienced a significantly higher biomass and yield in the tall stubble compared to the short and stripper header treatments Grimshaw 2011 had been suffering from three years of drought prior to the spring of 2011. This is likely the reason that the tall stubble was able to create favorable climatic conditions that benefited the canola similar to results of previous studies in semi-arid regions. It is very important to note that the tall and stripper header stubble did not create any increase in the occurrence of either

Blackleg or Sclerotinia. These diseases can cause serious yield loss so it is significant that the tall stubble treatments did not encourage any increase in disease pressure.

Tall stubble height has some potential to positively impact canola biomass and yield. Previous literature and this project show that arid regions or areas experiencing drought are the most likely to benefit from this stubble treatment. However, this study also shows that canola physiology allows this crop to compensate for low emergence and plant populations in terms of biomass and yield across the broad range of climatic zones in Western Canada.

3.6 References

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Chapter 4

4.1 Research Synthesis

The tall stubble caught significantly higher amounts of snow than the short stubble during the winter months. The locations (Swan Lake and Indian Head) that were sculpted in the fall during the 2011 and 2012 growing season generally matched previous data on barriers and their effects on snow catch. Despite the additional snow catch in the tall stubble treatments the spring soil moisture levels were not significantly different between treatments at the same locations. Overall tall stubble can be an effective barrier in trapping a greater amount of snow than short stubble. The lack of significantly different amounts of spring moisture between the tall and short treatments in 2011 and 2012 was the result of above average precipitation during the early part of the growing season (May and June). The entire growing season saw a general trend of above average precipitation and cooler temperatures during the early part of the growing season and then subsequent reduction in precipitation and increase in temperature during the later part of the season. This did not affect the evapotranspiration estimated at multiple locations in 2011 and 2012. Evapotranspiration was completely independent of stubble height consistent with previous research in the Swift Current area. This indicates that lack of ET response to stubble height is applicable over a range of different climatic regions.

The climatic conditions over 2011 and 2012 reduced the potential benefits of tall stubble. During emergence there were no significant differences in either canola emergence or number of canola plants among three stubble treatments (tall, short and stripper header) at any of the 11 site years. The growing season climatic conditions overshadowed any microclimate alterations and played the largest role in creating differences in canola response variables including emergence%, plant population, biomass production, yield and harvest index. With drier and warmer conditions during the early part of the growing season it is likely there would have been greater amounts of moisture more consistently in the tall and stripper header treatments as has been previously shown in the Swift Current area and at the one site in this study where biomass and yield responded to tall stubble. This would also likely have caused greater amounts of canola emergence in those treatments. Additionally, the physiology of the canola plant compensated for lower plant populations. Previous research had shown that if the canola population was over 20 plants m^{-2} and growing conditions were ideal, then canola can compensate for lower plant density. The number of plant populations in this study ranged from 28 to 156 m^{-2} all above the 20 plant threshold, therefore the canola with lower plant densities were able to compensate with the canola plant filling in spaces and producing a greater number of branches and pods. This increased plant growth caused yield and biomass to have no significant differences in 10 of the 11 sites years.

The results from the iButton stations showed tall (50 cm) stubble was unable to significantly alter near surface air temperature in any location during both seasons. The air temperature was analyzed 10 days prior to the 2nd leaf stage of development at all locations. This time period was viewed as the point which the tall stubble climatic alterations would create the most significant effect on canola development. Once the canola crop reached bolting stage it would begin to exceed the height of the tall stubble and climate alterations would not be expected. The air temperature during this time period also was not affected by the condition of the stubble. Those sites where the stubble was intact had no significant differences in GDH accumulated about the soil surface at 5, 20 and 50 cm compared to the sites with damaged stubble.

There is potential for stubble management to impact moisture conditions for canola the following year under dry conditions. The benefit from increased moisture would be expected to occur more frequently in the most arid regions of western Canada and less frequently in the more humid regions.

Based on observations from technical staff and producers, the stripper header and tall stubble did create problems during seeding. Above average moisture and the stubble being lodged over the winter caused the seeder to plug. Disks were ineffective in cutting through the lodged stubble and it would collect and bunch behind the seeder. These issues were more severe in the stripper header stubble treatments. However at sites were the stripper header stubble was sculpted to the tall 50 cm height during the fall seemed to reduce the risk of stubble causing issues during the seeding.

At the end of the growing season the biomass and yield showed a significant increase in tall stubble at one location over the 2011 and 2012 growing seasons, while the harvest index showed no significant treatment effects at any of the sites. The site which experienced a significantly higher biomass and yield in the tall stubble compared to the short and stripper header treatments (Grimshaw 2011) had been suffering from three years of drought prior to the spring of 2011. The conditions of the Grimshaw location were similar to the conditions at Swift Current where most of the previous research had taken place on the impacts of soil moisture and stubble. It is speculated that the tall stubble may have reduced ET sufficiently during the spring period compared to the short stubble to provide greater amounts of moisture for germination and early growth which then translated into greater biomass and yield at the end of the growing season.

It is very important to note that the tall and stripper header stubble did not create any increase in the occurrence of either Blackleg or Sclerotinia. These diseases can cause serious yield loss so it is significant that the tall stubble treatments did not encourage any increase in disease pressure.

The diseases are highly variable and still pose a serious threat to canola production across the country.

These results show that tall stubble height has some potential to positively impact the microclimate to create better growing conditions that increase biomass and yield. Previous literature and this project show that arid regions or areas experiencing drought are the most likely to experience significant benefits. Therefore it is recommended to leave stubble from 20 or 50 cm height in drought prone areas to help conserve moisture which should improve emergence of the crop but would not affect the overall yield of the crop. Canola physiology allows this crop to compensate for low emergence and plant populations and make up differences in biomass and yield at the end of the growing season across the broad range of climatic zones in Western Canada. The ability of the canola plants to compensate for low populations must be further researched if producers are able to lower the amount of seeds planted yet still maintain similar yields. Lower seeding rates will lower the input costs to the producer but care would be needed to ensure that the plant population does not crop below 40 per m^2 to minimize impacts of weather stress on yield.

4.2 Future Recommendations

There was possibly an issue in this study with the small number of replications at each site (either 3 or 4). The plot sizes were large and because of the immense distance between each site, more resources would be needed to increase the number of replicates in this type of study. Lack of replications reduced the statistical power of the analysis and could be a contributing factor in the lack of significant differences between treatments for some of the variables analyzed.

If this project was to be repeated, it would benefit from concentrating the sites in the more arid regions of western Saskatchewan, south and central Alberta and the Peace Country in northern

Alberta and British Columbia. This would reduce the overall distance between sites and improve the logistics to increase the number of replications at each test location and improve the statistical power of the analysis. This would likely provide a better analysis of tall stubble effects in dry areas, and more clearly define the areas and conditions under which the potential benefits could be expected.

Better determination of the conditions where tall stubble can benefit canola could facilitate a system where growing season conditions could be monitored to identify areas suffering from moisture stress and the potential benefit of tall stubble to catch more snow in the winter and potentially increase moisture reserves in the spring. Thus, better quantification of where and under what conditions tall stubble would be beneficial could give producers a useful tool along with other agronomic practices currently utilized to help combat moisture stress in the semi-arid climate of the Canadian Prairies.

5. Appendices

5.1 Appendix A- Growing Degree Hour Accumulation comparison of various heights per site location

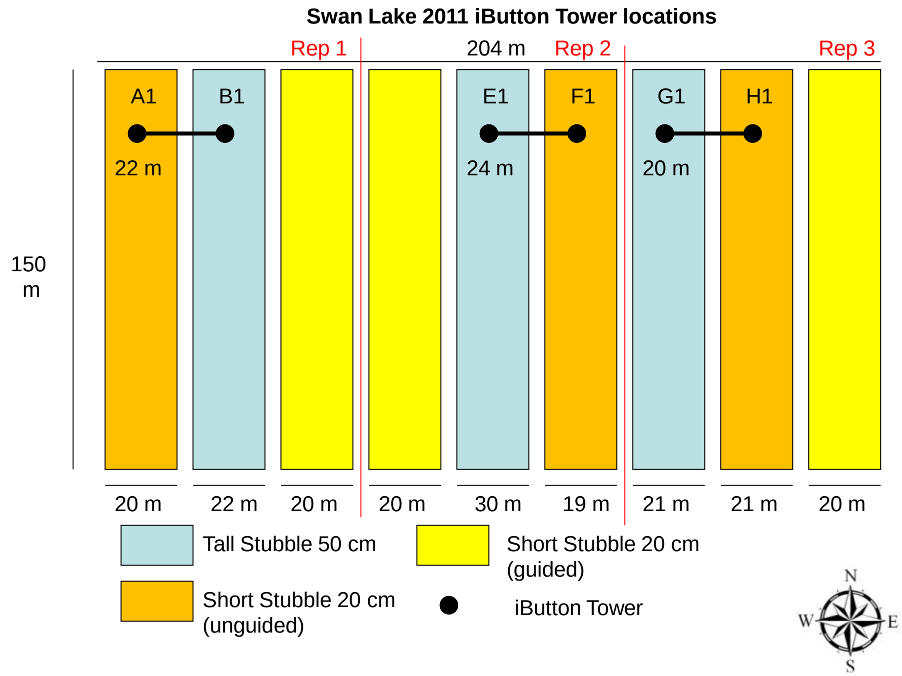
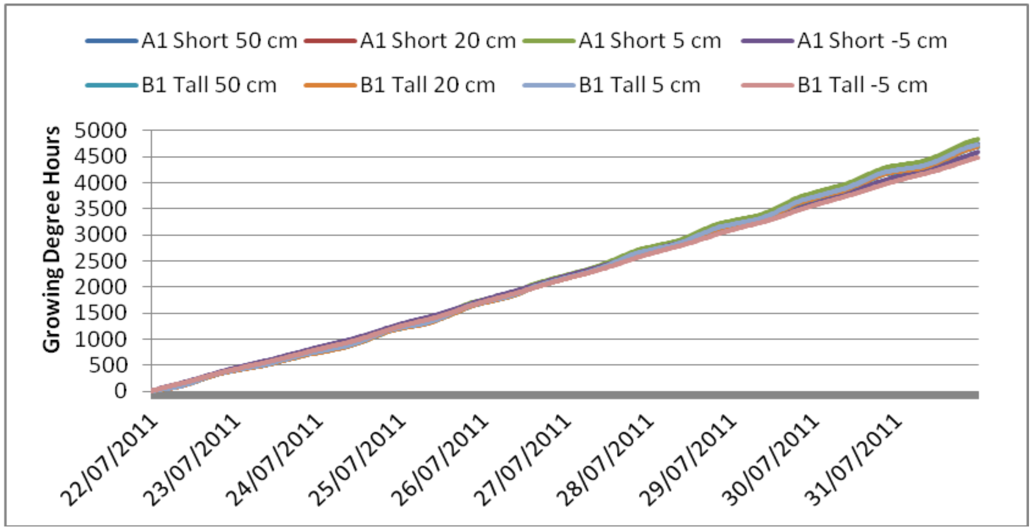


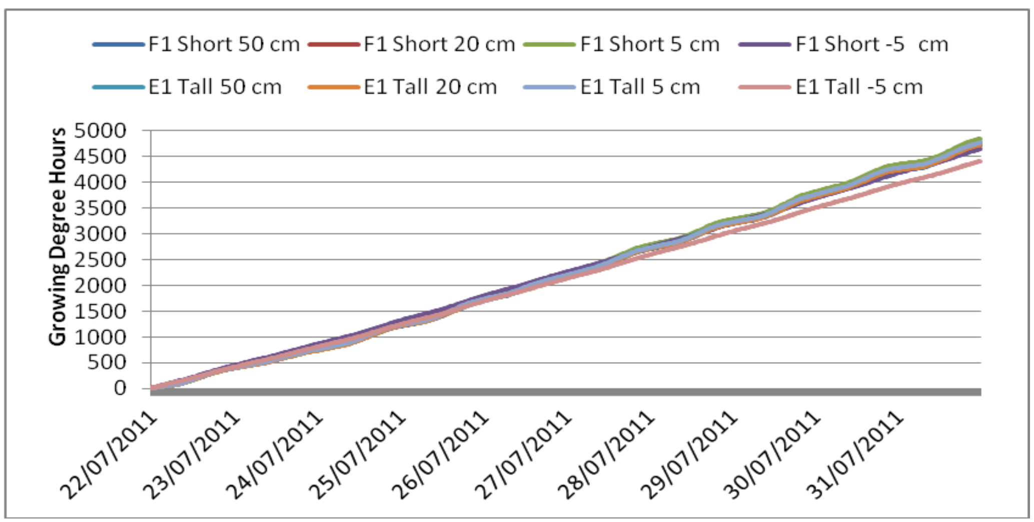
Table A.1 The Growing Degree Hours accumulated at Swan Lake in 2011

	A1 Short	B1 Tall	F1 Short	E1 Tall	H1 Short	G1 Tall
50 cm	4742.3	4690.9	4708.8	4762.1	4735.6	4663.8
20 cm	4726.0	4694.5	4773.3	4728.4	4919.2	4679.3
Above 5 cm	4831.2	4734.1	4845.7	4769.6	4900.0	4783.4
Below 5 cm	4584.3	4489.1	4651.4	4412.4	4657.9	4547.0

a)


A1 Short 50 cm
A1 Short 20 cm
A1 Short 5 cm
A1 Short -5 cm
B1 Tall 50 cm
B1 Tall 20 cm
B1 Tall 5 cm
B1 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
22/07/2011
23/07/2011
24/07/2011
25/07/2011
26/07/2011
27/07/2011
28/07/2011
29/07/2011
30/07/2011
31/07/2011

b)


F1 Short 50 cm
F1 Short 20 cm
F1 Short 5 cm
F1 Short -5 cm
E1 Tall 50 cm
E1 Tall 20 cm
E1 Tall 5 cm
E1 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
22/07/2011
23/07/2011
24/07/2011
25/07/2011
26/07/2011
27/07/2011
28/07/2011
29/07/2011
30/07/2011
31/07/2011

c)

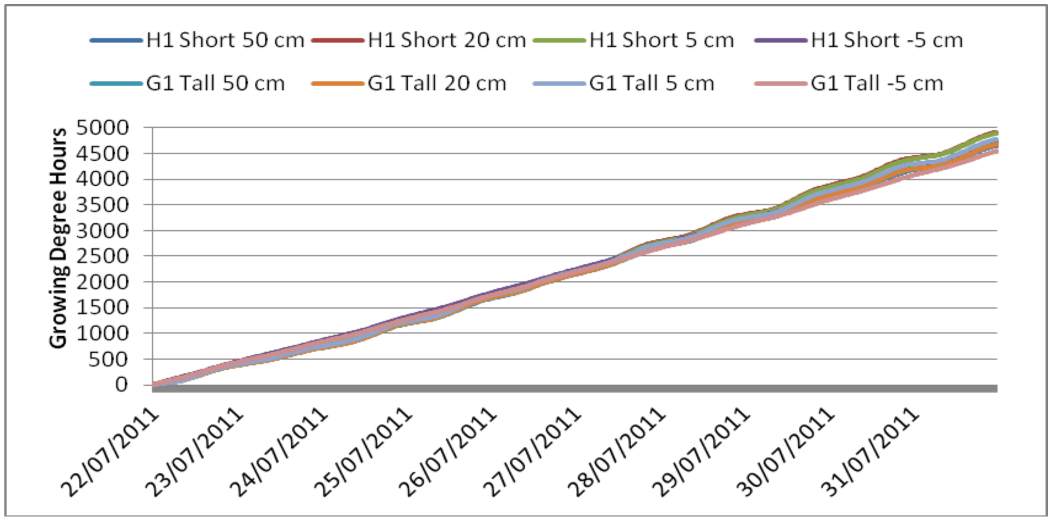


Figure A.1 Comparison of the short and tall stubble at Swan Lake during 2011 growing season a) comparison I-Button stations A1 short and B1 tall, b) comparison I-Button stations F1 short stubble and E1 tall stubble and c) comparison of I-Button stations H1 short stubble and G1 tall stubble.

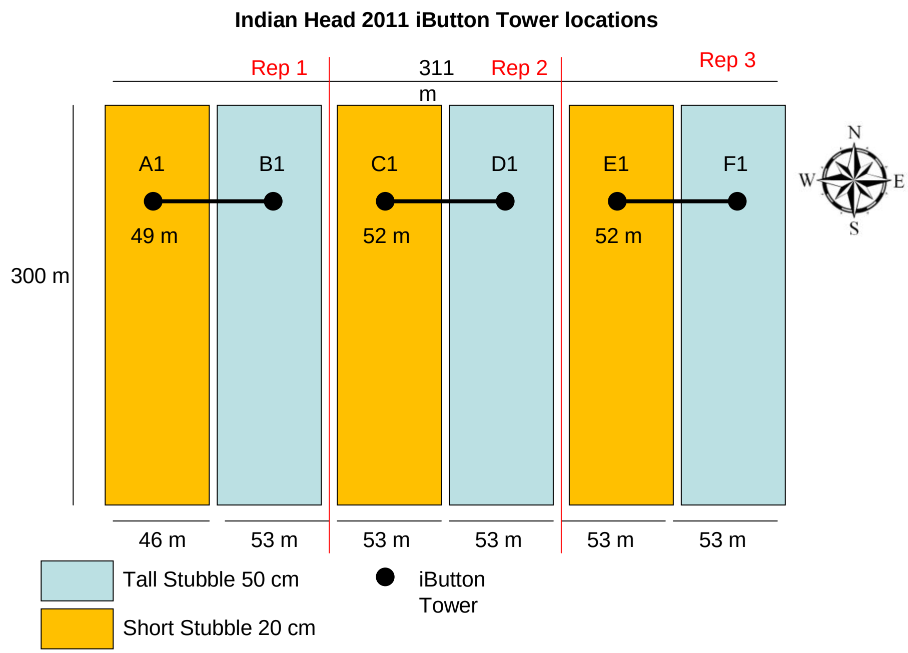
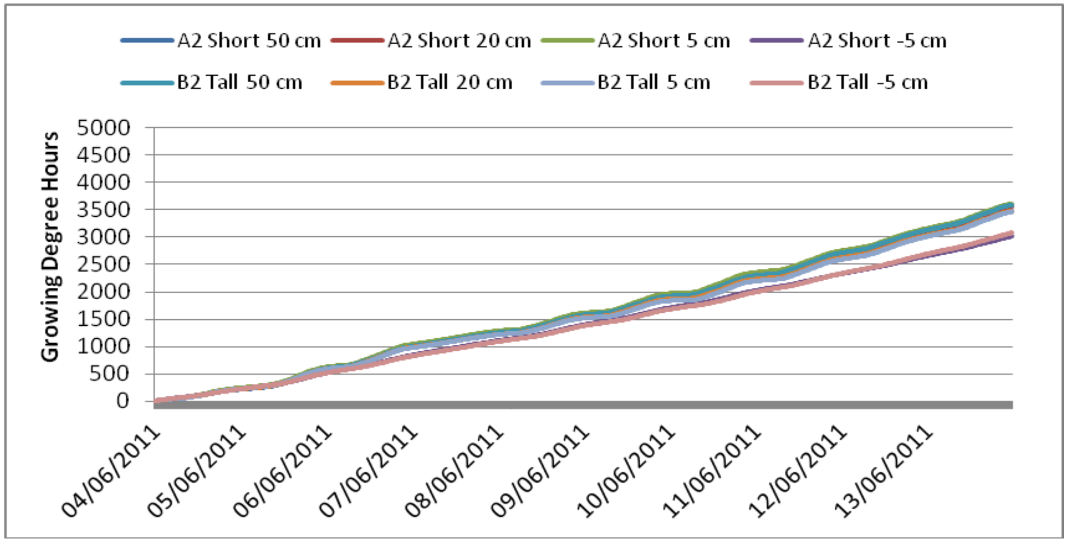


Table A.2 The Growing Degree Hours accumulated at Indian Head in 2011

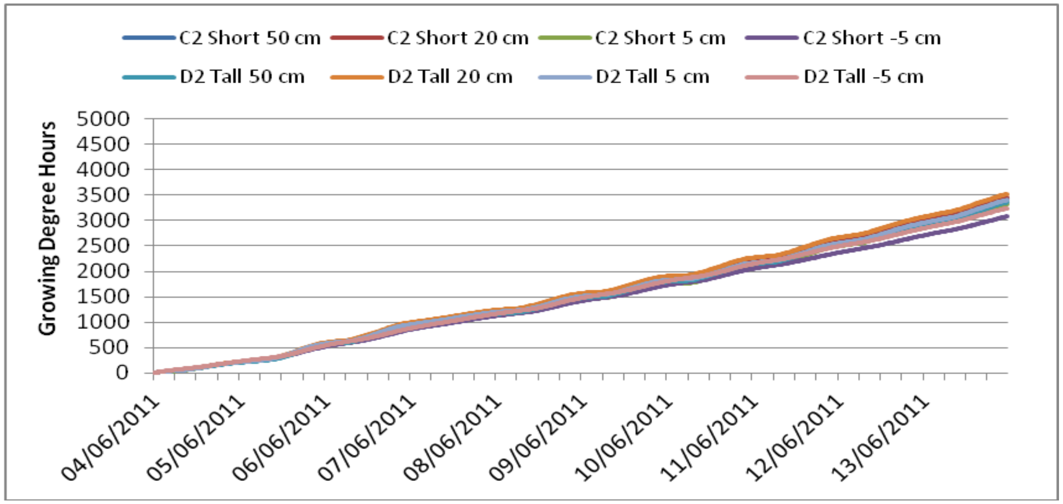
	A2 Short	B2 Tall	C2 Short	D2 Tall	E2 Short	F2 Tall
50 cm	3472.4	3595.0	3440.9	3361.0	3397.1	3496.9
20 cm	3561.6	3483.8	3450.2	3526.5	3477.2	3576.2
Above 5 cm	3614.8	3468.0	3323.6	3406.1	3192.4	3425.7
Below 5 cm	3020.4	3081.2	3086.4	3250.7	3023.8	2980.8

a)



A2 Short 50 cm
A2 Short 20 cm
A2 Short 5 cm
A2 Short -5 cm
B2 Tall 50 cm
B2 Tall 20 cm
B2 Tall 5 cm
B2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
04/06/2011
05/06/2011
06/06/2011
07/06/2011
08/06/2011
09/06/2011
10/06/2011
11/06/2011
12/06/2011
13/06/2011

b)


C2 Short 50 cm
C2 Short 20 cm
C2 Short 5 cm
C2 Short -5 cm
D2 Tall 50 cm
D2 Tall 20 cm
D2 Tall 5 cm
D2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
04/06/2011
05/06/2011
06/06/2011
07/06/2011
08/06/2011
09/06/2011
10/06/2011
11/06/2011
12/06/2011
13/06/2011

c)

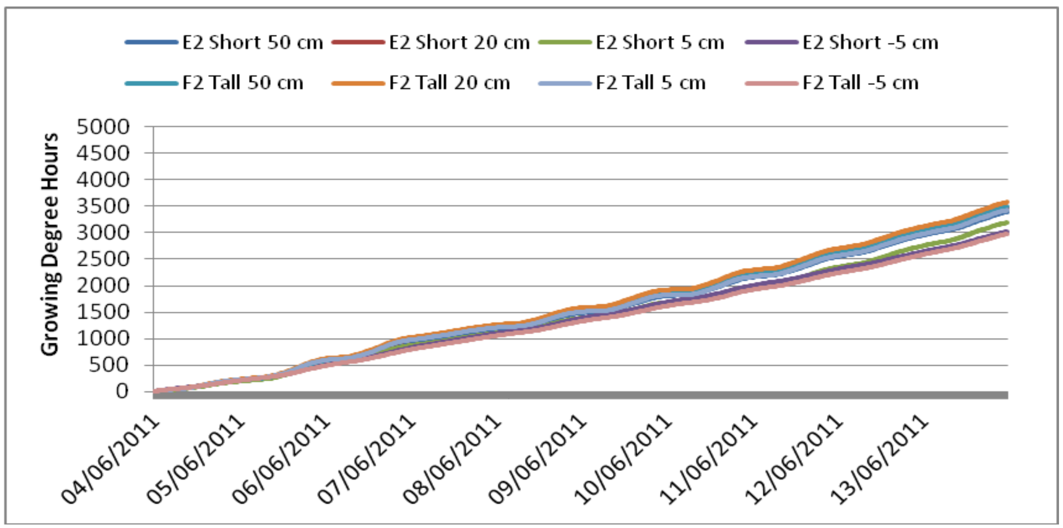

E2 Short 50 cm
E2 Short 20 cm
E2 Short 5 cm
E2 Short -5 cm
F2 Tall 50 cm
F2 Tall 20 cm
F2 Tall 5 cm
F2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
04/06/2011
05/06/2011
06/06/2011
07/06/2011
08/06/2011
09/06/2011
10/06/2011
11/06/2011
12/06/2011
13/06/2011

Figure A.2 Comparison of the short and tall stubble at Indian Head during the 2011 growing season a) comparison of I-Button stations A2 short and B2 tall, b) comparison of I-Button stations C2 short stubble and D2 tall stubble and c) comparison of I-Button stations E2 short stubble and F2 tall stubble.

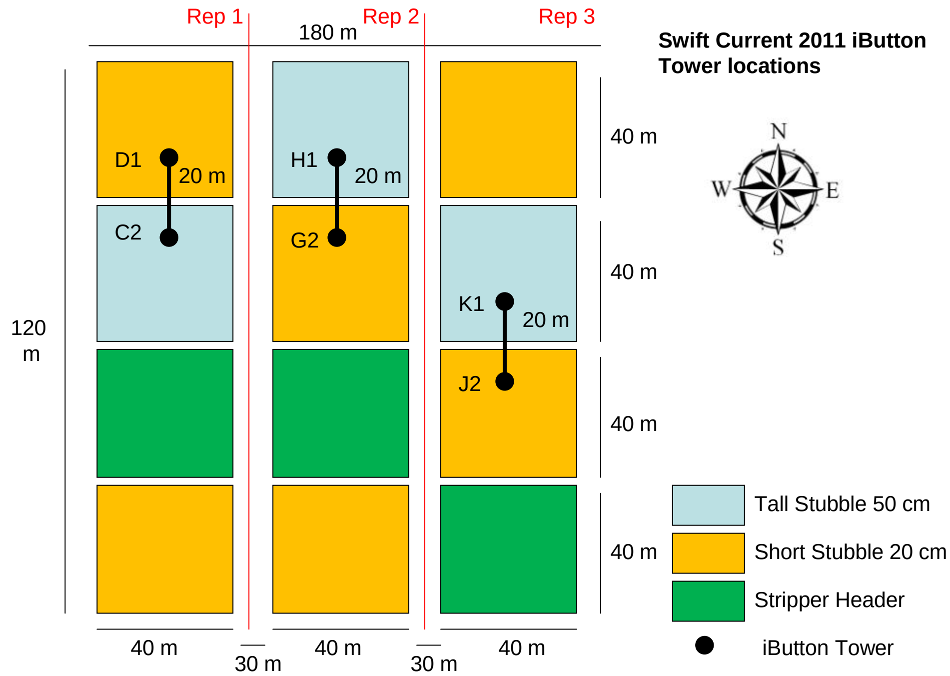
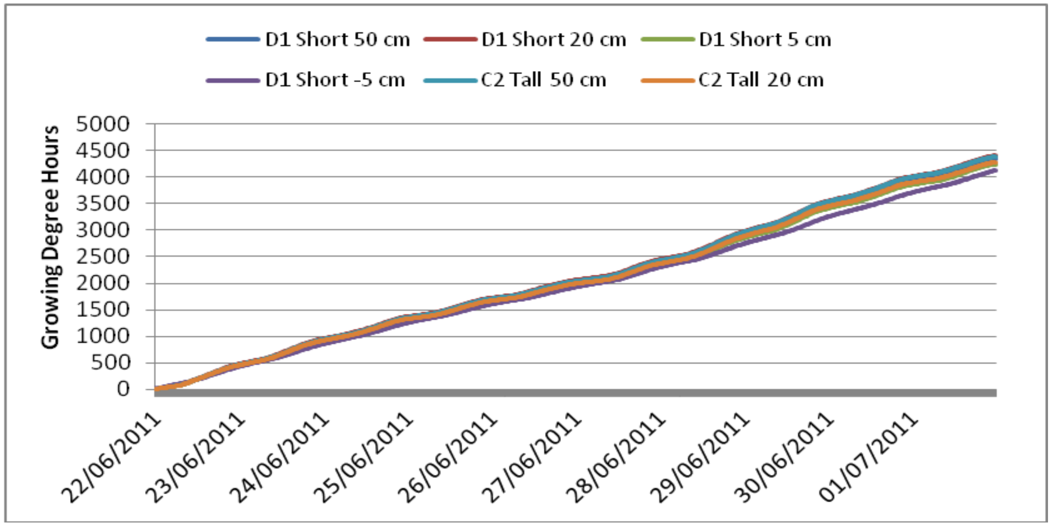


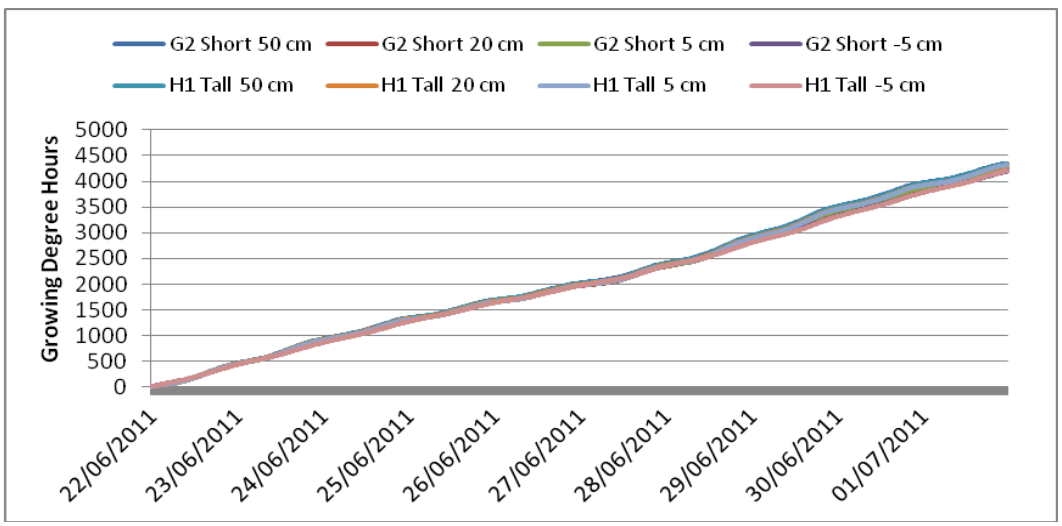
Table A.3 The Growing Degree Hours accumulated at Swift Current in 2011

	D1 Short	C2 Tall	G2 Short	H1 Tall	J2 Short	K1 Tall
50 cm	4338.4	4386.8	4345.7	4332.5	4368.3	4405.5
20 cm	4404.4	4277.8	4220.8	4302.2	4282.8	4239.4
Above 5 cm	4242.7	-	4252.5	4314.1	4098.4	4378.7
Below 5 cm	4130.5	-	4196.6	4208.4	4018.1	4009.9

a)


D1 Short 50 cm
D1 Short 20 cm
D1 Short 5 cm
D1 Short -5 cm
C2 Tall 50 cm
C2 Tall 20 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
22/06/2011
23/06/2011
24/06/2011
25/06/2011
26/06/2011
27/06/2011
28/06/2011
29/06/2011
30/06/2011
01/07/2011

b)


G2 Short 50 cm
G2 Short 20 cm
G2 Short 5 cm
G2 Short -5 cm
H1 Tall 50 cm
H1 Tall 20 cm
H1 Tall 5 cm
H1 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
22/06/2011
23/06/2011
24/06/2011
25/06/2011
26/06/2011
27/06/2011
28/06/2011
29/06/2011
30/06/2011
01/07/2011

c)

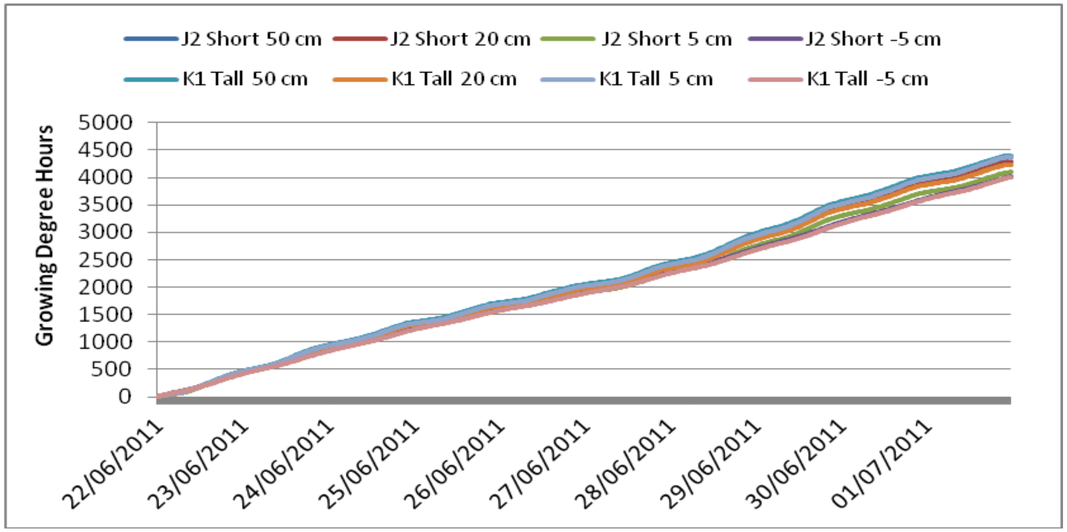


Figure A.3 Comparison of the short and tall stubble at Swift Current during the 2011 growing season a) comparison of I-Button stations tall C2 and D1 short, b) comparison of I-Button stations G2 tall stubble and H1 short stubble and c) comparison of I-Button stations K1 tall stubble and J2 short stubble.

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Grimshaw 2011 iButton Tower locations

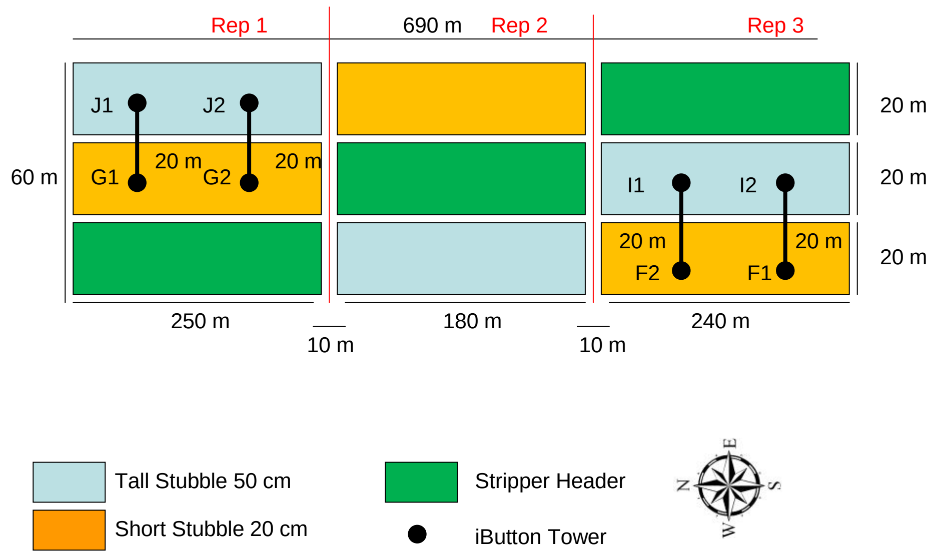
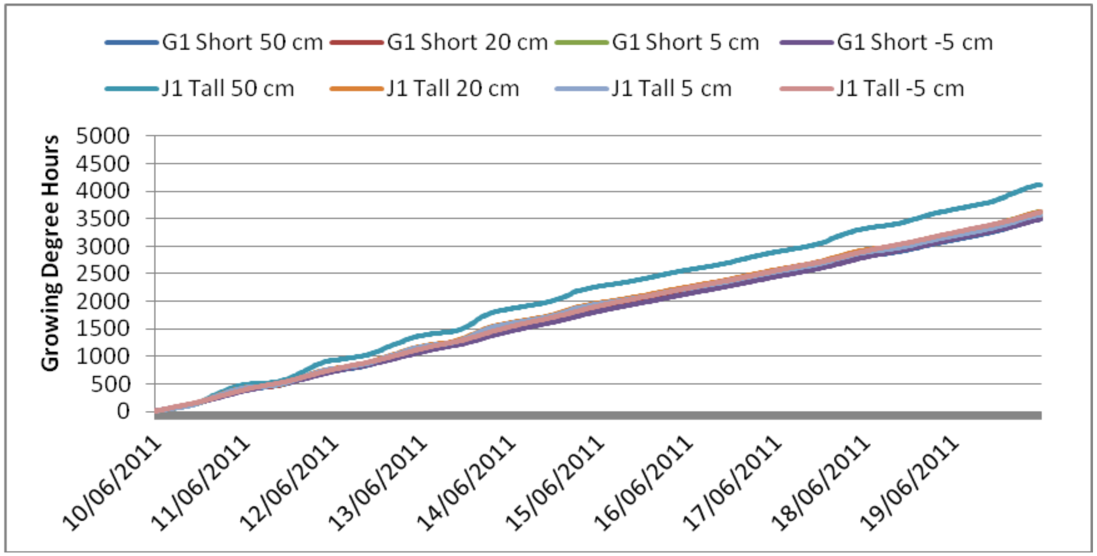


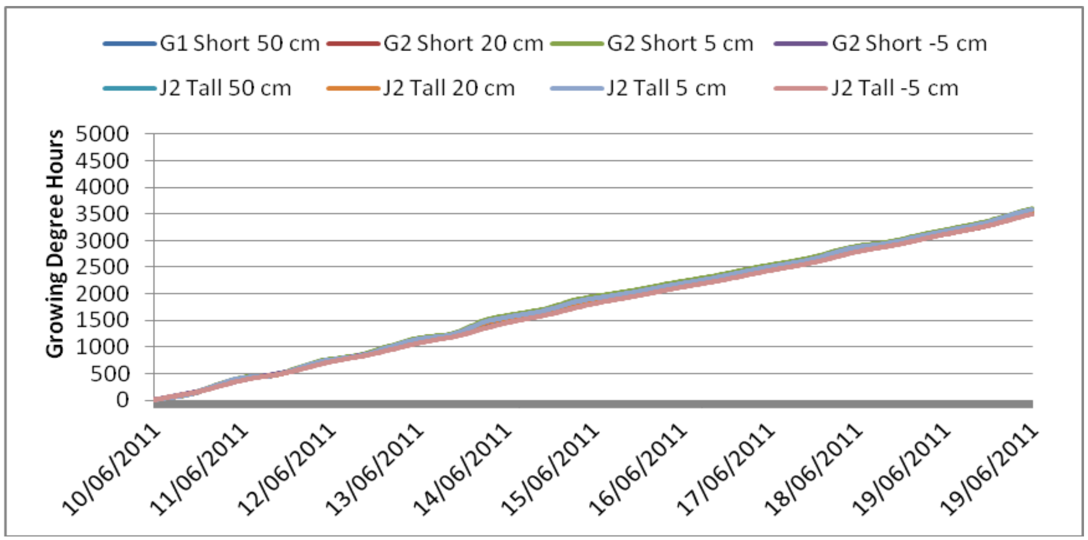
Table A.4 The Growing Degree Hours accumulated at Grimshaw in 2011

	G1 Short	J1 Tall	G2 Short	J2 Tall	F2 Short	I1 Tall	F1 Short	I2 Tall
50 cm	3492.2	4122.4	3583.5	3551.7	3554.0	3511.4	3528.5	3602.1
20 cm	3527.3	3626.5	3502.4	3535.8	3573.7	3595.9	3609.6	3635.3
Above 5 cm	3631.9	3571.3	3594.4	3578.6	3733.1	3735.9	3670.9	3730.8
Below 5 cm	3495.5	3616.5	3516.0	3499.5	3471.6	3613.4	3570.1	3572.8

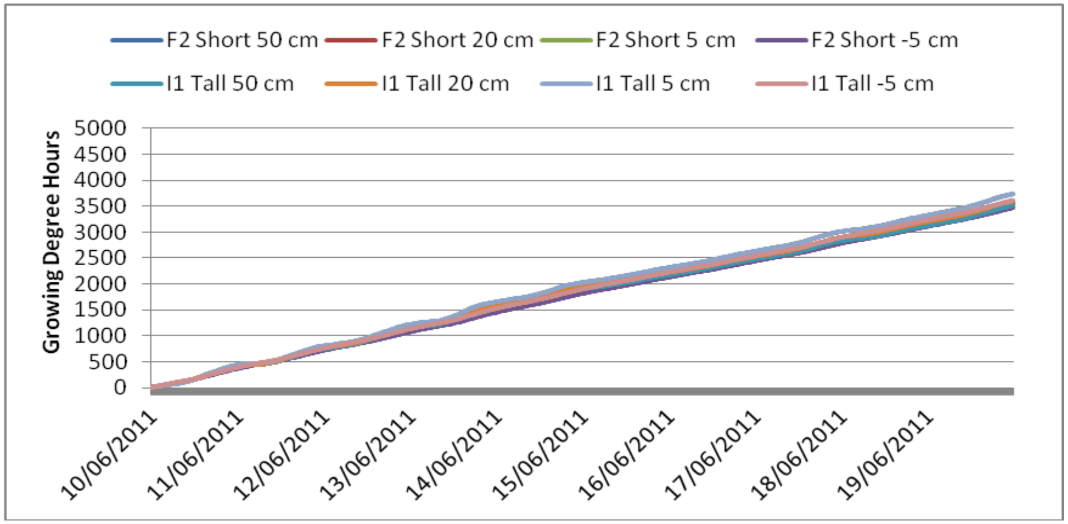
a)


G1 Short 50 cm
G1 Short 20 cm
G1 Short 5 cm
G1 Short -5 cm
J1 Tall 50 cm
J1 Tall 20 cm
J1 Tall 5 cm
J1 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
10/06/2011
11/06/2011
12/06/2011
13/06/2011
14/06/2011
15/06/2011
16/06/2011
17/06/2011
18/06/2011
19/06/2011

b)


G1 Short 50 cm
G2 Short 20 cm
G2 Short 5 cm
G2 Short -5 cm
J2 Tall 50 cm
J2 Tall 20 cm
J2 Tall 5 cm
J2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
10/06/2011
11/06/2011
12/06/2011
13/06/2011
14/06/2011
15/06/2011
16/06/2011
17/06/2011
18/06/2011
19/06/2011
19/06/2011

c)


F2 Short 50 cm
F2 Short 20 cm
F2 Short 5 cm
F2 Short -5 cm
I1 Tall 50 cm
I1 Tall 20 cm
I1 Tall 5 cm
I1 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
10/06/2011
11/06/2011
12/06/2011
13/06/2011
14/06/2011
15/06/2011
16/06/2011
17/06/2011
18/06/2011
19/06/2011

d)

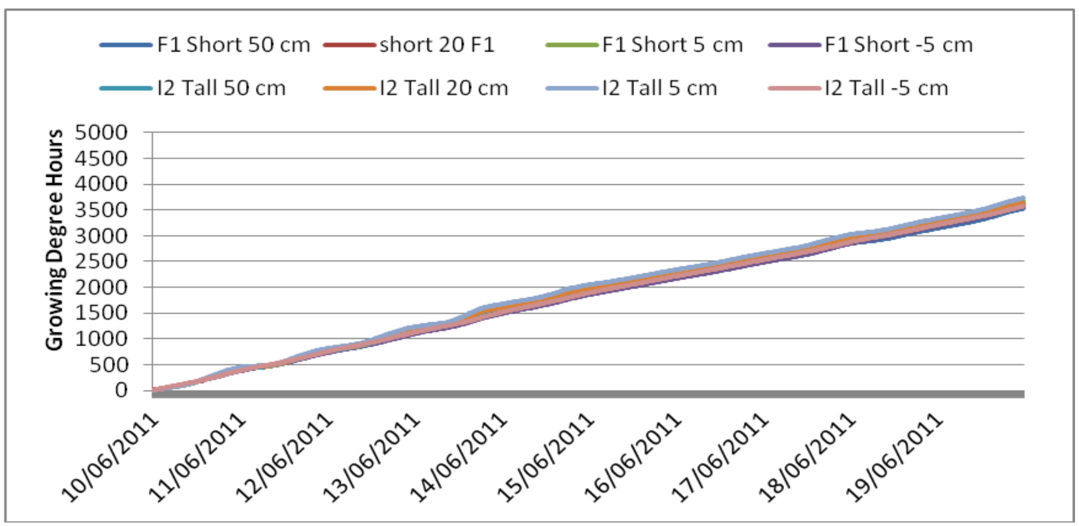

F1 Short 50 cm
short 20 F1
F1 Short 5 cm
F1 Short -5 cm
I2 Tall 50 cm
I2 Tall 20 cm
I2 Tall 5 cm
I2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
10/06/2011
11/06/2011
12/06/2011
13/06/2011
14/06/2011
15/06/2011
16/06/2011
17/06/2011
18/06/2011
19/06/2011

Figure A.4 Comparison of the short and tall stubble at Grimshaw during the 2011 growing season a) comparison of I-Button stations J1 tall stubble and G1 short stubble b) comparison of I-Button stations J2 tall stubble and G2 short stubble, c) comparison of I-Button stations I1 tall and F2 short and d) comparison of I-Button stations I2 tall stubble and F1 short stubble.

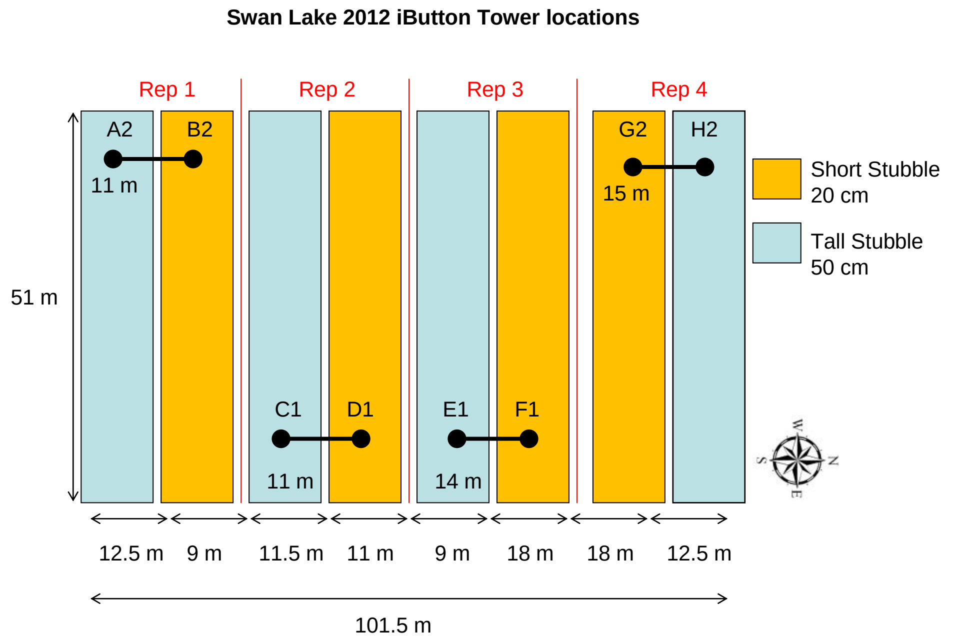
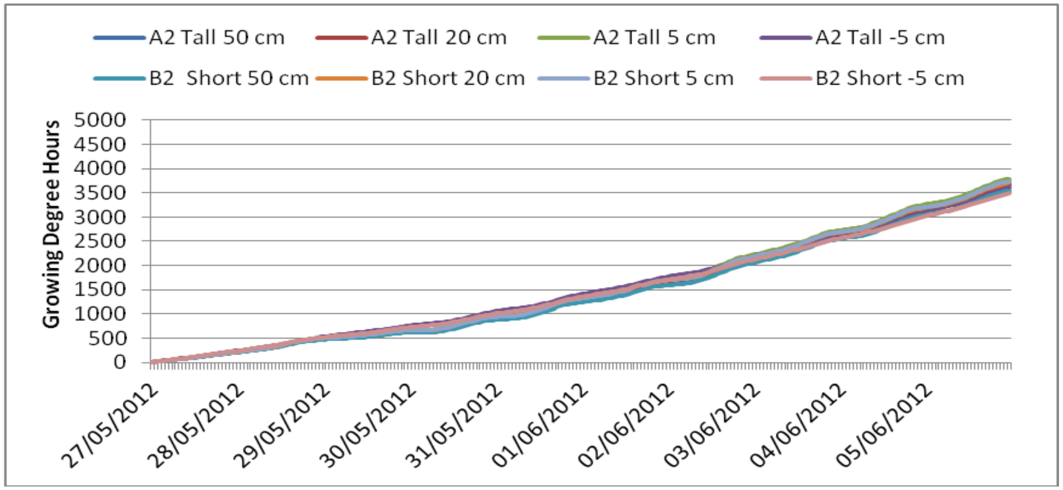


Table A.5 The Growing Degree Hours accumulated at Swan Lake in 2012

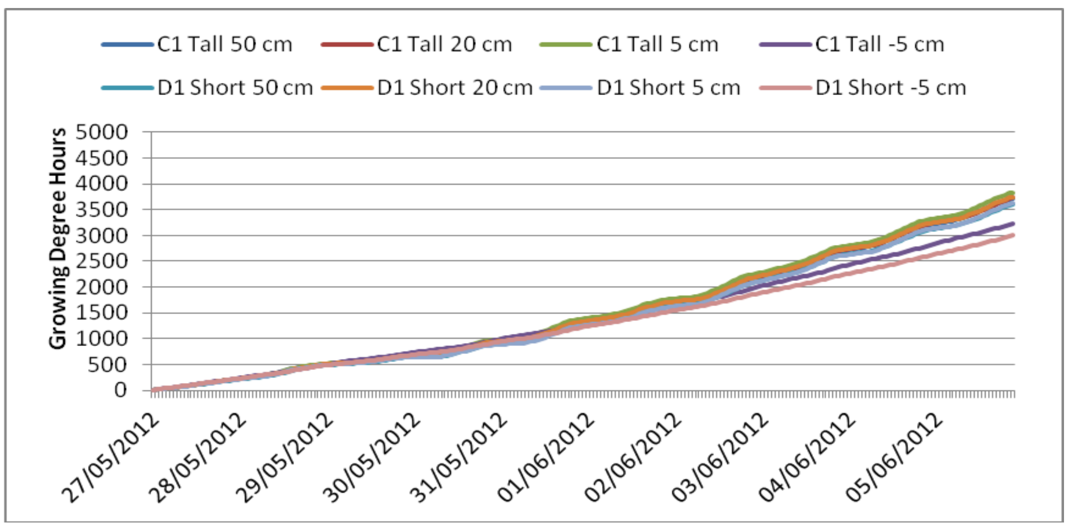
	A2 Tall	B2 Short	C1 Tall	D1 Short	E1 Tall	F1 Short	H2 Tall	G2 Short
50 cm	3680.5	3548.6	3717.6	3600.3	3721.1	3722.5	3721.6	3707.6
20 cm	3669.6	3714.3	3730.9	3747.8	3782.3	3779.2	3662.5	3808.6
Above 5 cm	3788.8	3741.1	3833.5	3626.4	3718.7	3798.1	3769.6	3797.1
Below 5 cm	3596.1	3496.5	3233.7	2998.4	3373.9	3707.8	3431.5	3705.0

a)



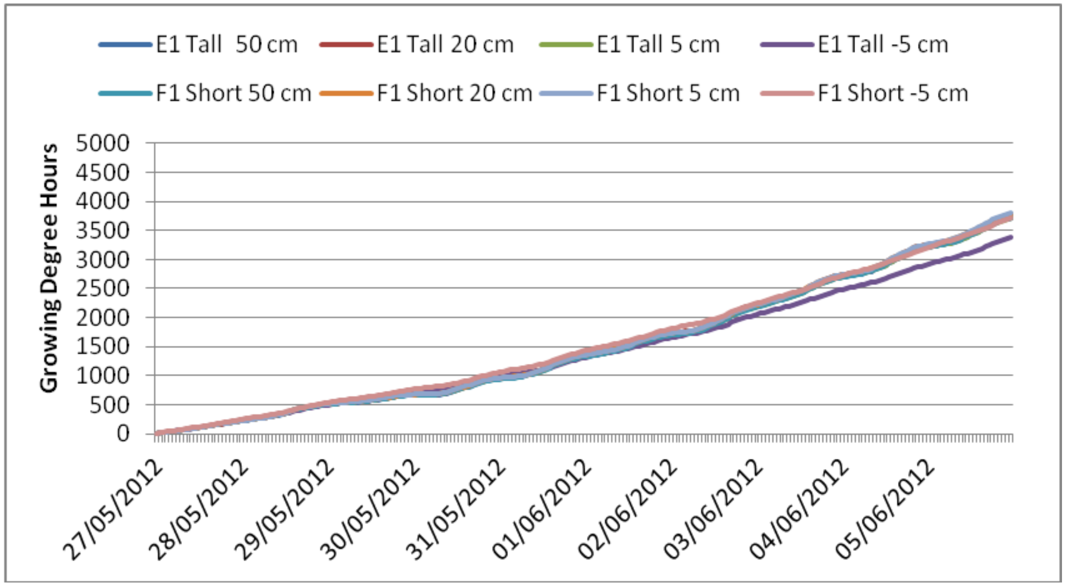
A2 Tall 50 cm
A2 Tall 20 cm
A2 Tall 5 cm
A2 Tall -5 cm
B2 Short 50 cm
B2 Short 20 cm
B2 Short 5 cm
B2 Short -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
27/05/2012
28/05/2012
29/05/2012
30/05/2012
31/05/2012
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012

b)



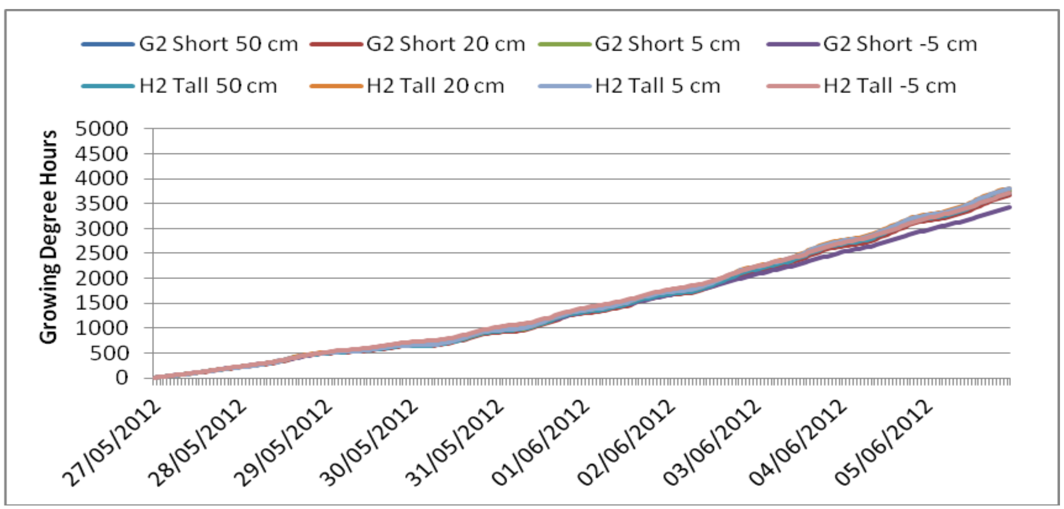
C1 Tall 50 cm
C1 Tall 20 cm
C1 Tall 5 cm
C1 Tall -5 cm
D1 Short 50 cm
D1 Short 20 cm
D1 Short 5 cm
D1 Short -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
27/05/2012
28/05/2012
29/05/2012
30/05/2012
31/05/2012
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012

c)



E1 Tall 50 cm
E1 Tall 20 cm
E1 Tall 5 cm
E1 Tall -5 cm
F1 Short 50 cm
F1 Short 20 cm
F1 Short 5 cm
F1 Short -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
27/05/2012
28/05/2012
29/05/2012
30/05/2012
31/05/2012
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012

d)



G2 Short 50 cm
G2 Short 20 cm
G2 Short 5 cm
G2 Short -5 cm
H2 Tall 50 cm
H2 Tall 20 cm
H2 Tall 5 cm
H2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
27/05/2012
28/05/2012
29/05/2012
30/05/2012
31/05/2012
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012

Figure A.5 Comparison of the short and tall stubble at Swan Lake during the 2012 growing season a) comparison of I-Button stations A2 tall and B2 short, b) comparison of I-Button stations C1 tall stubble and D1 short stubble, c) comparison of I-Button stations E1 tall stubble and F1 short stubble and d) comparison of I-Button stations H2 tall stubble and G2 short stubble.

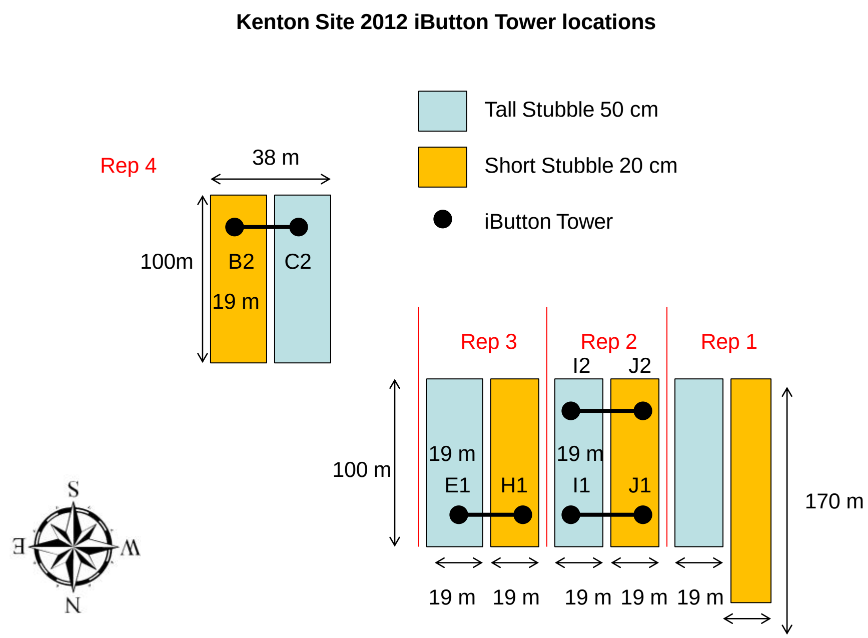
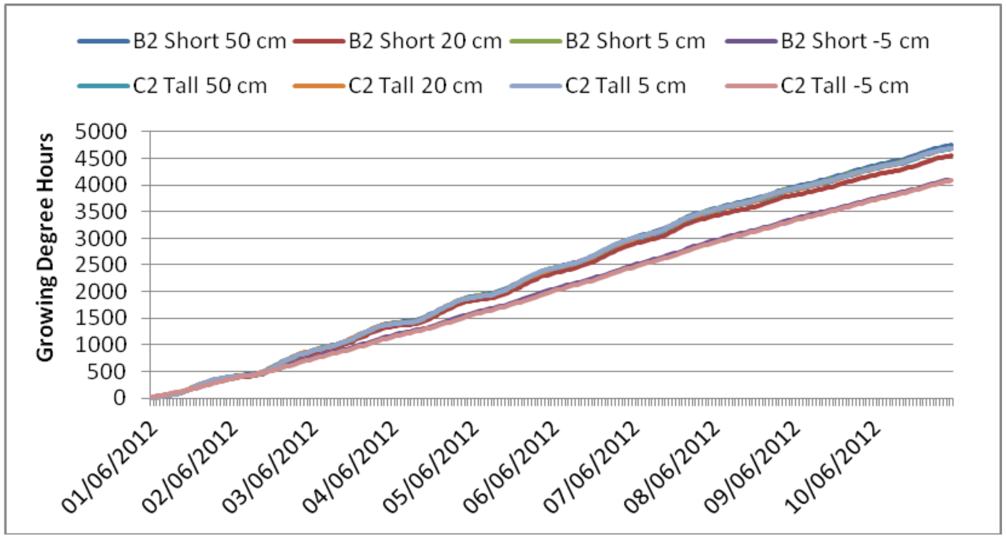


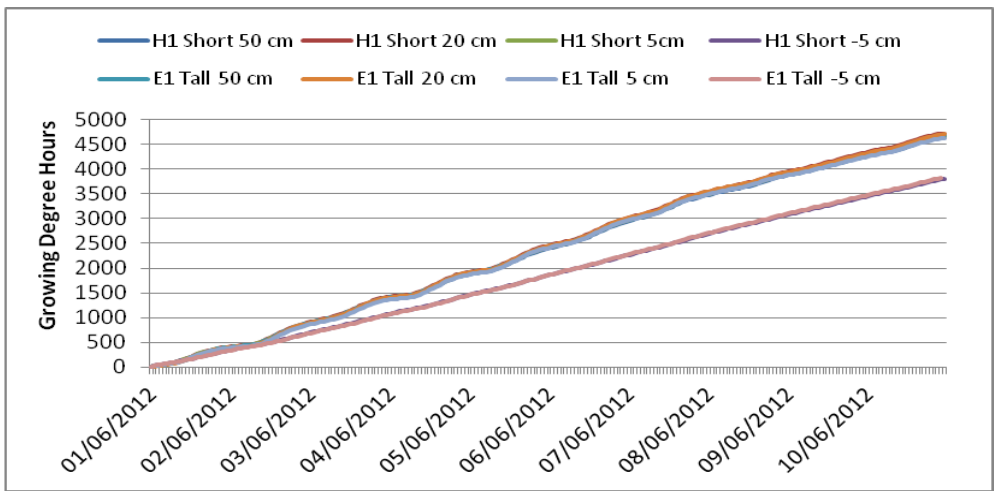
Table A.6 The Growing Degree Hours accumulated at Kenton in 2012

	C2 Tall	B2 Short	E1 Tall	H1 Short	I1 Tall	J1 Short	I2 Tall	J2 Short
50 cm	4675.9	4740.0	4672.8	4636.0	4752.6	4656.6	4616.1	4644.5
20 cm	4678.0	4539.0	4695.8	4715.4	4670.4	4736.0	4663.2	4752.6
Above 5 cm	4681.7	4682.8	4619.8	4644.5	4615.0	4772.2	4758.2	4555.9
Below 5 cm	4077.2	4098.5	3826.8	3797.7	3724.1	4044.9	4008.8	3912.1

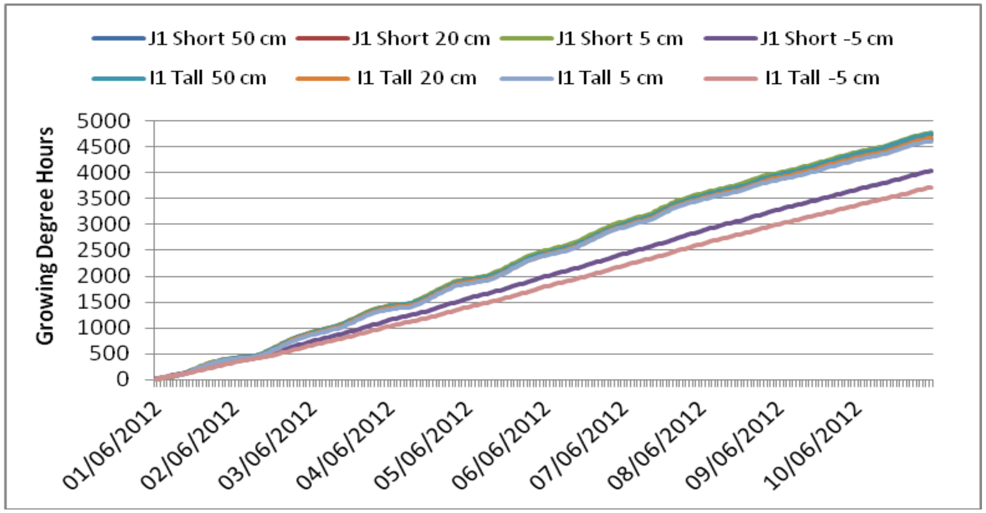
a)


B2 Short 50 cm
B2 Short 20 cm
B2 Short 5 cm
B2 Short -5 cm
C2 Tall 50 cm
C2 Tall 20 cm
C2 Tall 5 cm
C2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012
06/06/2012
07/06/2012
08/06/2012
09/06/2012
10/06/2012

b)


H1 Short 50 cm
H1 Short 20 cm
H1 Short 5cm
H1 Short -5 cm
E1 Tall 50 cm
E1 Tall 20 cm
E1 Tall 5 cm
E1 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012
06/06/2012
07/06/2012
08/06/2012
09/06/2012
10/06/2012

c)


J1 Short 50 cm
J1 Short 20 cm
J1 Short 5 cm
J1 Short -5 cm
I1 Tall 50 cm
I1 Tall 20 cm
I1 Tall 5 cm
I1 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012
06/06/2012
07/06/2012
08/06/2012
09/06/2012
10/06/2012

d)

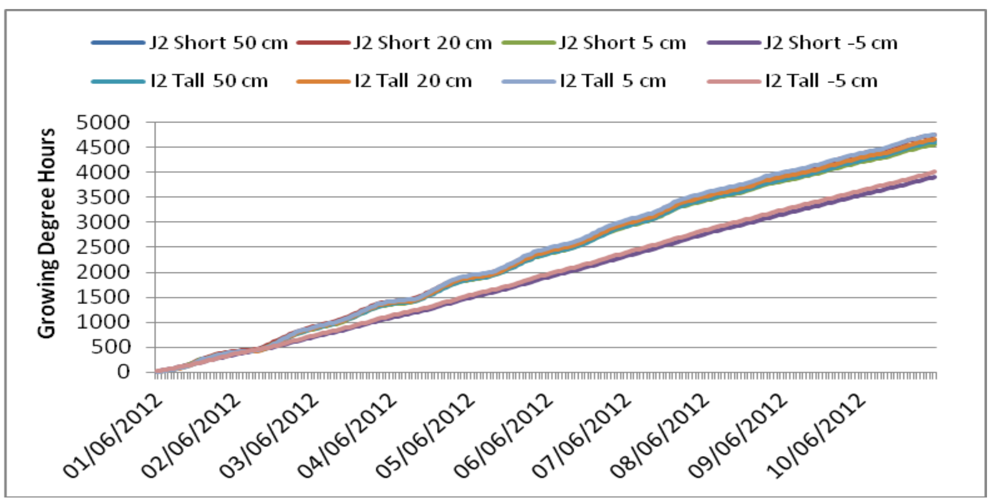

J2 Short 50 cm
J2 Short 20 cm
J2 Short 5 cm
J2 Short -5 cm
I2 Tall 50 cm
I2 Tall 20 cm
I2 Tall 5 cm
I2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012
06/06/2012
07/06/2012
08/06/2012
09/06/2012
10/06/2012

Figure A.6 Comparison of the short and tall stubble at Kenton during the 2012 growing season a) comparison of I-Button stations C2 tall and B2 short, b) comparison of I-Button stations E1 tall stubble and HI1 short stubble, c) comparison of I-Button stations I1 tall stubble and J1 short stubble and d) comparison of I-Button stations I2 tall stubble and J2 short stubble.

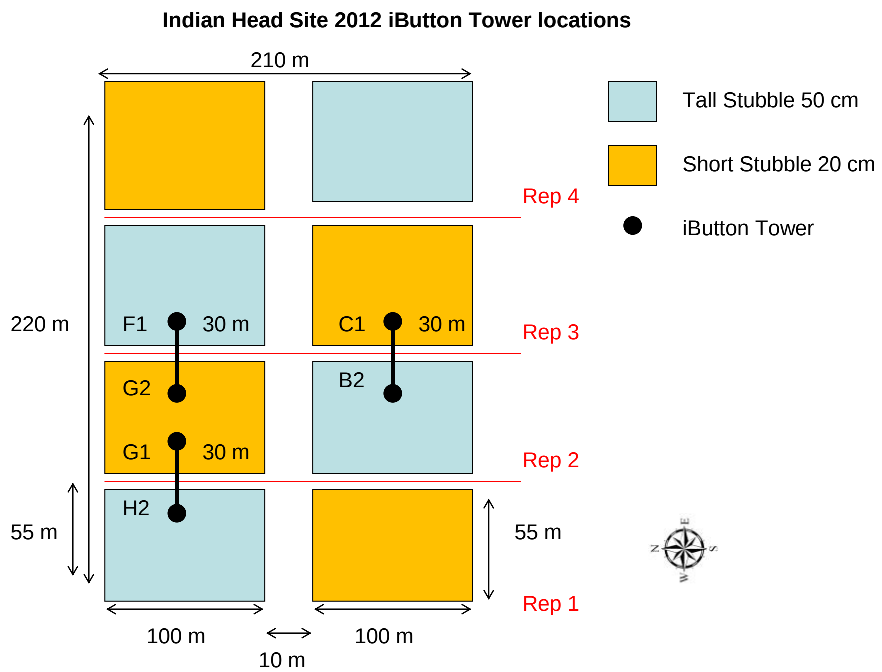
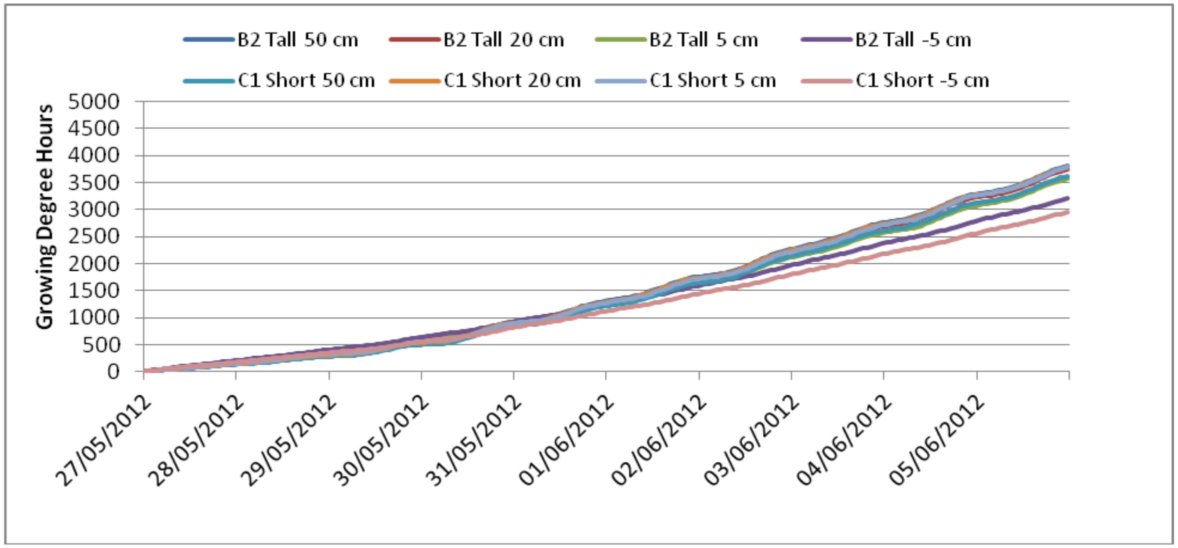


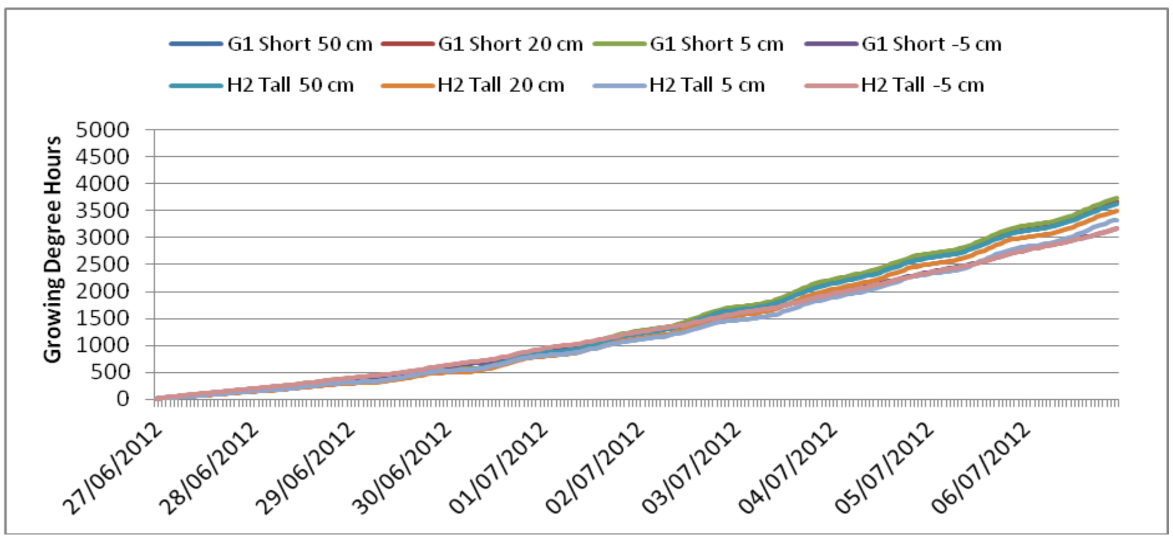
Table A.7 The Growing Degree Hours accumulated at Indian Head in 2012

	B2 Tall	C1 Short	F1 Tall	G2 Short	H2 Tall	G1 Short
50 cm	3628.0	3811.9	3710.2	3661.2	3628.5	3639.9
20 cm	3786.6	3748.8	3820.4	3731.3	3504.1	3667.1
Above 5 cm	3785.4	3581.4	3845.0	3856.7	3334.2	3728.9
Below 5 cm	2956.9	3205.1	3216.9	3082.1	3164.0	3164.7

a)


B2 Tall 50 cm
B2 Tall 20 cm
B2 Tall 5 cm
B2 Tall -5 cm
C1 Short 50 cm
C1 Short 20 cm
C1 Short 5 cm
C1 Short -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
27/05/2012
28/05/2012
29/05/2012
30/05/2012
31/05/2012
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012

b)


G1 Short 50 cm
G1 Short 20 cm
G1 Short 5 cm
G1 Short -5 cm
H2 Tall 50 cm
H2 Tall 20 cm
H2 Tall 5 cm
H2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
27/06/2012
28/06/2012
29/06/2012
30/06/2012
01/07/2012
02/07/2012
03/07/2012
04/07/2012
05/07/2012
06/07/2012

c)

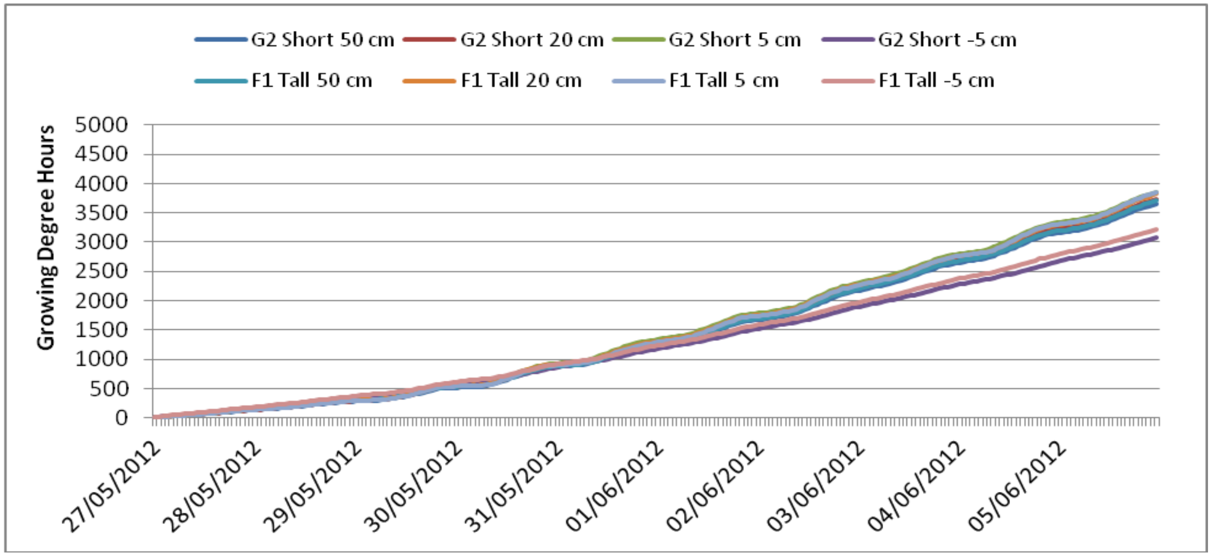


Figure A.7 Comparison of the short and tall stubble at Indian Head during the 2012 growing season a) comparison of I-Button stations B2 tall and C1 short, b) comparison of I-Button stations F1 tall stubble and G2 short stubble, c) comparison of I-Button stations H2 tall stubble and G1 short stubble

.

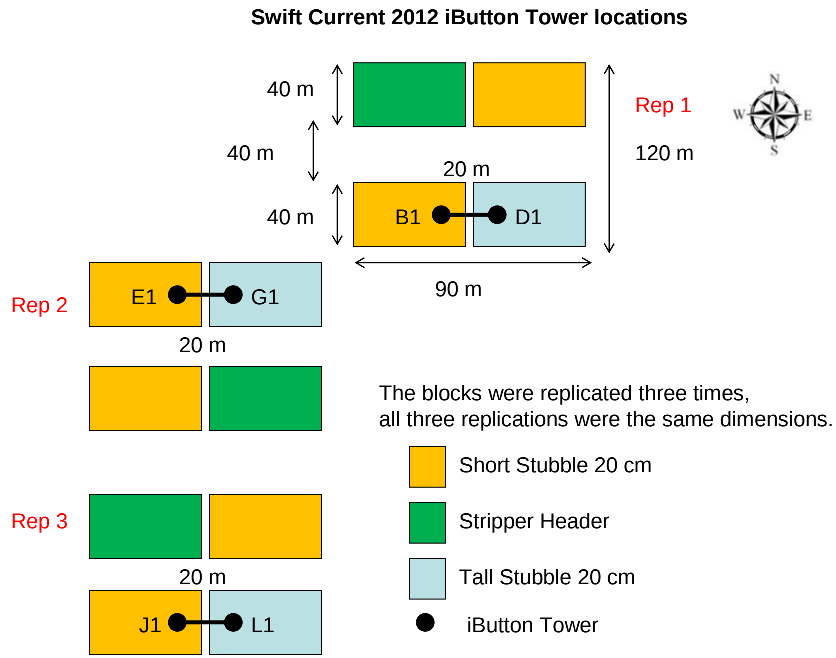
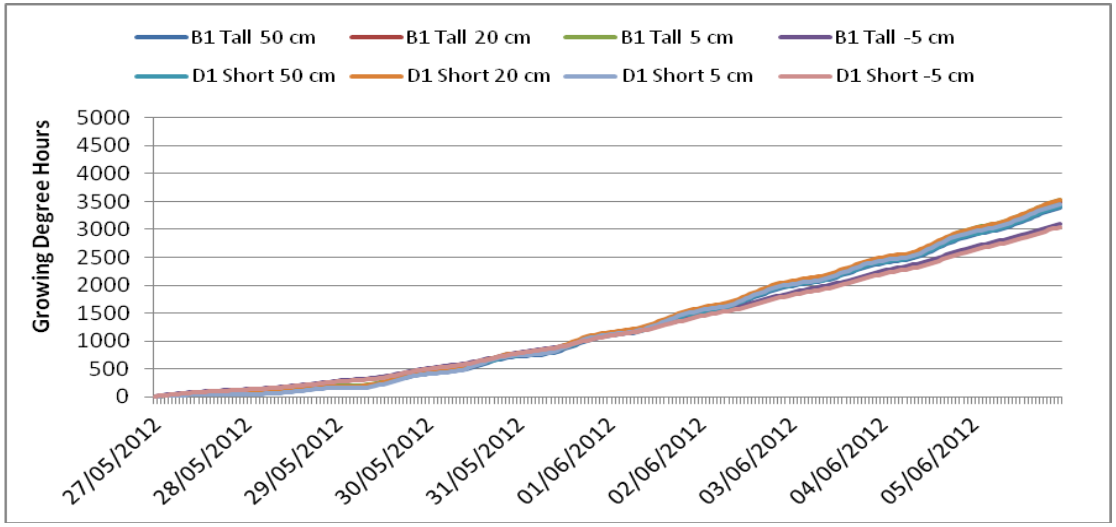


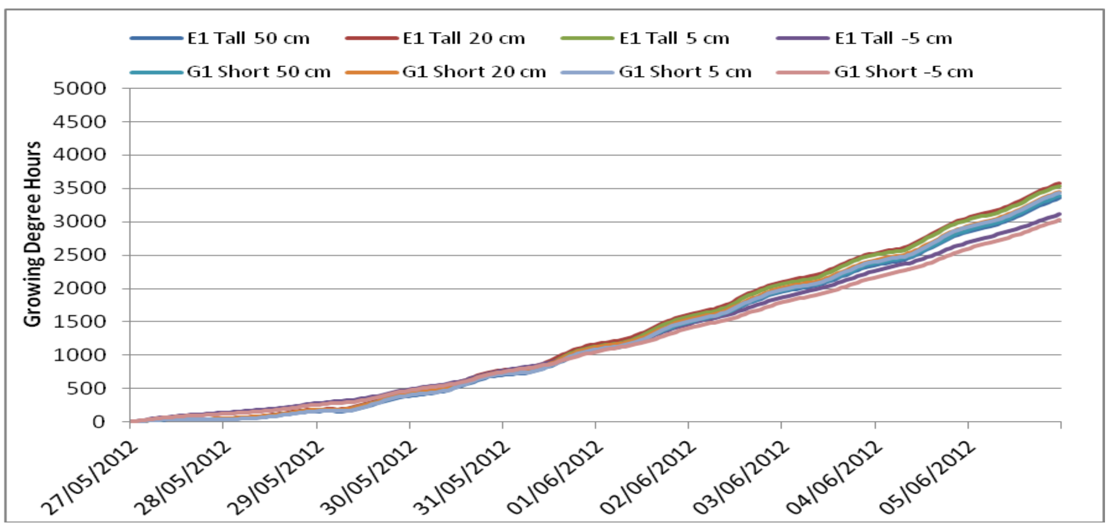
Table A.8 The Growing Degree Hours accumulated at Swift Current in 2012

	D1 Short	B1 Tall	G1 Short	E1Tall	L1 Short	J1 Tall
50 cm	3418.7	3400.1	3387.8	3353.7	3491.9	3440.2
20 cm	3527.4	3484.7	3452.2	3573.9	3430.0	3445.1
Above 5 cm	3456.5	3528.8	3431.9	3536.7	3519.1	3595.1
Below 5 cm	3046.9	3104.6	3025.1	3113.6	3036.0	-

a)


B1 Tall 50 cm
B1 Tall 20 cm
B1 Tall 5 cm
B1 Tall -5 cm
D1 Short 50 cm
D1 Short 20 cm
D1 Short 5 cm
D1 Short -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
27/05/2012
28/05/2012
29/05/2012
30/05/2012
31/05/2012
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012

b)


E1 Tall 50 cm
E1 Tall 20 cm
E1 Tall 5 cm
E1 Tall -5 cm
G1 Short 50 cm
G1 Short 20 cm
G1 Short 5 cm
G1 Short -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
27/05/2012
28/05/2012
29/05/2012
30/05/2012
31/05/2012
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012

c)

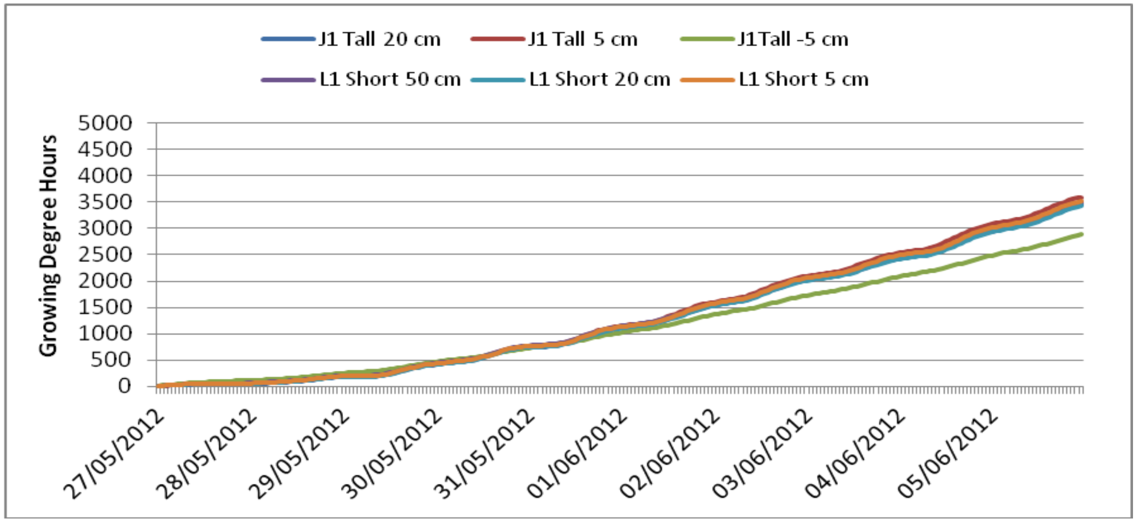


Figure A.8 Comparison of the short and tall stubble at Swift Current during the 2012 growing season a) comparison of I-Button stations B1 tall and D1 short, b) comparison of I-Button stations E1 tall stubble and G1 short stubble, c) comparison of I-Button stations J1 tall stubble and L1 short stubble

.

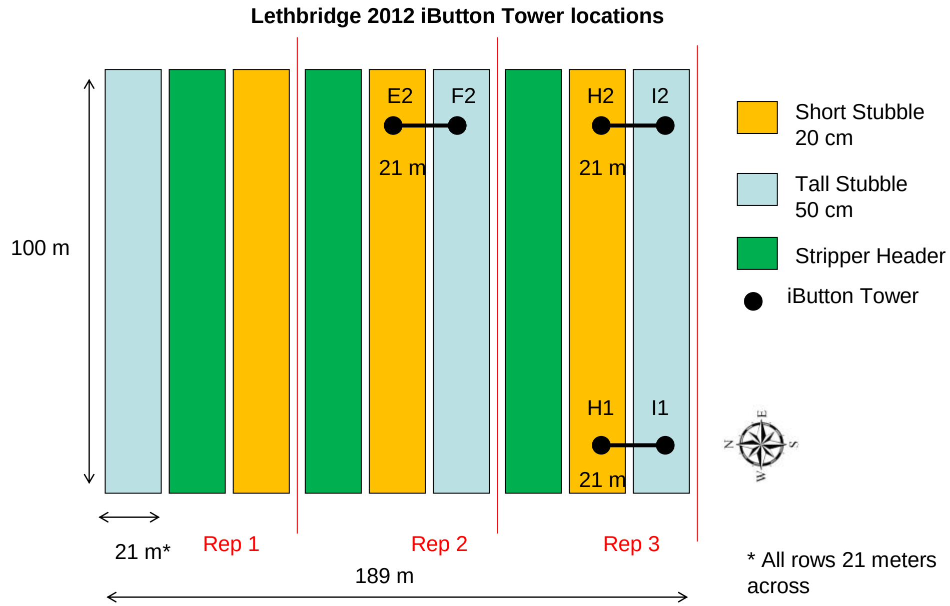
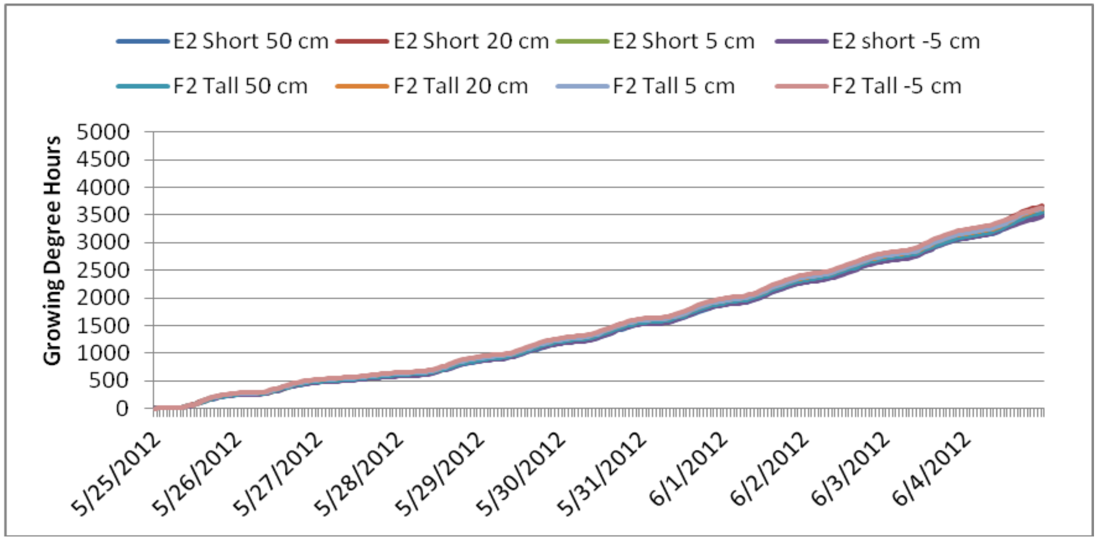


Table A.9 The Growing Degree Hours accumulated at Lethbridge in 2012

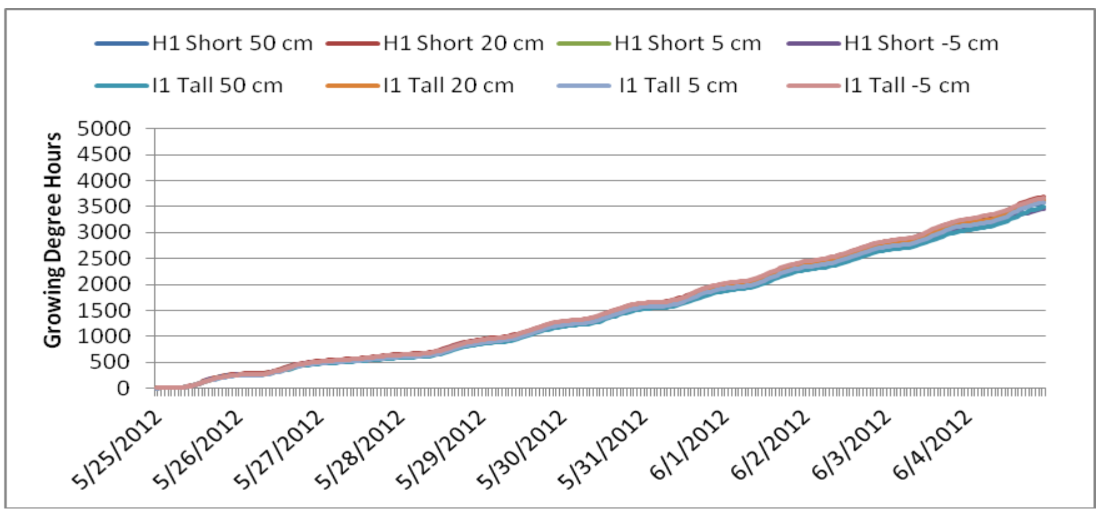
	E2 Short	F2 Tall	H1 Short	I1Tall	H2 Short	I2 Tall
50 cm	3516.0	3558.3	3581.7	3491.0	3500.8	3606.3
20 cm	3668.3	3611.7	3695.4	3630.9	3710.1	3627.5
Above 5 cm	3563.0	3620.2	3630.5	3594.2	3624.4	3728.6
Below 5 cm	3470.9	3632.4	3464.9	3675.2	3551.5	3523.5

a)



E2 Short 50 cm
E2 Short 20 cm
E2 Short 5 cm
E2 short -5 cm
F2 Tall 50 cm
F2 Tall 20 cm
F2 Tall 5 cm
F2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
5/25/2012
5/26/2012
5/27/2012
5/28/2012
5/29/2012
5/30/2012
5/31/2012
6/1/2012
6/2/2012
6/3/2012
6/4/2012

b)



H1 Short 50 cm
H1 Short 20 cm
H1 Short 5 cm
H1 Short -5 cm
I1 Tall 50 cm
I1 Tall 20 cm
I1 Tall 5 cm
I1 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
5/25/2012
5/26/2012
5/27/2012
5/28/2012
5/29/2012
5/30/2012
5/31/2012
6/1/2012
6/2/2012
6/3/2012
6/4/2012

c)

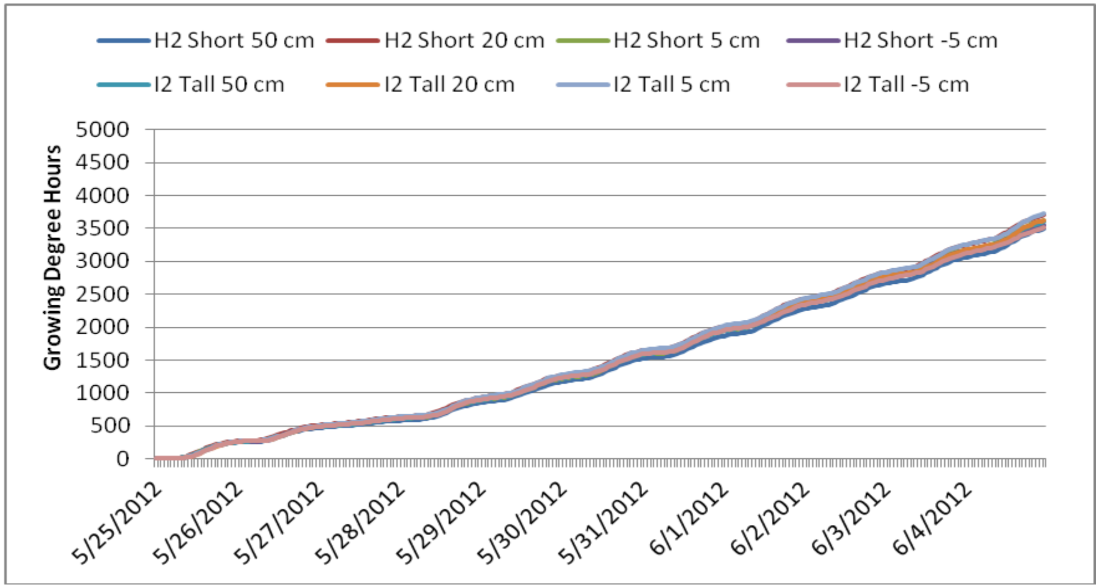


Figure A.9 Comparison of the short and tall stubble at Lethbridge during the 2012 growing season a) comparison of I-Button stations F2 tall and E2 short, b) comparison of I-Button stations I1 tall stubble and H1 short stubble, c) comparison of I-Button stations I2 tall stubble and H2 short stubble.

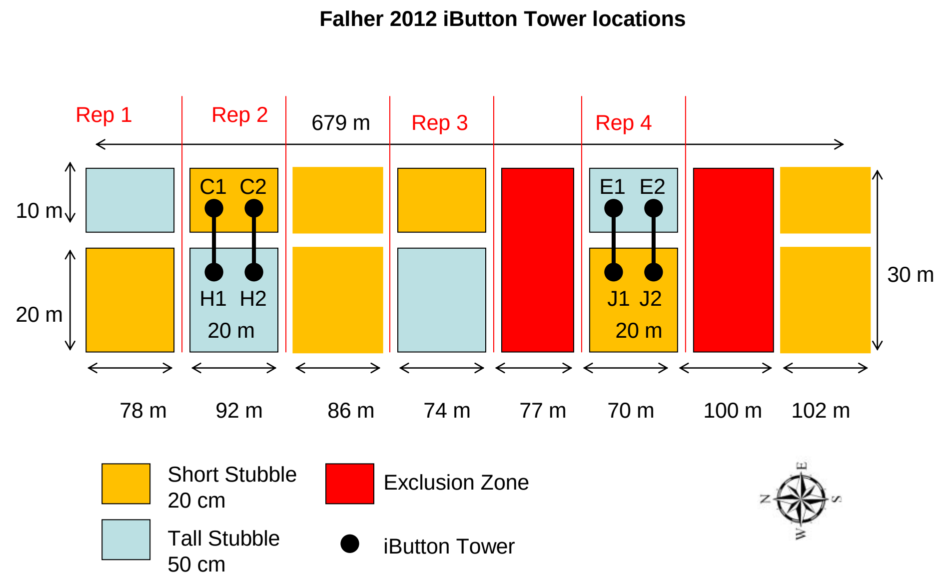
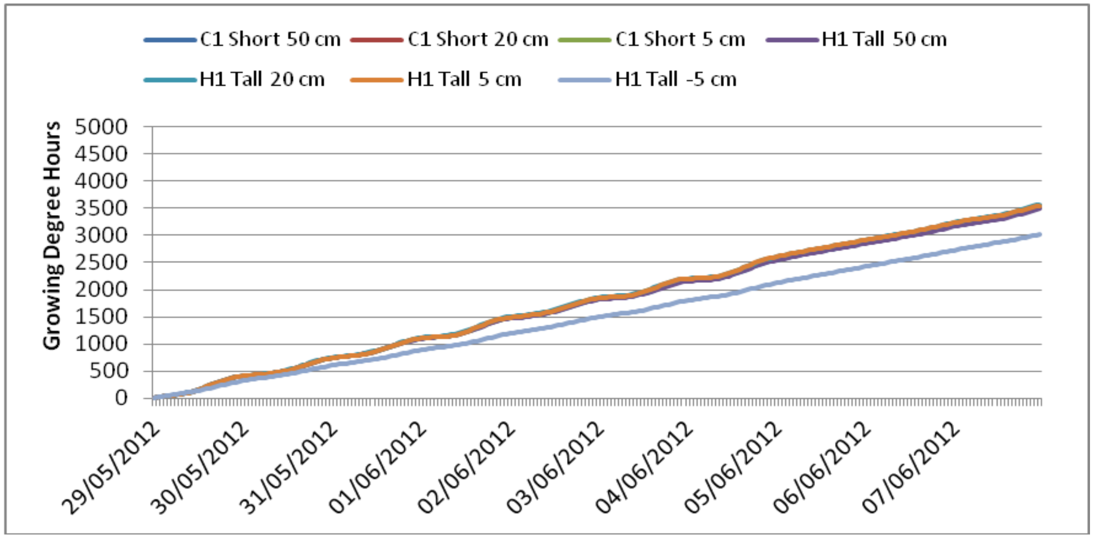


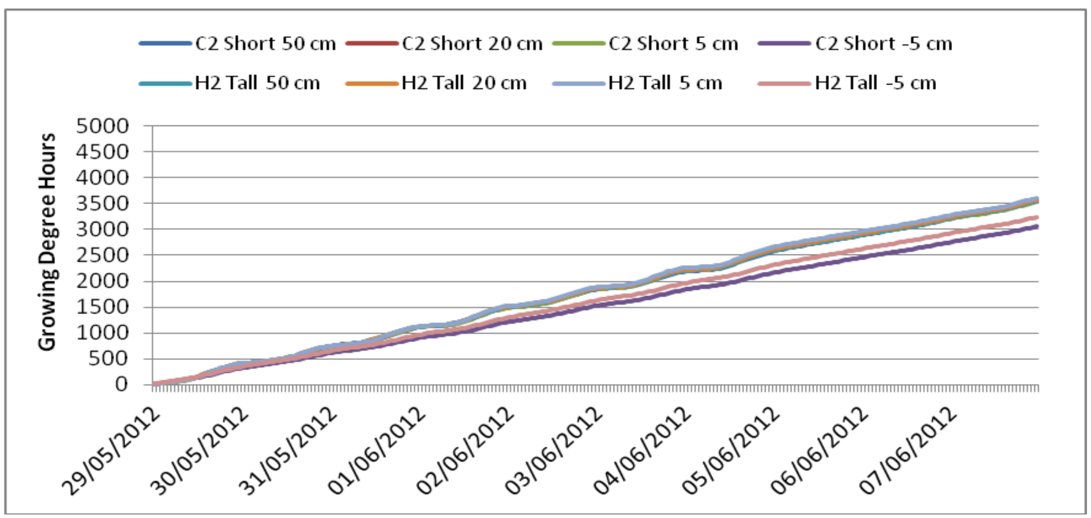
Table A.10 Growing Degree Hours at Falher in 2012

	C1 Short	H1 Tall	C2 Short	H2 Tall	E1 Short	J1 Tall	E2 Short	J2 Tall
50 cm	3521.4	3491.9	3570.2	3549.2	3615.7	3673.6	3589.7	3727.8
20 cm	3547.1	3570.0	3591.8	3569.0	3495.1	3647.5	3578.5	-
Above 5 cm	3547.4	3549.9	3538.6	3601.0	3594.8	3587.4	3682.5	3648.6
Below 5 cm	-	3021.7	3055.6	3235.8	3095.4	3000.3	3054.9	3106.0

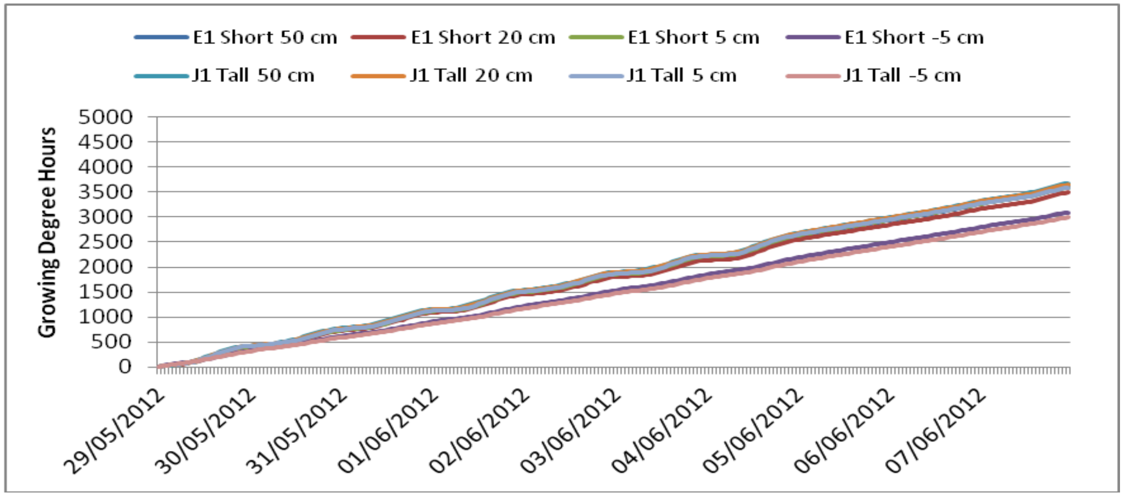
a)


C1 Short 50 cm
C1 Short 20 cm
C1 Short 5 cm
H1 Tall 50 cm
H1 Tall 20 cm
H1 Tall 5 cm
H1 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
29/05/2012
30/05/2012
31/05/2012
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012
06/06/2012
07/06/2012

b)

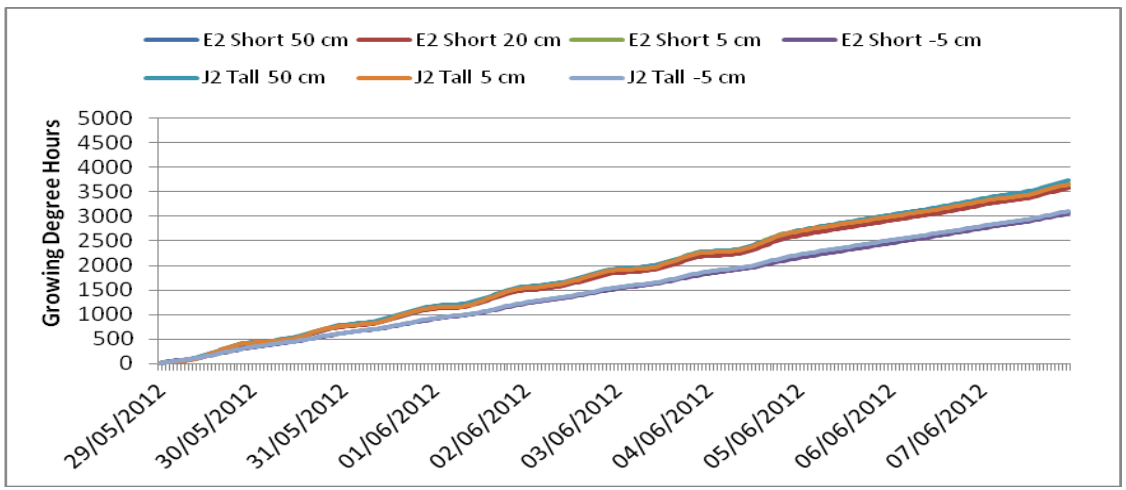

C2 Short 50 cm
C2 Short 20 cm
C2 Short 5 cm
C2 Short -5 cm
H2 Tall 50 cm
H2 Tall 20 cm
H2 Tall 5 cm
H2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
29/05/2012
30/05/2012
31/05/2012
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012
06/06/2012
07/06/2012

c)



E1 Short 50 cm
E1 Short 20 cm
E1 Short 5 cm
E1 Short -5 cm
J1 Tall 50 cm
J1 Tall 20 cm
J1 Tall 5 cm
J1 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
29/05/2012
30/05/2012
31/05/2012
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012
06/06/2012
07/06/2012

d)



E2 Short 50 cm
E2 Short 20 cm
E2 Short 5 cm
E2 Short -5 cm
J2 Tall 50 cm
J2 Tall 5 cm
J2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
29/05/2012
30/05/2012
31/05/2012
01/06/2012
02/06/2012
03/06/2012
04/06/2012
05/06/2012
06/06/2012
07/06/2012

Figure A.10 Comparison of the short and tall stubble at Falher during the 2012 growing season a) comparison of I-Button stations H1 tall and C1 short, b) comparison of I-Button stations H2 tall stubble and C1 short stubble, c) comparison of I-Button stations E1 tall stubble and J1 short stubble and d) comparison of I-Button stations E2 tall stubble and J2 short stubble.

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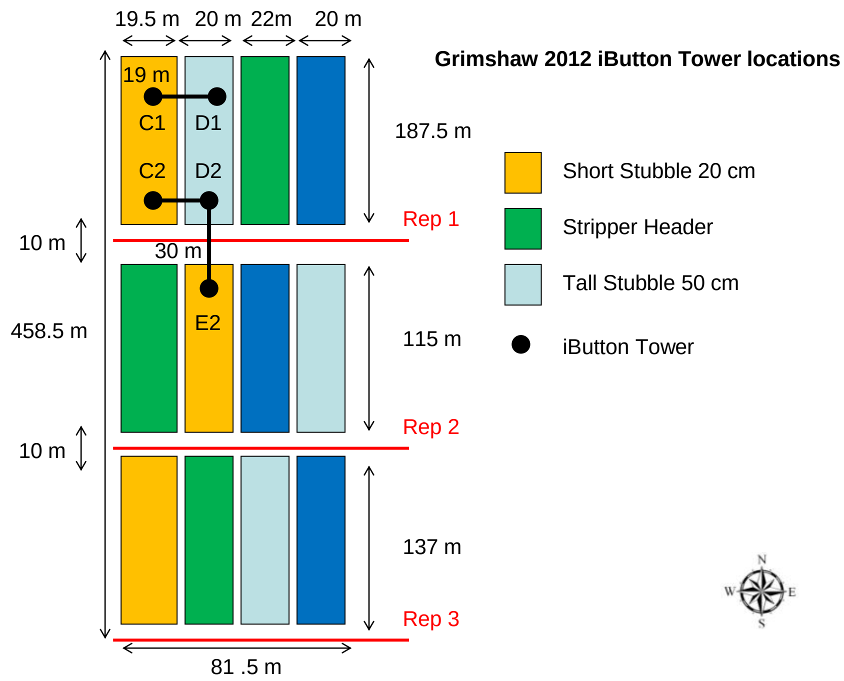
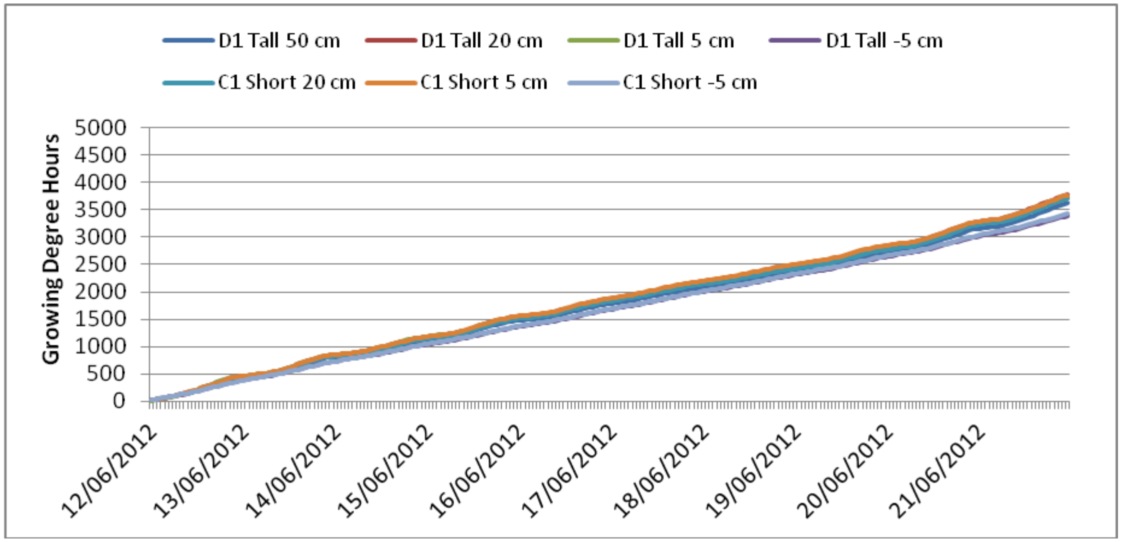


Table A.11 Growing Degree Hours at Grimshaw in 2012

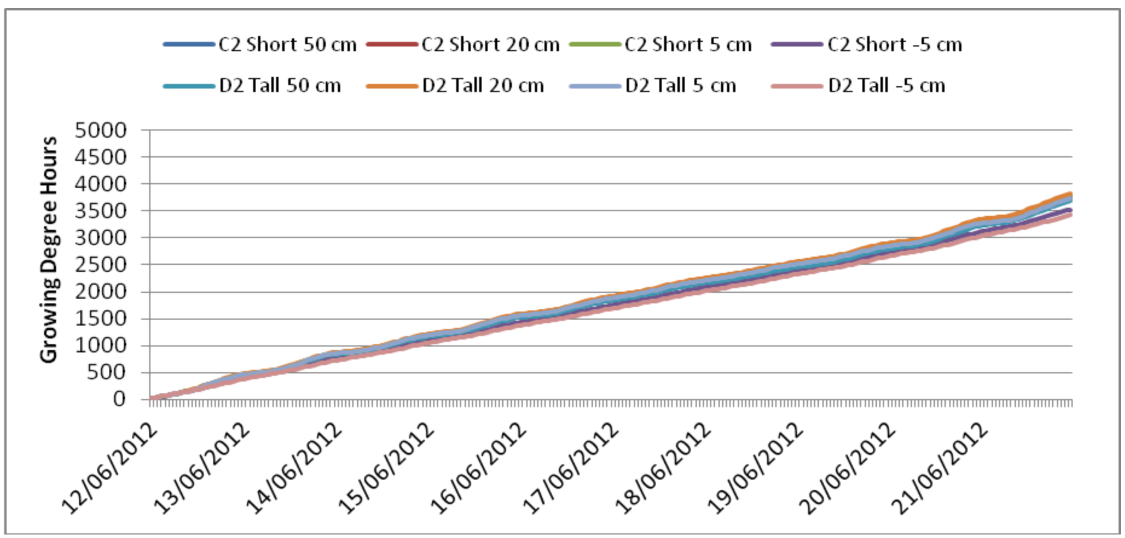
	C1 Short	D1 Tall	C2 Short	D2 Tall	E1 Short	D2 Tall
50 cm	-	3621.8	3698.5	3726.9	3667.9	3726.9
20 cm	3713.0	3772.4	3823.2	3774.0	3844.1	3774.0
Above 5 cm	3762.6	3710.4	3729.6	3802.2	3724.6	3802.2
Below 5 cm	3425.3	3394.0	3430.2	3526.5	3357.4	3526.5

a)



D1 Tall 50 cm
D1 Tall 20 cm
D1 Tall 5 cm
D1 Tall -5 cm
C1 Short 20 cm
C1 Short 5 cm
C1 Short -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
12/06/2012
13/06/2012
14/06/2012
15/06/2012
16/06/2012
17/06/2012
18/06/2012
19/06/2012
20/06/2012
21/06/2012

b)



C2 Short 50 cm
C2 Short 20 cm
C2 Short 5 cm
C2 Short -5 cm
D2 Tall 50 cm
D2 Tall 20 cm
D2 Tall 5 cm
D2 Tall -5 cm
Growing Degree Hours
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
12/06/2012
13/06/2012
14/06/2012
15/06/2012
16/06/2012
17/06/2012
18/06/2012
19/06/2012
20/06/2012
21/06/2012

c)

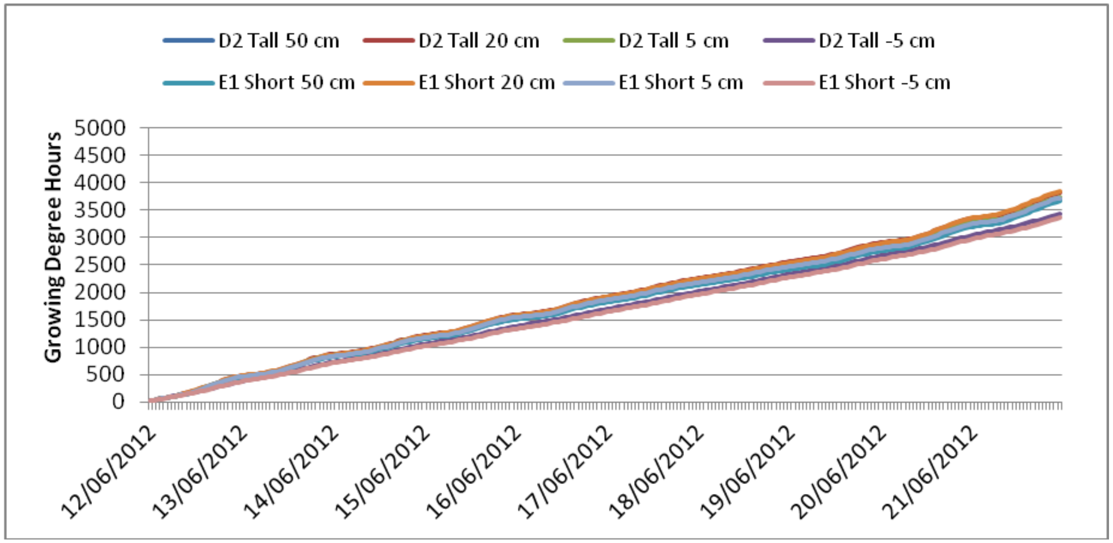


Figure A.11 Comparison of the short and tall stubble at Grimshaw during the 2012 growing season a) comparison of I-Button stations D1 tall and C1 short, b) comparison of I-Button stations D2 tall stubble and C2 short stubble, c) comparison of I-Button stations D2 tall stubble and E1 short stubble.

5.2 Appendix B- Site history 2008-2010

Table B.1. Swan Lake 2011 site background history of years 2008 - 2010

Table B.1.1 Mechanical Applications history Swan Lake 2011 1

Year	Type of seed Planted	Seeding Rate (lbs/acre)	Date of Seeding	Row Spacing (Inches)	Type of Machine	Speed of Machine (MPH)
2009	Canola	5.1	May.19th	10	Air drill	4.5
2008	RS Wheat	2	May.15th	10	Air drill	5

Table B.1.2 Fertilizer Applications history Swan Lake 2011

Year	Fertilizer Setting	Fertilizer (lbs/acre)	Rates of N, P and S applied	Date of Application	Speed of Machine (MPH)
2009	n\a	n\a	100-30-30	May.19th	4.5
2008	n\a	n\a	90-25-0	May.15th	5

Table B.1.3 Pesticide Applications history Swan Lake 2011

Year	Herbicides and Rate	Pesticides and Rate	Fungicides and Rate	Date of Application
2009	.5 L Glyphosate	Headline	Lance	n\a
2008	.5 L Glyphosate	Axial	Proline	n\a

Table B.1.4 Harvest History Swan Lake 2011

Year	Date of Harvest	Machine Used	Machine Speed (MPH)
2009	Sept.17	CX840	4.5-5
2008	Sept.3	CX840	4.5-5

Table B.2. Swan Lake 2012 site background history of years 2008 – 2010

Table B.2.1 Mechanical Applications history Swan Lake 2012

Year	Type of seed Planted	Seeding Rate (lbs/acre)	Date of Seeding	Row Spacing (Inches)	Type of Machine	Speed of Machine (MPH)
2010	Canola	5	May.18th	10	Air Drill	5
2009	R.S. Wheat	1.9	May.13th	10	Air Drill	5
2008	Canola	5.1	May.17th	10	Air Drill	4.75

Table B.2.2 Fertilizer Application history Swan Lake 2012

Year	Fertilizer Setting	Fertilizer (lbs/acre)	Rates of N, P and S applied	Date of Application	Speed of Machine (MPH)
2010	n\a	N 90	0-30-25	May.18th	5
2009	n\a	N 90	0-30-0	May.13th	5
2008	n\a	N 90	0-30-25	May.17th	4.75

Table B.2.3 Pesticide Application history Swan Lake 2012

Year	Herbicides and Rate	Pesticides and Rate	Fungicides and Rate	Date of Application
2010	.5L glyphosate	Axial	Headline, Twinline	n\a
2009	.5L glyphosate,	Puma, Thumper	Headline	n\a
2008	.5L Glyphosate,	Odyssey	Lance	n\a

Table B 2.4 Harvest History Swan Lake 2012

Year	**Date of Harvest**	**Machine Used**	**Machine Speed (MPH)**
2010	Sept.1st	CX 840	3.5-4
2009	Sept.9th	CX 840	3.5-4
2008	Sept.15th	CX840	3.5-4

Table B.3 Kenton 2012 site background history of years 2008 - 2010

Table B.3.1 Mechanical Application history Kenton

Year	Type of seed Planted	Seeding Rate (lbs/acre)	Date of Seeding	Row Spacing (Inches)	Type of Machine	Speed of Machine (MPH)
2010	Soybeans	60 lbs	June.5th	10	Disk	6
2009	Triticale	110 lbs	Sept.2nd	10	Disk	6
2008	Peas	150 lbs	May.10th	10	Disk	6

Table B.3.2 Fertilizer Application history Kenton

Year	Fertilizer Setting	Fertilizer (lbs/acre)	Rates of N, P and S applied	Date of Application	Speed of Machine (MPH)
2010	n\a	0-25-0	n\a	With Seed	n\a
2009	n\a	50-25-0	n\a	Broadcasted	n\a
2008	n\a	0-20-0	n\a	With Seed	n\a

Table B.3.3 Pesticide Application history Kenton

Year	Herbicides and Rate	Pesticides and Rate	Fungicides and Rate	Date of Application
2010	Roundup 2X	n\a	n\a	June.15th, July.2nd
2009	Bactil CM	n\a	n\a	June.1st
2008	Post/Pre Seed	n\a	n\a	June.5th

Table B.3.4 Harvest History Kenton

Year	Date of Harvest	Machine Used	Machine Speed (MPH)
2010	Oct.5th	JD 9660	4
2009	Aug.15th	JD 9500	4
2008	Aug.10th	JD 9600	4

Table B.4. Indian Head 2011 and 2012 site background history of years 2008 – 2010 (the locations of the two research plots were in close proximity to one another and share the same site history)

Table B.4.1 Mechanical Application history Indian Head

Year	Type of seed Planted	Seeding Rate (lbs/acer)	Date of Seeding	Row Spacing (Inches)	Type of Machine	Speed of Machine (MPH)
2010	CDC Golden Peas	15	May 15, 2010	12	Flexi-coil 5000 Air Hoe Drill/Flexi-coil 2340 VR Air Cart with 3rd tank	4.5
2009	Keet Canary Seed	35	May 14, 2010	12	Flexi-coil 5000 Air Hoe Drill/Flexi-coil 2340 VR Air Cart with 3rd tank	4.5
2008	Cereal Plots	n\a	n\a	n\a	n\a	n\a

Table B.4.2 Fertilizer Application history Indian Head

Year	Fertilizer Type	Fertilizer (lbs/acre)	Rates of N, P, and S applied	Date of Application	Speed of Machine (MPH)
2010	Nodulator Granular Inoculant - Clay	6.5	n/a	May 15, 2010	4.5
2009	28-0-0 (UAN)	212.9	59.6-0-0-0	May 14, 2	4.5
	11-52-0 (MAP)	48.1	5.3-25-0-0	May 14, 2	4.5
2008	n\a	n\a	n\a	n\a	n\a

Table B.4.3 Pesticide Application history Indian Head

Year	Pesticide or Application Type	Herbicides and Rate	Insecticides and Rate	Fungicides and Rate	Date of Application
2010	Pre-seeding – foliar	Factor 540 – 0.67 L/Ac	n\a	n\a	May.14,
	In crop foliar applied – 2.5-3.5 node	Odyssey – 17.3 g/acre Equinox – 0.08 L/Ac Merge – 0.5 L/100 L of sol.	n\a	n\a	June.7
	In crop foliar – 5 day into flower		n\a	Headline EC – 0.16 L/Ac	July.8
	Pre-harvest foliar	Round Up HC – 0.67 L/Ac	n\a	n\a	August.19
	Post-harvest foliar	Touchdown IQ – 0.7 L/Ac	n\a	n\a	October.21
2009	Pre-emergence foliar	Factor 540 – 0.67 L/Ac	n\a	n\a	May 28, 2009
	In crop foliar – Applied – 5 – 5.5 leaf	Banvel II – 0.117 L/Ac MCPA Amine 500 – 0.34 L/Ac	n\a	n\a	June.26
	In crop foliar – Applied – heads emerged and start of stem elongation	n\a	n\a	Bumper 418EC – 0.12 L/Ac	July.16
2008	n\a	n\a	n\a	n\a	n\a

Table B.4.4 Harvest History Indian Head 2011

Year	Date of Swath	Date of Harvest	Machine Used	Machine Speed (MPH)
2010	n/a	September.4	2003 N.H. CR940 Combine with 30' N.H. 94C Draper Header	4.0
2009	n/a	October.21	2003 N.H. CR940 Combine with 30' N.H. 94C Draper Header	2.2
2008	n\a	n\a	n\a	n\a

Table B.5. Swift Current 2011 site background history of years 2008 - 2010

Table B.5.1 Mechanical Application history Swift Current 2011

Year	Type of seed Planted	Seeding Rate (lbs/acre)	Date of Seeding	Row Spacing (Inches)	Type of Machine	Speed of Machine (MPH)
2009	Conventional Fallow	n/a	n/a	n/a	Morris 16 ft	4
2008	Wheat AC Lillan	63	May.28th	9 inch	Flexicoil	4

Table B.5.2 Fertilizer Application history Swift Current 2011

Year	Fertilizer Setting	Fertilizer (lbs/acre)	Rates of N, P and S applied	Date of Application	Speed of Machine (MPH)
2009	n/a	n/a	n/a	n/a	n/a
2008	15	40 45	11-52-0 46-0-0	May.28th May.28th	4 4

Table B.5.3 Pesticide Application history Swift Current 2011

Year	Herbicides and Rate	Pesticides and Rate	Fungicides and Rate	Date of Application
2009	n/a	n/a	n/a	n/a
2008	2 4D .25 lbs/ac In Crop (Horizon/BukrilM/Suncore)	n/a @ suggested rate	n/a	Nov.8th June.24th

Table B.5.4 Harvest History Swift Current 2011

Year	Date of Harvest	Machine Used	Machine Speed (MPH)
2009	n/a	n/a	n/a
2008	Sept.30	Massey 5500	1

Table B.6. Swift Current 2012 site background history of years 2008 - 2010

Table B.6.1 Mechanical Application history Swift Current 2012

Year	Type of seed Planted	Seeding Rate (lbs/acre)	Date of Seeding	Row Spacing (Inches)	Type of Machine	Speed of Machine (MPH)
2010	Fallow	n/a	n/a	n/a	Flexi Coil	4
2009	AC Lillian, Grande RR Banner	61 174 61	May.4 May.2 May.2	9 9 9	Flexi Coil Flexi Coil Flexi Coil	4 4 4
2008	RR Banner	61	May.6	9	Flex Coil	4

Table B6.2 Fertilizer Application history Swift Current 2012

Year	Fertilizer Setting	Fertilizer (lbs/acre)	Rates of N, P and S applied	Date of Application	Speed of Mac (MPH)
2010	n/a	n/a	n/a	n/a	n/a
2009	**Wheat-**				
	@ Suggested Setting	40 (with seed)	11-52-0	May.4th	4
	@ Suggested Settings	58 (with Seed)	39-0-0-6	May.4th	
	2A 30T 15T (old)	148	39-0-0-6	1 week after seeding	4
	Field Pea-	(Broadcasted)			
	@ Suggested				4
				May.4th	
	Settings	40 (with seed)	11-52-0		
				May.4th	
	@ Suggested Settings	58 (with Seed)	39-0-0-6		
	Canola-				2
				May.4th	
	@ Suggested Settings	40 (with seed)	11-52-0		
				May.4th	
	@Suggested Settings	58 (with Seed)	39-0-0-6		2
				1 Week after seeding	
	2A 30T 15T (old)	148	39-0-0-6		4
		(Broadcasted)			4
					4
2008	Canola				
	@ Suggested Settings	40 lbs/ac (with seed)	11-52-0	May.6th	4
	@Suggested Settings	58 (with Seed)	39-0-0-2	May.6th	
	2A 30T 15T (old)	189	39-0-0-2	1 Week after seeding	4
		(Broadcasted)			
					4

Table B.6.3 Pesticide Application Swift Current 2012

Year	Herbicides and Rate	Pesticides and Rate	Fungicides and Rate	Date of Application
2010	Weather Max Weather Max Ruster/24 D Ruster Ruster	.33 .33 1/.61 1 1	n\a	May.11 June.21st June.28th July.28th Aug.28th
2009	Horizon Odyseey Weather Max	95 .17 g/ac granular w/t Merge adjuvant 500 ml/100l H2O .66 l/ac	n\a	June.11th June.11th June.11th
2008	Weather Max	.66 l/ac	n\a	June.6th

Table B.6.4 Harvest History Swift Current 2012

Year	Date of Harvest	Machine Used	Machine Speed (MPH)
2010	n/a	n/a	n/a
2009	Aug.10th Aug.10th Sept.1st	Massey 550 Massey 550 Massey 550	2 2 2

2008	Spet.12th	Massey 550	2

Table B.7. Lethbridge 2012 site background history of years 2008 - 2010

Table B.7.1 Mechanical Application history Lethbridge

Year	Type of seed Planted	Seeding Rate (lbs/acre)	Date of Seeding	Row Spacing (Inches)	Type of Machine	Speed of Machine (MPH)
2010	Durum	140	Apr.30	7.5	JD disk	7
2009	Peas	190	May.3	7.5	JD disk	7
2008	HRW wheat	125	Sept.18	7.5	JD disk	7

Table B.7.2 Fertilizer Application history Lethbridge

Year	Fertilizer Setting	Fertilizer (lbs/acre)	Rates of N, P and S applied	Date of Application	Speed of Machine (MPH)
2010	Band	250 N	80 lbs 12-40-10-1z	Late Oct	7
2009	inoculant	0	25 lbs 12-40-10-1z	n\a	7
2008	Sp topdress	250 N	80 lbs 20-20	Mar	7

Table B.7.3 Pesticide Application history Lethbridge

Year	Herbicides and Rate	Pesticides and Rate	Fungicides and Rate	Date of Application
2010	Avades Target/Horizon Label	n\a	Quilt label	Late June
2009	RDP pursuit Poast	n\a	n\a	Apr May
2008	n\a	n\a	n\a	n\a

Table B.7.4 Harvest History Lethbridge

Year	Date of Harvest	Machine Used	Machine Speed
2010	Sept 20	7120/stripper	n\a
2009	Aug 15	7120/stripper	n\a
2008	Aug 25	7120/stripper	n\a

Table B.8. Falher 2012 site background history of years 2008 - 2010

Table B.8.1 Mechanical Application history Falher

Year	Type of seed Planted	Seeding Rate (lbs/acre)	Date of Seeding	Row Spacing (Inches)	Type of Machine	Speed of Machine (MPH)
2010	45H26	4	May3	12	Seed Master	5.5
2009	CDC Meadow	3	May 1	12	Seed Master	5.5
2008	CPS 5700	2.6	May 6	12	Seed Master	5.5

Table B.8.2 Fertilizer Application history Falher

Year	Fertilizer Setting	Fertilizer (lbs/acre)	Rates of N, P and S applied	Date of Application	Speed of Machine (MPH)
2010	110-45-25-19	391 lbs blend	110N, 45P, 25K, 19S	May3	5.5
2009	No Fert			May 1	5.5
2008	100-25-20-0	288 lbs blend	100N, 25P, 20K,0S	May 6	5.5

Table B.8.3 Pesticide Application history Falher

Year	Herbicides and Rate	Pesticides and Rate	Fungicides and Rate	Date of Application
2010	Pre-seed Round-up and incrop 0.5l/ac equiv	n\a	n\a	unknown
2009	Pre-seed Round-up In-crop Viper	n\a	n\a	unknown
2008	Pre seed-Prepass In-crop Frontline	Axial	n\a	unknown

Table B.8.4 Harvest History Falher

Year	Date of Harvest	Machine Used	Machine Speed
2010	Sept 15	Case IH 8010	5 mph
2009	Aug 15	Case IH 8010	5 mph
2008	Sept 18	Case IH 8010	4 mph

Table B.9. Grimshaw 2011 (M2 Field) site background history of years 2008 - 2010

Table B.9.1 Mechanical Application history Grimshaw 2011

Year	Type of seed Planted	Seeding Rate (lbs/acre)	Date of Seeding	Row Spacing (Inches)	Type of Machine	Speed of Machine (MPH)
2010	HRS Wheat	2.5	May 11	10	HB 8000	4.5
2009	RR Canola	5	May 25	10	HB 8000	4.5
2008	CF Canola	5	June 1	10	HB 8000	4.5

Table B.9.2 Fertilizer Application history Grimshaw 2011

Year	Fertilizer Setting	Fertilizer (lbs/acre)	Rates of N, P and S applied	Date of Application	Speed of Machine (MPH)
2010	n/a	N-60	0-25-0	May 11	4.5
2009	n/a	N-80	0-18-0	May 11	4.5
2008	n/a	N-75	0-15,-18	June 1	4.5

Table B.9.3 Pesticide Application history Grimshaw 2011

Year	Herbicides	Herbicide Rate	Pesticide and Fungicides and Rate	Date of Application
2010	RU, Harmony K	0.5 l/ac, recommended rate	n/a	May 8, May 31
2009	RU	0.5 l/ac	n/a	May 8, June 30, July 10
2008	RU, Solo	0.5 l/ac, Recommended rate	n/a	May 28, June 26

Table B.9.4. Harvest History Grimshaw 2011

Year	Date of Harvest	Machine Used	Machine Speed
2010	Sept 24	JD 8820, JD 7720	3-4 mph
2009	Oct 25	JD 8820, JD 7720	4 mph
2008	Oct 17	JD 7720	n\a

Table B.10. Grimshaw 2012 (Cargill Field) site background history of years 2008 - 2010

Table B.10.1 Mechanical Application history Grimshaw 2012

Year	Type of seed Planted	Rate Seed was Planted	Date of Seeding	Row Spacing	Type of Machine	Speed of Machine (MPH)
2010	RR Canola	8 lb/ac	May 17	10"	Haybuster 8000	4.5 mph
2009	RR Canola	8 lb/ac	May 31	10"	HB 8000	4.5 mph
2008	HRS Wheat	2.15 bu/ac	May 27	10"	HB 8000	4.5 mph

Table B.10.2 Fertilizer Application history Grimshaw 2012

Year	Fertilizer Setting	Fertilizer Pounds per Acre Applied	Rates of N, P and S applied	Date of Application	Speed of Machine (PPH)
2010	n/a	N-20	P-18, S-21	May 16	4.5 mph
2009	n/a	N-52	P-10, S-16	May 31	4.5 mph
2008	n/a	N-44	P-11	May 27	4.5 mph

Table B.10.3 Pesticide Application history Grimshaw 2012

Year	Herbicides	Herbicide Rate	Pesticide and Fungicides and Rate	Date of Application
2010	RU	0.5 l/ac	N/A	May 3, June 6, June 27
2009	RU	0.5 l/ac	N/A	May 29, July 3, Sept 11
2008	Harmony SG	Recommended rate	N/A	June 27

Table B.10.4 Harvest History Grimshaw 2012

Year	Date of Harvest	Machine Used	Machine Speed
2010	Sept 29	JD 8820, JD 7720	4.5 mph
2009	Oct 20	JD 8820. JD 7720	4.5 mph
2008	Oct 4	JD 7720, JD 7700	4 mph