WHEAT (*TRITICUM AESTIVUM*) RESIDUE MANAGEMENT BEFORE GROWING SOYBEAN (*GLYCINE MAX*) IN MANITOBA

BY

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ABSTRACT

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Soybean (*Glycine max* L. Merr.) is a relatively new, long season crop for Manitoba that has experienced significant growth in hectares within the past 10 years. There is a lack of applied research to accompany the expansion of soybean into the short growing season regions of Manitoba, including how to manage the residue of the preceding crop that facilitates soil warming and quick emergence of soybean in the spring that does not rely on the use of tillage. In this study, a soybean test crop was established at three site years into fall wheat residue management treatments that include fall conventional tillage (disc), strip till, no-till tall stubble (40 cm), no-till short stubble (15 cm), and a no-till fall rye cover crop. The effect of wheat residue management treatments on soil moisture and soil temperature at 5 cm during the early growing season was inconsistent between site years. The effect of wheat residue management treatments on cumulative soil temperature (growing degree hours) was consistent between site years before planting, with the strip till (in-row) residue management treatment accumulating the most growing degree hours followed by the disc and tall stubble treatments. Overall, the in-row portion of strip till often had one of the warmest soil temperatures at 5 cm during the day after planting, and often had a significantly drier soil at the time of planting compared to all other residue management treatments. There was no significant difference in soybean yield between residue management treatments at one out of two site years. In the other site year, the strip till and tall stubble treatment were significantly greater than the short stubble and fall rye treatments. However, the no-till tall stubble treatment was not significantly different from the disc and strip till residue management treatments. This research indicates that conventional tillage is not

necessary before growing soybean in Manitoba to achieve soil warming and quick emergence of

soybean in the spring.

1. INTRODUCTION

Manitoba has experienced substantial growth in soybean (*Glycine max* L. Merr.) production within the past ten years, reaching over 900,000 hectares in 2017 (Statistics Canada, 2018a). New, short season soybean varieties have allowed for the expansion of soybean into the western and northern agriculture regions of Manitoba where a short growing season is experienced. The main risk for growing soybean in Manitoba is the potential for a killing frost in the spring or fall. Manitoba has a relatively short growing season compared to other major soybean growing regions in Ontario and the Upper Midwest of the United States. Farmers utilize management practices, such as tillage, to allow for an early planting date and to help extend the growing season.

Tillage is a common practice before growing soybean in Manitoba to facilitate soil warming and drying in the spring to allow for early soybean establishment and accelerated growth. As soybean expands into western Manitoba, an area typically under reduced till or no-till management, farmers are returning to the use of tillage to prepare the seedbed as they add soybean into their crop rotation. This is concerning since soybean is successfully grown under no-till management in other major soybean growing regions of Ontario and the United States. Additionally, soybean is a low residue crop and the risk of soil erosion is increased when tillage is used. A study in North Dakota found no-till soybean yield to be 141 kg ha^{-1} (6%) greater than conventionally tilled soybean when averaged across 12 years (2003 to 2014) (Endres, 2015). A study in Ontario observed a 302 kg ha^{-1} soybean yield response to conventional tillage compared to no-till on a heavy textured soil; however, on a light textured soil there was no yield difference between tillage treatments (Bohner, 2013).

There are also studies that show a yield reduction for soybean managed under no-till management compared to conventional tillage. Surface residue has been found to have an inverse relationship with soybean yield; as the level of surface residue increases, soybean yield decreases (Vyn et al., 1998). A soybean yield reduction from increased surface residue was also observed by Vanhie et al. (2015) in Ontario, but the yield reduction was due in part to the type of seeding equipment used rather than the level of surface residue itself. Studies suggest that with proper seeding equipment and residue management, the yield reduction that is sometimes observed under no-till management may be avoided (Vyn et al., 1998; Vanhie et al., 2015; Endres, 2015).

There are many different approaches to residue management available to farmers. Residue management can be classified into three different categories: conventional tillage, reduced tillage and no-till. There are benefits and challenges to every residue management practice, and the best approach often varies from farm to farm. Conventional tillage is used to reduce the surface residue ground cover and help dry and warm the soil (Hatfield et al., 2001). Reduced tillage, such a strip till, utilizes tillage in a narrow zone to help dry and warm the soil, but leaves residue on the soil surface between tillage zones to reduce the risk of soil erosion by wind and water (Morrison, 2002). No-till leaves the soil surface undisturbed to reduce soil erosion but may take longer for the soil to warm and dry out (Hatfield and Prueger, 1996). To limit the effects of surface residue on soil warming and drying, the architecture of the residue can be manipulated to achieve different goals, such as cutting the residue short vs. tall (Bristow, 1988). The addition of a winter cover crop to a no-till residue management system can also be used to reduce the impact of soil erosion and help manage the soil moisture through transpiration of a living crop (Wagner-Riddle et al., 1994).

There is a need for soybean agronomy research in Manitoba to assist farmers as soybean continues to expand across the province. The short growing season for soybean production in Manitoba creates new challenges that may not be accounted for in previous research that has taken place in other major soybean growing regions. Therefore, the focus of our research was to determine if tillage is necessary before growing soybean in Manitoba and to assess the impact of reduced and no-till residue management practices in wheat stubble on soybean growth and yield in Manitoba. The main objectives of this study were to determine the effect of wheat residue management on:

1) Surface residue ground cover.

2) Soil properties such as soil moisture and soil temperature.

3) Soybean plant establishment, growth, and seed yield.

We hypothesized that as the intensity of tillage decreased, the level of surface residue ground cover would increase. This increase in surface residue would result in a decrease in soil temperature, an increase in soil moisture, and a decrease in soybean seed yield.

2. LITERATURE REVIEW

2.1 Tillage

Tillage has been an integral part of agriculture around the world since humans began to grow their own food. Tools and machinery used for tillage are often depicted as a symbol of agriculture, the moldboard plow being an example. On the Canadian Prairies, the moldboard plow was first used when European settlers colonized the area between 1885 and 1920 to "break" the sod of the native prairie and prepare the land for cropping (Anderson, 1975). This intensive form of tillage was seen as beneficial to aerate the soil, improve soil structure, control pests, and provide a quality seed bed (Awada et al., 2014). However, the use of the moldboard plow with the practice of summer fallow (controlling weeds on uncropped land) quickly led to intense soil degradation and wind erosion events, particularly in the 1930's (Anderson, 1975).

Soil degradation lead early scientists to question the sustainability of crop production on the Prairies and several experimental research farms were established to address the problems associated with dryland farming (Janzen, 2001). The use of shelterbelts, surface residue conservation, reduced tillage, and the use of herbicides to control weeds as an alternative to tillage brought soil erosion events by wind under control (Anderson, 1975). Reduced tillage options that replaced the moldboard plow to conserve surface residue consist of blade and disc tillage implements. Heavy-duty cultivators were popular alternatives to the moldboard plow for primary tillage (Manitoba Agriculture, 2008) and are still used on farms across the prairies.

Tillage is a common management practice in Manitoba as nearly 80% of the land that was prepared for seeding in 2016 used some form of tillage (Statistics Canada, 2018b). Some of the benefits for tillage include weed control, disease management, aerate and dry the soil, prepare the seedbed, manage residue, and facilitate faster residue decomposition (Kumar and

Goh, 1999). A quality seedbed ensures that there will be good seed to soil contact when seeding a crop to provide high germination and uniform emergence. Depending on the seeding equipment used, surface residue can interfere with the seed to soil contact when seeding (Hovermale et al., 1979). Residue management should begin when harvesting the previous crop, ensuring the residue is either removed or chopped and spread evenly across the soil surface (Veseth, 1986). Good residue management at harvest does not always happen, requiring the need for tillage to help chop and size the residue into smaller pieces for decomposition.

The benefits of tillage should always be weighed against the potential negative impacts that tillage may cause on the physical, chemical and biological properties of the soil. Soil degradation, soil erosion, compaction, soil surface crusting, reduced soil microbial populations, and loss of soil organic matter have all been associated with the use of tillage (Brady and Weil, 2008). The intensity of tillage within the cropping system will often influence the positive and negative effects of tillage differently; therefore, it is important to look at all tillage and residue management practices within a system.

The reliance on tillage within Manitoba is of concern with the introduction of new, low residue crops. An increase in the use of tillage before a low-residue crop is concerning due to the increased risk of erosion and soil degradation. Soybean is a low residue, warm season crop that requires a long growing season to reach maturity in Manitoba. The growing season in Manitoba can range from >2550 CHU in south central Manitoba to <2250 CHU in north west Manitoba, with a trend of decreasing CHU as you move from south central to western Manitoba and Saskatchewan (Manitoba Pulse & Soybean Growers, 2017). New soybean varieties have been developed for the short growing regions of Manitoba and Saskatchewan, allowing soybeans to expand into areas they have not been commonly grown in before. However, the risk of a fall

frost is still high in these short growing regions and farmers take every effort to maximize the growing season to grow this new crop.

Approximately 20% of the agriculture land in Manitoba is managed using a no-till residue management system with the majority of this occurring in western Manitoba (Statistics Canada, 2016). As soybean production expands to the shorter growing regions of western Manitoba, a resurgence of tillage is being reported on historical, no-till land (Isaccs, 2018). This is due to a common belief by farmers that soybean requires a black, warm soil for a seed bed to facilitate quick germination and emergence to reach maturity by the end of the growing season. Other soybean growing regions that also experience a short growing season have had success with growing soybean under no-till residue management systems. Tillage experiments at Carrington, North Dakota have shown a 141 kg ha^{-1} seed yield advantage to soybean production under no-till residue management systems compared to conventional tillage over a 12 year time period, suggesting that soybeans do not require "black" soil (Endres, 2015). This literature review will discuss the effects of residue management options on surface residue ground cover, soil properties such as soil moisture and temperature, and soybean growth and yield.

2.2   Residue Management Practices and the Effect on Surface Residue

Farmers have options for many residue management practices, ranging from primary and secondary tillage operations to cover crops and no-till practices that can influence the surface residue architecture. The impact on soil surface crop residue levels vary between all residue management practices, which allows them to be categorized into three groups: conventional tillage, reduced tillage, and no-till.

2.2.1 Conventional Tillage

Conventional tillage incorporates and buries most of the crop residue into the soil, leaving much of the soil surface exposed to wind and water erosion. In Manitoba, conventional tillage typically involves primary tillage in the fall and subsequent passes of secondary tillage in the fall and spring to prepare the seedbed. The moldboard plow was the first conventional tillage tool used on the prairies; however, this tool is rarely used anymore on the Canadian Prairies. More common conventional tillage tools consist of double discs and deep-till cultivators that invert the soil. Approximately 43% of the total acres seeded in Manitoba are under a conventional tillage system (Hofmann, 2015), with the majority of those acres located in central and eastern Manitoba.

2.2.2 Reduced Tillage

Reduced tillage, or more commonly referred to as conservation tillage, is defined by the FAO (1993) as "any tillage or planting system in which at least 30% of the soil surface is covered by plant residue after planting." Common reduced tillage residue management practices include vertical tillage, strip tillage, shallow cultivation, and harrowing. Approximately 35% of the acres seeded in Manitoba were under a reduced tillage system based on the 2006 Census of Agriculture (Hofmann, 2015), with these acres spread throughout Manitoba.

Strip tillage is a unique form of reduced tillage, as it combines characteristics of both no-till and conventional till systems. Strip tillage is defined by Morrison (2002) as "any row-crop cultural practice that restricts soil and residue disturbance to less than 25% of the field area." To achieve this, an implement with shanks or coulters is used to disturb only the soil in which the crop will be directly planted into. For example, if the row spacing of the crop is 76 cm, the

disturbed area of the soil will be less than 19 cm in width, leaving the remaining soil undisturbed. The theory behind strip till is to provide the benefits of a conventional tillage system in the seed row while maintaining residue cover and soil structure within the inter-row to reduce soil erosion and maintain moisture conservation.

2.2.3 No-Till

No-till is the practice of direct seeding into undisturbed soil with at least 30% residue cover (Triplett and Dick, 2008). The adoption of no-till across the prairies was made possible due to 1) new seeding equipment and technology to seed into undisturbed soil and residue, 2) the introduction of broad spectrum herbicides, and 3) the use of cropping systems that break up the disease and pest lifecycles that were previously controlled with the use of tillage (Awada et al., 2014). More than 50% of the acres on the prairies are under a no-till cropping system, but only 20% of the acres in Manitoba are under no-till management (Awada et al., 2014; Hofmann, 2015; Statistics Canada, 2018b), confined mainly to western Manitoba.

Residue management in no-till cropping systems can be more challenging than a conventional tillage or reduced tillage cropping system. Without the use of tillage, one of the only opportunities to control how the residue is managed within the field is at the time of harvest. Ideally, residue is chopped and spread evenly across the entire field behind the combine after harvesting (Veseth, 1986). Even distribution of residue on the soil surface will facilitate easier seeding the following spring and allow consistent warming and drying of the soil across the field (Veseth, 1986). In addition to the distribution of residue within the field, residue architecture can also be manipulated at the time of harvest by cutting the straw high and leaving the unharvested residue tall (42 cm) or cutting the straw closer to the ground and leaving the unharvested residue short (15 cm) (Cutforth and McConkey, 1997).

2.2.4   Fall Rye as a Cover Crop

Cover crops have the potential to play many roles within a cropping system. The term cover crop refers to a crop grown during the time between cash crops to keep cover on an otherwise bare soil (Kaspar and Singer, 2011). When a cover crop is grown, it can provide erosion control, fertility management, improve soil quality, soil water management, and may provide weed and pest management (Unger and Vigil, 1998; Sarrantonio and Gallandt, 2003; Kaspar and Singer, 2011). One of the challenges to growing a cover crop is choosing a species that can be established easily in the fall and meet the intended goals of the cover crop. Fall rye is a popular choice in cold climates due to its abilities to grow and germinate in soil temperature as low as 4°C, overwinter, and still provide an extensive fibrous root system that anchors the soil to prevent soil erosion in the fall and spring (Sarrantonio and Gallandt, 2003).

Having a living fall rye cover crop during the late fall and early spring can influence the soil microclimate. The fibrous root system can influence soil moisture content through evapotranspiration and root channels (Wagger and Mengel, 1988; Unger and Vigil, 1998; Westgate et al., 2005; Qi and Helmers, 2010; Krueger et al., 2011; Flood and Entz, 2018), while the increase in surface residue and vegetative biomass can influence soil temperature (Wagger and Mengel, 1988; Wagner-Riddle et al., 1994). Timing of fall rye desiccation can help manage the positive or negative effects of a cover crop on the soil microclimate and the impact on a subsequent crop (Wagner-Riddle et al., 1994; De Bruin et al., 2005; Westgate et al., 2005; Krueger et al., 2011; Flood and Entz, 2018).

2.3   Effects of Residue Management on Soil Properties

2.3.1   Soil Nitrogen Dynamics and Soybean

Crop residue breakdown and decomposition is a complex process that is influenced by: 1) chemical composition of the residue, 2) environmental factors, and 3) residue size and placement (Kumar and Goh, 1999). Microorganisms are mainly responsible for the breakdown of crop residues, using the carbon in plant residue for respiration. This releases CO_2 and provides energy to the microorganism (Chen et al., 2014). Carbon to nitrogen ratios (C:N) are commonly used to predict mineralization and immobilization of soil nutrients, such as nitrogen. Generally, a balanced microbial diet consists of a C:N ratio of 24:1 (Brady and Weil, 2008). Crop residues with a C:N ratio less than 24:1 often results in nitrogen mineralization (release of nutrients), while residue with a C:N ratio greater than 24:1 often result in nitrogen immobilization (tie up nutrients). Crops with a low C:N ratio are often young legume crops, such as hairy vetch (C:N ratio of 11:1) or young alfalfa hay (C:N ratio of 13:1) (USDA-NRCS, 2011). Cereal crop residue often have a high C:N ratio, such as mature wheat residue with a C:N ratio of 80:1 (USDA-NRCS, 2011).

Residue management treatments that vary in the amount of tillage have an influence on the soil nitrogen dynamics within a cropping system. Previous research by Schoenau and Campbell (1996) suggest that nitrogen immobilization is greater under reduced and no-till systems compared to conventional tillage systems. Tillage is known to decrease the organic nitrogen pool within the soil by exposing previously protected organic matter to microbial degradation, resulting in an increase in mineralized soil nitrogen (Kristensen et al., 2003). There are many factors that can influence the time it takes for nitrogen mineralization to occur, such as soil temperature, soil moisture, soil pH, freezing and thawing, aerobic and anaerobic conditions,

and soil salinity (Stanford et al., 1973; Vigil and Kissel, 1995; Kumar and Goh, 1999; Ryan et al., 2000). Soil temperature likely has the greatest influence on nitrogen mineralization and crop residue breakdown in Manitoba from the time of fall tillage to spring planting due to the cold soils during winter. The optimum soil temperature for N mineralization is 35°C and as the soil temperature approaches the freezing point, that rate of N mineralization is reduced to the point where it essentially does not occur (Vigil and Kissel, 1995).

Crop residue type and tillage system also effect the rate of N mineralization from organic material. Research by Lupwayi et al. (2004) compared the N release of wheat compared to different crop residue types over a 52 week time period in conventional and no-till systems on a sandy loam Gray Luvisol in northern Alberta. They determined that only 22% of the N within the wheat residue was released under the conventional till system, resulting in only 2 kg N ha^{-1} added to the system. There was no significant difference in nitrogen mineralization between the conventional tillage and no-till system. This suggests that the nitrogen mineralization for tillage and no-till residue management systems of wheat stubble was similar from the time of harvest until the following spring when weather conditions are cold in Northern Alberta.

Soybeans form a symbiotic relationship with *Bradyrhizobium* bacteria that biologically fix nitrogen from the atmosphere, contributing to approximately 50-60% of the total plant nitrogen (Salvagiotti et al., 2008). The remaining nitrogen taken up by the soybean plant comes from other sources, such as residual and/or mineralized inorganic nitrogen within the soil (Unkovich and Pate, 2000; Schipanski et al., 2010). Biological nitrogen fixation (BNF) does not occur until the soybean has reached the second or third trifoliate growth stage. Soybeans rely on seed reserves and root uptake from the soil before BNF occurs (Zapata and Danso, 1987). The greatest assimilation rates of nitrogen from BNF occur during the reproductive stages, with the

majority of the nitrogen within the plant coming from BNF during this period (Zapata and Danso, 1987).

The level of nitrogen within the soil in the form of nitrate can influence the effectiveness of BNF of soybean and subsequently, soybean yield. As the level of soil nitrate increases in the soil, the effectiveness of BNF to fix and supply nitrogen to the soybean plant decreases (Herridge and Brockwell, 1988; Streeter, 1988). Research by Schipanski et al. (2010) explored the relationship between BNF in soybean across a range of soil and environmental conditions. The researchers established research plots in 13 commercial fields in New York state that vary in management history and soil classification – fine sandy loam to gravelly silt loam. When determining which factors had the greatest inhibition on soybean nodulation, a coarse soil texture was the main factor followed by high residual nitrogen (Schipanski et al., 2010). Stone et al. (1985) explored the effect of residual nitrate and applied nitrogen on soybean yield on a Eudora silt loam near Manhattan, Kansas. Soybean yield increased with added fertilizer when the residual soil nitrate was less than 190 kg ha^{-1}, but decreased when the residual amount was greater than 190 kg ha^{-1} within a 180 cm soil profile. The reduction in soybean yield was attributed to the reduction of BNF when residual soil nitrate was greater than 190 kg ha^{-1}.

Tillage influenced soybean nodulation in Australia (Hughes and Herridge, 1989). When comparing the number of nodules on soybean plants established under conventional tillage and no-till, the no-till soybean had 30% more nodules on average than the conventional till soybean. Possible explanations provided by the researchers for the increased nodulation of soybean under no-till management was less residual nitrate (2 kg ha^{-1}) compared to the conventional till plots (22 kg ha^{-1}), and the protection against the effect of extreme soil temperature and moisture

fluctuations on *Bradyrizobium* populations from the increased soil cover within the no-till system (Hughes and Herridge, 1989).

2.3.2 Soil Moisture

Residue management practices influence soil moisture by affecting water infiltration rates and water evaporation. It is not uncommon to experience both excess moisture and drought conditions within the same growing season on the prairies. Goals for managing residue on the prairies related to soil moisture are typically to: 1) alleviate excess moisture conditions in the spring, 2) conserve soil moisture late in the growing season or 3) a combination of both.

Excess moisture is most often a problem in the spring for heavy textured soils as it can reduce field trafficability and delay seeding (Bedard-Haughn, 2009). Early seeding is important for many crops in Manitoba as the yield potential decreases as seeding is delayed (MASC, 2016). There are two main strategies to manage excess moisture: the first is to use residue management practices to maximize infiltration and drying of the soil, while the second is to remove water from the soil profile with drainage or cultural practices such as cover crops that transpire water (Bedard-Haughn, 2009). Tillage helps to facilitate soil drying by reducing or removing residue from the soil surface to allow solar radiation to reach the soil and increase evapotranspiration; up to 30% reduction of soil moisture compared to no-till (Gauer et al., 1982). The soil is also aerated through tillage by mixing and loosening the soil (Hatfield et al., 2001). Reduced tillage and no-till alleviate excess moisture differently than conventional tillage. Reduced tillage and no-till help to maximize infiltration rates by maintaining soil aggregate stability, soil structure, and maintaining root channels and macropores within the soil (Brady and Weil, 2008).

Many studies have shown that soil moisture tends to be greater when tillage is reduced and residue is left on the soil surface compared to a conventional till system (Gauer et al., 1982; Grevers et al., 1986; Brandt, 1992; Lafond et al., 1992; Hatfield and Prueger, 1996; Opoku and Vyn, 1997; Vyn et al., 1998; Mitchell et al., 2012; Vanhie et al., 2015). A study in Manitoba by Gauer et al. (1982) observed a 30% (0.1 m^3 m^{-3}) reduction in spring soil moisture using conventional tillage compared to no-till on a clay loam soil. Grevers et al. (1986) observed an average loss of 4.9 cm of soil moisture for conventional tillage compared to an average loss of 0.8 cm of soil moisture for no-till during the time between spring snow melt and the time of spring seeding on a heavy clay to loam soil texture in Saskatchewan. Lafond et al. (1992) measured spring soil moisture under wheat stubble conditions in conventional tillage, minimum till, and no-till conditions and found that zero till and minimum till had a soil profile from 0 to 120 cm that was 87% saturated compared to conventional till that was 82% saturated on a heavy clay soil texture in Saskatchewan. All studies attributed the differences observed in soil moisture to decreased evaporation, increased infiltration, and increased snow capture by stubble resulting in greater spring soil water recharge for no-till compared to conventional tillage (Gauer et al., 1982; Grevers et al., 1986; Lafond et al., 1992).

Some research has indicated that a difference in soil moisture between tillage and no-till is due to the difference in residue cover rather than tillage itself. Vyn et al. (1998) observed a difference of 0.10 cm^3 cm^{-3} in volumetric moisture content in the top 15 cm of soil when measured in the spring between fall tillage and no-till residue management treatments with surface residue remaining on the soil surface. When the surface residue was removed from the no-till treatment and the soil was left bare, a difference in volumetric moisture content was no

longer observed. This suggest that surface residue had a greater influence on volumetric moisture content that tillage itself.

Strip tillage is a form of residue management that falls in between no-till and conventional tillage in the amount of soil disturbance and residue remaining on the soil surface. Based on the reduced level of soil disturbance, one could hypothesise that the soil moisture content at or near the soil surface would also fall between no-till and conventional till soil moisture contents when averaged across the in-row and inter-row portions of strip till. In a study located in Iowa on a loam to clay loam soil, Licht and Al-Kaisi (2005) determined that there was no significant difference in surface soil moisture content between strip till, no-till, and conventional till tillage systems measured at 0-15 cm soil profile at corn emergence. Janovicek et al. (2006) did not observe a difference in soil moisture for strip till compared to no-till and fall tillage treatments in southwestern Ontario that varied in soil textures; however, they observed a difference of 0.02 to 0.04 m^3 m^{-3} between no-till and fall tillage, including strip till, at five out of nine site years. Overstreet et al. (2007) found that strip till retained 3.5 to 5.5% greater soil moisture content than the conventional till treatment when the soil profile was near full saturation when measured in season at Prosper, North Dakota. It was noted that under wet conditions, the extra holding capacity of the strip till system could be seen as a disadvantage, but would be an advantage during a dry year (Overstreet et al., 2007).

Soil moisture differences have been observed between the in-row and inter-row portions of strip till. Tabatabaeekoloor (2011) compared the soil moisture content between the in-row and inter-row portion of strip till applied to corn stubble on a clay soil in Iran. The in-row portion of strip till was consistently drier than the inter-row portion of strip till, approximately 18% drier at the 5 cm, 15 cm and 25 cm soil depths. The moisture difference between the in-row and inter-

row portions of strip till are consistent with moisture differences between conventional tillage and no-till residue management treatments presented earlier in this section; however, the moisture differences within the strip till system occur within 38 cm of each other.

The use of fall rye as a cover crop can contribute to evapotranspiration of water by the living plants. A 1465 kg ha^{-1} fall rye cover crop reduced soil moisture by 25% (13 g g^{-1} at 0-10 cm depth) on a fine sandy loam soil in the spring compared to a no rye cover crop, when rainfall was approximately 50% of the normal precipitation in Manitoba (Flood and Entz, 2018). When rainfall was near normal the following year, a reduction in soil moisture was not observed between the presence or absence of a fall rye cover crop (Flood and Entz, 2018). De Bruin et al. (2005) observed a fall rye cover crop reduce soil moisture on a silt loam and clay loam soil by 35 g kg^{-1} in a 0-15 cm profile when rainfall was below normal but did not observe a reduction in soil water the following year when rainfall was above normal. Qi and Helmers (2010) initiated an experiment in Iowa using lysimeters to determine the potential evapotranspiration of a fall rye cover crop on a fine loamy soil. The researchers determined that a fall rye cover crop with approximately 2.7 Mg ha^{-1} had an evapotranspiration rate of 2.4 mm day^{-1} during the month of May compared to 1.5 mm day^{-1} for a bare soil with no fall rye cover crop (Qi and Helmers, 2010).

Delaying the desiccation timing of fall rye and increasing the time a fall rye cover crop grows during the spring can help to reduce soil moisture content at the time of planting. Liebel et al. (1992) observed that fall rye terminated at planting contained 4-6 cm less water in a 55 cm silt loam soil profile compared to fall rye terminated two weeks before planting and a conventional tillage treatment. These differences were due to the transpiration of water by the living fall rye. Krueger et al. (2011) had similar observations for water depletion between fall rye desiccated

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early at tillering and fall rye desiccated 3-4 weeks later at stem elongation on a silt loam soil at

Morris, MN. The late fall rye desiccation timing had 13% greater water depletion (2.6 cm total

water at 60 cm) in 2008 and 18% greater water depletion at the 30 cm soil depth in 2009

(Krueger et al., 2011). However, rainfall has the ability to change differences in soil moisture

after fall rye has been desiccated. Krueger et al. (2011) reported that a reduction in soil moisture

from fall rye was no longer observed after fall rye desiccation when rainfall was at or above

normal. A reduction in soil moisture from fall rye before desiccation was also reported by

Wagner-Riddle et al. (1994), but a difference in soil moisture after fall rye desiccation was no

longer observed when a significant rainfall of 15 mm or more occurred.

Mulch from desiccated fall rye cover crops can also be used to conserve soil moisture

during the growing season when left undisturbed on the soil surface. Wagner-Riddle et al. (1994)

observed a 26% reduction in the rate of soil drying when fall rye was desiccated early (2.2 Mg

ha^{-1} dry matter) compared to late (3.5 Mg ha^{-1}) at one site year. The following year, the

researchers reported no difference in the rate of soil drying when fall rye was desiccated early

(3.4 Mg ha^{-1} dry matter) and late (4.8 Mg ha^{-1}). This suggests that more than 2.2 Mg ha^{-1} of dry

matter was needed to reduce the drying rate of the soil, with 3.4 Mg ha^{-1} of dry matter observed

to be sufficient to reduce the drying rate in this study (Wagner-Riddle et al., 1994). Liebl et al.

(1992) observed a fall rye cover crop conserve soil moisture by approximately 0.05 m^3 m^{-3} in the

0 to 25 cm soil profile compared to a bare soil when rainfall was above normal at one site year in

Illinois. At a site year with normal rainfall, the effects of soil moisture conservation from a

desiccated fall rye mulch were not observed in their study (Liebl et al., 1992).

The timing of fall rye desiccation can potentially reduce surface soil moisture in the

spring (De Bruin et al., 2005; Qi and Helmers, 2010; Flood and Entz, 2018) which may allow for

earlier planting, but also conserve soil moisture later in the growing season (Liebl et al., 1992; Wagner-Riddle et al., 1994). However, after a crop has been planted, it is harder to quantify the direct effects of a fall rye mulch on in-season evaporation because soil moisture dynamics are confounded by the transpiration of water by the growing soybean crop.

2.3.3   Soil Temperature

Soil temperature can be influenced by residue management practices that vary the amount of crop residue that remains on the soil surface (Brady and Weil, 2008). The effect that crop residues have on the physical processes behind wetting-drying and heating-cooling of a soil are closely related. Crop residue acts as a buffer, intercepting solar radiation that heats and evaporates water from the soil (Horton et al., 1996). A wet soil will take longer to heat than a dry soil because the water-filled pore space of a wet soil requires more energy to heat than the air-filled pore space of a dry soil (Brady and Weil, 2008). Any residue management practice that limits the evaporation of water from the soil will also limit the soil heating capabilities of that soil (Horton et al., 1996).

Soil temperature for conventional tillage is usually warmer than no-till during the early growing season from May to June (Gauer et al., 1982; Malhi and O'sullivan, 1990; Beyaert et al., 2002). Gauer et al. (1982) observed conventional tillage to be 0.5 to 1°C warmer than a no-till soil with wheat residue spread evenly across the soil surface during the first two weeks after planting in Manitoba. Malhi and O'sullivan (1990) observed the average soil temperature at 5 cm depth in barley stubble for conventional till to be 1.1°C warmer than no-till during May in Alberta. Beyaert et al. (2002) observed a lower soil temperature for no-till compared to conventional till on 75% of the days observed at 4 cm from the time of corn planting until the

end of corn emergence in Ontario. The difference observed between the mean soil temperature for conventional till and no-till increased as the air temperature increased (Beyaert et al., 2002).

Differences in soil temperature between conventional tillage and no-till residue management practices are not always consistent. Hatfield and Prueger (1996) found that the greatest difference in mean soil temperature between no-till and conventional tillage practices occur in the fall, with very little variation in the spring soil temperature for corn stubble. No-till plots remained warmer in the fall compared to conventional tillage treatments at 1 and 10 cm below the soil surface, which allowed for prolonged biological activity and crop residue degradation for no-till residue management practices in the fall (Hatfield and Prueger, 1996). Gauer et al. (1982) observed a different soil temperature trend when wheat residue was spread evenly across the no-till treatment compared to the a conventional till treatment on a clay loam soil. When the soil temperature reached the maximum for the day, the no-till treatment was 4^oC warmer than the conventional till treatment at the 2.5 cm soil depth (Gauer et al., 1982).

The architecture of the residue that covers the soil surface influences how the soil warms. Bristow (1988) compared the soil temperature regimes between similar amounts of *Stylosanthes hamata* cv. Verano residue mulch (0.37 kg ha^{-1}) that was vertically-oriented (22 cm of residue standing up), residue that was horizontally-oriented (5 cm of residue laying on the surface), and a bare soil in Townsville, Australia. The difference in soil temperature did not occur until the soil began to dry. The soil with vertical residue began to warm up faster and had a higher maximum soil temperature than the soil with horizontally-oriented residue during the day (Bristow, 1988). Solar radiation was intercepted less by residue that had vertical architecture, allowing more radiation to reach the soil surface. Similar findings have been observed by Flerchinger et al. (2003) where vertical wheat stubble (23 cm tall) warmed faster than horizontal stubble (2.5 cm

tall) and bare soil by trapping and retaining heat more efficiently. Cutforth et al. (2002) observed soil temperature between wheat stubble cut tall (25 to 36 cm), wheat stubble cut short (15 to 18 cm) and conventional tillage from the time of planting until mid growing season in Saskatchewan. When the daily soil temperature was averaged across three growing seasons from 1996 to 1998, the conventional tillage treatment was 0.8^oC warmer than the tall stubble treatment, while the short stubble treatment was not significantly different from tall stubble or conventional till treatment (Cutforth et al., 2002).

Strip till combines characteristics of both conventional till and no-till residue management systems, which is reflected in the soil temperature regimes within the strip till system. During the spring, the in-row portion of strip till warms up similarly to that of a bare soil applied to barley stubble (Hares and Novak, 1992). Wall & Stobbe (1984) found that the in-row portion of strip till had a maximum soil temperature at 5 cm that was equal to or occasionally greater than that of a conventionally tilled soil in the spring in Manitoba. The researchers also recorded soil temperature in the inter-row portion of strip till and the mean soil temperatures at 5 cm for the in-row and inter-row portions of strip till were not significantly different, even though temperature tended to be warmer in-row (20.1^oC) compared to inter-row (17.3^oC) (Wall and Stobbe, 1984). Tabatabaeekoloor (2011) observed similar trends in soil temperature between the in-row and inter-row portion of strip till. The in-row portion was approximately 2^oC warmer than the inter-row portion of strip till during the day at 0-10 cm, 10-20 cm, and 20-30 cm soil depth applied to corn stubble (Tabatabaeekoloor, 2011).

The soil temperature differences between residue management practices are similar when the soil warms during the day and cools during the night. When soil temperature is compared to air temperature, there is generally a lag in soil temperature observed when a soil warms during

the day and cools during the night (Parton and Logan, 1981). Residue acts as insulation on the soil surface, allowing no-till soils with residue on the soil surface to warm and cool slower than a conventionally tilled soil with little residue. Unlike maximum soil temperature, there is generally little difference in minimum soil temperatures between residue management practices (Wall and Stobbe, 1984). Bristow (1988) found that the minimum soil temperatures for residue management practices converge at night just before sunrise, regardless of residue management practice or maximum day time soil temperature.

2.3.4   Cumulative Soil Temperature

Air temperature has been widely used to predict crop emergence and development rates (Ritchie and NeSmith, 1991). The two most common heat-unit systems used to accumulate thermal time using air temperature are Growing Degree Days (GDD) and Corn Heat Units (CHU) (Ritchie and NeSmith, 1991). There have been several attempts to adapt these heat-unit systems for soil temperature, since soil temperature influences crop emergence and development during the seedling stages of most crops (Gauer et al., 1982; Swan et al., 1987; Ritchie and NeSmith, 1991; Opoku and Vyn, 1997; Bullock et al., 2012).

Soil residue cover influences soil temperature; therefore, soil temperature accumulation can be used to compare crop emergence and plant development over time between different residue management practices. However, there are other factors that can influence crop emergence and plant development. Opoku & Vyn (1997) attempted to use a soil GDD model to predict the time until 50% emergence for corn for different residue management practices in Ontario. Although there was success in using soil GDD to quantify soil accumulation differences between residue management practices, soil GDD alone could not be correlated to corn emergence within this study.

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2.4   Soybean Response to Residue Management and Soil Properties

2.4.1   Soybean Emergence

Cold soils and inadequate soil moisture can increase the time it takes for soybeans to emerge after planting. Delayed soybean emergence increases the risks of seedling disease (*Rhizoctonia solani, Fusarium solani* f. sp. *phaseoli, Phytophthora sojae,* and *Pythium* spp.) as the seed remains in the soil longer (Bradley, 2008). To ensure quick emergence and reduce the risks of seedling morality, soil temperature is often used as a recommendation for when to plant soybean in Manitoba. The recommended time to plant soybean in Manitoba is between May 15 to 25, and an average soil temperature of at least 10°C and rising before planting (Manitoba Agriculture, 2017).

According to Hatfield and Egli (1974), the optimal soil temperature to plant soybean that results in the quickest emergence is 25°C to 30°C. It is unrealistic to wait until a soil temperature of 25°C to plant soybeans in Manitoba as the growing season is too short to allow for this. Alternatively, soybeans that are planted and imbibed in a soil with a soil temperature 10°C or lower are at risk of chilling injury (Bramlage et al., 1978). Seedling desiccation, cracked cotyledons, and decreased hypocotyl growth rate are all symptoms of chilling injury (Hobbs and Obendorf, 1972). To avoid chilling injury, soybeans should not be planted into a soil that is less than 10°C, either by delaying the planting date or using residue management practices that facilitate soil warming.

Soybean requires a minimum seed moisture content of 50% before germination will occur (Hunter and Erickson, 1952). When seeds germinate in soil with a moisture content below the minimum requirement for germination, the soybean seed may imbibe water and swell, but fail to fully germinate. Helms et al. (1996) found that a gravimetric soil water content of 0.09 kg

kg^{-1} dry soil or greater on a Glyndon silty clay loam soil resulted in 94% soybean emergence within their incubator study. However, a gravimetric soil water content of 0.07 kg kg^{-1} dry soil resulted in only 27% to 65% emergence, depending on the soil temperature regime used within the study (Helms et al., 1996). At this low gravimetric soil water content of 0.07 kg kg^{-1} dry soil, it was observed that the soybeans had sufficient water to imbibe but insufficient water for the radicle to emergence for the testa.

Dry soil moisture conditions during seeding in Manitoba can occur; however, experiencing a loss in soybean from dry seed bed conditions is not common. From 1998 until 2017, there have only been three crop insurance claims in soybean for dry seedbed conditions compared to 460 claims for excess moisture (drowning) during this same period (Manitoba Agricultural Services Corporation, 2018). A rainfall event in Manitoba at the time of seeding or during emergence for soybean is likely, which alleviates the risks of a dry seed bed (Environment and Climate Change Canada, 2018).

Residue management practices can influence the rate of emergence and final plant population of a soybean crop. In Ontario, Vyn et al. (1998) observed a delay in soybean emergence by approximately one day for a no-till wheat residue management treatment with residue compared to tillage and no-till wheat residue management treatments with residue removed. Plant populations were also reduced by 40,000 to 220,000 plants ha^{-1} when planting into no-till conditions with residue compared to any other residue management treatment (Vyn et al., 1998). Slower emergence has also been observed under a fall rye cover crop compared to no cover crop for soybean (Wagner-Riddle et al., 1994) and dry bean (Flood and Entz, 2018) test crops. Flood and Entz (2018) reported a reduction in dry bean plant stand of 33% (14 plants m^{-2})

at one site year when planted into a fall rye cover crop treatment with 4286 kg ha^{-1} biomass compared to no cover crop treatment at Carman, Manitoba.

Residue management practices may not influence the rate of soybean emergence or final plant stand (Lueschen et al., 1992; Janovicek et al., 2006; Kiszonas, 2010; Vanhie et al., 2015). Vanhie et al. (2015) and Janovicek et al. (2006) found no difference in soybean emergence for tillage and no-till residue management treatments applied to corn stubble in Ontario on a Huron silty clay loam and Perth loam soil. Lueschen et al. (1992) measured the days to 50% emergence and final plant population of soybean planted into tillage and no-till residue management treatments applied to corn and wheat stubble in south central Minnesota on loam to clay loam soils. When averaged for all site years, tillage influenced the days to 50% emergence under the corn-soybean rotation (less than 3 days difference between treatments) but not under the wheat-soybean rotation.

Planter type or seeding equipment have an influence on emergence and plant populations. Vanhie et al. (2015) found an advantage of 7.7 plants m^{-2} at V3 growth stage for using a row-unit planter (40.3 plants m^{-2}) compared to a disc drill (32.6 plants m^{-2}) when averaged across tillage system, various residue removal treatments, and field locations. Possible reasons for improved plant populations while using a row-unit planter include row-unit coulters and superior depth control compared to using a disc drill (Vanhie et al., 2015). The effect of a planter reducing soybean emergence when planting into high residue situations has also been observed by Wagner-Riddle et al. (1994). A no-till planter was used to plant into a fall rye cover crop with large amounts of residue and resulted in poor seed to soil contact reducing the plant population. When a different planter (no-till drill) was used the following year in large amounts of residue cover, a reduction in plant population was not observed (Wagner-Riddle et al., 1994). This

suggests that a reduction in emergence from residue management practices was also related to the planter that was used, not only the effect of the residue management practice itself.

2.4.2 Soybean Growth and Development

Residue management practices influence early soybean growth and development. Temperature has the greatest influence on soybean vegetative development before growth stage V5, with cold temperatures delaying the rate of soybean development and warm temperatures enhancing the rate of soybean development between vegetative growth stages (Fehr and Caviness, 1971). Compared to conventional tillage, soil temperature is often cooler under no-till residue management practices (Gauer et al., 1982; Hatfield and Prueger, 1996), which has the potential to delay soybean development under no-till conditions. Vanhie et al. (2015) observed advanced soybean development (<0.5 trifoliate) in corn stubble when crop residue was removed from the soil surface (26% surface residue ground cover remaining) compared to residue management treatments when crop residue was not removed (61% surface residue ground cover). However, this difference in early soybean development was not associated with soybean yield at the end of the growing season (Vanhie et al., 2015).

No-till conditions can decrease soybean biomass during the growing season. Vyn et al. (1998) determined that soybean had accumulated significantly more biomass five weeks after planting in fall tillage treatments compared to a no-till treatment with residue left undisturbed. No significant difference in accumulated biomass was observed when surface residue was baled and removed from the no-till treatment compared to fall moldboard plow, at five out of six site years (Vyn et al., 1998). This suggests that the additional mulch on the soil surface in the no-till system was limiting early season soybean growth in this study. There is evidence that soybeans can undergo compensatory growth during their reproductive stages if growth was limited during

the vegetative growth stages (Yusuf et al., 1999; Pedersen and Lauer, 2004). Prior to growth stage R6, Yusuf et al. (1999) observed no-till soybeans accumulate 15 to 20% less biomass compared to conventional till soybeans in a corn-soybean rotation in Illinois. After growth stage R6, no difference in accumulated biomass was observed between conventional till and no-till soybeans due to an increase in crop growth rate for the no-till soybeans after R2. Similar observations of increased crop growth and dry matter accumulation were reported by Pedersen and Lauer (2004) in Wisconsin between conventional till and no-till tillage systems, but no difference in early season biomass accumulation was observed in this study. Based on the compensatory growth observations by Yusuf et al. (1999) and Pedersen and Lauer (2004), it would have been of interest to see if the early season differences observed by Vyn et al. (1998) would have persisted late in the growing season as well.

Differences in soybean growth and development are not always observed between residue management treatments. Kiszonas (2010) observed no difference in above ground soybean biomass accumulation between conventional and no-till treatments in a corn-soybean rotation in Iowa. Janovicek et al. (2006) observed no difference in accumulated biomass between no-till, strip till, and a spring coulter tillage pass applied to corn stubble. However, mid season biomass was reduced by 65% to 75% under no-till (0.75 mg ha^{-1} biomass) compared to fall moldboard plow (1.13 mg ha^{-1} biomass) (Janovicek et al., 2006).

Soybean plant height can be influenced by previous crop stubble height. Hovermale et al. (1979) compared the effect of three different small grain stubble heights (10.2 cm, 20.3 cm, and 35.6 cm) on soybean height and found that the tallest stubble produced the tallest plants (91.7 cm), but there was no difference between the low stubble (85.1 cm plant height) and medium stubble (85.9 cm plant height) heights. The trend for plant height was also consistent for pod

height in this study. A tall plant height is not always desired as soybean lodging increased in each of the stubble treatments from a rating of 1.1 for short stubble to 3.4 for tall stubble on a 1-5 rating scale, where 1 equals all plants erect and 5 equals all plants prostrate (Hovermale et al., 1979).

The presences of a fall rye cover crop and its management can influence soybean plant height. Westgate et al. (2005) found that mechanical desiccation of fall rye using a stalk chopper produced shorter soybean plants (40 to 50 cm) than chemical desiccation (80 cm), regardless of the timing of desiccation. However, this difference was mainly due to the ineffectiveness of the mechanical desiccation of fall rye, resulting in fall rye regrowth and competing with soybean for water and light resources. When comparing the timing of fall rye desiccation using chemical control, the later the desiccation timing of fall rye (boot or anthesis) produced shorter plants compared to a desiccation timing of 2nd node for fall rye (Westgate et al., 2005). However, the difference in soybean height between the desiccation timings was minimal, varying between 5 and 10 cm for the shortest and tallest plant heights. Moore et al. (1994) found no effect on soybean plant height when planted into a fall rye cover crop that was desiccated and mowed a week before planting compared to no cover crop in Ontario.

Fall rye cover crops also influence the growth and development of dry bean test crops in Manitoba. Flood and Entz (2018) measured the effect of the presence or absence of a fall rye cover crop and the timing of fall rye desiccation on dry bean growth and development. A fall rye cover crop delayed dry bean development at only one out of four site years when bean development was slowed by three days compared to the no fall rye control treatment (Flood and Entz, 2018). Fall rye reduced dry bean biomass at two out of four site years by approximately 450 kg ha^{-1} compared to the no fall rye control. Late timing of fall rye desiccation decreased dry

bean biomass at three out of four site years when the early desiccation timing (555 to 1570 kg ha^{-1} fall rye biomass) resulted in 501 kg ha^{-1} to 1105 kg ha^{-1} greater dry bean biomass accumulation compared to the late desiccation timing (1245 to 4162 kg ha^{-1}) (Flood and Entz, 2018). It is unknown if a fall rye cover crop will have a similar influence on a soybean test crop in Manitoba.

2.4.3   Soybean Yield

Manitoba farmers are concerned that any delay in early season growth of soybean will result in a yield loss or potential to not reach full maturity by the end of the growing season. Soybean yield response to residue management practices have been variable in residue management studies in Ontario and MidWest USA (Vyn et al., 1998; Vetsch et al., 2007; Endres, 2015; Daigh et al., 2018), and differences in early season soybean growth between residue management treatments do not always translate into a yield response. Yusuf et al. (1999) observed soybeans under no-till management appeared to accumulate less biomass at the beginning of the growing season compared to soybeans under conventional till management, yet the soybeans under no-till management yielded the same as the soybeans managed using conventional tillage (Yusuf et al., 1999).

When averaged across multiple years, soybeans grown under no-till management in North Dakota yielded more than soybeans grown under conventional tillage. Averaged across 12 years, no-till soybean yielded 141 kg ha^{-1} more than soybean planted into conventional tillage at Carrington, North Dakota (Endres, 2015). Residue management studies in North Dakota and Minnesota conducted from 1999 to 2014 to compare reduced tillage systems for soybean found that soybean managed under no-till, strip till, or direct seeded in spring yielded 4% more than conventionally tilled soybeans across 37 site years (Endres, 2015).

Conversely, several residue management studies comparing tillage and no-till have observed soybean yield to be unresponsive to tillage. Daigh et al., (2018) compared the soybean yield response to tillage in a corn-soybean rotation at eight locations in the Midwest USA for five years from multiple studies and determined that there was no soybean yield difference between chisel plow and no-till following corn when averaged across all site years. Pedersen and Lauer (2003b) observed no soybean yield response to tillage system (conventional tillage and no-till) when averaged across four site years in Wisconsin. However, a previous study reported by Pedersen and Lauer comparing tillage system (conventional tillage and no-till) in Wisconsin found that soybean planted into a no-till system yielded 6.1% more than conventional tillage when averaged across all site years (Pedersen and Lauer, 2003a). Variability in rainfall, temperature, and soil pathogens are speculated for the contradicting results between the two studies (Pedersen and Lauer, 2003b).

Al-Kaisi et al. (2016) compared soybean yield response to tillage and crop rotation from 2003 to 2013 in Iowa at seven locations. Tillage systems included no-till, strip-tillage, chisel plow, deep rip, and moldboard plow. Under the corn-soybean rotation, a soybean yield response to tillage system was observed only 12 out of 49 site years during this study. When soybean yield response was significant, conventional tillage treatments (chisel plow, deep rip, and moldboard plow) resulted in at least 0.5 Mg ha^{-1} more yield compared to strip till and no-till (Al-Kaisi et al., 2016).

Several other studies have found greater soybean yields in conventional tillage compared to no-till. Vetsch et al. (2007) found a 0.07 Mg ha^{-1} (2%) increase in soybean yield for conventional tillage (chisel plow and spring field cultivation) compared to no-till applied to corn stubble in Minnesota when averaged across four years. Vyn et al. (1998) found a 5-29% increase

in soybean yield when using a fall zone tillage (strip till) or fall disc tillage system before planting soybean compared to planting soybean into a no-till system in Ontario. Improvement in soybean yield when using fall tillage compared to a no-till system was attributed to improved seedbed conditions in the seed row where soybean was planted. A higher proportion of fine soil aggregates (<5 mm in diameter) and lower penetrometer resistance are characteristics that the researchers identified as being improved seedbed conditions compared to the no-till system (Vyn et al., 1998).

When comparing crop yield for different residue management practices and tillage systems, the previous cropping history and tillage system should be taken into consideration. A meta-analysis by Pittelkow et al. (2015) analyzed 678 studies from all areas of the world to determine when no-till cropping systems yield more than conventional till systems. It was concluded that no-till cropping systems yield the highest under rain fed, dry climates, and that there was no yield difference between no-till and conventional till systems for legume and oilseed crops such as soybean (Pittelkow et al., 2015). In some cases, when a no-till system was in only the first or second year of no-till management, crop yields were less than conventional till yields when all crops were considered. Once a field was managed under no-till conditions for three to four years, differences in yield between conventional till and no-till were no longer observed (Pittelkow et al., 2015). This meta analysis also concluded that the greatest influence on yield when all crops were considered was when crop rotation and residue retention (not removed from the field) were followed (Pittelkow et al., 2015).

Cover crops can have a varying effect on soybean yield depending on the management of the cover crop. Wagner-Riddle et al. (1994) observed the soybean yield response of soybean planted into a fall rye cover crop in Ontario with an early and late fall rye desiccation timing in

the spring before planting. When the fall rye desiccation timings were compared to a conventional tillage check, soybean yield was unresponsive to fall rye desiccation timings in this study (Wagner-Riddle et al., 1994). In another study comparing fall rye desiccation timings on soybean yield in Illinois, there was a significant reduction in soybean yield when the fall rye cover crop was desiccated at the time of planting compared to two weeks before planting (Liebl et al., 1992). The reduction in soybean yield was determined to be caused by the additional biomass accumulation for the later fall rye desiccation timing which reduced the soybean plant population by 32-45% compared to a conventional tillage check (Liebl et al., 1992). This suggests that an early desiccation timing of fall rye is beneficial to minimize fall rye biomass accumulation and reduce the risk of soybean yield loss due to a decrease in plant population. De Bruin et al. (2005) found similar results comparing fall rye desiccation timings and methods on soybean yield. When fall rye and weeds were controlled with herbicide before planting to reduce the regrowth of fall rye, soybean yields were not different from the no fall rye control. Therefore, if a fall rye cover crop is managed to limit resource competition, such as moisture and light, and soybean emergence, the yield response on a subsequent soybean crop should be minimal.

In some cases, problems with planting equipment can be the reason for reduced no-till soybean yields compared to planting soybeans into a conventional till system due to a reduction in plant population in the no-till system. Vanhie et al. (2015) conducted a study in Ontario comparing residue management practices in corn residue and different planting equipment for growing soybean. It was concluded that the yield difference for soybean between residue management practices was minimal when proper planting equipment was used that can handle lots of residue. The exception for reduced soybean yield was found in a no-till situation when corn stalks were chopped, and soybeans were planted with a disc drill. Large amounts of residue

and a rough soil surface were limitations for the disc drill with no residue management attachments before the seed row which reduced the seed to soil contact compared to a planter with superior depth control and residue management attachments (large cutting coulter) before the seed row (Vanhie et al., 2015).

2.5   Conclusion

Residue management practices that include tillage or reduced tillage have been researched extensively across the prairies and in the Northern Great Plains since the early 1900's. It is known that as the intensity of tillage increases, the level of surface residue decreases. Excess tillage leads to soil degradation and erosion by wind and water; therefore, residue management practices that reduce the amount of tillage are desired. To further reduce the risk of soil erosion, cover crops are being utilized between annual cash crops to extend the growing season and anchor the soil using plant roots. The use of a cover crop can also help to manage soil moisture by transpiring water during periods of growth. However, little cover crop research has been conducted under the short and cold growing season conditions of Manitoba, and it is unknown how a fall seeded cover crop will affect soybean growth and development.

The amount of surface residue and the architecture of the residue is shown to have the greatest influence on soil temperature and soil moisture rather than tillage itself. It is the act of tillage that reduces the surface residue that provides the soil drying and soil warming compared to a no-till soil with residue on the soil surface that creates a surface mulch. If this residue is removed within the no-till system or the residue has an upright architecture, similar soil temperature and soil moisture measurements are observed between the no-till and tillage residue management practices.

Research in Ontario and the upper Midwest of the United States have shown that soybean can be grown successfully under a reduced till or no-till system with no plant stand or yield reduction compared to a conventionally tilled system. In some cases, a reduced till or no-till system produces higher soybean yields than a conventionally tilled system. Based on these observations from the major soybean growing regions of Ontario and the upper Midwest of the United States, the following research question needs to be answered: Is conventional tillage necessary before planting soybean due to the cold and short growing season experienced in Manitoba? This research question is addressed by comparing residue management practices before planting soybean in Manitoba that include tillage and no-till, as well as a living fall rye cover crop.

3. MATERIALS AND METHODS

3.1 Site Description

This study was located at the Ian N. Morrison Research Farm near Carman, Manitoba (49.501157, -98.028185) from 2014 to 2015, and Westman Agriculture Diversification Organization (WADO) near Melita, Manitoba (49.264899, -100.994228) in 2015. The two locations represent different soybean production areas in Manitoba. Carman is typically under conventional tillage management and has less than 10 years of soybean history on the research farm, including the trial locations. Melita is typically under no-till management and although soybean has been grown at WADO, soybean has never been established on this experimental site. The long-term average total precipitation for Carman is 545 mm, with 319 mm of precipitation falling between May 1 and August 31 (Table 3.1). Melita has a long-term average total precipitation of 457 mm, with 255 mm falling between May 1 and August 31.

The experiment was established in the fall of the first year, and a soybean test crop was seeded the following spring to span a total of two years for a single site year. Trial locations are denoted by the year that the soybean test crop was established: Carman14, Carman15, and Melita15. All trial locations had wheat (*Triticum aestivum* L.) as the previous crop. The soil at Carman is a moderately-well to well-drained Orthic Black Chernozem in the Denham series with a loam texture, organic matter of 4.1% and pH of 5.5 (Manitoba Agriculture, 2010). The soil at Melita is a well-drained Orthic Black Chernozem in the Waskada series with a fine sandy loam texture, organic matter of 3.4% and pH of 7.6 (Manitoba Agriculture, 2010). Climatic data was obtained from weather stations in Carman and Melita and summarized in Table 3.1.

Table 3.1 Mean monthly temperature and precipitation during the growing season and long-term averages at Carman14, Carman15, and Melita15.

Location	Jan. - April[†]	May	June	July	Aug.	Sept.	Growing Season[‡]	Annual
Temperature[*]	------------------------------------- °C -------------------------------------							
Carman14		11.3	16.6	17.8	18.7	13.1	16.1	
Carman15		10.7	17.5	19.9	18.3	15.8	16.6	
LTA§		11.6	17.2	19.4	18.5	13.4	16.7	3.5
Melita15		11.2	18.0	20.3	19.0	14.6	17.1	
LTA¶		11.9	16.8	19.6	18.9	12.9	16.8	3.7
Precipitation[*]	-------------------------------------- mm --------------------------------------							
Carman14	65	31	117	48	122	47	318	
Carman15	54	99	75	109	47	42	330	
LTA§	84	70	96	79	75	49	319	545
Melita15	81	112	168	40	40	67	360	
LTA¶	87	55	78	70	52	37	255	457

* Source: Manitoba Agriculture and Environment and Climate Change Canada
† Cumulative total from January 1 to April 30.
‡ Growing season is May 1 to August 31.
§ Long term average (1981-2010) for Carman, MB (Environment and Climate Change Canada).
¶ Long term average (1981-2010) for Pierson, MB (Environment and Climate Change Canada), 19 km southwest of Melita.

3.2   Experimental Design

At each location, five residue management treatments were established in a randomized complete block design (RCBD) with four blocks. Residue management treatments included: 1) conventional tillage (disc), 2) strip tillage, 3) no-till with short stubble height (short stubble), 4) no-till with tall stubble height (tall stubble) and 5) fall rye (*Secale cereale* L.) living mulch (fall rye). The residue management treatments were chosen to leave varying levels of wheat residue on the soil surface and to be representative of current practices across Manitoba. All residue management treatments were applied in the fall before a soybean test crop was established. The

conventional tillage treatment in Carman had an additional spring cultivation pass in 2014 and 2015 before planting. Application dates for residue management treatments at each site year are reported in Table 3.2. The plot size was 18 m wide by 8 m length to accommodate the dimensions of the tillage equipment used. The residue management treatments were applied into wheat stubble that had been cut to a height of 40 cm at wheat harvest. Further descriptions of the treatments are described below, and pictures of the residue management treatments are presented in Figure 3.1.

1) *Conventional tillage* – At Carman14 and Carman15, two passes with a 4 m double disc were applied approximately one month apart from each other at a depth of 10 cm. The following spring, a light cultivator with packers was used for a shallow cultivation (7 cm) to create a smooth, black seedbed for planting soybean. At Melita15, a 2 m wide power take off (PTO) rotovator was used to work the ground black in the fall at a depth of 10 cm. No spring tillage occurred at Melita15.

2) *Strip tillage* – one pass with a 4-row strip till unit (2984 Maverick™ HR Plus®, Yetter Farm Equipment, Colchester, USA) on 76 cm row spacing was used at all site years. The tillage depth was between 15-20 cm.

3) *No-till tall stubble* – wheat stubble cut to a height of 40 cm at each site year.

4) *No-till short stubble* – wheat stubble cut to a height of 15 cm at each site year. At Carman14, a swather was used in the fall of 2013 to cut 40 cm tall stubble shorter and this cut straw was spread evenly back across the plot. At Carman15, a flail mower was used in the fall of 2014 to chop 40 cm tall stubble shorter and evenly distribute the stubble on the ground. At Melita15, a plot combine was used in the fall of 2014 to cut the 40 cm tall stubble shorter and spread the straw evenly across the plot.

5) *No-till fall rye living mulch* – fall rye (cv. Hazlet) was direct seeded into 40 cm tall stubble after wheat harvest at a seeding rate of 87 kg ha^{-1} at Carman14 and 100 kg ha^{-1} at Carman15 and Melita15. A disc drill with 20 cm row spacing was used at Carman14 and Carman15, while a shank type plot seeder with 20 cm row spacing was used at Melita15. The fall rye overwintered and was left to grow the following spring until desiccated with glyphosate (Roundup Transorb®, Monsanto Canada Inc.) at a rate of 890 g a.i. ha^{-1} immediately after soybean planting at each site year.

Table 3.2. Summary of residue management treatment application dates for Carman14, Carman15, and Melita15.

Treatment	Carman14	Carman15	Melita15
	---------------------------- Date ----------------------------		
	September 23, 2013	September 22, 2014	October 19, 2014
Conventional Till	Mid October, 2013	October 20, 2014	
	May 28, 2014	May 22, 2015	
Strip Till	October 8, 2013	September 17, 2014	October 19, 2014
No-Till Tall Stubble	n/a	n/a	n/a
No-Till Short Stubble	September 4, 2013	September 15, 2014	October 19, 2014
No-Till Fall Rye Seeding Date	September 17, 2013	September 17, 2014	September 19, 2014

A soybean test crop was established into residue management treatments the following spring at each site year. Dekalb 24-10 RY soybeans (Maturity Group 00.5), were planted on 76 cm row spacing at all site years. This variety was selected because it was a common mid-season variety for Manitoba and had a suitable maturity for both Carman and Melita. Soybean seeds were inoculated with *Bradyrhizobium japonicum* liquid inoculant (Optimize®, Monsanto Canada Inc.) at the recommended rate of 3 mL kg^{-1} seed at Carman site years along with granular inoculant (Cell-Tech®, Monsanto Canada Inc.) applied in furrow at a rate of 4.0 kg ha^{-1} at Carman14 and Carman15. Both liquid and granular forms of inoculant were used at Carman as

this was a common agronomic practice at the time for farmers seeding in fields with little history of soybean. Although the Melita site had no soybean history, the planter was not capable of applying granular inoculant with the seed. Thus, a double application of Cell-Tech® liquid inoculant was applied at 6 mL kg^{-1} to soybean seeds to ensure soybean inoculation. Soybeans were treated with thiamethoxam insecticide and metalaxyl-M and S-isomer, fludioxonil and sedaxane fungicide seed treatment (CruiserMaxx® Vibrance® Beans, Syngenta Canada Inc.) at all site years. Soybeans were planted at a seeding depth of 1.9 to 2.5 cm into soil moisture at all site years.

Different planting equipment was used for each site year to plant soybean. Planters were also equipped differently to plant through high amounts of residue. At Carman14, soybeans were planted at a seeding rate of 47 seeds m^{-2} on May 28 using a disc drill that had no residue management tools attached. At Carman15, soybeans were planted at a seeding rate of 31 seeds m^{-2} on May 22 using a disc precision vacuum planter (Haldrup SP-35, Poneto, IN) with a large cutting coulter in front of the seed disc to slice the residue. At Melita15, soybeans were planted at a seeding rate of 47 seeds m^{-2} on May 29 using a disc precision vacuum planter (John Deere 1755, Moline, IL) with row cleaners (2967 Rigid Row Cleaner, Yetter Farm Equipment, Colchester, IL) as a residue management tool.

There was no fertilizer applied at any site year in this study, a common practice for growing soybean in Manitoba. Weeds were controlled using glyphosate (Roundup Transorb®, Monsanto Canada Inc.) at a rate of 890 g a.i. ha^{-1} with a pre-emergence spray, and as needed in crop to a maximum of three applications.
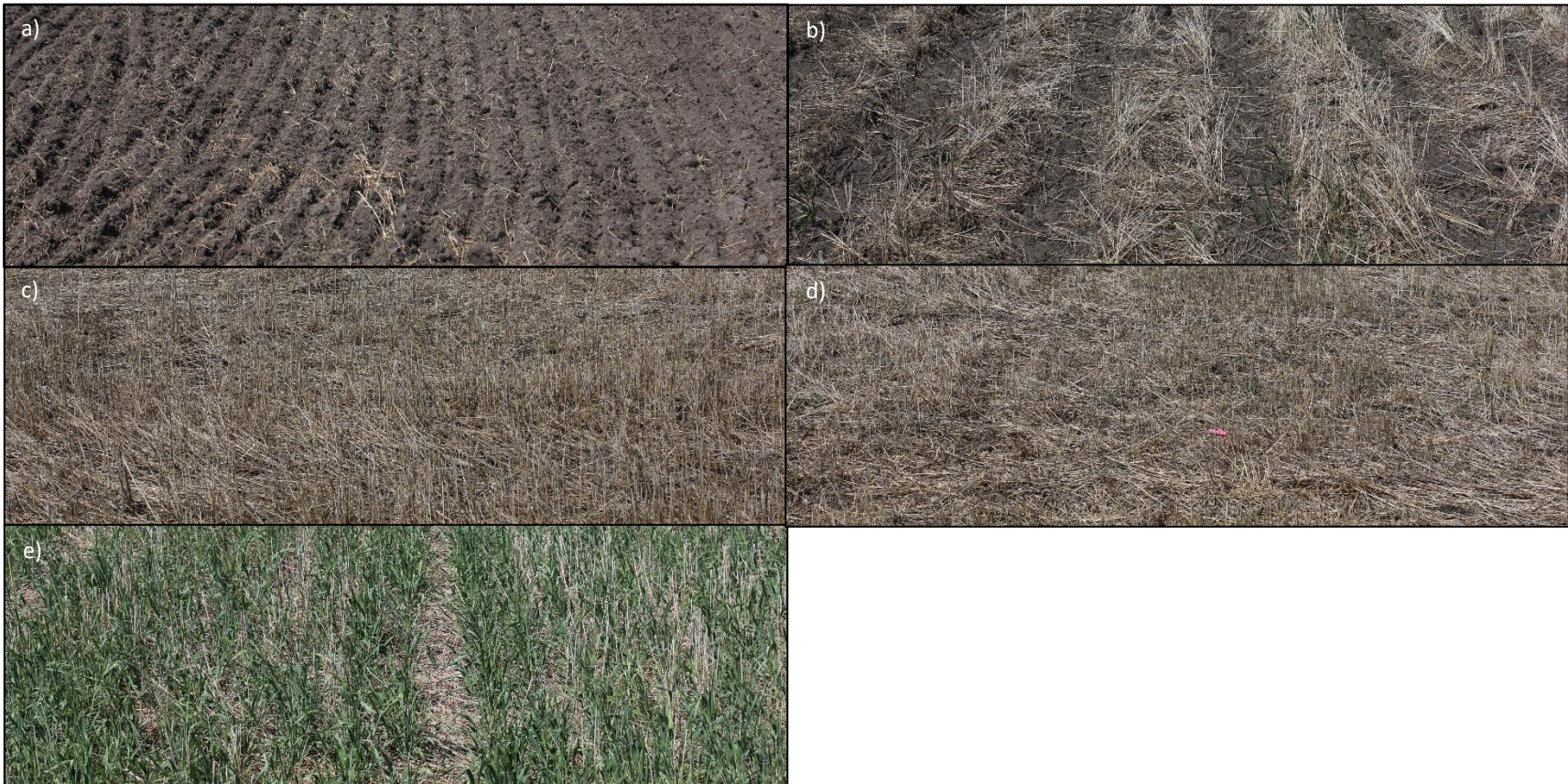
Figure 3.1. Residue management treatments the day of planting (May 22, 2015) at Carman15 including a) conventional tillage, b) strip tillage, c) no-till tall stubble, d) no-till short stubble, and e) fall rye living mulch.

The experimental site at Melita15 was abandoned on August 13, 2015 due to underlying soil characteristics causing sever drought symptoms that were not associated with the residue management treatments.

3.3   Data Collection

3.3.1   Percent Wheat Residue Ground Cover

Percent wheat residue ground cover was determined by photo analysis using ASSESS 2.0 (American Phytopathological Society, St. Paul, MN). Three pictures were taken at random in each plot in the spring on the day of planting. At Carman14, a 0.25 m^2 quadrat was placed on the ground and a picture was taken about 1 m above the soil surface. The 0.25 m^2 quadrat was then cropped within the picture and analyzed. At Carman15 and Melita15, a tripod was used to keep the camera height the same for all photos while facing the camera lens perpendicular to the ground. The entire area of the image was used to quantify residue cover using the image analysis software. For the strip till treatment, percent wheat residue ground cover was determined by including both the in-row and inter-row portion of strip till within the image, then calculating an overall average ground cover for strip till treatment. The in-row and inter-row portions of strip till were also determined separately by quantifying the residue within the picture for each of the strip till portions.

3.3.2   Soil Nitrate

Soil samples were collected at the time of soybean planting for each residue management treatment. Three cores were collected at random locations in each plot using a dutch auger from two depths: 0-15 cm and 15-60 cm, the subsamples within each depth were homogenized, and a composite sample was analyzed for each plot. Samples were refrigerated at 4°C until shipped for

analysis. Soil nitrate-N was analyzed using the cadmium reduction method (Agvise Laboratories, Northwood, ND).

3.3.3 Soil Moisture

Soil moisture was measured as volumetric water content (m^3 m^{-3}) using EC-5 soil moisture sensors (METER Group, Inc., Pullman, WA). Soil moisture sensors remained in the soil and spot readings were taken one to three times a week for the entire growing season using a ProCheck hand held reader (METER Group, Inc., Pullman, WA). Moisture sensors were installed at 5 cm for all site years two to six weeks before planting. The sensors were removed before soybean planting and reinstalled at 5 and 30 cm after planting in the seed row. For the strip till treatment, soil moisture sensors were installed within the in-row and inter-row portion of strip till. Soil moisture measurements were taken until the end of the growing season, or once soybean leaf drop had occurred.

3.3.4 Soil Temperature

Soil temperature was measured at 5 and 30 cm below the soil surface using DS1922L iButton® data loggers (Maxim Integrated, San Jose, CA) on an hourly basis from mid April to September. Each residue management treatment had one sensor at 5 and 30 cm per plot, except for strip till which had a set of iButtons at 5 and 30 cm within the in-row and inter-row portion of strip till. At Carman14, temperature sensors were installed before planting at 5 and 30 cm using a wooden stake to hold the iButtons in place and the stake was pounded into the soil to the desired depth. The stake was removed during planting and reinstalled in the centre between two seed rows after planting occurred. At Carman15 and Melita15, iButtons were installed in the spring before planting only at 5 cm by placing the iButtons directly in the soil. The iButtons were removed from the soil the day of planting. After planting, iButtons were installed at 5 and 30 cm

using the wooden stake method, and the stake was placed within the seed row. The iButtons remained in the soil for the entire growing season and removed once soybean leaf drop occurred.

3.3.5 Cumulative Soil Temperature

Temperature accumulation was calculated using a growing degree hour (GDH) formula for soil temperature adapted from the growing degree day (GDD) calculation for air temperature (Ritchie and NeSmith, 1991). The use of GDH was used instead of GDD to observe smaller differences in heat accumulation above a base temperature that may not be observed with a GDD formula. The accumulation of GDH is the sum of the hourly soil temperature at 5 cm below the soil surface (T_{soil}), subtracting the base temperature of 10°C (T_b) when T_{soil} is greater than or equal to T_b. A base temperature of 10°C was used based on minimum temperature threshold for soybean development determined by Brown (1960).

$$GDH = \sum T_{Soil} - T_b \; when \; T_{soil} \geq T_b \qquad [1]$$

Cumulative soil temperature was calculated before planting and during the emergence period after planting at each site year.

3.3.6 Soybean Emergence and Population Density

Soybean emergence was measured 7 to 22 days after planting at all site years. At Carman14, plant population was measured 7, 14, and 21 days after planting by counting the plant density of two meters of row at two random locations per plot. At Carman14, plant count sampling location within the plot was selected at random for each sampling date. For Carman15 and Melita15, more detailed and consistent emergence counts were performed. Three meters of row were counted at two random locations per plot for a total of six meters of row length. Plant counts were conducted three times per week at Carman15, and once per week at Melita15. In

2015, the area where the plant counts were performed was flagged and subsequent plant counts were taken at the same row location.

3.3.7   Soybean Biomass

Soybean plant biomass was measured at soybean reproductive stage R5 at Carman15. This was the only site year that plant biomass was recorded as it was only considered for observation after the 2014 growing season. Soybean plants were cut on August 4, 2015 just above the soil surface in two randomly selected rows that were 2 m in length for a total sample area of 3.048 m^2 per plot. The sample was weighed in the field immediately, and a subsample of five random soybean plants per plot were taken to determine moisture content. The subsamples were dried in an oven at 60ºC for 48 hours and weighed. The moisture content of the subsample was applied to the larger sample to calculate dry biomass of the sample.

3.3.8   Soybean Canopy Closure

The date of soybean closure was determined visually by estimating the day when the soybean canopy completely covered the area between the soybean rows.

3.3.9   Soybean Plant and Pod Height

Plant heights were taken in both years at Carman within four days of soybean harvest at full maturity. The height of three randomly selected plants were measured and averaged per plot. Height measurements were taken from the soil surface to the top of a fully erect plant. In 2015, plant height was also measured on August 4, the same day a plant biomass was sampled. Plant height was measured using a meter stick from the soil surface to the top of a fully erect plant with the top trifoliate extended.

Pod heights were measured in 2015 at Carman on the day of harvest (September 21) using a meter stick from the soil surface to the top of the first pod bearing node. Six plants were randomly sampled and averaged per plot.

3.3.10 Soybean Yield

Soybean harvest occurred October 2 and September 21 at Carman14 and Carman15, respectively. A plot combine (Kinkaid 8-XP, Haven, KS) was used to collect soybean seed for yield. Six rows of soybean were harvested from each plot for the full length of the plot (approximately 37 m^2 harvest area), and the seed was collected to be weighed. Before weighing, seed samples were cleaned using a seed cleaner (Clipper, A.T. Ferrell Company Inc., Bluffton, IN) and the seed moisture content was measured using a grain analysis computer (GAC® 2500-AGRI, DICKEY-John, Auburn, IL). Moisture content of the seed was adjusted to 13% for reporting soybean yields.

3.4 Spider Diagram to Compare Measurements

A spider diagram was created to summarize and compare the relative difference between major variables observed within the study averaged across all site years. Variables observed include surface residue ground cover, soil moisture at 5 cm from 14 days before planting until 21 days after planting, maximum soil temperature at 5 cm the day after planting, cumulative GDH from 21 days before planting until plating, cumulative GDH from planting until 21 days after planting, final soybean plant population at V1 growth stage, and soybean yield. The relative difference was determined for each residue management treatment by dividing the mean observed value to the average maximum value of all residue management treatments across all site years and multiplying by 100 to present the observed value as a percentage of the mean maximum value.

3.5   Statistical Analysis

Analysis of variance (ANOVA) was used to test treatment effects for all variables. All variables were analyzed using the PROC Glimmix procedure of SAS 9.4 (SAS Institute Inc. 2001), with treatment and site year as a fixed effect and block as a random effect nested in site year.

Soybean emergence data was analyzed with repeated measures using the PROC Glimmix procedure from SAS, with treatment and site year as a fixed effect and block as a random effect nested in site year. A binomial distribution was used for the emergence data and time was used in the repeated statement. The slice statement was used to partition the analysis of least square means when an interaction was observed.

Soil moisture, soil temperature, and cumulative growing degree hours were analyzed with repeated measures using the PROC Glimmix procedure of SAS, with treatment and site year as a fixed effect and block as a random effect nested in site year. Data from site years were combined for each variable and time (sampling date or hour) was used in the repeated statement. The slice statement was used to partition the analysis of least square means when an interaction was observed.

Regression analysis using Proc Reg was conducted to test for the significance of the linear model for the effect of surface residue ground cover at planting on accumulated GDH from planting until 21 days after planting. Individual data points were used in the regression analysis from each site year.

Differences between treatment means were considered significant at a *P<0.05*. Assumptions of ANOVA were verified using PROC Univariate to test for normality of residuals.

A departure from normality was considered significant if the Shapiro-Wilkes test probability

value was greater than 0.05 and by plotting the residuals.

4. RESULTS AND DISCUSSION

4.1 Wheat Residue Ground Cover

Wheat residue management treatments resulted in differences in percent residue ground cover before planting the soybean test crop. Residue management treatments ranged from 12% residue cover to 94% residue cover across all three site years (Table 4.1). The disc treatment at Carman15 had the lowest residue ground cover rating of 12% just before seeding. This value is below the threshold of 30% ground cover to meet the requirements of conservation tillage (FAO, 1993). The disc treatment at Carman14 and Melita15 also had the lowest ground cover rating for each site year compared to other residue management treatments; however, these values were greater than 30% ground cover and thus met the minimum criteria for conservation tillage.

Table 4.1. The effect of wheat residue management treatments on spring residue ground cover before planting soybean at Carman14, Carman15, and Melita15.

Treatment	Carman14	Carman15	Melita15
	----------------------------- % -----------------------------		
Disc	43 **b**†	12 **c**	48 **d**
Strip till*	41 **b**	44 **b**	58 **c**
Tall stubble	85 **a**	84 **a**	94 **a**
Short stubble	87 **a**	85 **a**	92 **a**
Fall rye‡	88 **a**	88 **a**	84 **b**
Source of Variation	*P>F*		
Treatment	<0.0001		
Site year	<0.0001		
Treatment x site year	<0.0001		

†Means within a column followed by a different letter are significantly different at *P<0.05* according to Fisher's LSD.
*Ground cover for strip till is an average of the in-row and inter-row portion of strip till.
‡Living fall rye and wheat residue ground cover.

The treatments that had the most ground cover were the treatments that didn't have any tillage. The ground cover for the short and tall stubble treatments was significantly greater than the strip till and disc treatments for all three sites, ranging from 84% to 94% ground cover. At

Carman14 and Carman15, spring residue ground cover in the fall rye treatment was not significantly different from the short and tall stubble treatments, even though the residue ground cover ratings included the previous wheat residue and the living fall rye ground cover. However, at Melita15, the fall rye treatment had significantly less ground cover than the short and tall stubble treatments. The difference between fall rye residue ground cover at Carman and Melita was likely due to the type of opener used to plant the fall rye at each location. A disc opener with minimal disturbance was used at Carman14 and Carman15, while a shank opener was used at Melita15 with more disturbance. The strip till treatment had a residue ground cover rating that was greater than the disc treatment at two out of three site years but less than the no-till treatments at all site years.

The residue ground cover rating for strip till includes an average for the in-row and inter-row portions of strip till which resulted in an intermediate ground cover rating when compared to other treatments. When the residue ground cover rating for strip till was determined for the in-row and inter-row portions separately, the in-row portion of strip till was more similar to the disc treatment while the inter-row portion of strip till was similar to the no-till treatments. The in-row residue ground cover rating for strip till at Carman14, Carman15, and Melita15 was 24%, 12%, and 17% at each while the inter-row portion of strip till was 83%, 72%, and 84%, respectively.

In addition to spring residue ground cover ratings, biomass samples of the fall rye were taken at the time of soybean planting for the fall rye treatment. The fall rye treatment had 946, 913, and 1877 kg ha^{-1} of biomass at Carman14, Carman15, and Melita15, respectively. At the time of biomass sampling, the fall rye was in a vegetative stage at Carman14 and Carman15 and was at early reproductive stages at Melita15. These fall rye biomass amounts were slightly below

fall rye biomass amounts reported by Flood and Entz (2018) (555 to 4162 kg ha^{-1}) and Evans et al. (2016) (4287 to 6921 kg ha^{-1}) in Manitoba at dry bean seeding.

Residue management treatments resulted in differences in surface residue ground cover. As the intensity of tillage increased, the level of surface residue ground cover decreased. There were three categories of treatments based on the amount of residue ground cover: 1) tall stubble, short stubble, and fall rye treatments had large amounts of ground cover, 2) strip till had a medium amount of ground cover when the in-row and inter-row portion were considered as an average, and 3) the disc treatment had a small amount of ground cover. The strip till treatment could be categorized in the high or low level of ground cover depending if residue ground cover was measured in-row (small amount of ground cover) or within the inter-row (large amount of ground cover) portion of strip till. The residue architecture for the tall and short stubble treatment were different, with the tall stubble treatment having a more upright architecture and the short stubble treatment having a more horizontal architecture creating a surface mulch.

4.2 Soil Nitrate

Fall residue management treatments that vary the amount of tillage provide the opportunity for different mineralization and immobilization processes of nitrogen to occur (Schoenau and Campbell, 1996). However, no differences in soil nitrate were measured at Carman14. At Carman15, there were significant differences in the amount of residual spring soil nitrate among residue management treatments for soils sampled from 0 to 15 cm, but not at the 15 to 60 cm soil depth (Table 4.2). The fall rye treatment had the lowest amount of spring soil test nitrate (7 kg N ha^{-1}) compared to all other residue management treatments at 0 to 15 cm soil depth. This was expected as the living fall rye can take up nitrogen within the roots and above

ground vegetation, which would reduce the residual soil nitrate within the soil. The disc

treatment had the largest amount of spring soil test nitrate at the 0 to 15 cm soil depth, followed

by the in-row portion of strip till.

Table 4.2. The effect of wheat residue management on soil nitrate levels at 0 to 15 cm and 15 to 60 cm soil depth before planting in May at Carman14 and Carman15.

Treatment	Carman14		Carman15	
	0-15 cm	15-60 cm	0-15 cm	15-60 cm
	----------------------- kg ha^{-1} -----------------------			
Disc	11	31	29 **a**	28
Strip till (in-row)	12	30	18 **b**	27
Tall stubble	9	41	15 **bc**	25
Short stubble	7	30	14 **bc**	32
Strip till (inter-row)	10	35	14 **c**	32
Fall rye	6	22	7 **d**	18

Source of Variation	$P>F$
Treatment	<0.0001
Site year	0.2326
Depth	0.0001
Treatment x site year	0.0025
Treatment x depth	0.0002
Depth x site year	<0.0001
Treatment x depth x site year	0.0175

†Means within a column followed by a different letter are significantly different at $P<0.05$ according to Fisher's LSD.

Soil nitrate trends were consistent with previous studies comparing residue management

treatments. Evans et al. (2016) observed a fall rye cover crop significantly reduce spring soil

nitrate levels by 30 kg N ha^{-1} at the 0 to 15 cm soil depth compared to a no cover crop control at

Carman, Manitoba. A reduction of 22 kg N ha^{-1} was observed for the fall rye treatment compared

to the disc treatment in the current study at the 0-15 cm soil depth at Carman15. Nuttall et al.

(1986) measured spring soil nitrate levels at 0-15 cm, 15-30 cm, and 30-60 cm soil depth in

several fall tillage (plow, cultivator, disc and double disc), no-till, and stubble burning treatments

in a continuous wheat rotation in the black soil zone of the Canadian Prairies. These researchers

observed no difference between spring soil nitrate levels at any sampling depth between residue

management treatments, similar to our measurements for Carman14 and for the 15-60 cm depth at Carman15.

4.3   Soil Moisture

Wheat residue management practices influence soil moisture based on the level of soil disturbance, surface residue ground cover and transpiration of a living crop. Spring soil moisture is a key factor for deciding when to plant a soybean crop in Manitoba. Excess moisture can delay planting by decreasing the trafficability of planting equipment in the field (Bedard-Haughn, 2009) while drought conditions can result in poor soybean germination if there is not enough moisture for soybean imbibition and germination (Helms et al., 1996). Late season soil moisture is an important consideration during periods of drought as soil moisture influences final grain yield of soybean (Doss et al., 1974). There were no significant differences in soil moisture among residue management treatments at 30 cm below the soil surface at any site year for the entire growing season (data not shown). However, spring soil moisture during the early season before and after planting is most critical for planting decisions and early soybean development and is the focus for this section.

Volumetric soil moisture content of wheat residue management treatments at 5 cm was measured from 14 days before planting (DBP) until 21 days after planting (DAP) at all three site years. There was no three-way interaction between residue management treatment, sampling date, and site year within this study. However, there were significant two-way interactions for residue management treatment and sampling date, and sampling date and site year (Table 4.3).

Table 4.3. The effect of wheat residue management treatments on volumetric moisture content at 5 cm from 14 days before planting (DBP) to 21 days after planting (DAP) at Carman14, Carman15, and Melita15.

Treatment	14 DBP	9 DBP	Planting	7 DAP	14 DAP	21 DAP
	------------------------------ m³ m⁻³ ------------------------------					
Disc	0.220 **b**	0.221 **b**	0.243 **b**	0.225 **c**	0.215 **b**	0.228 **bc**
Strip till (in-row)	0.181 **c**	0.177 **c**	0.190 **c**	0.235 **bc**	0.220 **b**	0.223 **c**
Strip till (inter-row)	0.250 **a**	0.238 **ab**	0.276 **a**	0.272 **a**	0.252 **a**	0.260 **ab**
Tall stubble	0.243 **ab**	0.242 **ab**	0.263 **ab**	0.265 **ab**	0.251 **a**	0.262 **a**
Short stubble	0.248 **a**	0.247 **a**	0.271 **a**	0.273 **a**	0.262 **a**	0.261 **a**
Fall Rye	0.255 **a**	0.240 **ab**	0.267 **ab**	0.250 **abc**	0.263 **a**	0.282 **a**
Site Year						
Carman14	0.205 **b**	0.212 **b**	0.238 **b**	0.280 **a**	0.215 **b**	0.273
Carman15	0.223 **b**	0.174 **c**	0.226 **b**	0.216 **b**	0.252 **a**	0.243
Melita15	0.270 **a**	0.296 **a**	0.291 **a**	0.280 **a**	0.265 **a**	0.242

Source of variation	$P>F$
Treatment	0.0002
Sampling date	<0.0001
Site year	0.0056
Treatment x sampling date	0.0092
Treatment x site year	0.1528
Sampling date x site year	<0.0001
Treatment x sampling date x site year	0.4417

†Means within a column followed by a different letter are significantly different at $P<0.05$ according to Fisher's LSD.

Moisture trends for sampling date at each site year are reflective of the accumulated precipitation. Melita15 was one of the wettest site years at all sampling dates before and after planting (Table 4.3). This is not surprising since the May and June accumulated precipitation at this site year was 203% and 215% greater than the long-term average, respectively (Table 3.1). The moisture trend for each sampling date at Carman14 and Carman15 was less consistent than Melita15 as the accumulated precipitation for each month was either above or below the long-term average for each month. For Carman14, the May and June accumulated precipitation was

37% and 156% of the long-term average, respectively. For Carman15, the May and June accumulated precipitation was 141% and 78% of the long-term average, respectively. The timing of rainfall within each month likely had an impact on volumetric moisture trends observed at each sampling date. The driest volumetric moisture content occurred 9 DBP at Carman15 when the accumulated precipitation was 141% of the long-term average; indicating the rainfall within this month occurred well before or after this sampling date. Evans et al. (2016) and Flood and Entz (2018) have also observed soil moisture trends that follow accumulated precipitation at each site year for cover crop studies in Manitoba.

The trend between wheat residue management treatments and sampling dates for all site years was not consistent as indicated by the significant interaction for residue management treatment and sampling date (Table 4.3). The strip till (in-row) residue management treatment was significantly drier than the disc treatment by 18% to 21% before soybean planting, but was not significantly different after planting. It is unclear why a shift in the soil moisture trend occurred before and after planting. A possible explanation for the difference between soil moisture in strip till before and after planting may be due to the effect of the planter on the soil properties, specifically bulk density, of the in-row portion of strip till, although this was not measured in the current study. Previous research shows soil moisture having no difference between strip till and conventional tillage in wheat and corn stubble (Licht and Al-Kaisi, 2005; Janovicek et al., 2006; Walther, 2017). Overstreet et al. (2007) observed the strip till system to have 3.5% to 5.5% greater moisture content compared to conventional tillage when the soil profile was near full saturation.

Fall rye had an increase in volumetric moisture content from before the fall rye desiccation compared to after the fall rye desiccation timing. The volumetric moisture content for

the fall rye treatment was not significantly different from the disc treatment at 9 DBP until 7 DAP (Table 4.3). Once the fall rye was desiccated and a surface mulch accumulated at 14 and 21 DAP, soil moisture in the fall rye treatment was 18% to 19% wetter than the disc treatment. These changes in soil moisture before and after planting are likely due to the transition from living fall rye depleting soil moisture through transpiration before planting to the mulch effect of the terminated fall rye after planting. Wagner-Riddle et al. (1994) observed similar results between an early termination and late termination timing of fall rye. The additional 1300 kg ha^{-1} of rye mulch dry matter accumulated between the early and late desiccation timings reduced the soil drying rate between the two desiccation timings and resulted in ~13% greater soil moisture for the late desiccation timing treatment compared to the early desiccation timing treatment (Wagner-Riddle et al., 1994). Westgate et al. (2005) also concluded that additional fall rye mulch (4610 kg ha^{-2}) after termination can conserve soil moisture by as much as 0.325 kg kg^{-1} during the vegetative stages of soybean.

Generally, the tillage treatments are numerically drier than the no-till treatments across all sampling dates, although significant differences were not always observed. A visualization of wheat residue management trends across site years for soil moisture can be seen in the Figure 7.1 of the appendix. No-till residue management has been shown to have greater surface soil moisture compared to conventional tillage by Gauer et al. (1982), Lafond et al. (1992), and Vyn et al. (1998). The short stubble treatment was one of the wettest residue management treatments at all sampling dates, being consistently wetter than the disc and strip till (in-row) treatments by 11% to 28% in the current study. The tall stubble treatment was consistently about 26% wetter than the strip till (in-row) residue management treatment before planting, and wetter than the disc and strip till (in-row) residue management treatments at 14 DAP and 21 DAP by 12% to

14%. These differences in soil moisture between conventional tillage and no-till are consistent with previous research. Gauer et al. (1982) observed a reduction in spring soil moisture of 30% (0.1 m^3 m^{-3}) for conventional till compared to no-till on a clay loam textured soil in Manitoba. Lafond et al. (1992) observed 10% less soil moisture in a 0-30 cm soil profile for conventional till compared to no-till on a heavy clay texture soil in Saskatchewan on wheat stubble. Vyn et al. (1998) observed a reduction of soil moisture by ~30% for fall tillage compared to no-till treatments when residue was not baled and removed from the no-till treatment on a loam to silty clay loam soil in Ontario. However, when the residue was completely removed from the no-till treatment (bare soil) in the Vyn et al. (1998) study, a difference in volumetric moisture content between no-till (bare soil) and fall tillage was not observed. This suggests that surface residue had a greater influence on volumetric moisture content than tillage itself.

Stubble height had an influence on soil moisture differences and the relationship with tillage treatments. The short stubble treatment was consistently wetter than the disc and strip till (in-row) residue management treatments; however, the tall stubble treatment was not significantly different than the disc treatment before and at planting (Table 4.3**Error! Reference source not found.**). A possible explanation for this observation is that the upright architecture of the tall stubble increased the drying coefficient of the soil to similar levels of a bare, tilled soil. However, Cutforth and McConkey (1997) determined that evapotranspiration was independent of stubble height when comparing evapotranspiration between cultivated, short (~15 cm), and tall stubble (~42 cm) treatments on the Canadian Prairies. The effect of short and tall stubble treatments can also influence snow capture during the winter. Cardillo et al. (2015) measured the snow pack accumulation between short and tall stubble treatments in Manitoba and Saskatchewan and found that tall stubble consistently held more snow than short stubble; up to

110 mm snow pack water equivalent greater than short stubble. The increased snow capture resulted in greater soil water recharge in the spring which provided greater soil moisture into the growing season under dry conditions.

Fall seeded cover crops can be used to manage soil moisture without tillage since a living cover crop actively growing transpires water to reduce the moisture content of the soil. It was hypothesized that the fall rye treatment would have a lower soil moisture content than the short and tall stubble treatments before fall rye desiccation. The soil moisture in the fall rye treatment was not significantly different from the short or tall stubble treatment at any sampling date (Table 4.3); therefore, we reject our hypothesis. Accumulated precipitation during the month of May and June was generally at or above the long-term average for each site year (78% to 215% of the long-term average), with the exception of Carman14 in May which was 37% of the long-term average. Flood and Entz (2018) observed a 25% reduction in soil water for a fall rye cover crop, compared to a control with no cover crop when accumulated precipitation was ~50% of the long-term average at the same location (Carman, MB) as the current study. When rainfall was near normal, soil moisture was not affected by the presence or absence of a fall rye cover crop (Flood and Entz, 2018). Previous cover crop studies at Carman, MB have also shown no difference in soil moisture for crops grown with or without a fall rye cover crop when precipitation was at or above normal (Podolsky et al., 2016; Evans et al., 2016).

4.4   Soil Temperature

Soil temperature is often used as a recommendation for when to plant soybean in Manitoba (Manitoba Agriculture, 2017). Tillage and surface residue ground cover influence soil temperature, and any factor that increases soil temperature before and after planting is desirable.

All residue management treatments were above the recommended average soil temperature of 10ºC for planting soybeans in Manitoba at all three site years the day after planting (Figure 4.1, Figure 4.2 and Figure 4.3). Therefore, soil temperature at planting was not considered a limitation for any residue management treatment tested within this study.
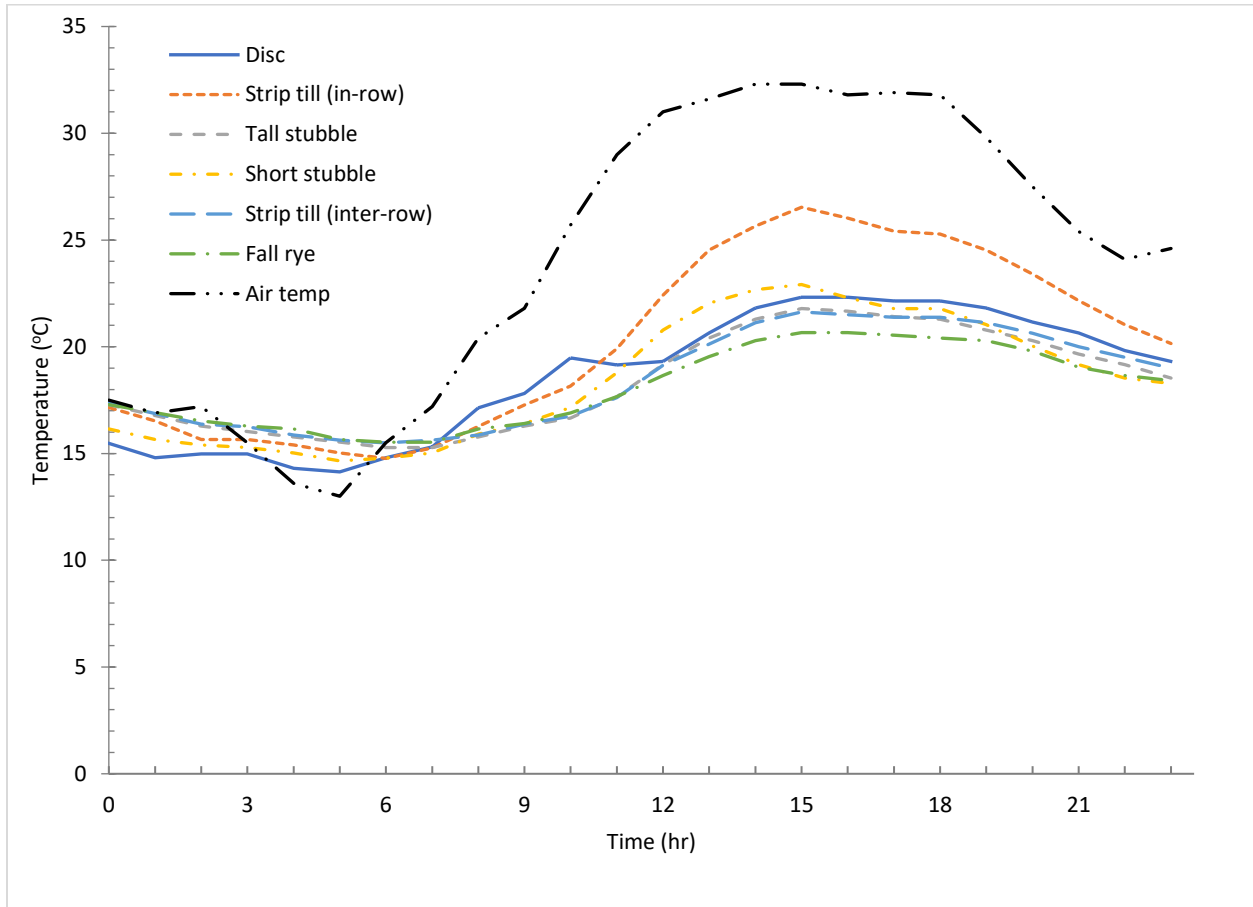
Figure 4.1. The effect of wheat residue management treatments on soil temperature at 5 cm below the soil surface at Carman14 the day after planting on May 29.
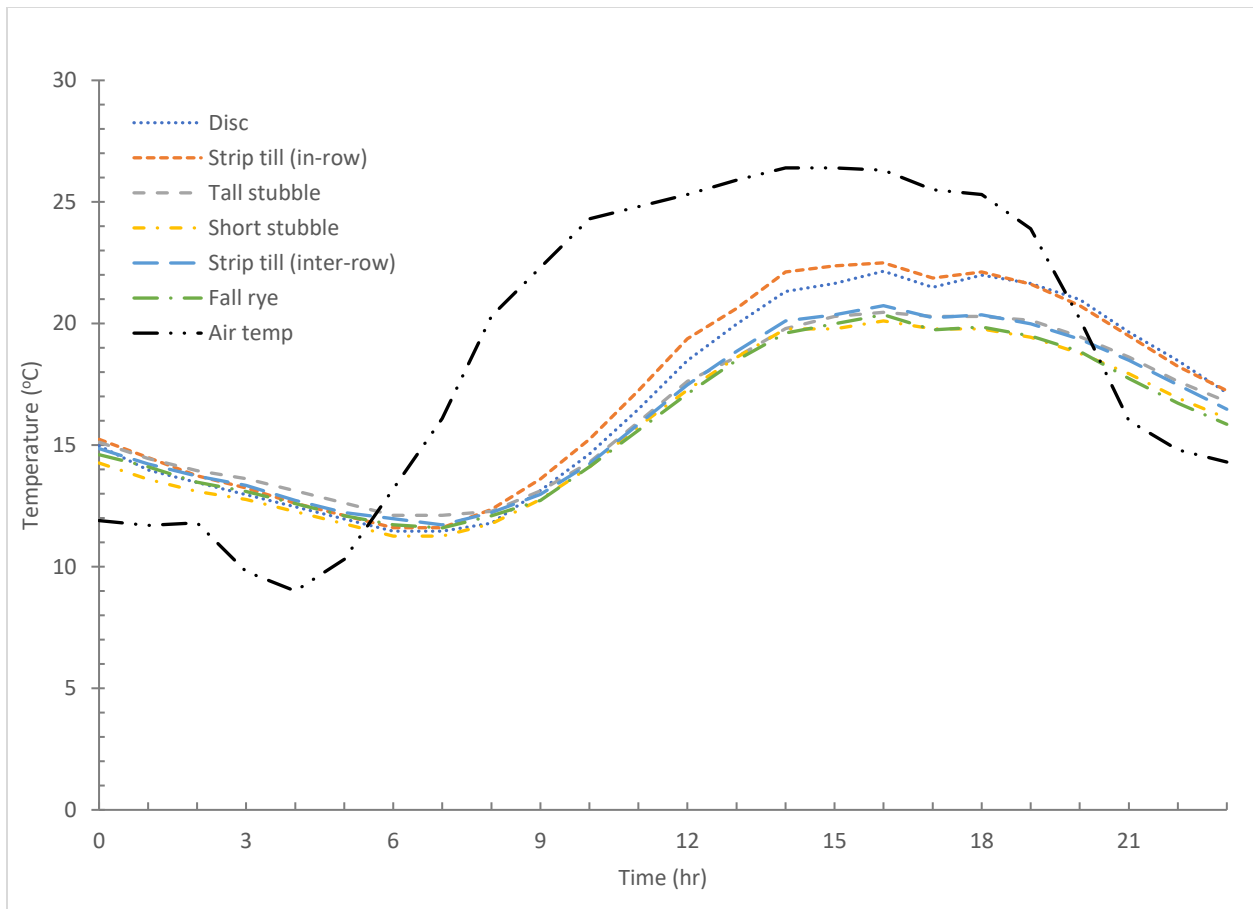
Figure 4.2. The effect of wheat residue management treatments on soil temperature at 5 cm below the soil surface at Carman15 the day after planting on May 23.
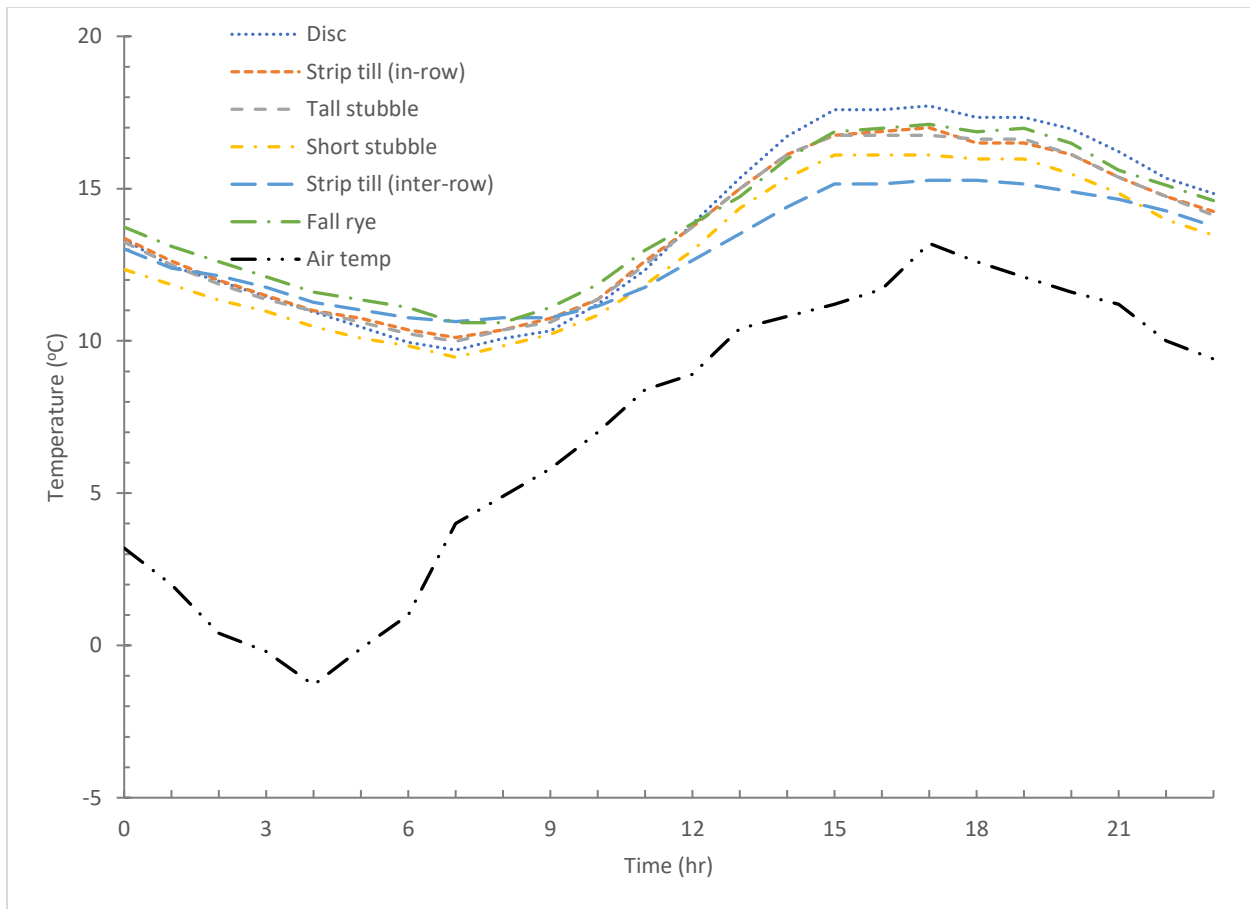
Figure 4.3. The effect of wheat residue management treatments on soil temperature at 5 cm below the soil surface at Melita15 the day after planting on May 30.

Daily soil temperature variation was measured over a nine-day period in May at Carman15 (Figure 4.4). The difference in soil temperature between residue management treatments were the greatest during the day as the soil temperature reached the maximum, and least at night. Generally, treatments with low residue ground cover (eg. disc and in-row strip till) achieved a higher maximum soil temperature during the day compared to residue management treatments with increased residue ground cover (no-till treatments) that resulted in a lower maximum soil temperature. There was a significant two-way interaction between residue management treatment and site year for soil temperature the day after planting (Table 4.4). In Figure 4.5, the strip till in-row and disc treatment are 0.9 to 2.5°C warmer than the no-till residue management treatments when they reach their maximum soil temperature. There was little

separation of soil temperature between residue management treatments at night, when

temperature was at their lowest.
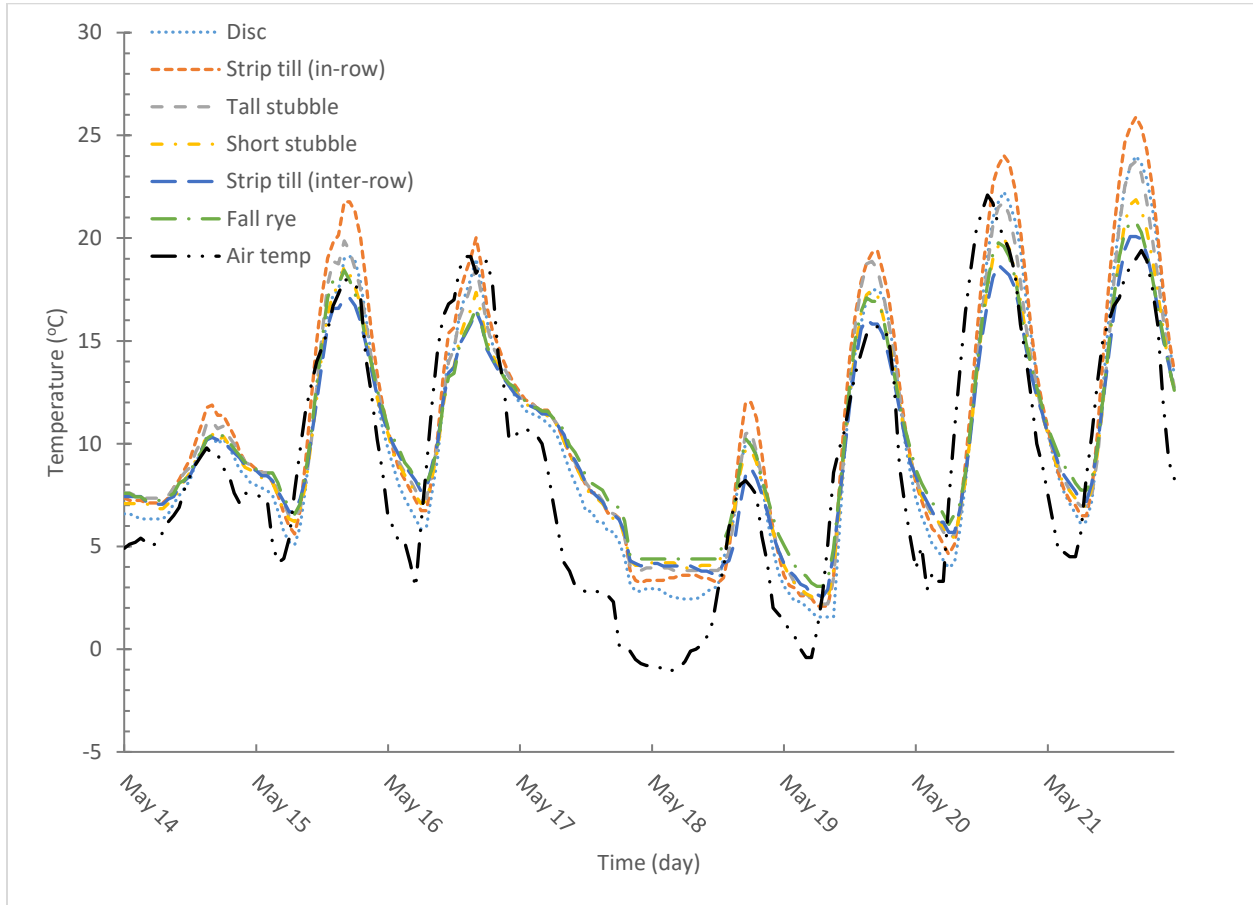
Figure 4.4. The effect of wheat residue management treatments on soil temperature at 5 cm below the soil surface at Carman15 the week before planting (May 14 to May 21).

Table 4.4. Analysis of variance (ANOVA) of effect of residue management treatment (treatment), site year, and time of day (hour) on soil temperature at 5 cm the day after planting.

Source of Variation	$P>F$
Treatment	<0.0001
Site year	<0.0001
Hour	<0.0001
Treatment x site year	0.0157
Treatment x hour	<0.0001
Hour x site year	<0.0001
Treatment x hour x site year	<0.0001
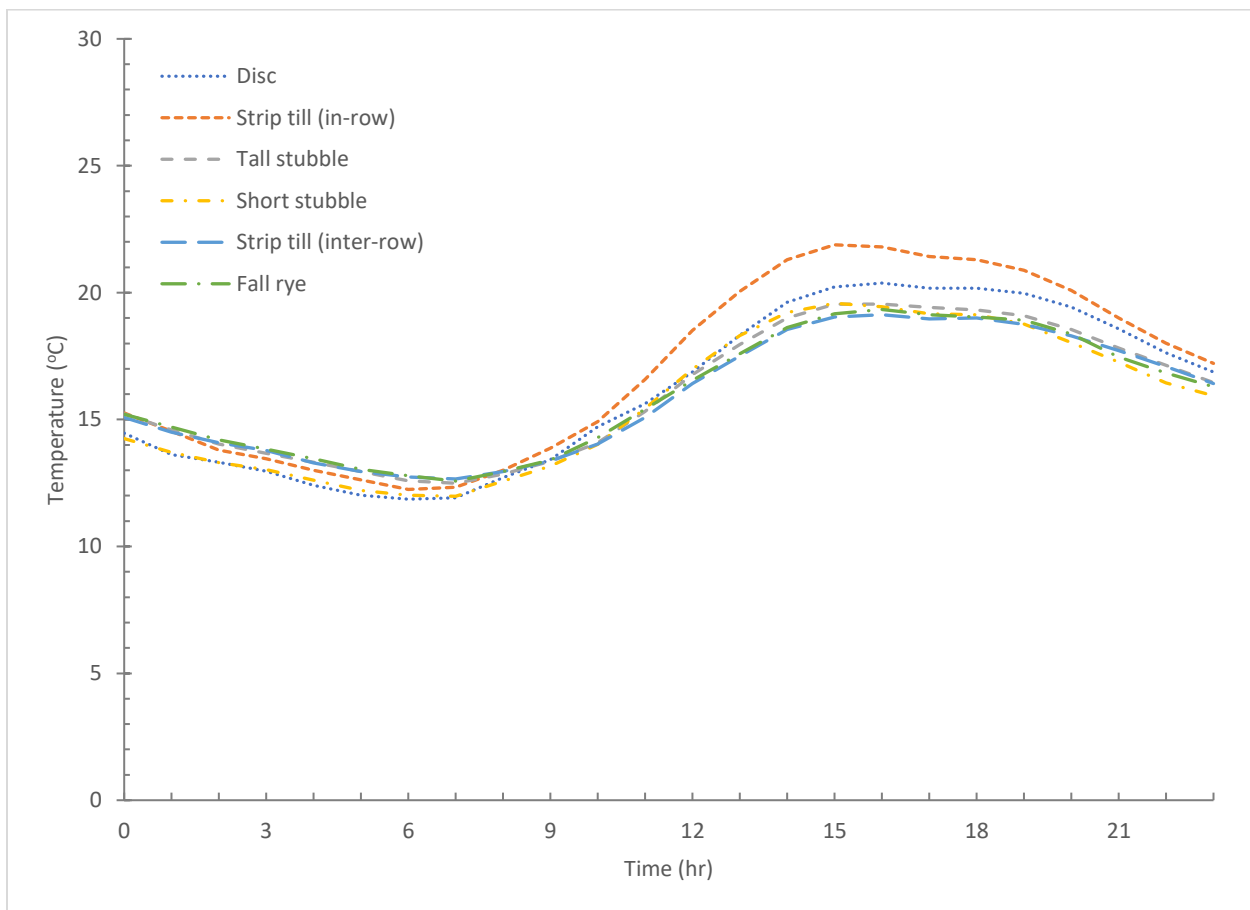
Figure 4.5. The effect of wheat residue management treatments on soil temperature at 5 cm below the soil surface averaged across all three site years the day after planting.

Licht and Al-Kaisi (2005) also observed that residue management treatment differences were greatest during the heat of the day. Their study compared the effect of soil temperature on tillage (strip till and chisel plow) and no-till residue management treatments in Iowa. Tillage

treatments were 1.4–1.9ºC warmer on average than the no-till treatment. These treatment differences were often not observed until hour 18 of the day; the time when maximum air temperature was observed (Licht and Al-Kaisi, 2005). The temperature range difference between the tillage and no-till treatments were attributed to the effect of soil disturbance from tillage, and the tillage effects on soil structure, bulk density, and water content of the soil on soil warming (Licht and Al-Kaisi, 2005). The same reasons may also be applied to the current study to help explain the temperature difference observed between the tillage and no-till residue management treatments.

A significant three-way interaction was observed between residue management treatment, hour, and site year the day after planting for soil temperature at 5 cm (Table 4.4). Air temperature trends at each site year likely contributed to the significant interaction observed when tillage treatments warmed and cooled faster than the no-till treatments. Differences in soil temperature between residue management treatments were observed at hour 0 and hour 3 at Carman14 (Table 4.5) as the soil temperature was cooling and the air temperature remained as warm as the soil temperature (Figure 4.1). Differences in soil temperature were not observed at Carman15 or Melita15 during these same hours probably because the air temperature was cooler than the soil temperature (Figure 4.2 and Figure 4.3). Melita15 was the only site that observed a significant difference between residue management treatments at hour 6 when the soil temperature was at the lowest. The air temperature was 8-10ºC cooler than the soil temperature at hour 6 at Melita15, while the air temperature at Carman14 and Carman15 was the same as the soil temperature at this hour. After hour 12 until hour 21, significant differences were observed between residue management treatments at all three site years as the soil temperature reached the

maximum and began to cool again. The air temperature was warmer than the soil temperature at

Caramn14 and Carman15 during the maximum but cooler than the soil temperature at Melita15.

Table 4.5. The effect of wheat residue management treatments on soil temperature at the 5 cm soil depth at three-hour intervals beginning at 12:00 AM (0 hr) the day after planting at Carman14 (May 29), Carman15 (May 23), and Melita15 (May 30).

Treatment	0 hr	3 hr	6 hr	9 hr	12 hr	15 hr	18 hr	21 hr
Carman14	-- °C --							
Disc	15.5 c[†]	15.0 c	14.8	17.8	19.3 c	22.3 b	22.2 b	20.7 b
Strip till (in-row)	17.2 ab	15.6 abc	14.8	17.3	22.4 a	26.5 a	25.3 a	22.2 a
Tall stubble	17.3 a	16.0 ab	15.3	16.3	19.2 c	21.8 bc	21.3 bc	19.7 bc
Short stubble	16.2 bc	15.3 bc	14.8	16.4	20.8 b	22.9 b	21.8 b	19.2 c
Strip till (inter-row)	17.4 a	16.2 a	15.5	16.4	19.1 c	21.6 bc	21.4 bc	20.0 bc
Fall rye	17.3 a	16.3 a	15.5	16.4	18.7 c	20.7 c	20.4 c	19.0 c
P>F	0.0049	0.0287	0.0589	0.0688	<0.0001	<0.0001	<0.0001	<0.0001
Carman15								
Disc	15.0	13	11.5	13.2	18.5 ab	21.7 ab	22.0 a	19.7 a
Strip till (in-row)	15.2	13.2	11.6	13.6	19.4 a	22.4 a	22.1 a	19.5 ab
Tall stubble	15.1	13.6	12.1	13.1	17.6 bc	20.3 bc	20.3 b	18.6 abc
Short stubble	14.2	12.7	11.2	12.7	17.2 bc	19.8 c	19.8 b	17.9 c
Strip till (inter-row)	14.9	13.3	12.0	13.0	17.5 bc	20.4 bc	20.4 b	18.5 bc
Fall rye	14.6	13.1	11.7	12.7	17.1 c	20.0 c	19.9 b	17.7 c
P>F	0.6301	0.6372	0.2479	0.7027	0.0049	0.0057	0.0003	0.0013
Melita15								
Disc	13.3	11.5	9.9 c	10.3	13.8	17.6 a	17.3 a	16.2 a
Strip till (in-row)	13.4	11.5	10.4 bc	10.7	13.7	16.7 a	16.5 abc	15.4 ab
Tall stubble	13.2	11.4	10.2 bc	10.6	13.7	16.8 a	16.6 ab	15.4 ab
Short stubble	12.3	11	9.8 c	10.2	13.0	16.1 ab	16.0 bc	14.9 b
Strip till (inter-row)	13.0	11.8	10.8 ab	10.8	12.6	15.1 b	15.3 c	14.6 b
Fall rye	13.7	12.1	11.1 a	11.1	13.9	16.9 a	16.9 ab	15.6 ab
P>F	0.2191	0.2078	0.0020	0.6852	0.2585	0.0391	0.0250	0.0415

†Means within a column followed by a different letter are significantly different at *P*<0.05 according to Fisher's LSD.

Air temperature had an influence on the three-way interaction for soil temperature trends

between residue management treatments at each site year the day after planting when soil

temperature reached the maximum for the day. Carman14, Carman15, and Melita15 had a

maximum air temperature of 32°C, 26°C, and 12°C, respectively the day after planting (Figure

4.1, Figure 4.2, and Figure 4.3). The warmest air temperature observed at Carman14 resulted in a temperature range of 5.8°C between the maximum and minimum soil temperature between residue management treatments at hour 15, while it was only 2.6°C and 2.5°C at Carman15 and Melita15 for the same hour, respectively (Table 4.5). The largest range in maximum temperature at Carman14 was due to strip till (in-row) being much warmer than all other residue management treatments. Strip till (in-row) and disc behaved similarly at Carman15 under a more normal high air temperature of 26°C, generally being the two warmest residue management treatments from hour 12 to hour 21. The no-till treatments were generally cooler than the strip till (in-row) residue management treatment at both Carman14 and Carman15 during this same period. Under the cool air temperature conditions experienced at Melita15, the no-till treatments behaved more similar to the tillage treatments. This was likely due to the insulating properties of the surface residue within the no-till treatments that help to retain heat, while the decreased surface residue within the disc and strip till treatments make them more susceptible to heat loss during cold periods (Horton et al., 1996). It was also observed that the fall rye treatment was one of the warmest residue management treatments at Melita15; a unique observation that was not observed at Carman14 or Carman15 (Table 4.5).

Surface residue ground cover is known to influence soil temperature trends between residue management treatments. Surface residue ground cover acts as a buffer to soil temperature by insulating the soil surface (Horton et al., 1996). Gauer et al. (1982) observed soil temperature to be 0.5-1°C warmer under conventional tillage applied to wheat stubble than no-till with surface residue spread evenly across the soil surface. Malhi and O'sullivan (1990) and Beyaert et al. (2002) also observed conventional till to be 1-2°C warmer than no-till residue management treatments in Alberta and Saskatchewan. In the current study, the disc treatment was observed to

be up to 1.5°C warmer than the short or tall stubble treatment on occasion, supporting the observation from the researchers presented earlier. However, when Gauer et al. (1982) removed the surface residue from the no-till treatment, the disc treatment was observed to be 2°C cooler than the no-till treatment, suggesting that the surface residue on its own also had an influence on soil temperature.

Surface residue and air temperature are known to influence soil temperature trends between tillage and no-till residue management treatments. Beyaert et al. (2002) reported that the difference in mean daily soil temperature between tillage and no-till treatments increased under warm air temperature compared to cool air temperature. This observation was observed in the current study when the difference in soil temperature between tillage and no-till treatments was the greatest when the air temperature was the warmest at Carman14 and the least when the air temperature was the coolest at Melita15 the day after planting. In the current study, the tall stubble treatment appears to be slightly warmer than the short stubble treatment, although not significantly different, due to the mean separation often being different between the disc and short stubble treatment but not for the disc and tall stubble treatment during the heat of the day. Cutforth and McConkey (1997) did not observe a difference in soil temperature at 5 cm between tall (25-36 cm) and short (15-18 cm) stubble treatments during the early growing season; however, soil temperature was reported as daily average soil temperature over multiple days within their study. It would have been interesting to see if there were treatment differences if maximum soil temperature was reported within a single day rather than the daily average.

To fully understand the influence of surface residue and tillage on soil temperature, the differences between the in-row and inter-row portion of strip till are explored in Figure 4.6. On average, there was a temperature difference of 3.2 to 4.4°C between the in-row and inter-row

portion of strip till at 5 cm during the period of maximum soil temperature for the day. Wall and Stobbe (1984) observed a similar difference of 4.2°C at 2.5 cm below the soil surface between the in-row and inter-row portion of strip till when averaged across 10 sampling dates from May 21 to July 17 in Manitoba. This soil temperature trend was generally similar at a depth of 5 cm in their study when averaged across the same sampling dates. However, soil temperatures were not significantly different between the in-row and inter-row portion of strip till at the 5 cm soil depth.

During the periods of minimum soil temperature, the differences between the in-row and inter-row portion of strip till are related to air temperature at that time (Figure 4.6). On May 30, the air temperature remained above the minimum soil temperature and the in-row portion of strip till appeared slightly warmer than the inter-row portion of strip till. On all other days, the air temperature falls below the minimum soil temperature and the in-row portion of strip till becomes approximately 1°C cooler than the inter-row portion of strip till for 6 to 8 hours at night. Tillage within the in-row portion of strip till eliminated the surface residue, aerated the soil and facilitated soil drying; the inverse effects of the inter-row portion of strip till without tillage. These temperature differences between the in-row and inter-row portion of strip till occur 38 cm apart from each other, representing the influence of surface residue, tillage, and soil moisture on the soil warming and cooling properties of a soil.
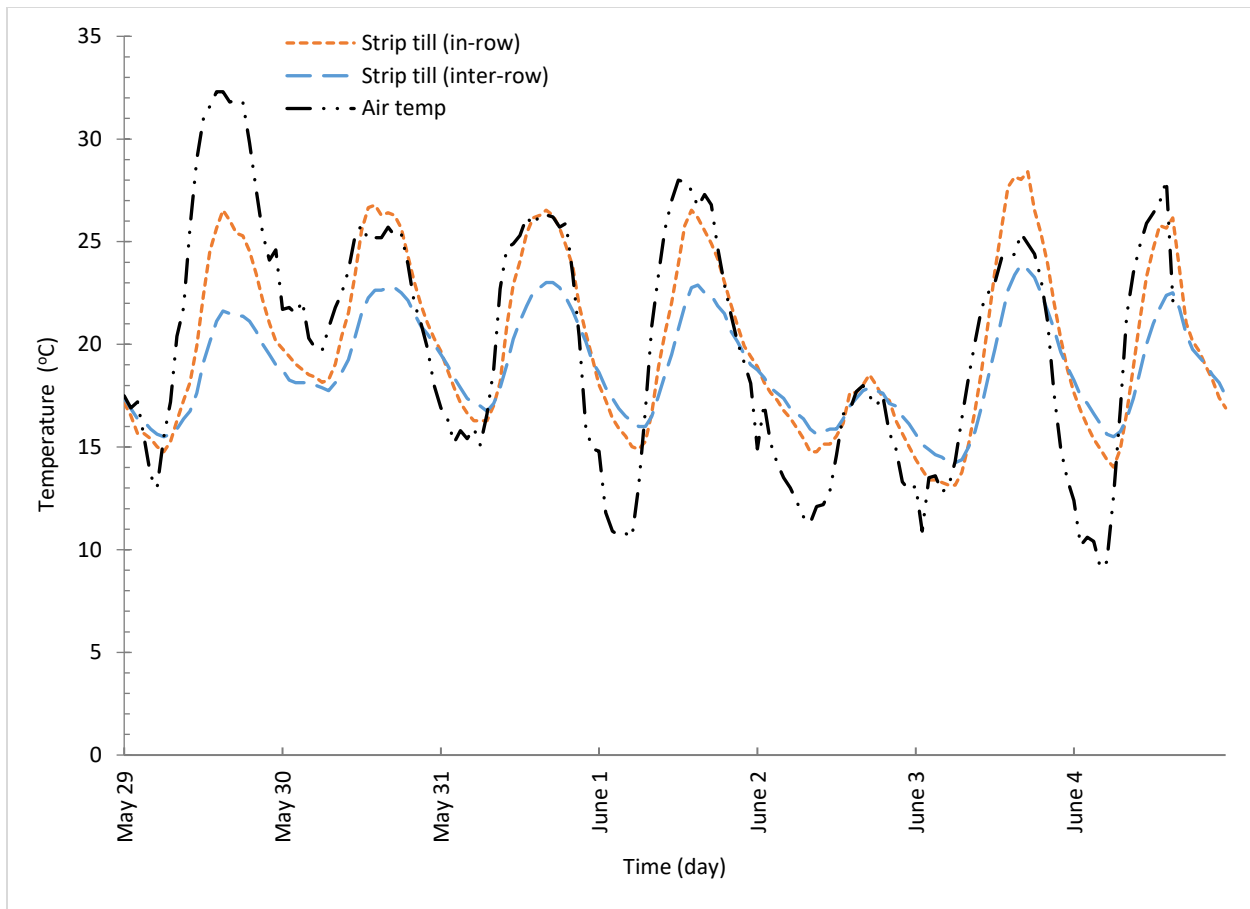
Figure 4.6. The effect of wheat residue management treatments on soil temperature at 5 cm below the soil surface at Carman14 from May 29 to June 4 comparing strip till (in-row) and strip till (inter-row).

Soybean canopy closure influenced the effect of residue treatments on surface soil temperature at 5 cm late in the growing season. For example, the canopy closed between the 76 cm row spacing for soybean around July 27 at Carman15; soybean growth stage R4. The soil temperature trends that were observed at the time of planting changed when the soybean canopy closed and there were no differences in soil temperature at 5 cm between residue management treatments on July 27 during all sampling periods (Figure 4.7). The effect of soybean canopy closure on reducing soil temperature differences for a bare soil compared to a mulched soil was also observed by Wagner-Riddle et al. (1994) in Ontario. Soil temperature differences between

bare and mulch covered soil were observed early in the growing season, but diminished as soybean canopy closure occurred.
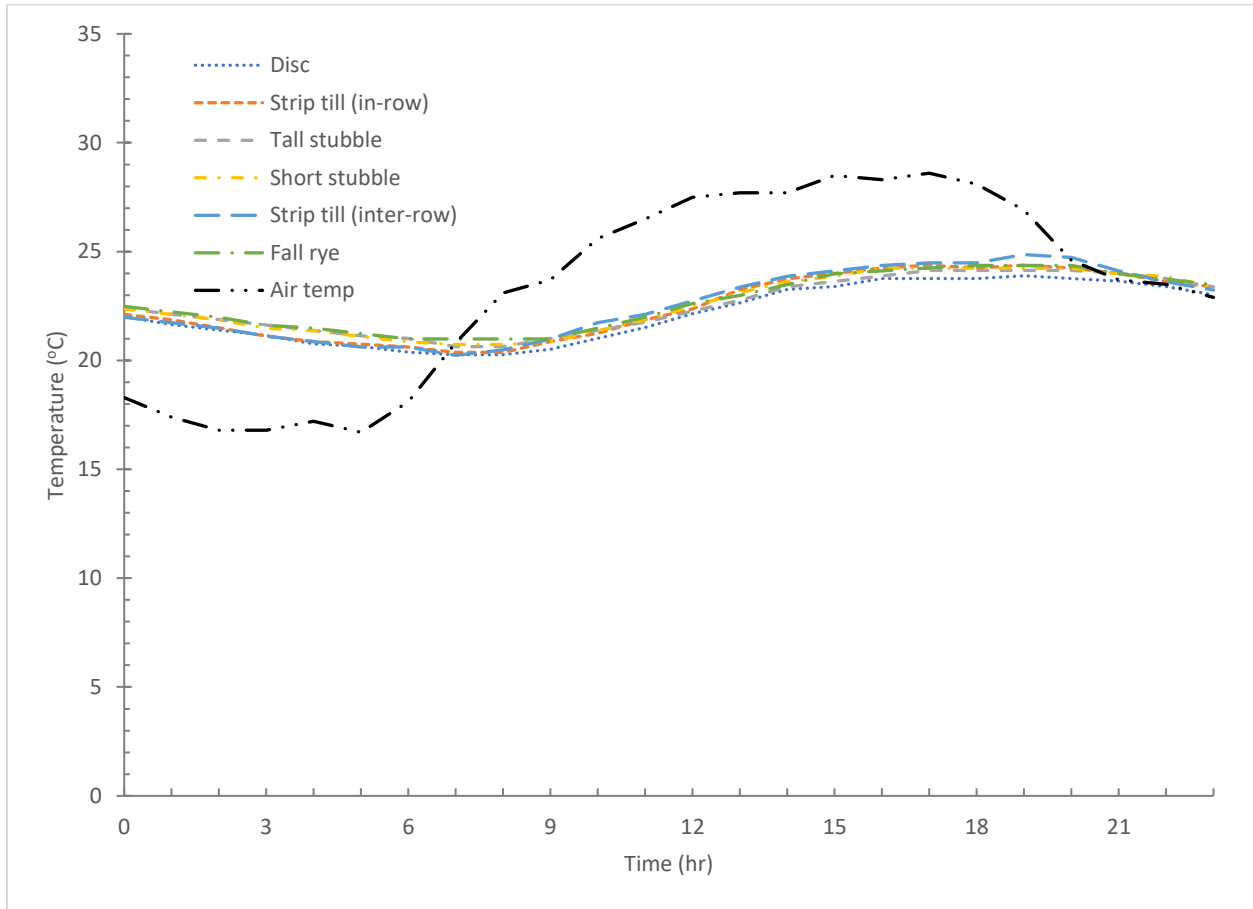
Figure 4.7. The effect of wheat residue management treatments on soil temperature at 5 cm below the soil surface at Carman15 on July 27 around soybean canopy closure.

If the soybean canopy does not close during the growing season, soil warming trends are still present late in the growing season. At Carman14, the soybean canopy did not close and the soil temperature sensors were located between the rows of the soybeans; different from the temperature sensor location within the soybean row at Carman15. When the soybean canopy was not closed, soil warming trends remained similar to the trends observed at the time of seeding at Carman14. The disc treatment had a higher soil temperature during the day on July 15 compared to all other residue management treatments (Figure 4.8). This trend might not have been

observed if temperature sensors were located within the soybean seed row or if the soybean canopy had fully closed.
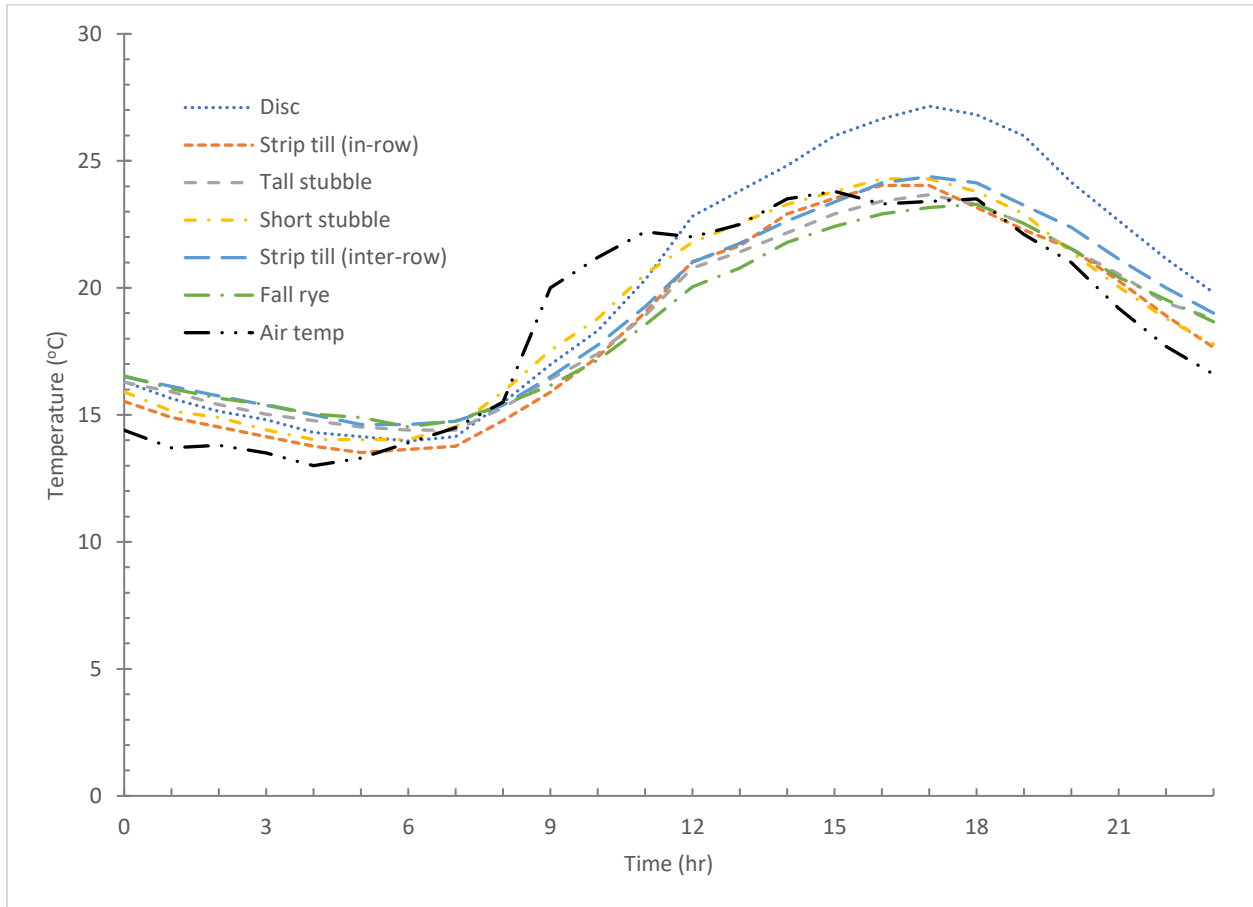
Figure 4.8. The effect of wheat residue management treatments on soil temperature at 5 cm below the soil surface at Carman14 on July 15 around soybean canopy closure.

Soil temperature at 30 cm below the surface was observed for the entire growing season to assess the effect of residue management treatments on soil temperature within the deeper portion of the rooting zone. The maximum soil temperature at 30 cm below the surface was observed on July 13 and July 14 for all residue management treatments at Carman15 (data not shown). The maximum soil temperature ranged from 22°C and 22.5°C during these days and there was no significant difference between residue management treatments (P=0.6378). The residue management treatments reached their maximum soil temperature approximately 14 days

before the soybean canopy closed. The optimum rooting zone soil temperature for nodule development and nitrogen fixation of soybean is 25°C (Jones and Tisdale, 1921). All residue management treatments were below this optimum soil temperature. We hypothesized that the disc treatment would have had a warmer soil temperature and the fall rye treatment would have had a cooler soil temperature at 30 cm depth compared to all other residue management treatments; however, this was not observed within this study.

4.5   Cumulative Soil Temperature

A residue management treatment that provides a warm seedbed to facilitate quick germination and emergence of soybean is desirable. Hourly soil temperature trends for residue management treatments varied between the warmest and coolest periods of the day, making it difficult to determine if there was a residue management treatment that provided a warmer seedbed overall compared to another. To determine the effect of residue management treatments on soil temperature over time, a cumulative soil temperature approach was used. This approach was based on the growing degree day model commonly used for air temperature to assess plant development but applied to soil conditions (Ritchie and NeSmith, 1991).

Wheat residue management treatments that contained tillage accumulated up to 26% more growing degree hours (GDH) than no-till residue management treatments for soil temperature at 5 cm from 21 DBP until the day of planting averaged across all three site years (Table 4.6). Strip till (in-row) accumulated the greatest GDH during this accumulation period, 16% more GDH than the disc treatment and 26% more than the short stubble and fall rye treatments.

Accumulated GDH for soil temperature at 5 cm was 35-39% greater at Melita15 than

Carman14 and Carman15 when GDH was accumulated from 21 DBP until the day of planting.

This is an indication that soil temperature leading up to soybean planting at Melita15 was

warmer compared to the other two site years.

Table 4.6. The effect of wheat residue management treatments on accumulated growing degree hours (GDH) with a base temperature 10ºC at 5 cm below the soil surface from 21 days before planting until the time of planting at Carman14, Carman15, and Melita15.

Treatment	Accumulated GDH
	ºC
Disc	1318 **b**
Strip till (in-row)	1574 **a**
Tall stubble	1303 **bc**
Short stubble	1161 **c**
Fall rye	1164 **c**
Site	
Carman14	1063 **b**
Carman15	1119 **b**
Melita15	1731 **a**
Source of Variation	*P>F*
Treatment	<0.0001
Site year	<0.0001
Treatment x site year	0.7977

†Means within a column followed by a different letter are significantly different at *P<0.05* according to Fisher's LSD.

After soybean planting, there was a significant three-way interaction between residue

management treatments, time, and site year for accumulated GDH at 5 cm (Table 4.7). There

was no significant difference in accumulated GDH between residue management treatments on

any accumulation period at Carman15. At Carman14, strip till (in-row) accumulated ~15% more

GDH than no-till residue management treatments but was not significantly different from the

disc treatment at the early, mid, and late accumulation periods. At this site year, there was no

significant difference between the disc treatment and any other residue management treatment at

the early accumulation date. After the early accumulation date, the disc treatment had

accumulated 11% more GDH than the tall and short stubble treatment at the mid and late

accumulation dates.

Table 4.7. Influence of wheat residue management treatments (Treatment) on accumulated growing degree hours (GDH) (base temperature 10°C) at 5 cm below the soil surface from the time of planting until approximately 8 (Early), 15 (Mid), and 21 (Late) days after planting (Time) at Carman14, Carman15, and Melita15 (Site Year).

	Carman14			Carman15			Melita15		
Treatment	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
	---------------------------------- Accumulated GDH ----------------------------------								
Disc	1748 **ab**	3096 **ab**	4028 **ab**	1558	2104	3755	1578 **ab**	2623 **a**	4085 **ab**
Strip till (in-row)	1910 **a**	3299 **a**	4240 **a**	1590	2134	3757	1493 **b**	2501 **ab**	3872 **ab**
Tall stubble	1618 **b**	2768 **c**	3626 **bc**	1464	1993	3553	1537 **b**	2538 **ab**	3879 **ab**
Short stubble	1609 **b**	2724 **c**	3581 **c**	1369	1877	3441	1415 **b**	2369 **b**	3655 **b**
Fall rye	1610 **b**	2813 **bc**	3712 **bc**	1476	2035	3626	1725 **a**	2728 **a**	4034 **a**
Source of Variation	$P>F$								
Treatment	0.0009								
Site year	0.0002								
Time	<0.0001								
Treatment x site year	0.1379								
Treatment x time	0.0041								
Site year x time	<0.0001								
Treatment x site year x time	0.0255								

†Means within a column followed by a different letter are significantly different at $P<0.05$ according to Fisher's LSD.

At Melita15, the fall rye treatment had one of the highest accumulated GDH at all

accumulation periods and accumulated 9-18% more GDH than the short stubble treatment. The

general trend of tillage treatments accumulating more GDH than the no-till treatments was not

observed at this site year. For all sampling periods, the disc and strip till (in-row) residue

management treatments were not significantly different from the no-till treatments except for the

strip till (in-row) and fall rye treatments at the early accumulation period, and the disc and short

stubble treatments at the mid accumulation period.

It has been suggested by Swan et al. (1996) and Opoku and Vyn (1997) that the main influence on accumulated soil temperature is percent residue ground cover. In the current study, regression analysis of percent residue ground cover and accumulated GDH indicated a linear inverse relationship between these two variables from planting to 21 DAP pooled across all three site years (Figure 4.9). However, the relationship was weak (R-Square = 0.11), which suggests that there were other factors other than residue cover that were influencing accumulated GDH over this time period.

$y = 3.171x + 3985.7$
$R^2 = 0.11$
$p = 0.0121$

X-axis: % Residue Ground Cover
Y-axis: Growing Degree Hour (°C)

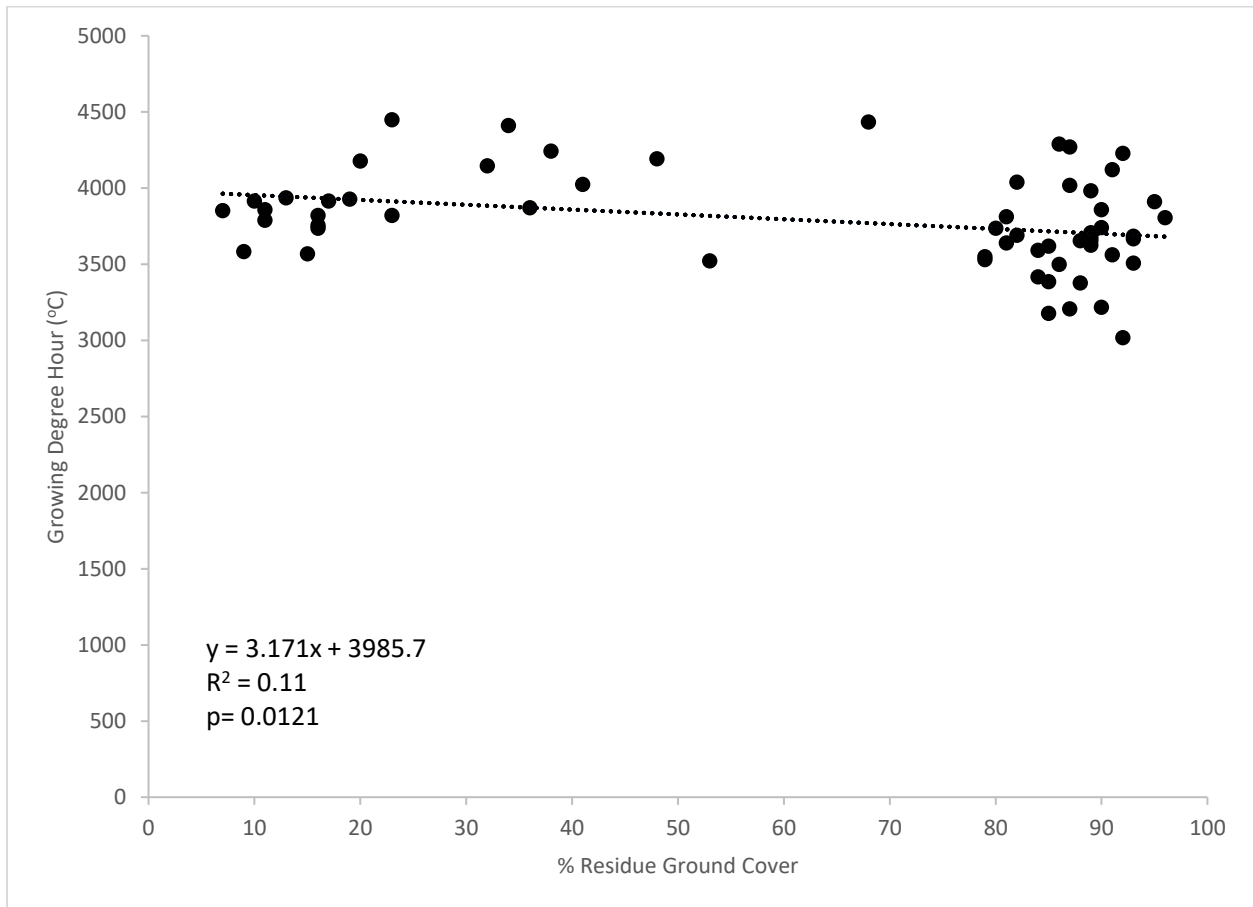**Figure 4.9.** The effect of wheat residue ground cover on accumulated growing degree hours from the time of planting until 21 days after planting pooled across three site years. Symbols represent individual observations for each replicate and site year.

Evans (2015) did not observe a difference in accumulated growing degree days (GDD) with a base temperature of 0°C from 31 DBP to the time of planting between a fall rye cover

crop and conventional tillage in Manitoba. Possible explanations provided by Evans for not observing a difference in soil GDD were high soil moisture content in all residue management treatments and the vertical orientation of growing fall rye. Soil moisture likely had an influence in the current study. A wet soil takes longer to heat than a dry soil and any residue management practice that limits the evaporation of water from the soil will also limit the heating capabilities of the soil (Horton et al., 1996). Within the current study, residue management treatments that contained tillage were among the driest treatments before planting compared to no-till residue management treatments (Table 4.3), which may explain the differences observed in accumulated GDH between the tillage and no-till residue management treatments before planting. After planting, the trend in soil moisture continued for the tillage and no-till residue management treatments averaged across site years; however, the trend of accumulated GDH after planting was not consistent between site years suggesting that additional factors other than just soil moisture, alone, may have also had an influence on accumulated GDH in this study.

4.6   Soybean Emergence

Residue management treatments influenced soybean emergence and soybean plant density at the V1 growth stage. Quick and uniform soybean emergence is desired to reduce the risks of seedling disease in the spring and minimize the risk of fall frost on soybean maturity at the end of the growing season. The current recommended plant population for soybean in Manitoba is 40 plants m^{-2} (Manitoba Agriculture, 2017). The average final plant populations at Carman14, Carman15, and Melita15 were 30, 27, and 45 plants m^{-2}, respectively. Carman14 was below the recommended plant population due to poor overall emergence (63% of seeds emerged) (Table 4.8). Carman15 and Melita15 had high overall emergence (81% and 95% of seeds emerged,

respectively); however, Carman15 was below the recommended average plant population due to a low seeding rate.

In this study, the soybean emergence period was from the time of planting until an increase in soybean plant population was no longer observed approximately 21 days later. There was a two-way interaction for soybean emergence between residue management treatment and sampling date, residue management treatment and site year, and site year and sampling date (Table 4.8). For the residue management treatment and sampling date interaction, the strip till treatment had the highest percent emergence compared to all other residue management treatments at 10 days after planting (DAP) (Table 4.8). This suggests that strip till emerged the quickest out of all residue management treatments. Strip till was also observed to have the highest percent emergence at 14 DAP and had one of the highest percent emergence at 21 DAP compared to other residue management treatments. The short stubble treatment had the fewest plants emerged at 10 DAP compared to other residue management treatments, suggesting that the short stubble treatment was the slowest to emerge. However, the final plant population for the short stubble treatment was among the highest at 21 DAP. The disc treatment was observed to have one of the lowest plant populations at all sampling dates and was not significantly different from the fall rye treatment. The tall stubble treatment was neither the greatest or lowest plant population among treatments at 10 and 14 DAP, but had one of the highest plant populations at the end of the emergence period. The residue management treatment by site year interaction can be seen in Table 7.1 of the appendix.

Table 4.8. The effect of wheat residue management treatments and site year on soybean emergence relative to the seeding rate at 10 days after planting (DAP), 15 DAP, and 21 DAP.

Treatment	Days after Planting		
	10	14	21
	--------------------------------- % ---------------------------------		
Disc	28 **b**[†]	69 **bc**	72 **bc**
Strip till	57 **a**	83 **a**	82 **a**
Tall stubble	30 **b**	72 **b**	77 **ab**
Short stubble	20 **c**	67 **bc**	77 **ab**
Fall Rye	27 **b**	63 **c**	70 **c**
Site year			
Carman14	40 **a**	62 **c**	63 **c**
Carman15	31 **b**	72 **b**	81 **b**
Melita15	18 **c**	88 **a**	95 **a**
Source of Variation	*P>F*		
Treatment	<0.0001		
DAP	<0.0001		
Site year	<0.0001		
Treatment x DAP	<0.0001		
Treatment x site year	0.0006		
DAP x site year	<0.0001		
Treatment x DAP x site year	0.0800		

†Means within a column followed by a different letter are significantly different at *P<0.05* according to Fisher's LSD.

The effect of residue management treatments on the rate of soybean emergence can be compared using the count of percent soybean emergence at 10 DAP between residue management treatments, because this was the earlies timing for plant counts. The strip till treatment had the highest percent of soybean plants emerged at 10 DAP, having 47-51% more plants emerged than the disc, tall stubble, and fall rye residue management treatments, and 64% more plants emerged than the short stubble treatment when averaged across all site years (Table 4.8). Residue management studies in Ontario that included strip till as a fall tillage treatment have not reported an increase in the rate of soybean emergence compared to other residue

management treatments (Vyn et al., 1998; Janovicek et al., 2006). Soil temperature is known to influence the rate of soybean emergence (Hatfield and Egli, 1974). The soil temperature of strip till (in-row) was consistently one of the warmest residue management treatments at all site years which may explain the quick emergence compared to all other residue management treatments. The short stubble treatment was observed to have the least percent soybean plants emerged at 10 DAP compared to all other residue management treatments in the current study, which may also be due to the soil temperature trends observed within this residue management treatment. This is consistent with observations by Vyn et al. (1998) who observed a no-till treatment with residue emerge approximately one day slower than tillage and no-till residue management treatments with residue removed. Explanations for the delayed emergence observed by Vyn et al. (1998) were poor seed bed conditions due to high surface residue, lower proportions of fine soil aggregates, and generally more soil moisture in the no-till treatment. In the current study, soil moisture was generally observed to be greater in the no-till treatments, but it is unclear if more surface residue had an influence on soybean emergence. Soil temperature was not measured by Vyn et al. (1998) and it would have been interesting to see if temperature was also influencing the rate of soybean emergence like it may have been in the current study. Carman14 was observed to have the highest percent emergence at 10 DAP, followed by Carman15 and Melita15. The maximum soil temperature observed the day after planting for Carman14, Carman15, and Melita15 was 26.5, 22.4, and 16.9°C, respectively, which may have influenced the percent soybean emergence trend observed for each site year at 10 DAP.

The fall rye treatment had one of the lowest final plant stands at 21 DAP but was not different from the disc treatment at all site years (Table 4.8). Wagner-Riddle et al. (1994) reported a lower plant population for soybean planted into fall rye compared to conventional

tillage with no fall rye at one site year. The researchers indicated the reduced plant population at this site year was due to reduced seed to soil contact when planted into fall rye, a factor that was not measured in the current study. When good seed to soil contact was achieved by the researchers at other site years, no difference in plant population was reported between fall rye and conventional tillage. Flood and Entz (2018) reported a 33% reduction in dry bean plant population when planted into a fall rye cover crop (4286 kg ha^{-1} biomass) compared to a no cover crop tillage treatment in Manitoba at one out of four site years under dry conditions. Under typical moisture conditions, a reduction in dry bean population density was not observed between a fall rye cover crop and conventional tillage. The moisture conditions were observed to be normal within the current study and no difference in final plant population between the disc and fall rye treatment were observed.

4.7   Soybean Growth

4.7.1   Vegetative Biomass

Wheat residue management treatments influenced soybean growth when total plant biomass and plant height was measured at the R5 growth stage. At Carman15, the disc treatment accumulated 734 and 955 kg ha^{-1} more total vegetative biomass than the tall stubble and fall rye treatments, respectively (Table 4.9). The biomass for short stubble and strip till treatments was not significantly different from any other residue management treatment. The larger plant biomass for the disc treatment was likely a result of an increase in plant height. The disc treatment had a plant height of 99 cm at the time of biomass sampling, significantly taller than all other residue management treatments by 6 to 9 cm.

Table 4.9. The effect of wheat residue management on soybean plant biomass and soybean plant height at R5 soybean growth stage at Carman15.

Treatment	Plant biomass	Plant height
	kg ha^{-1}	cm
Disc	5116 **a**†	99 **a**
Strip till	4555 **ab**	93 **b**
Tall stubble	4382 **b**	91 **b**
Short stubble	4569 **ab**	90 **b**
Fall rye	4161 **b**	91 **b**
P>F	0.0435	<0.0001

†Means within a column followed by a different letter are significantly different at *P*<0.05 according to Fisher's LSD.

Previous studies have observed a decrease in soybean biomass as a result of increase amounts of residue at planting. Vyn et al. (1998) observed a decrease in soybean biomass at five weeks after planting as the level of wheat residue increased in residue management treatments. In that study, no-till soybeans had significantly less vegetative biomass compared to fall moldboard plow; however, there was no significant difference between fall chisel or fall disc treatments at one out of six site years in Ontario (Vyn et al., 1998). Janovicek et al. (2006) also observed significant differences in above ground biomass for various residue management treatments when all soybean plants harvested from a fixed area. However, the effect of row spacing was also being observed in this study and different plant population were present within the residue management treatments. When above ground biomass was reported on a per plant basis, taking into account the differences in plant stand between treatments, a significant difference between residue management treatments was no longer observed (Janovicek et al., 2006). This suggests that plant density can influence above ground biomass when measured on a fixed area basis and the biomass per plant was not considered within the current study.

4.7.2 Plant Height

Residue management affected soybean plant height observed between residue management treatments in 2014 and 2015. However, the effect of residue management treatment varied with site year. At Carman14, the average plant height was 65 cm which was shorter than the average plant height of 86 cm at Carman15 before harvest (Table 4.10). The average growing season temperature from May to August was slightly cooler by 0.5°C in 2014 compared to 2015 (Table 3.1), which may have influenced the overall plant height between the two years. Within each site year, the tillage treatments were among the tallest at harvest in 2014 and 2015, while the no-till treatments were among the shortest. Strip till had the tallest plant height in 2014 (70 cm), while the disc treatment had the tallest plant in 2015 (95 cm). The fall rye treatment consistently had one of the shortest plant heights at harvest in 2014 and 2015 at 58 cm and 83 cm, respectively.

Table 4.10. The effect of wheat residue management on soybean plant height at harvest at Carman14 and Carman15.

Treatment	Carman14	Carman15
	--------------------- cm ---------------------	
Disc	65 b†	95 a
Strip till	70 a	87 b
Tall stubble	65 b	86 b
Short stubble	64 b	80 c
Fall rye	58 c	83 bc
Source of Variation	$P>F$	
Treatment	<0.0001	
Site year	<0.0001	
Treatment x site year	<0.0001	

†Means within a column followed by a different letter are significantly different at $P<0.05$ according to Fisher's LSD.

Previous research does not support the observation that a fall rye cover crop decreases soybean plant height. Moore et al. (1994) found there was no effect on plant height when

soybean was planted into a fall rye cover crop compared to a bare soil when plant height was recorded at the end of the growing season. Westgate et al. (2005) observed no effect in Iowa on soybean plant height when fall rye was chemically controlled at either the 2nd node, boot, or anthesis growth stage in 2003. However. slight differences in plant height were observed in 2002 between fall rye cover crop desiccation timings, but the difference in plant height varied by only 5 to 10 cm from the shortest to tallest treatment (Westgate et al., 2005).

Stubble height has been shown to influence soybean plant height in previous research. Hovermale et al. (1979) observed soybean plants that were significantly taller by 5 cm when planted into tall stubble (35.6 cm) compared to medium (20.3 cm) and short (10.2 cm) stubble height. In the current study, stubble height influenced plant height in 2015 but not in 2014. The tall stubble treatment was 5 cm taller than the short stubble treatment, which is consistent with the observations by Hovermale et al. (1979).

4.7.3 Pod Height

The height of the lowest pod on a soybean plant is important for determining the harvestability of soybean. Increased pod height facilitates combine harvesting by raising the pods further up off the ground, reducing harvest losses. Residue management did not affect pod height at Carman15, the only site year that pod height was measured. All residue management treatments had a pod height of 12 cm from the soil surface to the first pod bearing node. Hovermale et al. (1979) observed similar trends for both pod and plant height for soybean planted into different wheat stubble heights. Soybean planted into tall stubble had a higher pod height than soybean planted into short and medium stubble heights as a result of an increase in soybean branching height of 3 cm for the tall stubble treatment (Hovermale et al., 1979).

4.8   Soybean Seed Yield

The effect of residue management treatments on soybean seed yield is considered the main factor for farmers when evaluating residue management practices. The residue management treatment that provides the maximum yield can be considered the most desirable for some farmers, regardless of the cost associated with that residue management treatment. Residue management affected seed yield Carman14 but not at Carman15 (Table 4.11). At Carman14, strip till and tall stubble had a significantly greater soybean yield (669 kg ha^{-1}) than the fall rye treatment. The yield for the disc treatment was not significantly different from any other residue management treatment except for the fall rye treatment.

Table 4.11. Effect of wheat residue management on soybean seed yield at Carman14 and Carman15.

Treatment	Carman14	Carman15
	------------- kg ha^{-1} -------------	
Disc	2364 **ab**†	3575
Strip tillage	2624 **a**	3662
Tall stubble	2602 **a**	3583
Short stubble	2262 **b**	3654
Fall rye	1955 **c**	3656
Source of Variation	*P>F*	
Treatment	0.0274	
Site year	<0.0001	
Treatment x site year	0.0119	

†Means within a column followed by a different letter are significantly different at *P*<0.05 according to Fisher's LSD.

The average soybean yield for all treatments was higher in 2015 than 2014. There was a difference of 1,265 kg ha^{-1} between the average yield of 3,626 kg ha^{-1} in 2015 and 2,361 kg ha^{-1} in 2014. Above normal daily temperature and more consistent rainfall during the 2015 growing season provided better growing conditions for soybean compared to the 2014 growing season (Table 3.1). Residue management treatments had no effect on soybean yield in studies located in North Dakota and Ontario. Endres (2015) observed a 141 kg ha^{-1} (6%) increase in soybean yield

across 12 years for soybean seeded into no-till compared to conventional till in North Dakota. In a different study, there was a 4% increase in soybean yield across 37 site years in North Dakota for soybean grown in a reduced tillage system, (no-till, strip till, or fall tillage) compared to soybean established into fall or spring tillage treatments (Endres, 2015). In Ontario, Wagner-Riddle et al. (1994) found no difference in soybean yield between soybeans planted into conventional till compared to soybeans planted into fall rye, regardless of fall rye desiccation timing. These finding support the measurement at Carman15 in the current study, but not at Carman14 as a treatment difference was observed only for the Carman14 site year.

High levels of surface residue ground cover and no-till residue management practices have been shown to reduce soybean yield compared to conventional tillage in Ontario. Vyn et al. (1998) found soybean yield was negatively correlated with surface residue. In their wheat residue management experiment, fall strip till and fall disc tillage systems increased soybean yield 5 to 29% relative to the no-till treatments; however, when the surface residue was removed from the no-till plots, there was no significant difference between the no-till treatment compared to the fall tillage treatments (Vyn et al., 1998). This observation of increasing soybean yield as surface residue is removed resulted in a negative correlation between surface residue and soybean yield. Within the current study, the level of surface residue on its own did not seem to have an influence on soybean yield as there was no significant yield response observed in 2015 and the tall stubble treatment was among the highest yielding treatments in 2014.

The seeding equipment used to plant soybean can have an influence on soybean yield. A corn residue management study conducted in southern Ontario by Vanhie et al. (2015) compared a row unit planter and a disc drill across fall and spring tillage and no-till treatments. Soybeans planted with a row unit planter yielded 130 kg ha^{-1} more than soybeans planted using a no-till

drill. There was no significant difference in soybean yield across tillage system when the row unit planter was used; however, there was significant difference in yield when the disc drill was used (Vanhie et al., 2015). It was concluded that tillage system had less of an impact on soybean performance when seedbed conditions were good, but decreased performance was observed under certain residue management and seeding implement combinations.

Different seeding equipment was used within the current study at Carman14 and Carman15. Soybeans were seeded using a disc drill at Carman14 and row unit planter with a large cutting coulter was used at Carman15. Based on the conclusions from the Vanhie et al. (2015) study, the yield differences observed at Carman14 could be influenced by the less capable seeding equipment that was used. The disc drill used that year had inadequate residue management capabilities, which might have limited its planting accuracy under high residue situations, such as seeding into the fall rye treatment at Carman14. The seeder used at Carman14 probably contributed to the variability in plant stand that was observed (Table 4.8), which may have also had an influence on soybean seed yield at the end of the growing season. However, a reduction in soybean establishment was also observed for the disc treatment which had low levels of residue ground cover compared to the fall rye treatment. Regardless, soybean yield results for that year may have been different if a planter with residue management tools was used.

4.9   Summary

The objective of this study was to determine the effect of wheat residue management treatments on surface residue ground cover, soil properties such as soil moisture and soil temperature, and soybean growth, development, and yield. A spider diagram is presented in Figure 4.10 to help show the connection between the many variables measured within this study. When comparing means across all site years, several trends were observed for wheat residue management treatments. In the spider diagram, tillage treatments decreased surface residue ground cover and decreased soil moisture relative to other residue management treatments. Maximum soil temperature and cumulative GDH before planting increased for one out of two tillage treatments. Tillage treatments had no effect on final plant population or soybean yield compared to no-till wheat residue management treatments in the spider diagram (Figure 4.10).

Within the no-till treatments in the spider diagram, there was often little or inconsistent differences observed among the no-till treatments for all variables. In the spider diagram, the strip till (in-row) residue management treatment increased soil temperature, soybean emergence, and yield compared to other residue management treatments observed within this study.

It was hypothesized that wheat residue management treatments that contained tillage would behave similarly across all site years compared to no-till residue management treatments. However, several variables had a significant treatment by site year interaction, or significant treatment by sampling date interaction, and are thus oversimplified in Figure 4.10 including: surface residue ground cover, soil moisture at 5 cm, soil temperature at 5 cm, cumulative GDH from planting until 21 DAP, and soybean yield.
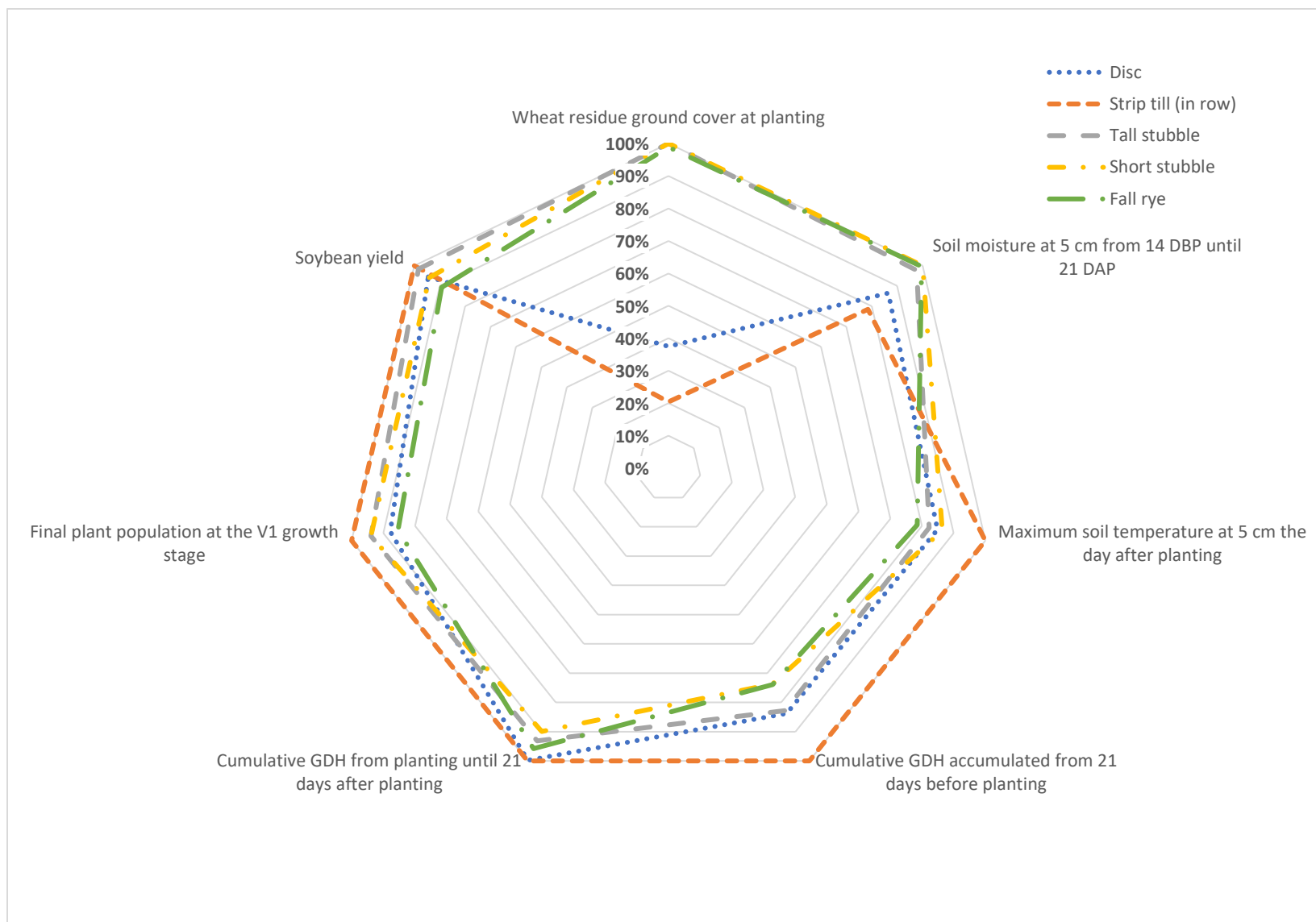
Figure 4.10. Average relative difference between wheat residue management treatments for select soil properties and soybean response variables across all three site years.

5. GENERAL DISCUSSION

The objectives of this study were to determine the effect of wheat residue management treatments on surface residue ground cover, soil properties such as soil moisture and soil temperature, and soybean growth, development, and yield in an effort to reduce tillage before growing soybean in Manitoba. The findings of this study suggest that tillage can be reduced or eliminated for growing soybean in Manitoba. Wheat residue management studies have been initiated in Manitoba and the prairie provinces before; however, this is one of the first wheat residue management studies in Manitoba to include a soybean test crop. The use of sensors for continuous data collection of moisture and temperature make a unique contribution to previous residue management studies in Manitoba. The inclusion of a fall rye cover crop as a residue management system that is not under organic management in Manitoba makes a unique contribution, as well.

Tillage is used to incorporate residue on the soil surface; therefore, it was expected that as the intensity of tillage increased, the level of surface residue ground cover would decrease. This trend was observed within the current study with the no-till treatments maintaining 84-94% surface residue ground cover while the tillage treatments were reduced to 12-48% surface residue ground cover. The range in percent residue ground cover is consistent with a residue management study conducted by Opoku and Vyn (1997) where only 10% residue ground cover remained after tillage in wheat stubble and no-till treatments had more than 60% residue ground cover in the spring.

A major finding of this study was to measure the relationship between spring soil moisture and soil temperature differences before and after soybean planting. One of the main reasons for tillage is to create a bare soil to dry the soil and allow for quicker soil warming in the

spring. We hypothesized that the disc treatment would have the lowest soil moisture and warmest soil temperature of all residue management treatments. This hypothesis was rejected since the disc treatment did not have the lowest soil moisture averaged across all site years and had a maximum soil temperature that was not different from the no-till residue management treatments. Horton et al. (1996) reviewed the effects of surface residue ground cover on soil moisture and soil temperature. The researchers noted that as the level of crop residue decreased, soil moisture decreased, and the rate of soil warming increased. Within the current study, the slight increase in the percent residue ground cover for disc treatment compared to the strip till (in-row) treatment increased soil moisture slightly and decreased soil temperature to values that were similar to no-till residue management treatments.

At two out of three site years, the surface residue ground cover was greater than 40% for the disc treatment, possibly contributing to the rejection of our hypothesis. A limitation of this study was not decreasing the surface residue ground cover to less than 30% within the disc treatment, the threshold for conservation tillage, at all site years to determine the effect of a bare soil on soil properties. The slow speed of tillage equipment in a small plot research setting may have contributed to not achieving a reduction of surface residue ground cover to less than 30% within the disc treatment. The typical small plot dimension of 2 m wide x 8 m length was adjusted to 18 m wide x 8 m length in this study to accommodate the width of some larger tillage equipment and allow for any snow capture differences that may occur between residue management treatments. The plot length should have also been adjusted in this study to allow tillage equipment to reach proper operating speed over a longer distance which was not often achieved in an 8 m length plot. It is difficult to determine what the implications were for the relative slow operating speed of tillage equipment within this trial; however, future research

should increase the plot length to achieve optimum operation of tillage equipment or consider an on-farm research method that utilizes farmers fields, tillage equipment, and operating speeds.

If the use of tillage is necessary to create a uniform seedbed at planting, strip till is a management option that provides targeted tillage in the seed row while leaving the remaining soil between the seed row undisturbed. Early planting can be achieved with strip till due to the soil warming properties of the tilled portion of the strip and the trafficability of the undisturbed soil between the strips. The in-row portion of strip till had a significantly drier soil and often had the warmest soil temperature during the day compared to all other residue management practices. This trend was also observed before planting soybean into corn stubble by Walther (2017) when comparing strip-till to disc and vertical tillage in Manitoba.

Manitoba has a greater potential for excess moisture during the spring compared to drought conditions, especially in the Red River Valley; therefore, tillage is often used as a tool to manage excess moisture (Bedard-Haughn, 2009). We hypothesized that a fall rye cover crop would reduce the volumetric water content of the soil before planting soybean due to the transpiration of water by the cover crop compared to other treatments. This hypothesis was rejected since the fall rye cover crop had a volumetric water content that was either the same or higher than the no-till and disc treatments at the time of planting for all site years. This observation is consistent with previous cover crop research in Manitoba which did not document a significant reduction in spring soil moisture from winter cover crops compared to tillage under normal or excess moisture conditions (Podolsky et al., 2016; Evans et al., 2016). However, a reduction in soil moisture by a fall rye cover crop has been observed by Flood and Entz (2018) under drought conditions in Manitoba. It can be concluded that cover crops are as effective as

tillage for managing soil moisture without the use of tillage, while still providing the benefits of a no-till seedbed.

The economic research question of this study was: how does residue management treatments impact soybean seed yield? We hypothesized that as the level of surface residue ground cover increased, soybean yield would decrease. This hypothesis was rejected since there was no effect of residue management on soybean yield in 2015, and when a yield response was observed in 2014, the tall stubble treatment had one of the highest soybean yields and highest residue ground cover ratings. These results suggest that yield response was not related to percent residue ground cover in this study.

It is unclear why a soybean yield response was observed at Carman14 and not at Carman15. Soybean establishment was worse at Carman14 compared to Carman15; an average of 63% of seeds emerged in 2014 compared to 81% of seeds emerged at Carman15 averaged across all residue management treatments. The seeding equipment used at Carman14 probably contributed to poor emergence at this site year; however, the final plant population for residue management treatments were not significantly different from one site year to the next. Soil moisture trends were observed between residue management treatments at each sampling date but were not significantly different between site years. Soil temperature trends at 5 cm were observed between residue management treatments the day after planting between site years but are not consistent with the yield observation trends. Therefore, it may not be just one factor that contributed to the yield difference observed at Carman14, but possibly many factors combined that had an influence on soybean yield. The interaction of all variables combined was not within the scope of this study, and a conclusion cannot be drawn.

Overall, this research demonstrated that wheat residue management treatments that do not rely on tillage can have little to no effect on soybean establishment and yield compared to conventional tillage on loam soils in south central Manitoba. The tall stubble treatment often had similar results to the disc treatment and was considered superior to the short stubble and fall rye treatments. The wheat residue management treatment that was the most consistent and often the most superior for all variables observed within this study was the strip till treatment. Farmers who want to reduce tillage before growing soybean in Manitoba but do not want to eliminate tillage from their residue management system should consider strip till as a viable option to replace conventional tillage.

Cover crop research is limited in Manitoba. The majority of cover crop research in Manitoba has been conducted under organic management, and there is further need to investigate the challenges and success of shoulder season cover crops in conventional cropping systems in Manitoba. Based on this study, the use of a fall rye cover crop before planting soybean in Manitoba can be successful. However, further research is needed to determine the effect of cover crops on different soil types and growing conditions through out the province of Manitoba before full adoption is considered.

In the current study, soybeans were planted into warm soil conditions that were within the normal planting range in Manitoba. Further research is needed to assess these residue management treatments with an early planting date and cold soils. Residue management treatments in this study were tested on a loam soil texture and additional testing is needed on all major soil textures in Manitoba, especially the heavy clay soil texture in the Red River Valley. Trial locations need to follow the adoption of soybean into western Manitoba where the challenge of a short growing season and cold soil is greater than the current trial locations. Also,

to fully determine the effects of planting soybean into a no-till residue management system, this experiment should be established on a field that has been under no-till management for more than a year as the level of surface residue may be higher and have a greater effect on soil properties and arbuscular mycorrhizal fungi. Additionally, further cover crop research is needed to determine the long-term benefits or limitations of using a cover crop under the short growing season conditions experienced in Manitoba.

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7. APPENDICES

Table 7.1 The effect of wheat residue management treatments on percent survivability of the seeding rate at Carman14, Carman15, and Melita15.

	Site Year		
Treatment	Carman14	Carman15	Melita15
	---------------- % survivability of seeding rate ----------------		
Disc	50 **bc**	66 **abc**	66 **b**
Strip till	76 **a**	73 **a**	74 **a**
Tall stubble	56 **b**	70 **ab**	64 **b**
Short stubble	50 **bc**	64 **c**	63 **b**
Fall Rye	43 **c**	64 **bc**	70 **b**

†Means within a column followed by a different letter are significantly different at *P*<0.05 according to Fisher's LSD.

Table 7.2. The effect of wheat residue management treatments on soybean emergence 10 days after planting (DAP), 15 DAP, and 21 DAP at Carman14, Carman15 and Melita15.

	Carman14			Carman15			Melita15		
	10 dap	15 dap	21 dap	10 dap	15 dap	22 dap	10 dap	15 dap	21 dap
Treatment	--- plants m^2 ---								
Disc	15 **b**†	28 **bc**	28 **b**	12 **b**	22	26	7 **ab**	42 **ab**	44
Strip till	34 **a**	42 **a**	37 **a**	16 **a**	25	27	16 **a**	43 **a**	45
Tall stubble	19 **b**	31 **b**	31 **ab**	11 **bc**	24	28	5 **bc**	40 **b**	45
Short stubble	14 **b**	26 **bc**	31 **ab**	4 **d**	24	26	2 **c**	41 **b**	46
Fall rye	13 **b**	23 **c**	25 **b**	7 **c**	23	26	14 **a**	40 **b**	43
P>F	<0.0001	<0.0001	0.0115	<0.0001	0.0754	0.4445	<0.0001	0.0086	0.1288

†Means within a column followed by a different letter are significantly different at *P*<0.05 according to Fisher's LSD.
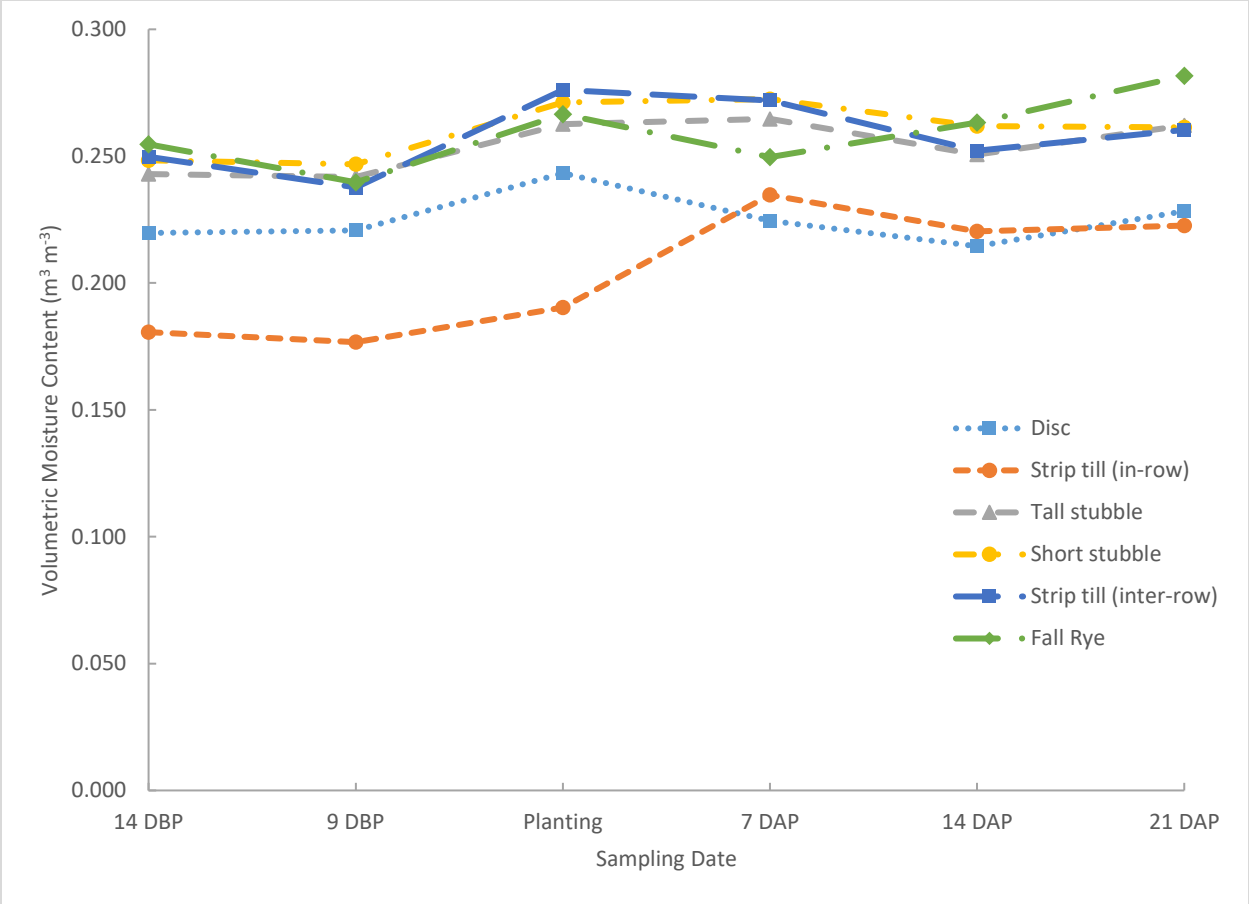
Figure 7.1. The effect of wheat residue management treatments on volumetric moisture content at 5 cm from 14 days before planting (DBP) until 21 days after planting (DAP) averaged from Carman14, Carman15, and Melita15.
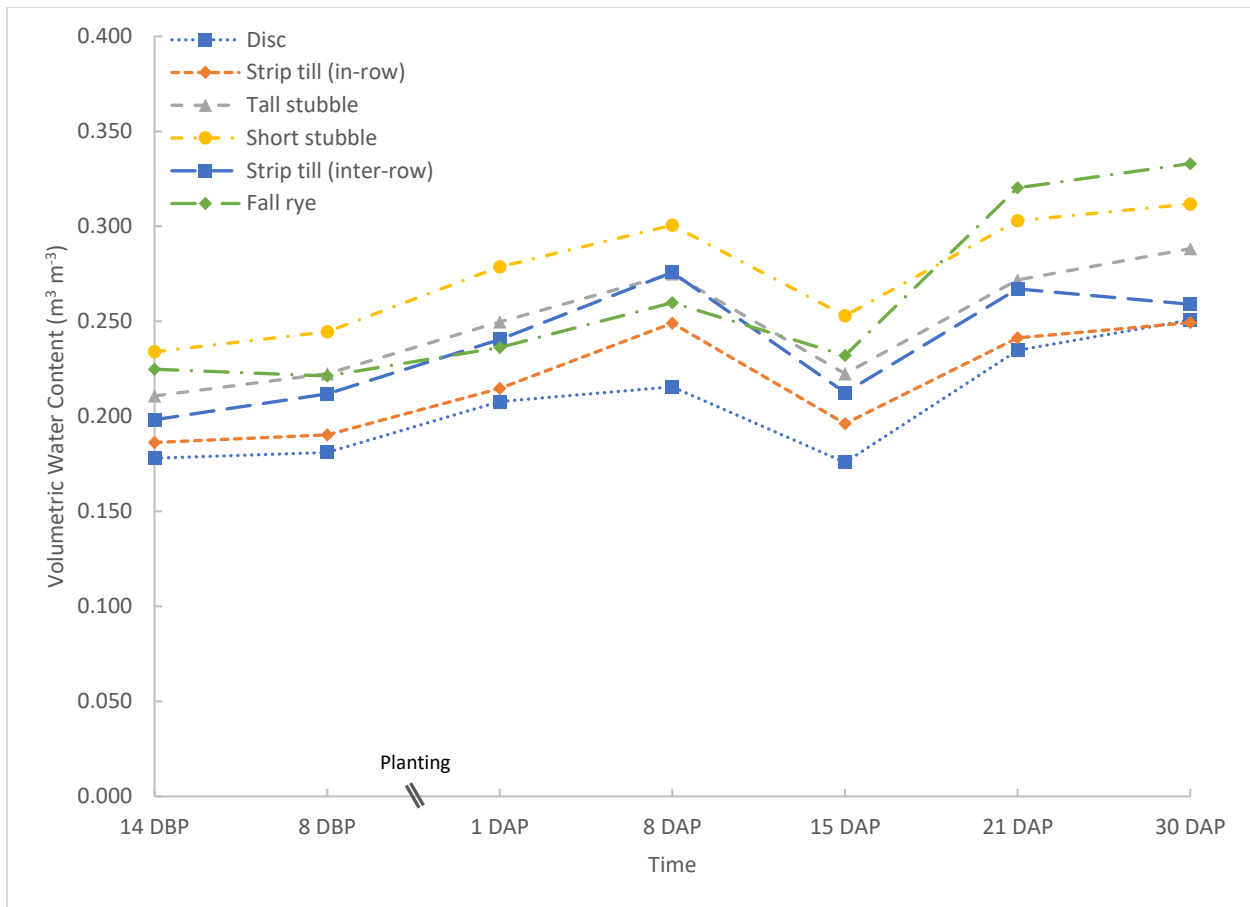
Figure 7.2. The effect of wheat residue management treatments on volumetric moisture content at 5 cm from 14 days before planting (DBP) to 30 days after planting (DAP) at Carman14.
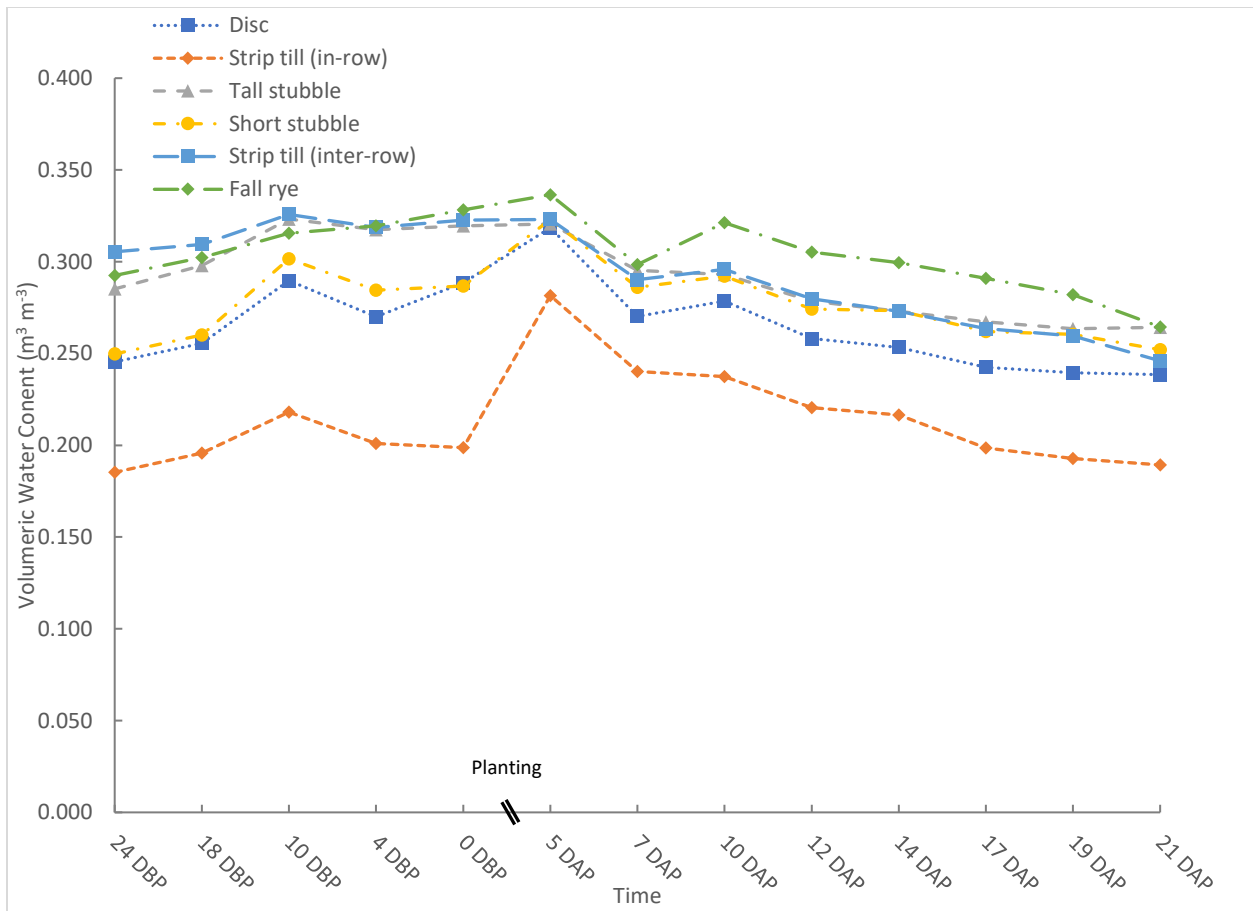
Figure 7.3. The effect of wheat residue management treatments on volumetric moisture content at 5 cm from 24 days before planting (DBP) and to 21 days after planting (DAP) at Melita15
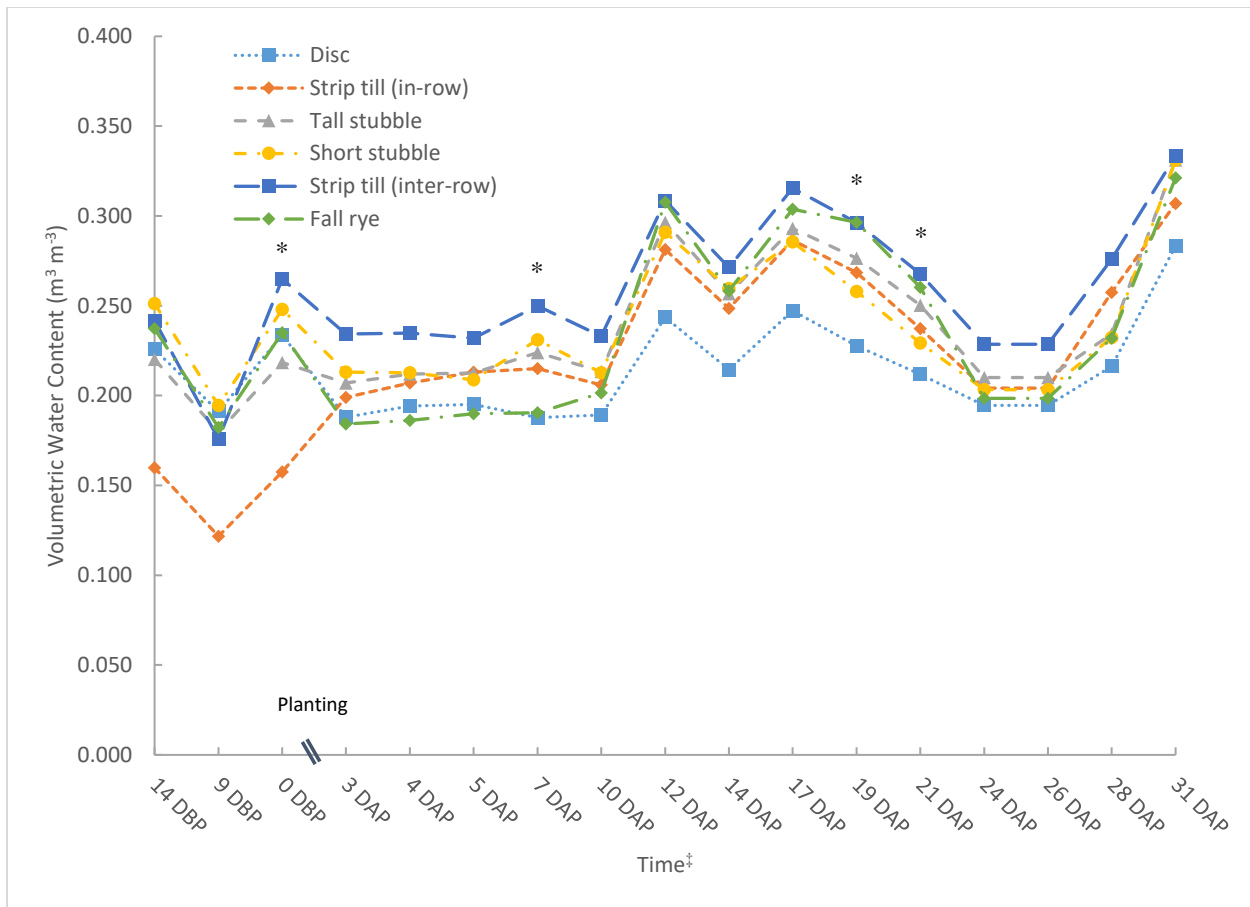
Figure 7.4. The effect of wheat residue management treatments on volumetric moisture content at 5 cm over the period from 14 days before planting (DBP) to 31 days after planting (DAP) at Carman15. Sampling dates with a * contain significant treatment differences at *P<0.05* according to Fisher's LSD for that sampling date.