CORN (*ZEA MAYS L.*) RESIDUE MANAGEMENT FOR SOYBEAN (*GLYCINE MAX* L.) PRODUCTION: ON-FARM EXPERIMENT

BY

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ABSTRACT

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The large amount of corn residue left after harvest is associated with challenges for farmers growing corn in Manitoba. This project looks at the impact of different tillage equipment to manage corn residue on soybean and soil conditions.

The experiment was set up as an on-farm trial in four locations in Manitoba on sandy soils. Four tillage practices were compared: 1) conventional double disc; 2) vertical till high disturbance; 3) vertical till low disturbance and 4) strip till.

Differences in soil temperature and moisture as a result of residue management treatments did not lead to significant differences in soybean emergence and final plant stand in three out of four site-years. At harvest, soybean grain yield did not vary significantly among treatments ($p=0.6267$, CV 6.65%) in all site-years. Economic analysis identified significant time and cost savings for strip till compared to the other treatments.

Keywords: corn residue management, soybean, tillage, economics

1 INTRODUCTION

Manitoba is one of the most northern provinces in the continent of North America where corn *(Zea mays L.)* is commercially grown for grain. However, the growing season in Manitoba is short. Most parts in the Red River Valley and the escarpment area (former shoreline of Lake Agassiz) in Manitoba have a frost free period of 115 to 125 days (Government of Manitoba, 2016a). Corn requires 110 to 120 days after planting to reach full maturity. The risk of not reaching full maturity in time before a killing frost or drying before snowfall therefore exists and high drying cost for the harvested grain can occur (Government of Manitoba, 2016a). This might be one of the reasons that corn hectares have been stable for the last 5 years in Manitoba. In 2016 the province of Manitoba reported 139,600 ha of corn seeded which accounts for 2.4% of its total seeded hectares (Statistics Canada, 2016). In the neighbouring state of North Dakota, 14.7% of the land (1,146,000 ha) was seeded with corn in 2016 (USDA, 2016). This indicates that the adoption of corn in Manitoba is very low. However in recent years, the seed industry in Manitoba has announced substantial investment into developing short growing season corn varieties for western Canada (DuPont Pioneer, 2013, Monsanto, 2013). These new hybrids should be suitable for the short growing season condition in Manitoba and therefore corn may become more abundant in Manitoba. However, even if industry does succeed in breeding adapted corn for short growing seasons like Manitoba, the introduction of corn into the rotation in Manitoba will come with other agronomic challenges that could cause problems for the following crop.

Corn leaves an excessive amount of residue behind after harvest compared to other crops in the Northern Great Plains. Research has shown that corn residue itself is hard to decompose due to its high C/N ratio (Beyaert and Voroney, 2011). Corn residue can therefore create problems for the following crop and its seedbed preparation by hindering the seed-soil-contact (Beyaert and Voroney, 2011, Markowski, 2013). This is a challenge for farmers interested in growing corn in the shorter growing season areas of Manitoba and has the potential to impede the proposed expansion of corn in Manitoba. These problems can be overcome by tillage (Randall, et al., 2002).

Many different tillage tools exist for corn residue management. Conventional implements such as double disc have a slow working rate compared to newer equipment. Lower surface residue after tillage results in the potential for the soil to warm up faster (Gauer, et al., 1982, Gupta, et al., 1984). This can be advantageous but at the same time leaves the soil prone to wind erosion (Triplett and Dick, 2008). Reduced tillage systems are an intermediate option between no till and conventional till. They might alleviate the problem of soil erosion while insuring soil warming. Many different tillage implements that allow for reduced tillage are available and the definition of a reduced tillage system is vague. Two implements capable of reducing tillage, vertical till and strip till, were used in this thesis. The vertical till implement was further subdivided into vertical till low disturbance as well as vertical till high disturbance. Vertical till and strip till gained popularity in the Northern Great Plains in recent years for many reasons (King, 2016, Lovell, 2017, Lyseng, 2014, Pearce, 2014a, Pearce, 2014b, Whetter, 2017). However, these two implements must be run at high working speed in order to function properly. These high speeds cannot be achieved in a small plot setting. On-farm trials were therefore necessarily.

Studies in Minnesota have shown that these newer tillage implements influence soil temperature and soil moisture (DeJong-Hughes, 2011, Nowatzki, et al., 2011). No data was found about soil temperature and moisture for Manitoba conditions. This thesis addressed this lack of information by collecting and analysing a unique continuous dataset of soil temperature and moisture which is discussed in in the Soil Chapter (see Section 4.1) in detail. Soil temperature and moisture have been shown to influence soybean emergence (Cox, 2016, Helms, et al., 1996a, Helms, et al., 1996b, Jones and Gamble, 1993) and are therefore key for growing soybean in this short growing season environment.

Soybean *(Glycine max L.)* is a major crop in Manitoba. In 2016, a total of 657,600 ha of soybean was seeded (Statistics Canada, 2016). Soybean is a warm season crop and requires 105 to 125 days to reach full maturity after planting (Manitoba Pulse and Soybean Growers, 2016). As soybean hectares are growing in Manitoba and soybean often follows corn in eastern Canada and in the USA, this thesis looked at the impact of different tillage equipment to manage corn residue on soybean. The influence of these tillage implements on soybean is discussed in the soybean chapter (see Section 4.2). Research that looked particularly at corn residue management for soybean production in Manitoba was not found in the literature. The scope of the literature review was therefore broadened to the Northern Great Plains. There is limited non-peer-reviewed literature conducted in the Northern Great Plains on corn residue management for soybean production. This research showed no significant differences in soybean yield among tillage treatments (DeJong-Hughes and Coulter, 2013, Stahl, 2011). However, this research was conducted further south than Manitoba where the growing season is longer. Research under Manitoba conditions is therefore needed.

Equipment evaluations by farmers are often driven by economics. As these trials were conducted on-farm it was important to include economics in this thesis. Replicated machinery measurements including fuel consumption, horse power requirement and draft loads for these newer tillage implements were not found in the literature. These measurements were therefore conducted in a separate on-farm field study. These measurements were then used to achieve more accurate tillage cost for an overall economic analysis of each tillage system. The economics chapter (see Section 4.3) described this separate field study as well as calculating the cost for these different tillage implements.

The objective of this study was to compare vertical till low disturbance, vertical till high disturbance and strip till with the standard tillage practice double disc to see the impact on:

1. Soil
2. Soybean
3. Economics

These objectives led to the overall hypothesis: Strip till achieves the same yield as the standard tillage practice double disc but can outperform all other tillage treatments in the overall economics due to lower total costs for preparing a seedbed for soybean production.

To test this overall hypothesis, several more detailed hypotheses were tested:

I. Residue ground cover is lowest in double disc followed by vertical till high disturbance, vertical till low disturbance and strip till.

II. Accumulated soil temperature at planting depth varies among treatments at the time of crop emergence.

III. Higher corn residue ground cover leads to lower accumulated soil temperature at emergence at planting depth.

IV. Soil moisture at planting depth was sufficient for soybean emergence in all treatments at the time of crop emergence.

V. Soil moisture uptake by soybean roots at rooting zone depth varies among corn residue management treatments after a rain event.

VI. The intensity of tillage influences soybean development stages such as emergence, flowering and maturing.

VII. The intensity of tillage influences soybean growth characteristics such as plant height, lowest pod height, and yield.

VIII. Fuel consumption, draft forces, and horsepower requirements vary among tillage treatments to manage corn residue.

IX. Differences in soybean yield, time required to conduct tillage operations, and tractor requirements will identify an economically optimal tillage implement to manage corn residue before soybean.

2 LITERATURE REVIEW

2.1 Scope of Literature Review

For many years spring wheat (*Triticum aestivum* L.) was the predominant crop in the Northern Great Plains (Padbury, et al., 2002). In recent years, corn and soybean crops have become more abundant in the Northern Great Plains. In Manitoba, corn and soybean hectares have double and tripled in the last six years, respectively (Statistics Canada, 2016). This was mainly driven by market prices, new early maturing cultivars and new available tillage equipment. However, the expansion of corn in the Northern Great Plains could be impeded for two main reasons: 1) Corn leaves a large amount of residue behind after harvest that is difficult to manage with current tools and 2) this residue can cause issues for seedbed preparation and emergence for subsequent crops. Observed low temperatures in a short growing season environment could also potentially influence the following crop. Fall and spring tillage is the management practice most commonly used to mitigate the problems of residue in order to create a good seed bed. Soybeans sometime follow corn in the rotation and therefore this thesis looks at the influence of different tillage equipment for corn residue management on soybeans within the context of crop production practices and rotations within the Northern Great Plains.

There is limited current research on corn residue management available specifically for Manitoba especially for newer tillage equipment such as vertical till and strip till. Therefore, this literature review focused on Manitoba when literature was available, but expanded the scope to the agroecoregion of the Northern Great Plains when a lack of information was present. The objective of this literature review is to understand the impact of tillage systems on the crop and soils, influence of the climate characteristics of Northern Great Plains on these differences, as well as challenges associated with corn residue and soybean production. The experiment conducted for this thesis did not include any no till treatment. No till was therefore not a main focus of this literature review.

The literature review starts by discussing the agroecoregion of the Northern Great Plains (see Section 2.2) and addresses different tillage systems as well as their impact on soil properties, decomposition and soil food web (see Section 2.3). Section 2.4.3 talks about tillage specifically for corn residue. It is followed by a general discussion about corn (see Section 2.4) and soybean (see Section 2.5) including why corn residue is hard to decompose and what the impacts of tillage on soybean phenology and morphology are. Section 2.6 looks at research that tried to assess specifically the impact of corn residue management on soybean. The last section looks at the economic analysis of different tillage treatments (see Section 2.7).

2.2 Northern Great Plains

The Northern Great Plains is characterized by long and cold winters and short but warm summers and is a continental climate. Large diurnal ranges in temperatures and unpredictable short rain events associated with intense thundershowers are also characteristics of the region. Precipitation ranges between 300 and 500mm annually with precipitation between April and July of 165 to 269mm. Frost-free period ranges from 93 days in Alberta to 157 days in North Dakota (Padbury, et al., 2002).

The Northern Great Plains consists of the Canadian provinces Manitoba, Saskatchewan, Alberta and north-eastern British Columbia as well as the United States South Dakota, North Dakota, Montana, parts of north-eastern Wyoming and north-western Nebraska, according to Padbury, et al. (2002). The USDA Economic Research Service farm resource regions include parts of Colorado and parts of Minnesota as well (Toliver, et al., 2012). It was suggested that the Northern Great Plains area should be further subdivided into 14 agroecoregions. Those agroecoregions are mainly distinguished by latitude, closeness to the Rocky Mountains, regional soil types and abundance of natural vegetation (Padbury, et al., 2002). A literature review about the influence of tillage on corn and soybean by DeFelice, et al. (2006) subdivided the United States into three regions Northern, Transition and Southern/Western. In this distribution the Northern Great Plains defined by Padbury, et al. (2002) would intersect with all three regions. Thus, the definition of the region “Northern Great Plains” is not straight forward. For this literature review the definition from Padbury, et al. (2002) is used with a special focus on Manitoba.

Manitoba can be further subdivided into different agricultural areas. While a period of 105-125 frost-free days is usual in the southern part of the province, the growing degree days and soil types vary across the province. The former glacial lake Agassiz has formed three broad areas of contrasting soil texture. First, the bottom of the lake, known as the area Red River Valley with mainly fine textured soils like clay. Second, coarse textured soils around the escarpment (former shoreline of Lake Agassiz) such as sand and loamy sand. And thirdly west from the lake medium textured classes like loam and silt loam (Ellis, 1938, Government of Manitoba, 1998). The southern area (Winkler) has growing degree days of 1100 to 1150 with a base of 10°C. Most parts in the Red River Valley and the escarpment (Haywood, MacGregor) have 1000-1050 and more northern areas have only 900-950 (Neepawa) (Government of Manitoba, 2016d). Total accumulated precipitation in most parts of southern Manitoba would be over 500m whereas precipitation that falls in the time period when corn is growing ranges between 250-290mm in most parts of southern Manitoba, with lower values (230-250mm) around Winkler and Carman (Government of Manitoba, 2016c).The available soil water at planting for wheat is lower and the moisture stress for corn at grain stage is higher west of the escarpment (Government of Manitoba, 2016e). It is therefore noticeable that the western part of the province is dryer in important stages of crop development compared to the Red River Valley.

2.3 Tillage

The main purpose of tillage is to prepare a seedbed for the following crop (Randall, et al., 2002). A seedbed should provide the seed with adequate soil contact to assure it can absorb enough moisture for it to emerge (Cox, 2016). Crop residue can hinder the seed-soil-contact by being pushed into the seeding slot, which can lead to “hairpinning” (Beyaert and Voroney, 2011, Markowski, 2013). Hairpinning can lead to poor and uneven emergence of the seeded crop. Furthermore, a seedbed cannot be too coarse as otherwise the seed might fall down in the soil pores and will not be placed at the right depth. These ideal seedbed conditions were in the past mainly achieved by tillage. However, it is also possible to achieve those conditions with the right seeding equipment and therefore to no(t)-till.

This section talks about conventional till, no till as well as reduced tillage with newer tillage equipment such as vertical tillage and strip tillage. It then talks about regional differences in tillage before it introduces the impact of tillage on soil properties, such as soil temperature and moisture. Lastly, it elaborates on the influence of tillage on decomposition, soil organic content and soil food web.

2.3.1 Conventional Tillage

In conventional tillage systems, soil is physically disrupted. The main purpose of this disruption is to create a favourable environment for plant establishment and growth. Not only does the soil pore volume increase, but also a mineralization of nutrients occurs. Tillage treatments create a soil without any vegetation, facilitating emergence for the following crop. The burial of crop residues soil can help for weed control as well as lead to a faster warm-up of soil in spring. It also addresses the problem of hairpinning by residue. Among other methods for crop residue incorporation, mouldboard plough as well as chisel plough, double disc and ridge tillage are used as implements for tillage.

As Food and Agriculture Organisation of the United Nations FAO (2000) and Lal, et al. (2007) reported, the plough was used widely around the world in the past and became a symbol of agriculture. In the last 25 years, however, farmers have changed their mind about conventional tillage. Land degradation, one of the major problems facing today's agriculture, is one main reason they stopped using ploughs. Mechanical ploughing, often to a depth of 25 cm, leaves the soil vulnerable to wind and water erosion. In the Northern Great Plains though, mouldboard ploughs are rarely used, one reason might be the high operating costs per unit area (USDA, 1998). Therefore conventional tillage in the Northern Great Plains is mostly conducted through more shallow implements such as double discing, cultivators or harrows.

In Manitoba, conventional tillage, such as double disc and cultivators, are the most common tillage implements. According to the latest census in the Red River Valley and the escarpment area around 85-99.7% of the crop fields are tilled (Statistics Canada, 2011).

2.3.1.1 Double Disc

A common conventional tillage implement is double disc. A double disc, also known as a tandem disc, is a piece of equipment that works the soil twice in one pass. Commonly it includes two sets of concave shaped discs that follow after each other. The first set of discs get pulled into the soil, due to the concave shaped disc that is combined with the forward directed force from the tractor (Figure 2.1). The shape of the disc causes the soil to flip (Figure 2.1). The second set of discs facilitate a better mixture of the soil and therefore a smoother seedbed by flipping the soil again (Figure 2.2). The soil gets worked to a depth of 10 cm. The machinery can be operated up to a speed of 9 km h^{-1} (Mak, 2016).

Figure 2.1: Conventional tillage with double disc. Concave discs cause slicing and flipping of the soil. Photo Credit: Patrick A. Walther

Figure 2.2: Conventional tillage with double disc. Two sets of concave disc following after each other to assure a good mixture of residue into the soil. Photo Credit: Patrick A. Walther

The process of slicing and flipping the soil requires high draft forces from the tractor to pull the implement through the soil which causes ultimately high fuel consumption per hectare (Šarauskis, et al., 2014). This often leads to high operating and fuel costs for conventional tillage systems.

2.3.2 No-till

In the 1960's, farmers in North and South America started experimenting with conservation tillage and even "no-till". After harvesting they left their fields with surface residues and planted the following crop with specially designed planters. These planters open a small slot in the soil, guide the seed into it, and close the slot again, the seed being placed underneath the protective layer of mulch and soil (Food and Agriculture Organisation of the United Nations FAO, 2000). A no-till planter needs to have sufficient down pressure on the coulters or openers. This is of particularly important in heavy soils. If there is a lot of residue present, trash cleaners (see Figure 2.3), trash whippers or coulters can be an advantage to reduce the problem of hairpinning and to insure proper depth control for the seed placement (Traut, 1990). Extensive research has contributed to the adaption of no-till in the Canadian Prairies and the Northern Great Plains and was summarized by Campbell, et al. (2001) and Lal, et al. (2007). No-till studies conducted before the mid 80's need to be looked at with caution as it was only after that time that these improved planters for no-till were available (Randall, et al., 2002).

Figure 2.3: Tash cleaners can mitigate the problem of hairpinning. Photo Credit: Patrick A. Walther

The adoption of no-till started in the 1970's in the Northern Great Plains, however due to economic, technical, political and social reasons it was only widely adopted in the 90's (Awada, et al., 2014).

No-till has advantages and disadvantages. Generally, it is observed that in no-till, nutrients as well as water are conserved within the soil by improved adsorption and infiltration of water. Furthermore, a study postulated that no-till could reduce soil organic matter loss, due to a slower decomposition of the residue on the soil surface (Holland and Coleman, 1987). However, the impact of no-till systems on soil health, decomposition rate and soil food web is complex and nearly immeasurable. Research in this area needs to be conducted over a long time, to assure equilibrium in the soil system has been reached.

No-till systems also have their disadvantages. Weed control is reliant on herbicides rather than tillage. Research in Manitoba showed that no-till decreased soil temperature and the speed of soil warming in spring (Gauer, et al., 1982). This is a major problem in areas such as the Northern Great Plains, where the growing season is short. No-till is not typically practiced in the Red River Valley and the escarpment area (see Figure 2.10) where corn production in Manitoba is currently most common.

2.3.3 Reduced Tillage

Reduced tillage systems are an intermediate form between no-till and conventional till and may alleviate the problem of reduced soil warming. Many different tillage implements are available and the definition of a reduced tillage system is vague. The following two sections introduce two specific tillage implements, vertical till and strip till. These two implements are used in reduced tillage systems. These two implements have recently gained in popularity across the Northern Great Plains as several newspaper reports show (King, 2016, Lovell, 2017, Lyseng, 2014, Pearce, 2014a, Pearce, 2014b, Whetter, 2017).

2.3.3.1 Vertical Tillage

Vertical till has its origin in no-till systems. No-till farmers in the US in the early 2000's saw increased problems with accumulating corn residue on the surface and therefore lower soil spring temperatures. The accumulation was mainly driven by higher yielding corn cultivars that produced more residue so that the decomposition process was not fast enough (Pearce, 2014a). A machine needed to be invented that enabled farmers to slice through this residue layer to facilitate better water infiltration as well as air exchange in the soil. The equipment needed to be able to cut the residue into smaller piece to increase surface area so that the decomposition process can be accelerated, as well as move some soil close to the residue. Out of those needs vertical till was invented (Lyseng, 2013, Pearce, 2014a).

The definition of vertical till gets used for many different implements and is therefore not straight forward. True vertical till is tillage without horizontal soil movement and it is most often soil tillage to a depth of 10 cm or shallower (North Dakota State University NDSU, 2011). The implement is designed to stir or ridge the soil without inverting the soil (Lyseng, 2013). This means the surface residue has minimal incorporation. Vertical tillage equipment may use discs or shanks to disturb the soil. The discs are straight or rippled and have spacing from 18 to 25 cm (Presley, 2013) (see Figure 2.4).

In practice implements that are creating horizontal soil movement and therefore incorporate residue are still called vertical till (Lyseng, 2013). Farmers refer to units with straight, rippled or concave discs but with a slight angle on the disc (6° disc angle) to be vertical till implements (see Figure 2.6). These implements are also known as high speed disc among some farmers. Others even consider deep ripping (>50 cm) with shanks as vertical till, as only vertical soil movement (Lyseng, 2013) occurs. An article published in “on farm equipment” in 2014 with the title “What is Vertical Tillage Anyway?” asked the major equipment producer to define vertical till (Kanicki, 2014). Only one thing was clear, and that was that a clear definition did not exist. This disagreement in the industry and among farmers about the definition of vertical till needed to be addressed in this thesis.

For the purpose of this literature review and thesis vertical till was subdivided into vertical till low disturbance (0° disc angle) (see Figure 2.4 and Figure 2.5) and vertical till high disturbance (6° disc angle, straight or concave disc) (see Figure 2.6 and Figure 2.7). No literature was available that distinguished between those two different implements specifically. Considering that these two implements have two different fundamental approaches in terms of residue incorporation, research is needed to define and distinguish these implements.

Figure 2.4: Vertical till low disturbance (0° disc angle). Residue gets cut into smaller pieces and some vertical soil movement is observable behind the discs. Discs evenly disturbed over the width of the machinery every 19 cm followed by three sets of harrows and a rolling basket (not shown). Photo Credit: Patrick A. Walther

Figure 2.5: Vertical till low disturbance (0° disc angle). Some soil movement is observable by comparing to the no-till to the right and left. Photo Credit: Patrick A. Walther

Figure 2.6: Vertical till high disturbance (6° disc angle, concave disc). The disc creates horizontal soil movement by flipping the residue. Two sets of discs followed by a harrow and a packer. Photo Credit: Patrick A. Walther

Figure 2.7: Vertical till high disturbance (6° disc angle, concave disc). The angle of the disc creates much more soil disturbance than in vertical till low disturbance. Photo Credit: Patrick A. Walther

Both vertical till low and high disturbance equipment can be operated at a high speed. The operating speed of 14 km h^{-1} is 1.5 times faster than that of a double disc. This fast operating speed was one reason that this machine gained popularity among farmers (Wehspann, 2014). Vertical till units are often equipped with harrows or packers following behind the discs to insure an even residue distribution.

There are other reasons why vertical till might have gained popularity. It was mentioned that vertical till is an option to prepare a seedbed into wet soils and to reduce the chance of diseases flourishing when the residue has been buried (Lyseng, 2013). Lyseng (2013) also stated that soil warmed up from 7°C in the morning to 21°C in the afternoon after a vertical till operation (Lyseng, 2013). Statistics for these statements were not provided. The impact of vertical till onto soil temperature is of great interest as soil temperatures are critical in the short growing season environment of the Northern Great Plains. Independent, randomized and replicated research that addresses the impact of vertical till on soil temperature is therefore needed.

2.3.3.2 Strip Tillage

Strip till is a combination of conventional tillage and no-till. The soil only gets tilled in small strips where the seed is planted later with another seeding pass. This requires GPS guidance on the tractor, preferably with real-time kinetic (RTK) capabilities that insures a 2 cm accuracy. The area between the seed rows is untouched and is therefore no-till. It is considered a reduced tillage system as more than 30% of the residue is left on the surface after the operation (DeJong-Hughes and Vetsch, 2007).

Strip till was called zone tillage in its early days in the 2000's. At that time zone tillage became popular in the US among agronomists, but struggled with several challenges it had to overcome before it could be widely adopted on a large scale in the Northern Great Plains. Zone tillage did not initially include fertilizer placement. At that time, fertilizer was broadcasted and incorporated for crops such as corn, but with zone tillage the fertilizer was only incorporated on a small portion of the field. Guidance systems on the tractor at that time where not accurate enough to replant into the strips. Accurate fertilizer placement for the subsequent crop during the tillage operation as well as RTK for greater positioning accuracy on the tractors lead to a breakthrough of the then called strip till machinery (Pearce, 2014b). Strip till became popular in the Northern great Plains mainly in Minnesota and Wisconsin at that time for farmers on lighter soil and marginal ground who were looking for better fertilizer placement (Pearce, 2014b).

Strip till equipment consists of several different components. It uses shanks, discs, coulters or harrows to till the soil to a depth of 15 to 30 cm. The area between the strips is left undisturbed. When needed, fertilizer can be placed into the strip. (DeJong-Hughes and Vetsch, 2007, North Dakota State University NDSU, 2011, Nowatzki, et al., 2011). The arrangements of the different components can vary between manufactures. However, a standard strip till arrangement would look as shown in Figure 2.8. First, a cutting coulter slices the residue. This cutting coulter is then followed by two trash cleaners that push the residue aside. Therefore, crop residues are not incorporated into the soil when using strip till. After the trash cleaners a shank is installed that pulls up the soil. Attached to the shank are the fertilizer tubes. Following the shank are two berming discs used to create a berm with the soil. At the end there is a rolling basket to break down the clods into smaller pieces.

Figure 2.8: Strip till consisting of a cutting coulter to slice the residue followed by two trash cleaners that push the residue aside. After the trash cleaner a shank is installed that pulls up the soil. Attached to the shank are the fertilizer tubes. Next to the shank two berming discs are installed to create a berm with the soil. At the end there is a rolling basket (not shown) to break down the clods into smaller pieces. Photo Credit: Patrick A. Walther

Figure 2.9: Strip till tills only a small strip and leaves the area in-between the shanks untilled. This unit consist of two fertilizer carts for granular (white) and liquid (turquoise) fertilizer placement. Photo Credit: Patrick A. Walther

Strip till has an operating speed between double disc and vertical till. The operating speed of strip till is around 10.5 km h^{-1}. It is therefore slightly faster than double disc, but slower than vertical till. However, strip till is a one pass system since both fertilizer and tillage is done in one pass even in high residue crops such as corn (see Figure 2.9). Whereas in double disc or vertical till a minimum of two passes in corn residue is required. Overall, this saves the farmer time when preparing a seedbed (Nowatzki, et al., 2011).

Advantages of strip till are that the fertilizer is placed precisely where the crop needs it, as well as being a one pass system (Pearce, 2014b). Both fertilizer and tillage are being implemented in one pass, whereas in a conventional setting these operations need to be done in separate passes. Furthermore, non-peer-reviewed research in North Dakota has indicated that the soil in strip till warms up faster compared to other tillage treatments (Nowatzki, et al., 2011). Research that looked at the influence of this temperature increase on crop emergence is not available and therefore needed.

2.3.4 Regional Differences in Tillage Systems

There are regional differences in tillage systems within the Northern Great Plains, between the United States and Canada and within Canada.

No-till is more abundant in the United States compared to Canada (Triplett and Dick, 2008). In 2000 about 22.3 million hectares were seeded no-till in the United States, summing up to 20% of the total crop land. In the same year only 4.08 million hectares were reported as no-till in Canada which is equivalent to 11% of the total land with crops (Statistics Canada, 2008). The Northern Great Plains area in the United States showed similar no-till adoption compared to the provinces Alberta and Saskatchewan in Canada. On 42% of the cropped land in the Northern Great Plains area in the United States no-till or strip till is used. Another 7% of the land is partially adopted, meaning that farmers use no-till or strip till on some of their land (Wade, et al., 2015). North Dakota shows a higher percentage under no-till and strip till compared to the neighbouring province Manitoba in Canada. In 2012 in North Dakota 36% of the land was under no-till, 28% under reduced tillage and 36% under conventional tillage (USDA, 2012). Unfortunately, no county data is available for a further subdivision into different soil type areas.

There are differences in tillage practices within the Northern Great Plains in Canada in tillage abundance. Since 1991, Saskatchewan reports the largest adoption of no-till over three provinces in Canada that are in the Northern Great Plains. Starting at 10% in 1991, Saskatchewan reported in 2011 that 70% of the crops are managed under no-till. Meanwhile, reduced tillage systems became less popular in Saskatchewan in that period (26% to 20%). Alberta reported slightly lower no-till adoption than Saskatchewan. Starting at 3% in 1991, 65% of the farmed area was under no-till in 2011. Reduced tillage systems stayed around 22% with slightly higher reported numbers in 1996 and 2001. Manitoba showed clearly the least adoption of no-till. Reduced tillage and conventional tillage were both reported to be practiced on 38% of the farmed area in 2011. In comparing the three provinces, Manitoba (38%) has the highest conventional tillage adoption compared to Saskatchewan 10%, and Alberta 13% (Dumanski, et al., 1994, Statistics Canada, 2006, Statistics Canada, 2011, Statistics Canada, 2012). However, the adoption of no-till in Manitoba is higher further west, as farmers try to conserve moisture due to lower precipitation.

Within the province of Manitoba there are substantial differences in no-till adoption. In the Red River Valley only 0.3-15% of the cropland area was under no-till, whereas the most westerns parts of the province have no-till on 15-60% of their fields (Figure 2.10) (Statistics Canada, 2011). The Red River Valley is characterized by heavy clay soils (Ellis, 1938). Heavy soils can be challenging for no-till, as reduced trafficability and the challenge of seedbed preparation in a heavy clay soil result in a shorter time window for field operations. One other possible explanation on the distribution of no-till adoption is that the western part of the province is dryer during critical grain filling stages (Government of Manitoba, 2016e) and crops experience more moisture stress. Therefore, farmers are using no-till to conserve moisture and increase yield.

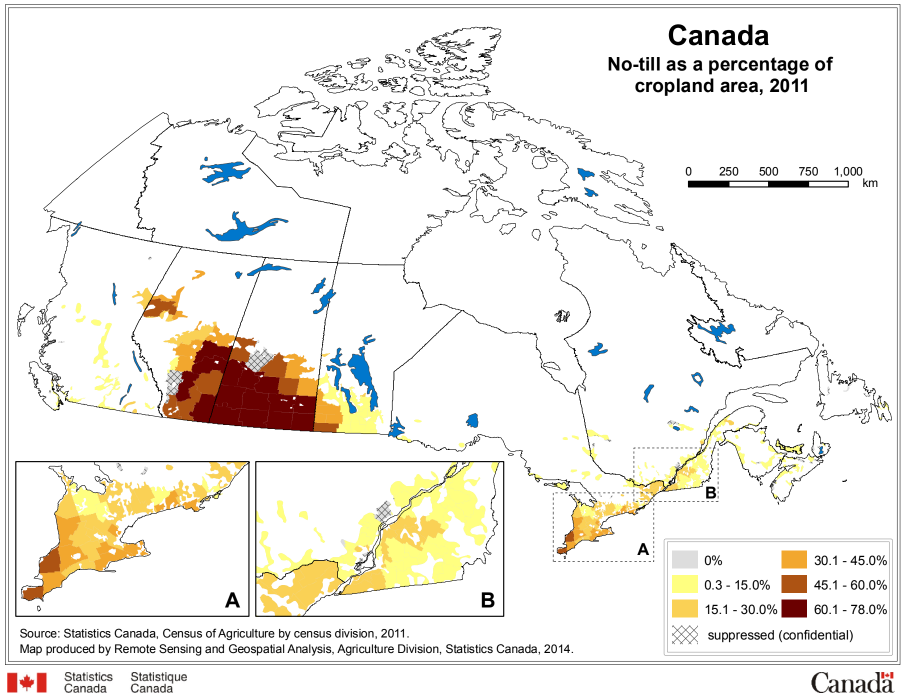

Figure 2.10: No-till as a percentage of cropland area in 2011 in Canada (Statistics Canada, 2011)

In the Northern Great Plains, strip till is used more in the United States than in Canada. Strip till does not appear in statistics in the Canadian provinces, whereas in the United States it is mentioned (Wade, et al., 2015). One may ask where these differences between US and Canada are coming from. One possible explanation is that the predominant crops in the Northern Great Plains in the US are corn and soybean, with the exception of North Dakota where wheat is more abundant (USDA, 2016). Corn and Soybean are often seeded as row crops in wide rows. Strip till was designed for row crops. In Canada on the other hand, wheat and canola are the most abundant crops (Statistics Canada, 2016). This likely one of the reasons why strip till is less prevalent in Canada (Zinkand, 2012) as the most common crops wheat and canola are often not seeded in wide rows (Canola Council of Canada, 2015). Although, interestingly when looking closely at the USDA statistics, the adoption of no-till and strip till was greatest in wheat fields. 63% of all wheat fields in the Northern Great Plains were reported as no-till or strip-till managed. That being said the statistics do not distinguish between no-till and strip till. Most likely most of the fields were managed under no-till as strip tilling wheat is less common (Wade, et al., 2015). Other sources for strip till abundance in the United States were not found. Statistics that break down the abundance of strip tillage, vertical tillage or double disc specifically, is lacking in Canada as well as in the United States.

2.3.5 Tillage Impact on Soil Properties

Even though tillage is mainly practiced for preparation of a good seedbed, it has many other influences on soil properties (see Section 2.3). This section reviews the influence of tillage on soil temperature and moisture, with an emphasis on tillage implements used in this study. This is of great importance in the short growing season of the Northern Great Plains (Gauer, et al., 1982).

2.3.5.1 Impact on Soil Temperature

Soil temperature varies by depth in a soil profile and with air temperature. Annual average soil temperatures to a depth of 30 cm are higher than air temperatures in the same time span (Stoller and Wax, 1973). Mean soil temperatures as well as their diurnal soil temperature amplitude both decrease with soil depth (Reid and Van Acker, 2005, Stoller and Wax, 1973).

Crop residue has an influence on average soil temperature as well as on the range in diurnal soil temperature change. A study of three different soils in Manitoba showed that soil temperatures under no-till were commonly lower than in conventional tilled fields during the entire growing season when the residue was left on the surface (Gauer, et al., 1982). However, during the coldest part of the day temperatures in no-till were usually equal to those under conventional tillage. The study also revealed that no-till and conventional tilled fields did not show any significant differences in soil temperature when residue was burned. between the treatments when burning the residue. This is in agreement with a study from Minnesota that showed soil temperature is much more sensitive to residue than to tillage treatments (Gupta, et al., 1984). This leads to the conclusion that crop residue is one of the main factors responsible for temperature differences in tillage experiments.

Crop residues influence solar transmittance and albedo. A lower solar transmittance leads to less radiation on to the soil surface. Studies showed that residue reduced the solar transmittance and increased shortwave albedo (Horton, et al., 1996, Teasdale and Mohler, 1993). The latter means that more shortwave radiation is reflected from the soil back into the atmosphere. The insulating effect of residue increases the resistance for heat and vapour transfer from soil to air, resulting in lower soil temperatures. Shen and Tanner (1990) reported that if the residue layer thickness increased the percentage of radiation that can be transmitted through it decreased. Several studies have shown that no-till fields warm up more slowly at the beginning of the season compared to conventional tilled fields (Fabrizzi, et al., 2005, Johnson and Lowery, 1985).

Soil temperature is affected by residue and tillage in the cold growing region of Manitoba. A study in Manitoba with fall tillage treatments reported that soil temperatures at a depth of 5 cm at the end of April were 1–2°C lower in treatments that had some residue left on the surface compared to tillage treatments that had no residue left over wintertime (in Bullied, et al., 2012, Friesen and Bonnefoy, 1972). Another study in the Interlake area of Manitoba showed differences in mean daily temperatures at 4 cm around June between spring tillage and no spring tillage in 3 out of 4 site years (Reid and Van Acker, 2005). However, the differences were less than 0.5°C with inconsistent trends. No differences in moisture content were reported.

Strip till showed similar soil temperature in the early season to conventional tillage systems. On-farm research showed that strip till soil was slightly warmer during the day time peak than soil treated with a disc ripper, which can be considered as conventional tillage (DeJong-Hughes, 2011). Strip till soil between the rows was always colder than soil under a disc ripper or mouldboard plough treatment. However, strip till soil in the row showed similar temperature to soil under a disc ripper. Research in 2006 and 2007 showed the same pattern in a continuous corn rotation for strip till, disc ripper and mouldboard plough (Nowatzki, et al., 2011). Both of these strip till experiments were conducted in Minnesota, which is not considered part of the Northern Great Plains but is within close proximity of Manitoba. Research with strip till in North Dakota showed similar soil temperature effects with strip till in the row compared to soil under a chisel plough but warmer temperatures than soil under no-till and vertical till (Langseth and Daigh, 2016). However, no statistical analysis was provided nor was it specified when those differences occurred. However, this was also the only trustworthy literature that was found about vertical tillage.

Replicated research in the Northern Great Plains that linked soil temperature with soybean emergence was not found. Soil temperature in the literature was only discussed on a qualitative basis or linked to emergence as estimated by regression equations (Gauer, et al., 1982). For example *"If your morning air temperature is 10°C and your soil temperature is 7°C… if you work that field with your vertical till machine to get some air movement, the soil will be 21°C by early afternoon and you can go seeding " (Lyseng, 2013).* This approached overlooks the natural diurnal temperature pattern that results in the typical temperature increase from morning to afternoon. Alternative approaches to quantify the accumulated soil temperature differences, such as growing degree hours (GDH) (Cardillo, 2014) are needed. Research that used this approach to evaluate differences between tillage systems was not found. This approach might have potential to link soil temperature with the agronomic issue of crop emergence. The research should include strip till and vertical till as these implements are gaining of importance in the Northern Great Plains (King, 2016, Lovell, 2017, Lyseng, 2014, Pearce, 2014a, Pearce, 2014b, Whetter, 2017).

2.3.5.2 Impact on Soil Moisture

No-till fields have higher moisture contents than tilled fields. Higher moisture contents up to a depth of 60cm during early and mid-season growth in no-till fields were reported in several studies (Blevins, et al., 1971, Borstlap and Entz, 1994, Enz, et al., 1988, Gauer, et al., 1982, Triplett and Dick, 2008). A study in Manitoba showed that whether the residue was removed or not, soil moisture was higher in no-till fields compared to conventional tilled fields (Gauer, et al., 1982). Studies suggested that these differences come from the stubble. Stubble can increase water use efficiency by decreasing evaporation and surface runoff. Stubble also increases infiltration and the amount of snow that gets trapped over winter time (Blevins, et al., 1971, Gauer, et al., 1982, Jones, et al., 1969, Moody, et al., 1963).

Strip till fields also have higher moisture content than conventionally tilled fields. Research in North Dakota showed that strip till has the ability of storing more moisture later in the growing season compared to conventional systems (Nowatzki, et al., 2011). This research also indicated that it has a higher water infiltration rate than a full tilled field. This is in agreement with Hares and Novak (1992) and Endres and Hendriks (2010) who report that strip till is a useful tool in the Northern Great Plains to conserve soil moisture. The mulch strip conserves moisture while the black strip should warm up faster and provide a good seedbed. Langseth and Daigh (2016) also reported higher soil moisture content for strip till between the row at 29% compared to chisel plow with 19%. Strip till in the row was 18%, the driest of all the treatments.

Vertical tillage showed moisture contents between strip till between the row and chisel plow. Vertical tillage showed 25% compared to no-till with 32% (Langseth and Daigh, 2016). Test of statistical significance were not provided. Other research showed no significant differences in volumetric soil moisture content between vertical till, no-till and double disc (Presley, 2013). However, the statistical analysis method to find differences among treatments was unclear.

Water infiltration rate studies showed no consecutive trend between different vertical tillage implements, no-till, and double disc (DeJong-Hughes, 2011, Presley, 2013).

2.3.5.3 Interaction between Soil Temperature and Soil Moisture

Residue has only a minor influence on soil temperature when soils are wet. Under wet conditions most of the solar radiation is used to evaporate water. When soils are drying out, the energy from the solar radiation begins to manifest as differences in soil temperature (Horton, et al., 1996). This is in accordance with other findings that showed that soil temperature is affected by soil moisture. A study by Bristow (1988) reported similar diurnal soil temperatures at 2.5 cm when soils are wet and a rapid increase of fluctuation when soils dry out in a no-till mulch (Bristow, 1988, in Bullied, et al., 2012).

The effect of soil temperature and moisture on emergence is complicated. A study showed that emergence is interrelated with light, soil temperature and soil moisture (Egley, 1986). Laboratory experiments with weeds have shown that temperature and moisture have a highly significant interaction effect on emergence (Erivelton, et al., 1999).

Research indicated that soil temperature is influenced by residue when soils are dry. Higher soil moisture contents were observed in no-till fields compared to conventional. Limited research is available that has repeated and randomized soil moisture and soil temperature data for the Northern Great Plains for different tillage implements. No research was found for the Northern Great Plains that linked soil temperature with soybean emergence. Research is needed, as the cold and short season in the Northern Great Plains is a key factor in emergence. Therefore, factors that are influence emergence need to be studied.

2.4 Corn

In this section, the current distribution of corn production in the Northern Great Plains will be reviewed along with the potential expansion of production currently proposed by the seed industry. This section will then address the production issues that accompany the inclusion of corn in a crop rotation, with the focus on corn residue management. The last section identifies knowledge gaps in the current best management practices for corn residue management in the Northern Great Plains.

2.4.1 Corn Abundance

Historically, drought resistant and short season crops like wheat were seeded on the Northern Great Plains. Since the introduction of conservation tillage systems, the production higher water use crops, such as corn and soybeans, has increased as well (Dumanski, et al., 1994). However, the abundance of corn varies across the Northern Great Plains. In 2016, the most western province of Alberta reported only 10,100 ha of corn seeded whereas Saskatchewan reported none. Manitoba on the other hand had 131,500 ha of corn seeded (Statistics Canada, 2016). In the same year North Dakota reported 1,416,450 ha of corn seeded (USDA, 2016). This clearly shows that the abundance of corn varies across the Northern Great Plains.

One reason for the difference in seeded area is the requirement for a long growing season and that is where the industry sees potential for expansion in the production area for corn. Monsanto announced in 2013 that they would be investing $100 million over the next 10 years to develop early maturing corn varieties that are suitable for the Northern Great Plains in Canada. Their goal was to expand the area of corn seeded in 2025 by 20 times, resulting in 4 million hectares (Monsanto, 2013). DuPont Pioneer sees similar potential and invested $2 million into a research facility in Carman, Manitoba to facilitate the wide establishment of corn in western Canada (DuPont Pioneer, 2013).

Early maturing corn varieties alone, will not solve all the problems that a farmer faces when including corn in a rotation. A production package for growers is needed otherwise the adoption of corn might not be as desired (Friesen, 2014). The package must include methods of how to manage the residue after harvesting the crop. Therefore, the next two sections explain why corn residue in particular is a challenge.

2.4.2 Corn Residue

Corn produces more residue than other crops. This results in an excessive amount of dry weight (5500 kg/ha) on the surface after harvesting, relative to other crops grown in the Northern Great Plains (Beyaert and Voroney, 2011). In comparison, soybean produces around 2900 kg/ha of residue, whereas wheat is closer to 3200 kg/ha (Beyaert and Voroney, 2011). This means that corn leaves over 1.5 times more residue behind than wheat or soybean after harvest (Beyaert and Voroney, 2011). This figures originate outside of the Northern Great Plains in southern Ontario. The actual amounts might have to be adapted for the Northern Great Plains. Other factors that influence the decomposition process of corn residue must also be considered.

Different crops leave different residues on the field, thereby creating unique environments following each crop with regards to both the larger chemical composition and the nutrient composition (Berg and McClaugherty, 2014). Lignin, is an example of a substance whose concentration varies between plant species and is known to slow down decomposition of plant residues (Berg and McClaugherty, 2014). In the initial phases of decomposition, easily degradable carbohydrates are decomposed first by the microbial community. The microbial community then needs to change in order to degrade lignin. The complex polymer structure of lignin is mainly degraded aerobically by specialized fungi (Kirk and Farrell, 1987).

Three factors are often used for modelling the decomposition of corn residue. Eldor (2007) explained that decomposition models often quantify the decomposability of soil inputs based on their carbon to nitrogen (C/N) ratio, their N content and the concentration of the resistant material such as lignin or chitin. Interestingly, the residues of wheat (*Triticum aestivum* L.), soybean (*Gylcine max* L.), rye (*Secale cereal* L.), tobacco (*Nicotiana tabacum* L.) and corn (*Zea mays* L.) show similar lignin contents (Beyaert and Voroney, 2011) (see Table 2.1). The plant's residue composition partitions into a pattern that is close to one third cellulose, one third hemicellulose, one sixth lignin, and one sixth hot water soluble material. However, the C/N ratio varies considerably between those crops. The C/N ratio in corn (62.3) is about 20 units higher than soybean residue (36.8) (Beyaert and Voroney, 2011).

Furthermore, the management practices for subsequent crops in the rotation can also influence the decomposition process or corn residue. As soybean varieties are planted earlier in the Northern Great Plains the amount of time for corn residue to break down in the environment before seeding of the subsequent crop is shorter. This can increase the potential nitrogen deficiency of subsequent crops as these residues tie up soil nitrogen for the decomposition process (Vanhie, et al., 2015).

Table 2.1: Dry weight, C/N ratio, and chemical composition of wheat, soybean, rye, tobacco and corn in southern Ontario (adapted from Beyaert and Voroney (2011))

Crop residue	Dry weight	C/N Ratio	Hot water soluble	Lignin	Hemicellulose	Cellulose
	g m^{-2}		%	%	%	%
Wheat	339	42.4	10.2	16.2	35.2	38.4
Soybean	332	36.8	25.1	14.0	21.8	39.1
Rye	267	68.2	8.6	16.8	33.4	41.2
Tobacco	131	34.8	36.9	9.8	25.6	27.7
Corn	575	62.3	11.8	14.5	35.9	37.7

Newer corn hybrids can aggravate the issue of slow residue decomposition. Corn hybrids with better disease and insect tolerance such as Bt-corn cultivars have increased yield. As harvest index stayed the same, these hybrids produce more residue (Tollenaar and Lee, 2006, Vanhie, et al., 2015). A literature review study of corn in North American found contradictory results about the lignin concentration of BT-corn (Yanni, et al., 2010). Some studies showed higher lignin concentration in BT-corn and assumed therefore decomposition would be slower while other studies showed no differences in lignin concentration between BT-corn and conventional. In a later study, the same authors of the literature review concluded that there was no difference in lignin content from non BT-corn and BT-corn. However, they showed faster decomposition of BT-corn stems compared to non BT-corn (Yanni, et al., 2011) indicating that BT should be included when looking at decomposition.

In the 90's "Stay Green" varieties were introduced into corn hybrids. These hybrids have the ability to retain green leaf with a later senescence of leaves. The delayed dry-down of corn stalks for stay-green varieties helped to increase corn yields (Thomas and Smart, 1993). However, the stalks are harder to decompose for soil microorganisms as plants stay longer green (Ferraretto and Shaver, 2015, Pearce, 2014a).

These challenges (amount of residue, C/N ratio, immobilized soil nitrogen and BT-traits) of corn residue are often overcome by burying the residue with tillage. A tillage study conducted outside of the Northern Great Plains, in eastern Canada, showed that corn residue that was buried in November at a depth of 5 cm lost roughly 35% of its initial mass by May with an additional 50% by June, and 75% by October (Burgess, et al., 2002). It was also found that residue left on the soil surface lost mass more slowly throughout the year independent from the tillage treatments (no-till, reduced till and conventional till) compared to buried residue at 5 cm. Buried residue in no-till compared to buried residue in conventional till were not significantly different from each other most of the time. Surface placed residue in no-till decomposed significantly slower compared to surface residue in conventional till (Burgess, et al., 2002). This suggests that the decomposition rate is mainly dependent on contact with soil. In this study, other soil conditions such as soil temperature, soil moisture or composition of the soil food web present in those tillage treatments seemed to have a minor influence compared to seed soil contact.

The question therefore for a farmer is what kind of tillage should be used to accomplish an optimal seedbed for the following crop in corn residue. Therefore, the next section focuses on best management practices for corn residue to achieve an optimal seedbed.

2.4.3 Best Management Practices Specifically for Corn Residue

Double disc, vertical till, strip till or no-till are only four out of several equipment options and combinations that can be used for corn residue management. However, only a few production guidelines for corn residue management are available to growers in the Northern Great Plains or Manitoba. The University of Minnesota, although not included as part of the Northern Great Plains, seems to be one of the only sources with available information. They have a guide called Tillage Best Management Practices for Corn-Soybean Rotations in the Minnesota River Basin (Randall, et al., 2002). They suggest that even in continuous no-till systems, some surface residue disturbance with tillage after corn might be helpful to achieve consistent yields. They have observed a slight yield penalty could be possible in continuous no-till corn. Strip till, ridge till and double disc are also suitable possibilities for corn residue management. Mouldboard plow had the same yield potential as the other treatments, however not enough residue was present to minimize erosion risk (Randall and Vetsch, 2005). North Dakota State University has an information brochure regarding strip till and states it is a viable option for corn residue management (Nowatzki, et al., 2011). Manitoba Agriculture, Food and Rural Development and the two grower associations, Manitoba Corn Growers Association and Manitoba Pulse and Soybean Growers Association, have no recommendation about tillage after corn harvest for soybean production. This illustrates that there is limited information available for a farmer in terms of best management practices for corn residue, especially for the newer tillage implements, such as vertical tillage and strip tillage, included in this study. There is also a need for a complete production package to support the continued expansion of these two crops in the Northern Great Plains (see Section 2.4.1).

2.5 Soybean

This thesis is about corn residue management. However, corn residue causes significant challenges for the subsequent crop. In the Northern Great Plains soybean often follows after corn in rotation (Dumanski, et al., 1994, Vanhie, et al., 2015, Wade, et al., 2015). Soybean have gained importance in Manitoba in recent years and production area is predicted to continue growing. Therefore this section reviews the abundance of soybean in Canada and then introduces the concept of soybean staging.

2.5.1 Soybean Abundance

Soybean production has seen a rapid increase in seeded hectares since the 2000's in Manitoba. The introduction of herbicide resistant soybean in the early 2000's and positive net revenue from 2007 has lead to a four-fold increase of soybean hectares from 2000 to 2007 to 87,000 ha in Manitoba (Beckie, et al., 2006, Kubinec, 2012, Statistics Canada, 2016). Almost ten years later, in 2016 Manitoba reported 657,600 ha of soybean across the province. That means the seeded area increased by 7.5 times since 2007 (Statistics Canada, 2016). Reported hectares in Saskatchewan and Alberta are much lower, but are assumed to be rising as the seed industry is developing shorter season varieties that are more suitable for those areas (Gabruch, 2014). Saskatchewan and Alberta have lower accumulated growing degree days than Manitoba (Government of Manitoba, 2016d). Therefore, current soybean varieties often cannot reach full maturity or are affected by frost in Alberta and Saskatchewan.

2.5.2 Critical Soybean Stages

Several stages are of importance in soybean production. Soybean can be staged in two different classification systems. The first is the more prevalent system in North America of vegetative (VE to V9) and reproductive (R1 to R8) stages and the second is the European BBCH (00 to 99) staging guide (Fehr, et al., 1971, Meier, 2001). The BBCH scale (Meier, 2001) is shown in Figure 2.11 and additional information is provided for a better understanding of the measured parameter in this thesis.

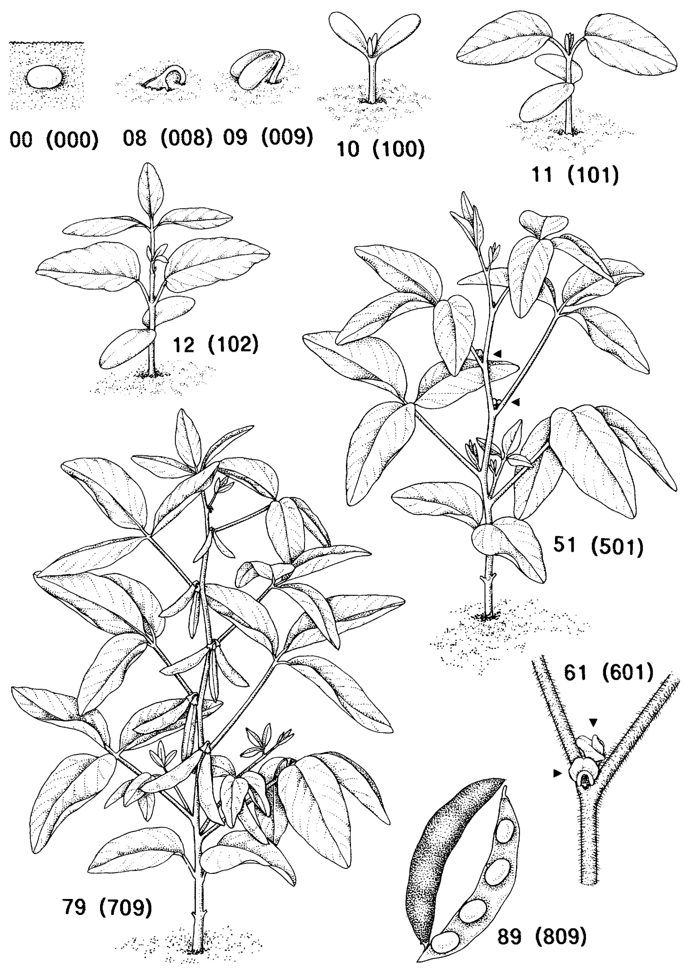

Figure 2.11: BBCH scale for soybean (Meier, 2001)

2.5.2.1 Emergence Stages 00 to 09

Soil temperature and moisture influence the rate of development from when the seed gets planted until it emerges. These stages are from the dry seed to the hypocotyl with cotyledons emerged above from soil. Soybean should be seeded into moist soil to a depth of 2-4 cm (Manitoba Pulse and Soybean Growers, 2016). At this stage soybean have to absorb half of its seed weight of moisture to emerge. If there is not enough moisture, emergence can be delayed (Cox, 2016). Soil temperatures that are too cold (<10°C) can lead to chilling injuries such as cracked cotyledons, reduced hypocotyl growth rates, and stand loss due to failed emergence (Bramlage, et al., 1978, Hobbs and Obendorf, 1972, Jones and Gamble, 1993). Temperature as low as 2°C for 5 minutes can already lead to chilling injuries in soybean seeds (Bramlage, et al., 1978). On the other hand, warm temperatures can also be a problem by causing protein denaturation in the seed (Henson, et al., 1980, Markowski, 2013).

Optimum temperatures for soybean emergence seem to be high and vary between cultivars. A laboratory experiment showed that constant temperatures of 10°C over 48 hours created 2-3 times less axis fresh weight of the soybean compared to temperatures at 25°C (Hatfield and Egli, 1974). Optimum emergence temperature for one cultivar was at 25°C whereas for the other at 35°C. Other researchers found optimum emergence temperatures and the best hypocotyl elongation for several soybean cultivars at 30°C and extremely slow elongation at 10°C (Delouche, 1953). Meanwhile, a field study in a sandy loam soil showed the best soybean emergence at 28°C and 15% soil moisture (Tyagi and Tripathi, 1983). Research in Manitoba is needed as it was shown that the optimal temperature for soybean emergence varies among cultivars (Hatfield and Egli, 1974). It was also reported that temperatures have less influence on emergence at high seed moisture levels (15-20%) compared to low moisture levels (5-10%). The importance of soil moisture on soybean emergence was proven in a field study using water vapour conditioned seeds (Markowski, 2013). The results showed lower yields for dry seeds (5%) compared to conditioned seeds (30%) while keeping the same soil temperatures across the treatments. In Manitoba it is recommended to plant soybean when the soil temperature is 10°C or higher so that soybean emerge in 7-17 days (Crop Chatter Manitoba, 2016, Manitoba Pulse and Soybean Growers, 2016). Soil temperature follows a diurnal pattern and this recommendation does not identify the timing of when soil temperature should be 10°C. The normal diurnal pattern makes therefore this recommendation hard to use soil temperate as a planting decision tool in practice.

2.5.2.2 Main Shoot Development Stages 10 to 19

These are the stages for main shoot development with trifoliate leaf on nodes unfolded. Active nitrogen fixation is starting during these stages (McWilliams, et al., 1999). On farm trials in North Dakota and Minnesota have shown that land rolling can be conducted until stage 13 without any plant stand reductions or yield losses (DeJong-Hughes, et al., 2012).

2.5.2.3 Flowering Stages 60 to 69

During this stage, 0 to 90% of soybean buds are flowering. Flowering is initiated between the first and the sixth node. Soybean plants have accumulated about 50% of their mature height (McWilliams, et al., 1999). Plants consume the highest amount of water during these stages and the number of seeds per plant are determined (Kranz and Specht, 2012).

2.5.2.4 Development of Pods Stages 70 to 79

These stages include the development of pods and seeds. From 60 to 75% of the soybean flowers are aborted by the plant during these stages. Any stress such as temperature, moisture or physical damage reduces yield by influencing total pod number, bean number per pod and seed size. These stages are the most critical stages for soybean in terms of yield (McWilliams, et al., 1999).

2.5.2.5 Ripening of Soybean Stages 80 to 99

This stage includes both the ripening of pods (80 to 89) and discolouring and falling of leaves (91 to 99). These stages can happen simultaneously. Stress at this time has almost no influence on yield unless pods are being dropped to the ground by physical damage such as hail. Seeds contain about 60% moisture at the beginning of stage 80 and can reduce their moisture content to 15% within five to ten days with good drying weather (McWilliams, et al., 1999).

2.5.3 Tillage Impact on Soybean Phenology and Morphology

The impact of tillage on soybean phenology and morphology was limited in a study by Vyn et al. (1998) in Ontario. No significant differences in emergence over time and final plant stands of soybean were observed among fall tillage treatments in wheat residue that included fall discing, chisel plow and zone tillage (Vyn, et al., 1998). The influence of tillage treatments after emergence on to soybean nodulation is not strong as well (Vyn, et al., 1998). However, this study was conducted near Wyoming, ON in an area with a longer frost free period of 160-170 days compared to the Northern Great Plains but similar precipitation between April and July (Ontario Ministry of Agriculure, 2013).

A study conducted in Minnesota showed no influence of tillage treatments on nodulation and nitrogen fixation of soybean in corn residue. This study was conducted on a clay loam. No-till, mouldboard plough, chisel plough and double disc showed no significant differences in soybean nodulation, total acetylene reduction activity, tap root and lateral root development (Lindemann, et al., 1982). However, tillage seems to have an influence on vegetative growth of soybean in biomass accumulation in BBCH 00 to 60 stages.

A study in corn residue showed higher total soybean biomass accumulation as well as higher pod dry mass early in the season in conventional tillage compared to no-till. However, the no-till treatments showed compensatory growth in stages 70 to 79 which lead to no significant yield differences at the end of the season (Yusuf, et al., 1999). Another study conducted in Ontario showed no significant differences in early season plant biomass (mid-July, most likely BBCH >69) for strip till, no-till, deep till and moldboard plow (Janovicek, et al., 2006).

Indirect influences of tillage treatments in soybean stages 10 to 60 are possible due to the creation of different microclimates above soil. It was shown that higher night-time air temperature (10°C vs 24°C) enhanced growth in stages 00 to 60. This led to earlier flowering (10 days) and earlier physiological maturity (12-16 days). Though, no differences were found at harvest for plant height and auxiliary branches. Seed yield was significantly higher with elevated night temperatures compared to the check, mainly due to differences in seed size and seeds per pod (Seddigh and Jolliff, 1984). These results are not surprising as several studies showed that a decrease in early-season vegetative growth (BBCH 10 to 60) could lead to a yield reduction due to insufficient leaf area index (Board and Hall, 1984, Egli and Leggett, 1973). In other words, cold night time temperature can lead to lower biomass accumulation and ultimately to lower yield.

In summary, it seems that soybean are only influenced by tillage during their vegetative development stages (10 to 60). Differences in slower early season growth in no-till are sometimes compensated for later in the soybean growing season and no yield differences are observed. However, several studies showed that lower vegetative growth early in the season could lead to yield reduction in soybean.

2.6 Corn Residue Management Impact on Soybean Yield

Many long and short term studies have been conducted that have involved corn residue and soybean test crops. Different conventional tillage systems, such as double disc, chisel plow, and mouldboard plough have similar soybean yields when applied to corn residue. A comparison of two intensive tillage treatments over 20 years in Ontario showed a 2.7% yield increase in chisel vs. mouldboard plow (Meyer-Aurich, et al., 2006). The study from Meyer-Aurich, et al. (2006) was conducted in Elora, ON. This location has many similar characteristics to the conditions in the Northern Great Plains such as a frost free period of 125-145 days (Ontario Ministry of Agriculure, 2013), similar precipitation between April and July (248mm) and a comparable mean temperature of 5.6°C (Statistics Canada, 2015). However, the observed yield differences were relatively small and those results are in accordance with other studies in Nebraska and Iowa. Wilhelm and Wortmann (2004) from Nebraska showed no significant effect of tillage on soybean yield after corn for chisel plow, double disc, moldboard plow, no-till, ridge-till, and subsoil tillage over 16 years. In Iowa, no significant differences were found between chisel plow and mouldboard plow in 21 site-years performed at two locations (Yin and Al-Kaisi, 2004). However these findings contradict Wilhelm and Wortmann (2004) who found that lower yields were observed for no-till compared to intensive tillage systems in Nebraska. Lindemann, et al. (1982) also reported lower yields in no-till compared to chisel, mouldboard plow, and double disc in Minnesota. Lower yields in no-till were attributed primarily to weed competition.

Lower yields of soybean grown on corn residue in no-till compared to conventional tillage have been found mainly in northern growing regions and in cool and wet growing seasons. This trend was identified in a metaanalysis review of no-till across the United States (Toliver, et al., 2012). This meta-analysis looked at 442 published tillage experiments with conventional tillage and no-till across 92 locations in the United States. The model of Toliver, et al. (2012) predicted an increased likelihood of lower yields when comparing no-till to tilled fields on sandy textured soils (logit coefficient 3.35) compared to clay-textured soil (logit coefficient 0.7822). Furthermore, bigger differences between no-till and conventional tillage were found in the southern regions of the United States compared to northern regions. In other words, no-till yielded similar compared tilled fields in northern regions with a slight hang to lower yields in no-till. Whereas the yield difference between tillage practices in the south seemed to be higher with no-till yielding more.

Although tillage treatment trends have been observed for soybean yield, few differences in soybean quality have been found. For example, a two-year field trial in the warmer and southern part of the United States in Illinois showed no differences in grain yield, oil, protein or moisture content in conventional vs no-till soybeans following corn (Yusuf, et al., 1999).

Older literature from the 1980s and 90s showed bigger differences between no-till and conventional till. Literature from Wisconsin (Guy and Oplinger, 1989, Meese, et al., 1991, Philbrook, et al., 1991) indicated significantly lower yields for soybean in corn residue for no-till compared to conventional till. However, as mentioned under section **Error! Reference source not found.** it could be that the planter used in those studies was not performing well in this heavy residue.

Other meta-analysis studies outside the Northern Great Plains across the United States and Canada showed similar results as Toliver, et al. (2012) about tillage systems and soybean yield. DeFelice, et al. (2006) found a slightly negative influence of no-till soybean in the upper Midwest and Canada. Looking only at the trials that where conducted in the Northern Great Plains the results are not as clear. Three locations in Minnesota summing up to a total of 19 site-years were reported by Lueschen, et al. (2013), and Lueschen, et al. (1992). In the timespan of 1982 to 1985 8 site-years showed no significant yield differences between no-till and spring discing (Lueschen, et al., 1992). Only two site-years showed significantly lower yield in no-till compared to discing. In the timespan between 1986 to 1988 no site-year showed a significant difference between no-till and chisel plow out of 9 site-years. These trials were conducted on loam and clay loam soils. Studies have indicated that these differences between no-till and double disc can be attributed to specific environments due to drought stress, diseases, or herbicides (Elmore, 1990, Elmore, 1991). Non-peer reviewed literature from Minnesota showed in a six year study no significant yield differences on soybean for no-till, double disc and chisel plow following corn (Randall and Vetsch, 2005).

Soybean grown in strip till seems to yield similarly than conventional till in wheat residue. Non-peer reviewed literature at the North Dakota State University in wheat residue showed in one out of the four years that strip till yielded significantly higher than conventional till (Endres and Hendriks, 2010). It was assumed that this yield gain was likely due to more soil moisture stored throughout the season. In the other three years no significant yield differences were observed between strip till and conventional till (Endres and Hendriks, 2010). Other non-peer reviewed research in Carberry and Portage la Prairie, Manitoba/Canada using strip till, no-till and conventional till into wheat residue reported no significant differences in soybean yield in the tillage treatments in two out of three site-years (CMCDC, 2010, CMCDC, 2011).

In long term trials, yields of crops grown with strip till have been found to be the same in corn residue compared to other tillage treatments. A long term trial over six years in Minnesota showed no significant yield differences for strip till, ridge till, no-till and chisel plow in soybean following corn (Stahl, 2011). A three year on-farm trial in Minnesota, showed no significant yield differences between strip till and chisel plow in corn residue either (DeJong-Hughes and Coulter, 2013). Vertical till yields similar to strip till, no-till and chisel plough. DeJong-Hughes and Coulter (2013) showed no significant yield differences on soybean following corn for no-till, chisel plow, strip till and vertical till in a three year on-farm trial in Minnesota. The findings of this on-farm study are in accordance with other literature outside of the Northern Great Plains.

Several non-peer reviewed studies conducted outside of the Northern Great Plains on corn residue for soybean production indicated no differences in soybean yield among vertical till, no-till and conventional till. Studies in Kansas showed in a four year study of on-farm trials no significant differences between vertical till and no-till (Adee, 2015, Presley, 2013). A four year study in Iowa showed no differences in soybean yield between no-till, chisel plow and some sort of vertical till conducted with harrows (VanDee, 2008). In contrast, a one year on-farm trial in Ohio showed significant higher plant stands and higher yields (+2.1 bu/ac) in vertical till compared to no-till (Watters and Douridas, 2013). Furthermore, a study in Ontario over 40 site years, with only two repetitions per location showed an average increase of less than 2 bu/ac in soybean yield in vertical till compared to no-till (Stewart, et al., 2009). Yield differences between vertical till and conventional till were higher on finer-textured soils. However, statistical analysis is not provided for all those sites and it is therefore not guaranteed that these reported differences are statistically significant.

Even though research does not report a clear yield reduction for no-till systems, in recent years producers in the Northern Great Plains have switched back from no-till to conventional or reduced tillage systems to manage corn residue stating the problem of the increased amount of corn residue (Vanhie, et al., 2015). Increasing corn residue can have several negative influences on soybean yields as Vanhie, et al. (2015) explains. More residue can cause slower evapotranspiration and therefore cooler soils. When soybean early in the season have not developed their nodules yet, N deficiency could occur as the decomposition of the residue by microbes could immobilize the residual N in soil. The colder soils could hinder overall N mineralization. Lack of N in early stages could lead to inadequate nodule formation in soybean and therefore overall N deficiency in later stages. However, the common understanding is that soil N needs to be low in order for good nodulation to happen. Lower soil temperatures could lead to stand reduction and later emergence. Other research confirms a negative correlation between surface residue and yield (Vyn, et al., 1998). Given these findings, total corn residue removal for ethanol production might seem like a good option to solve the problem of increasing residue amounts. However, soybean yields were lower in the Northern Great Plains after total removal of corn residue (Wilhelm, et al., 2004).

Several studies have shown that soybean seeded into poorly drained soils with no-till yielded less compared to conventional tillage (DeFelice, et al., 2006, Dick, et al., 1991, Lal, et al., 2007, Roland, 1993, Vyn, et al., 1994, Yin and Al-Kaisi, 2004). Other conclusions about soybean yields under no-tillage or reduced tillage systems are not as clear. Soybean yield differences between a range of tillage treatments seems to be negligible. To quantify the true soybean response to tillage after corn, residue research across multiple years at different locations and soil types is required. Several studies conclude that different tillage treatments have only a minor influence on soybean yield (Nowatzki, et al., 2011). Research showed only small differences between the national average of no-till vs conventional till (DeFelice, et al., 2006) and no changes of yield after no-till adaption can be observed over time (Yin and Al-Kaisi, 2004).

2.7 Economic analysis of tillage systems

An important consideration when looking at an economic analysis is the types of variables considered in the analysis. This scope needs to be defined based on the timeline for the analysis (short vs. long term) as well as the range and type of costs factored into the analysis. Timelines can range from one year to a multi-year rotation period or to generations of farmers. The breadth of an economic analysis can be conducted at a farm level, including external cost such as environmental cost by emitting greenhouse gases, or the analysis can also be much narrower and look only at factors such as yield or weed pressure (Townsend, et al., 2016). Often economic returns from one crop in one growing season are used in an economic analysis. Differences between the revenue of the crop grown and the total input cost (excluding land cost) per land unit are reported (Yin and Al-Kaisi, 2004). Machinery costs can be further subdivided into variable or use- related costs and fixed or overhead costs. Examples for variable costs would be fuel, lubrication and labour whereas for fixed costs it would be interest, insurance or housing (Lazarus, 2016).

Economic analysis has been used to compare different tillage implements in previous agronomy research. No significant differences in economic return were shown between chisel and mouldboard plow using a 20 year data set from a long term study in Ontario on a corn soybean rotation (Meyer-Aurich, et al., 2006). Other studies have shown advantages from reduced tillage systems from an environmental standpoint. Several studies have shown that reduced tillage also lowered greenhouse gas emission, nutrients runoff of and sediments (Holland, 2004), and fuel consumption (Šarauskis, et al., 2014) in general compared to conventional tillage. However, these environmental benefits are rarely included in economic analyses as they are currently challenging to quantify. Moreover, economic analysis studies that were conducted in the Northern Great Plains often report only an economic return or only machinery costs.

Six studies conducted in Iowa on corn residue showed no clear benefits in economic returns of no-till compared to seven other tillage systems over the entire period of the study ranging from 8-15 years (Yin and Al-Kaisi, 2004). This study included no-till, molboard plow, chisel plow, ridge tillage, alternative tillage, reduced tillage and field cultivation. Differences between tillage systems at certain locations in economic returns were found when the 15 years were subdivided into 5 year periods, but there was no overall trend observed over the entire study length. In contrast, a study conducted in Ontario on corn residue showed increased profitability for mouldboard plow compared to no-till over 5 years (Janovicek, et al., 2006).

Strip till as a tillage system on corn residue has shown lower costs and no yield reduction compared to conventional tillage systems. Nowatzki, et al. (2011) in North Dakota reported that when changing from conventional tillage to strip till the cost can increase by US$ 10.63 per acre. However, on-farm trials in Minnesota over three years on corn residue for soybean production reported US$ 5.9 per acre lower cost for strip till compared to a conventional system where more than one tillage pass is needed in the conventional tillage system. Soybean yields were not significantly different across the treatments, however economic returns were not calculated (DeJong-Hughes and Coulter, 2013). Strip till also showed lower CO_2 losses compared to moldboard plow and discing (Nowatzki, et al., 2011). therefore strip till could lower external costs in the future if carbon taxes are introduced. Furthermore, with improved seed beds created using strip till, there might be opportunities to reduce seeding rates and therefore reduce seed cost (Pearce, 2014b).

Vertical till as a tillage system on corn residue showed higher costs than strip till but lower costs than conventional till. The on-farm trial from Minnesota reported cost per acre of US$19.72 for vertical till compared to strip till (US$ 14.60) and conventional till (US$ 20.48) (DeJong-Hughes and Coulter, 2013). Another on-farm study in Ohio showed an increase in net return of US$ 12 per acre for vertical till compared to no-till (Watters and Douridas, 2013).

Considering that one bushel of soybean is worth US$ 9.75 (Bloomberg, 2016), this would be equivalent to a net return increase of 1.2 bu/acre compared to no-till. However, these numbers should be verified for the Northern Great Plains area.

Different vertical till implements showed various horsepower requirements per meter implement width. Industry reported horsepower requirement ranging from 17 up to 32 kW/m^{-1} implement width (Presley, 2013). This means that in an economic analysis the cost of different sizes of tractors would have to be considered as part of the analysis when comparing between tillage implements.

2.8 Conclusion

This literature review showed that the definition of the Northern Great Plains varies between sources. Conventional, reduced, and no-till showed advantages and disadvantages on many levels. Peer-reviewed literature about new strip till and vertical till implements is lacking. The current non-peer-reviewed literature suggests that there are no significant differences in yield among strip till, vertical till and double disc. However, many proposed advantages of these implements come from industry sources and have not been verified with independent research. Further research with these implements is therefore needed.

This review showed that tillage has an influence on soil properties as well as on corn residue management in the Northern Great Plains region. Tillage helps to accelerate the decomposition process of crop residue. Residue was shown to have the biggest influence on soil temperature compared to many other factors. Residue has only a minor influence on soil temperature when soils are wet. Limited research was found that looked at soil temperature accumulations early in the season. No research was found that linked corn residue cover with cumulative soil temperature in the Northern Great Plains, especially for new tillage tools, such as strip tillage or vertical tillage. Furthermore, no field research was found that linked accumulated soil temperature with crop emergence.

Corn residue was found to have unique properties compared to other crop residues. These properties caused challenges for producers in the Northern Great Plains. Unfortunately, few best management practices for corn residue management have been identified for use in the Northern Great Plains.

Tillage had only minor influences on soybean phenology, morphology and yield. Differences between tillage systems in terms of yield were found, however only small yield differences were reported and these results contradicted each other within the Northern Great Plains region. For quantifying the true soybean response to tillage after corn residue, research across multiple years at different locations and soil types is required.

Only limited research was found that had a complete economic analysis for corn residue management for soybean production in the Northern Great Plains. Farmer's decisions are often based on profitability which points out the importance of an economic analysis when comparing these different tillage implements.

Several studies in the past showed the differences on many levels between no-till and conventional till (Campbell, et al., 2001, Lal, et al., 2007). However, this research does not include newer tillage equipment, such as vertical till and strip till. These gaps in the literature led to the research objective of the current project to compare vertical till low disturbance, vertical till high disturbance and strip till with the standard tillage practice double disc.

3 MATERIALS AND METHODS

3.1 Site Description

This research was conducted at four different on-farm locations in Manitoba, Canada: MacGregor, MB and Winkler, MB in 2015 and in MacGregor and Haywood, MB in 2016. Sites were selected based on farmer volunteers that were willing to host experiments. The soil texture was similar among the four site-years.

3.1.1 Winkler 2015

The soil texture was a sandy loam. Soils were Gleyed Rego Black Chernozem Reinland Series (RLD)(Class 2M), an Orthic Black Chernozem Reinfeld Series (RFD)(Class 1), and a poorly drained Rego Humic Gleysol Blumengart Series (BMG)(Class 3I). Topsoil had a pH level of 8.1, 2% organic matter and a cation exchange capacity of 30.1 meq.

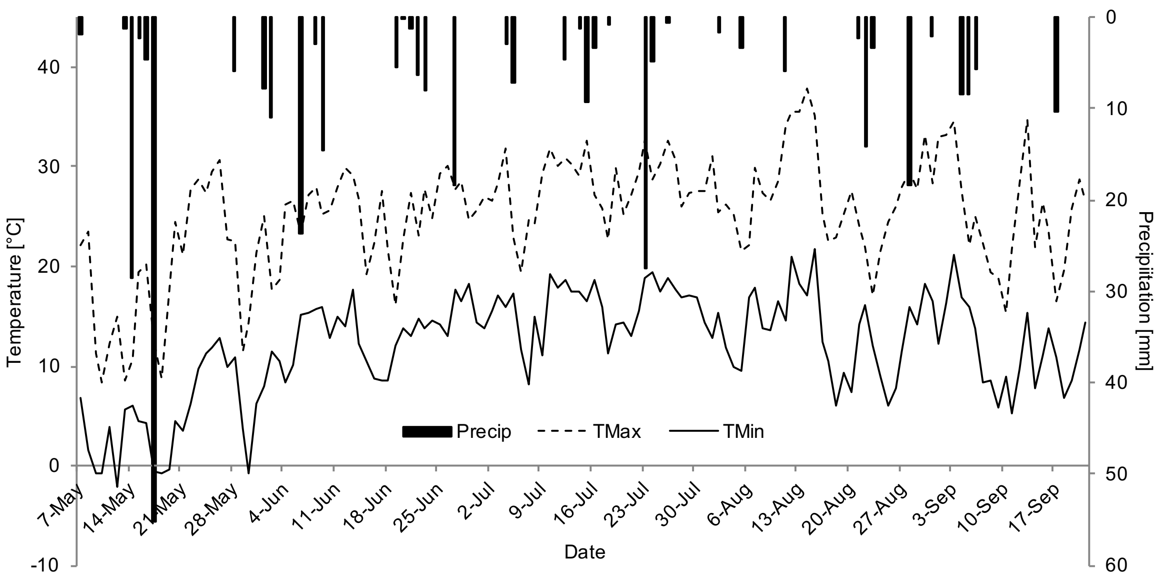

Figure 3.1: Daily minimum and maximum temperature and daily accumulated precipitation in Winkler 2015 from soybean seeding (May 2nd -4th 2015) to harvest (Sept. 21st 2015)

A warm and early spring was observed at this location which led to early seeding. Average monthly temperatures in March were 3 to 4°C above normal (Agriculture and Agri-Food Canada, 2015). However, an extended cool period just after seeding in May was observed with several minimum temperatures that dropped below 10°C.

3.1.2 MacGregor 2015

The soil texture was a sandy loam. Soils were imperfectly drained Gleyed Black Chernozem Willowcrest Series (WWC)(Class 3M) and poorly drained Rego Humic Gleysol Lelant Series (LLT)(Class 5W). Topsoil had a pH level of 8.0, 2.7% organic matter and a cation exchange capacity of 24.1 meq.

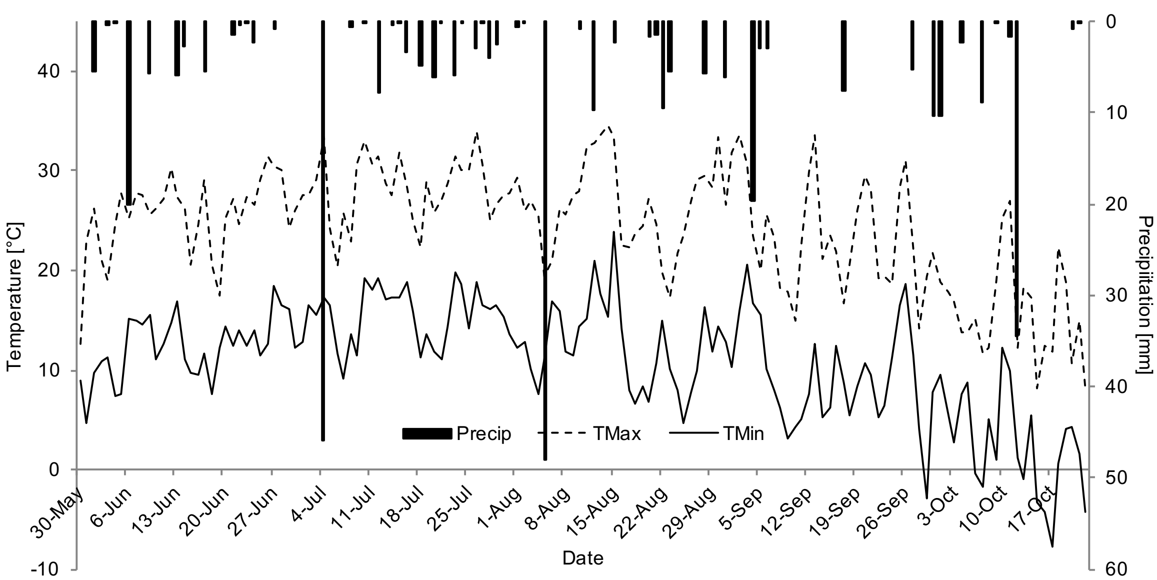

Figure 3.2: Daily minimum and maximum temperature and daily accumulated precipitation in MacGregor 2015 from soybean seeding (May 30th 2015) to harvest (Oct. 22nd 2015)

Temperatures were low at the beginning of May, but increased towards the end of May. This led the farmer to decide to seed once conditions were warmer. Minimum temperature started to drop at the end of September and frost occurred on several nights when soybean had already reached maturity.

3.1.3 Haywood 2016

The soil texture was a loamy sand. Soils were imperfectly drained Gleyed Rego Black Chernozem Almassippi Series (ASS)(Class 3M) and poorly drained Rego Humic Gleysol Lelant Series (LLT)(Class 4W). Topsoil had a pH level of 8.1, 2.2% organic matter and a cation exchange capacity of 25.1 meq.

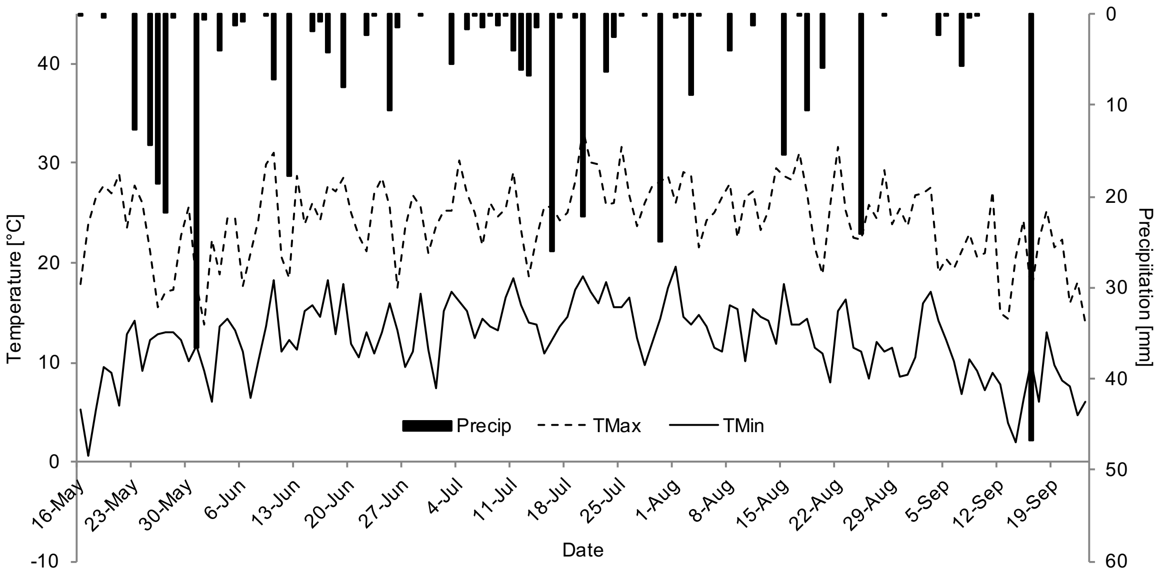

Figure 3.3: Daily minimum and maximum temperature and daily accumulated precipitation in Haywood 2016 from soybean seeding (May 16th 2016) to harvest (Sept. 23rd 2016)

Spring was dry which led to delayed seeding at this location and a short drought beginning of May was observed (Agriculture and Agri-Food Canada, 2016). Precipitations in late May and early July led to enough soil moisture for emergence.

3.1.4 MacGregor 2016

The soil texture was a loamy sand. Soils were carbonated Gleyed Rego Black Chernozem Rosebank Series (RBK)(Class 2M) and imperfectly drained Gleyed Black Chernozem Willowcrest Series (WWC)(Class 3M). Topsoil had a pH level of 8.1, 2.8% organic matter and a cation exchange capacity of 26.2 meq.

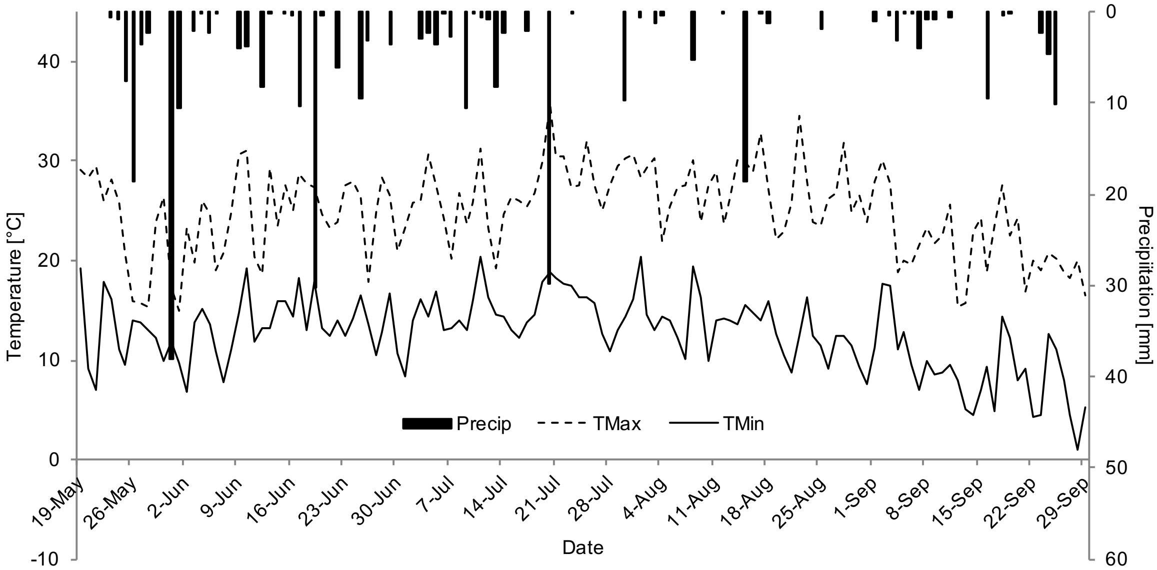

Figure 3.4: Daily minimum and maximum temperature and daily accumulated precipitation in MacGregor 2016 from soybean seeding (May 19th 2016) to harvest (Sept. 29th 2016)

Spring was dry which led to delayed seeding at this location. A short drought beginning of May was observed early in the season (Agriculture and Agri-Food Canada, 2016). Precipitation in late May and early July provided enough soil moisture for soybean emergence.

3.2 Experimental Design and Residue Management Treatments

The experiment was set up as a randomized complete block design (RCBD). Winkler 2015 and MacGregor 2016 had four blocks and four different tillage practices: 1) conventional double disc; 2) vertical till high disturbance; 3) vertical till low disturbance; 4) strip till (see Figure 2.1, Figure 2.4, Figure 2.6, Figure 2.8). MacGregor 2015 had only three blocks with all four tillage practices. Haywood 2016 had four blocks but only three tillage practices. In Haywood 2016 conventional double disc, vertical till high disturbance and strip till were used. Different machinery was used at each site but each set of equipment had the following characteristics (Table 3.1). Double disc was defined as two sets of concave shaped discs that follow after each other. Vertical till low disturbance was defined as a tillage equipment with straight or waffled discs that were set on a 0° angle. The operation of this did not invert the soil. Vertical till high disturbance equipment had either straight discs with 7° angle or concaved discs that inverted the soil. Shank type strip till equipment was used with the trash cleaners set so that it pushed the residue aside without moving soil. Despite using different tillage equipment at each site, similar residue cover was achieved in each corn residue management treatment.

Plot length varied among site-years due to conditions at harvest and is further discussed in the next section.

Table 3.1: Summary of tillage equipment used to create corn residue management treatments at Winkler 2015, MacGregor 2015, Haywood 2016 and MacGregor 2016 site-years.

Site-year	**Tillage Equipment Category**	**Manufacturer**	**Model**	**Manufacturer Location**	**Operating Speed**	**Tillage Depth**	**Equipment Width**	**Date of Tillage**
					km h^{-1}	cm	m	
Winkler 2015	Double disc	John Deere	637 Disc	Moline, USA	9.5	5.1-10.2	13.7	Oct 31st 2014
	Vertical till high disturbance	Mandako	Twister 3220 7°	Plum Coulee, Canada	14.0	7.6-10.2	9.8	
	Vertical till low disturbance	Mandako	Twister 3220 0°	Plum Coulee, Canada	14.0	7.6-10.2	9.8	
	Strip till	Elmers	Strip till	Altona, Canada	10	15.3	6	
MacGregor 2015	Double disc	Summers	Diamond Disc	Devils Lake, USA	9.5	5.1-10.2	8.1	May 28th 2015
	Vertical till high disturbance	Pöttinger	TerraDisc 6000	Grieskirchen, Austria	14.0	7.6-10.2	6	
	Vertical till low disturbance	Salford	RTS 570	Osceola, USA	14.0	7.6-10.2	9.1	
	Strip till	Orthman	1tRIPr 12row	Lexington, USA	10	15.3	9.1	
Haywood 2016	Double disc	Summers	Diamond Disc	Devils Lake, USA	9.5	5.1-10.2	8.1	May 10th 2016
	Vertical till high disturbance	Pöttinger	TerraDisc 6000	Grieskirchen, Austria	14.0	7.6-10.2	6	
	Strip till	Orthman	1tRIPr 12row	Lexington, USA	14.0	15.3	9.1	
MacGregor 2016	Double disc	Summers	Diamond Disc	Devils Lake, USA	9.5	5.1-10.2	8.1	Apr. 29th 2016
	Vertical till high disturbance	Pöttinger	TerraDisc 6000	Grieskirchen, Austria	14.0	7.6-10.2	6	
	Vertical till low disturbance	Salford	RTS 570	Osceola, USA	14.0	7.6-10.2	9.1	
	Strip till	Orthman	1tRIPr 12row	Lexington, USA	10	15.3	9.1	

3.3 Soybean Test Crop Management Field Operations

Planting and harvesting dates depended on weather, soil conditions and the standard practices of the on-farm collaborator. Date therefore varied among site-years. Tillage was conducted in spring for all site-years with the exception of Winkler in 2015 where it was conducted in fall (Table 3.2). Winkler 2015 was seeded earlier than all other site-years. Site-years in 2015 were rolled with a standard land roller to smooth over the tillage operations and therefore facilitate harvest. Site-years in 2016 were not rolled due to farmers preference and high soil moisture conditions at ideal timing for rolling operation. Harvest took place during the last week of September in three out of four site-years.

Table 3.2: Date of field operation for planting, rolling and harvesting for Winkler 2015, MacGregor 2015, Haywood 2016 and MacGregor 2016 site-years.

Field Operation	Winkler 2015	MacGregor 2015	Haywood 2016	MacGregor 2016
Planting Date	May 02nd -04th 2015	May 30th 2015	May 16th 2016	May 19th 2016
Rolling Date	May 04th 2015	June 22nd 2015	N/A	N/A
Harvest Date	Sept. 21st 2015	Oct 22nd 2015	Sept. 23rd 2016	Sept. 29th 2016

The previous crop at all sites was corn and the test crop grown after residue management treatments was soybean. Corn was harvested without a chopper header in MacGregor 2015, MacGregor 2016 and Haywood 2015 and with a chopper header in Winkler 2015. Corn residue was evenly distributed with a straw chopper behind the combine. Average spring corn residue dry matter was 9962 kg ha^{-1} in Winkler 2015, 7334 kg ha^{-1} in MacGregor 2016 and 13’494 kg ha^{-1} in Haywood 2016. Corn dry matter samples were not retrieved for MacGregor 2015 but by visual assessment of the field in spring, they were similar to Winkler 2015. Soybean were seeded in 76 cm rows into the corn residue (Table 3.3). At all sites an air seeder without trash cleaners was used to plant seeds. Soybean variety, soybean maturity group, targeted planting population, and planting depth varied across the site-years due to farmer preferences, different conditions at planting and farmer best management practice (Table 3.3). These management practices were uniform within a site-year across tillage treatments.

Table 3.3: Seeding and crop protection practices for soybean test crops grown in Winkler 2015, MacGregor 2015, Haywood 2016 and MacGregor 2016 site-years

Seeding	**Winkler 2015**	**MacGregor 2015**	**Haywood 2015**	**MacGregor 2016**
Previous Crop	Corn	Corn	Corn	Twin row corn
Soybean Variety	TH 32OO4R2Y	LS 005R22	NSC Richer RR2Y	LS 005R22
Soybean Variety Maturity Group	00.4	00.5	00.7	00.5
Targeted plant population (plants/ha)	415,000	370,657	371,287	407,722
Opener type on planter	Double disc	Disc	Disc	Disc
Seed depth (cm)	5.4	2.6	3.1	3.1
Inoculant	CMV + Xite Bio (1.5 rate)	TagTeam (3 rate)	TagTeam (3 rate)	Cell Tech 889.6 ml/ha
Row spacing (cm)	76	76	76	76
Herbicide	Glyphosate 2.47 l/ha a.i. 11 May 2015	Glyphosate 2.47l/ha a.i. 10 June 2015	Glyphosate 2.47 l/ha a.i. 15 June 2016	Clethodim 0.19 l/ha a.i. 24 June 2016
	Glyphosate 1.85 l/ha a.i. + Quizalofop P-Ethyl 0.74 l/ha a.i. May 30th 2015	Glyphosate 2.47 l/ha a.i. + Clethodim 0.19 l/ha a.i June 06th 2015	Glyphosate 2.47 l/ha a.i. + Clethodim 0.19 l/ha a.i July 14th 2016	Glyphosate 1.66 l/ha a.i. July 15th 2016

Weed management was conducted by the farmer based on best management practices. Practices were uniform throughout all treatments within a site-year and were similar among site-years. Two herbicide applications were made for all site-years and in specific site-years (MacGregor 2015 and MacGregor 2016), a tank mix was used for controlling volunteer corn. No fungicide or insecticide was used on the seed. No foliar insecticide or fungicide treatments were applied to soybean at any of the sites as the economic thresholds were not reached. Soybean test crops were not fertilized at any point in time.

Plot length varied among site-years due to conditions at harvest. Harvest was conducted with a commercial combine in Winkler 2015, MacGregor 2015 and MacGregor 2016 whereas in Haywood 2016 a small plot combine was used. In Winkler 2015, 14 rows per plot were harvested with the total field length of 689 m. In MacGregor 2015, 14 rows at a length of 368 m (Block 1) and 535 m (Block 2 and 3) were harvested due to an extended area that was not seeded. Block 1 had high spring soil moisture and the plot was therefore shorter than Blocks 2 and 3. In MacGregor 2016, 14 rows with the total field length of 290 m were harvested. Due to space constraints, the Haywood 2016 site had to be set up with smaller field scale plots. However, plots were still large enough to use commercial tillage equipment. At harvest, a small plot combine with two rows was used to harvest the soybean test crop. At harvest, length was further shortened due to areas that were drowned out. In Haywood 2016 a total of 30 m were harvested in each plot.

3.4 Data Collection

3.4.1 Soil

Pictures for surface residue cover were taken with a 16 mp Ricoh WG-4 camera (Chūō, Japan). Pictures were taken between tillage and seeding. One picture per plot was taken. Pictures were then analysed with the program Assess 2.0 (Winnipeg, Canada) by using the agronomist panel with the colour pane L (Lamari, 2008). The lab colour space describes mathematically all perceivable colors in the three dimensions L for lightness which allows to distinction of residue from soil.

Soil temperature was measured with Maxim iButton DS1922L (San Jose, USA) at 5 and 30 cm soil depth. iButtons were inserted into wooden stakes (61x3.8x2.5 cm) with 1.5 cm pre-drilled holes that fit the iButtons to improve depth placement (Bartley, 2015). One sensor was used per plot and depth and measurements were logged on an hourly basis.

Volumetric soil moisture was measured with a Decagon EC-5 moisture sensors (Pullman, USA) at 5 and 30 cm soil depth and recorded hourly with Decagon EM50 data loggers. One sensor was used per plot at each depth. Air temperature, relative humidity and precipitation were all measured with a Spectrum WatchDog 1000 Series Micro Station (Aurora, USA) at the edge of the field at each site.

Growing degree hours (GDH) for soil temperature was calculated by adding the hourly recorded soil temperature at the 5 cm depth (T_{soil}) and subtracting a base temperature of 10°C (T_b). Negative values generated by the calculation of GDH were set as zero. Calculations were conducted in R cran (Version 3.2.3 2015-12-10). The base temperature of 10°C was chosen as suggested for soybean by Brown (1960).

$$\mathrm{GDH} = \sum T_{soil} - T_b\, , for\ GDH = \mathbb{R}_{\geq 0} \quad [Eq. 1]$$

Cumulative GDH were calculated for three time periods. The first calculation was a daily sum. GDH were summed for the first ten days after planting by accumulating the hourly soil temperature per day for the analysis in section 4.1.2.6. These daily accumulated GDH were then accumulated over a 10 day period for the second calculation in section 4.1.2.7 to achieve total accumulated GDH to explore the relationship between residue cover and total accumulated GDH for the first ten days after planting. The third calculation was for days to 50% and 100% emergence. Total accumulated GDH were extended beyond the range of 10 days after planting until 50% and 100% soybean emergence was reached (see section 4.1.2.8).

3.4.2 Soybean

Soybean development stages were assessed by the European BBCH (00 to 99) staging guide (Fehr, et al., 1971, Meier, 2001). The more abundant system in North America of vegetative (VE to V9) and reproductive (R1 to R8) stages was not used as it is not a continuous numbering system that allows for statistical analysis with ANOVA.

Soybean emergence was counted each Monday, Wednesday and Friday until stage 14. Plant counts were made at 5 m of the seeding row, at two neighbouring rows. Development staging was done in the same 10 m for development stages 0 to 14 on 10 randomly chosen plants. Plants were then marked with a flag. Flowering was counted on a total of 80 (Winkler 2015), 144 (MacGregor 2015), 72 (Haywood 2016) and 96 (MacGregor 2016) randomly selected plants, respectively.

Lowest pod height was assessed by measuring the distance between the bottom of the pod and the ground at harvest. The distance from the ground to the lowest pod was chosen as this determines whether or not the pod can be caught by the combine header. At least 40 randomly chosen pods per plot were measured at all site-years. Plant height was measured on 10 randomly chosen plants at harvest. Pods per plant were counted on the same 10 plants but only in 2016. Physiological maturity was based on a visual rating for leaf and pod colour when walking across the plot.

Aerial imagery was captured with a multispectral camera (Parrot Sequoia, Paris France) mounted on a quadcopter UAV (3DR Solo, Berkeley USA) at the pod filling development stage (BBCH stage 75 to 79). Bands captured were 550 nm (+/-40nm), 660 nm (+/-40 nm), 735 nm (+/-10 nm) and 790 nm (+/-40 nm). A side and frontal overlap of 75% was chosen. The stitching software (MicaSense Atlas imagery analytics, Seattle USA) was used to create a .geotiff file. A handheld GPS (Garmin 72H, Schaffhausen Switzerland) was used to mark the boarders of the plots. The raster calculator in QGIS 2.12.1 Lyon was used to calculate the Normalized Difference Vegetation Index (NDVI) and Normalized Red Edge Index (NDRE) (MicaSense, 2017).

$$NDVI = \frac{NIR - RRED}{NIR + RRED}\ , for\ NIR\ 790nm\ and\ RED\ 660nm \qquad [Eq. 2]$$

$$NDRE = \frac{NIR - REDEDGE}{NIR + REDEDGE}\ , for\ NIR\ 790nm\ and\ REDEDGE\ 735nm \qquad [Eq. 3]$$

Statistical analysis of these indices was then conducted with ANOVA and the Proc Mixed procedure of SAS 9.4 (Cary, USA) (SAS Institute, 2017) by site-year.

The weighing method for grain yield varied between site-years. In Winkler 2015, a calibrated Seed Tender weigh wagon (Convey-all WT 290, Winkler Canada) was used. In MacGregor 2015 and 2016, a calibrated graincart (Kinze 1050, Williamsburg USA) was used with a weighing kit (Agrimatics Libra Cart kit by Triplestar Manufacturing, MacGregor Canada). In Haywood 2016, grain was harvested into bags that were then weighed with a Sartorius (Göttingen, Germany) F61S electronic scale. Yield was adjusted to 13% moisture content at all site-years.

Grain moisture was measured using the Dickey-John GAC 2500-UGMA grain analysis computer (Auburn, USA). Soybean oil and protein content was measured with a near infrared transmission machine (Foss Infratec™ 1241 Grain Analyzer; Hilleroed, Denmark). One composite sample per plot was analysed.

3.4.3 Economics

Machinery performance measurements were measured in collaboration with Prairie Agriculture Machinery Institute (PAMI) in Portage la Prairie, Canada. Detailed materials and methods for these measurements can be found in the final report (Mak, 2016) (see Appendix 6.5). A tractor (John Deere 9510R, Moline USA) with a custom built “load cart” from PAMI was used to conduct these measurements in corn residue. Speed, work rate, draft load, power requirement and fuel consumption of double disc, vertical till low disturbance, vertical till high disturbance and strip till implements were measured. A GPS tracking device and the tractor’s controller area network (CAN bus) readout was used for work rates, fuel consumption and power requirement calculations.

This experiment was conducted on a sandy soil in MacGregor, MB and on a loamy soil in Beaver, MB. Measurements were conducted for one and two passes, however due to field conditions, second passes were not possible at all locations. As soybean trials were conducted on sandy soils, data collected in MacGregor was used for the cost analysis. Unfortunately, no complete dataset was available for the second pass in MacGregor, therefore data for the first pass was taken for cost analysis. Costs for second passes were then multiplied by two for treatments double disc, vertical till low disturbance and vertical till high disturbance. In practice, costs for a second tillage pass would be slightly higher than the first pass as fuel consumption and power requirement would increases on second pass due to more slip of tractor tires and more soil movement of the implement (see 6.5, page 3).

To assess costs of tillage implements, a spreadsheet calculator was used. The economic analysis was conducted with the excel spreadsheet from the University of Minnesota (Lazarus, 2016). It was selected because it allowed the adaptation of factors, such as tractor requirement, fuel consumption and work speed.

The custom rate and rental rate guide for field equipment from the Government of Manitoba was used to adapt the American spreadsheet to Manitoba conditions and therefore achieve more representative costs (Government of Manitoba, 2017). The calculator was adapted with the following parameters: fuel cost (Can$ 0.929/litre), field efficiency (80%), insurance and housing (1% of original purchase price), labour rate (Can$ 20) and total financing rate (6.5%). Fuel consumption and tractor requirements (kW m^{-1}) were adjusted based on the actual measured data in the field trial in MacGregor on the sandy soil.

Purchase price for double disc and vertical till were based on the custom and rental rate guide from the Government of Manitoba. The purchase price was based on individual quotes from equipment dealers (Personal Communication: Brueland, 2017, Haarberg, 2017), prices on marketbook.com, and the suggestions of an extension agronomist working in the field of tillage research (Personal Communication: DeJong-Hughes, 2017). An exchange rate of US$ = 1.29 Can$ was used for prices in US$.

The purchase price for tractors (power unit) was based on the custom and rental rate guide from the Government of Manitoba (Government of Manitoba, 2017). For double disc, strip till and vertical till low disturbance, front wheel assist tractors were used and for vertical till high disturbance, a four-wheel drive tractor was used for the calculations.

Annual hours of use were based on the custom and rental rate guide from the Government of Manitoba for double disc and vertical till. The annual use for strip till was assumed to be similar to the one for double disc as no other source was available and double disc and strip till operate at a similar speed resulting in similar annual hours of use (Personal Communication: Arnott, 2017).

Equipment repair and maintenance costs for Manitoba could not be found specifically for strip till and vertical till. It was assumed that they are similar to double disc, due to recommendations from William Lazarus (Personal Communication: Lazarus, 2016). Repair and maintenance costs were estimated by ASABE Standards (2006) and Wu and Perry (2004). The custom and rental rate guide from the Government of Manitoba suggested a fixed repair rate of 3 to 3.5% of the purchase price divided by the annual hours of use (Government of Manitoba, 2017). When back calculating the repair and maintenance costs in the Minnesota spread sheet, they were only 2.2% of the purchase price. Therefore, farmers must keep in mind these differences and make adjustments based on their repairing strategies if needed.

3.5 Statistical Analysis

Statistical analysis was conducted with SAS 9.4 (SAS Institute Inc., Cary, USA) for ANOVA and repeated measurement analysis. R cran (Version 3.2.3 2015-12-10) was used for regression analysis.

3.5.1 ANOVA

Analysis of variance was conducted to compare corn residue management treatment differences in residue cover, soybean growth characteristics, soybean moisture, soybean protein, soybean oil and soybean yield measurements using the Proc Mixed procedure of SAS 9.4 (SAS Institute, 2017). Fields volunteered by farmers that agreed to host this on-farm experiment were sandy soils in Manitoba. Thus, site-years were considered random effects in the ANOVA within this narrowed scope of inference. Blocks were nested within each site-year and treated as random factors in the ANOVA. Preliminary analysis showed that there was no significant interaction between treatment and site-year effects for soybean yield, a key variable in the study. Several treatment means were compared within site-year. These were variables that required repeated measurement analysis (soil temperature, soil moisture, soybean phenological development stages) (SAS Institute, 2017) and did not allow for averaging over site-years as well as machinery performance measurements due to their contrasting soil types. Mean separation between treatments was determined using the Tukey-Kramer test with a probability level for significance of 0.05. Assumptions of ANOVA were tested using the Proc Univariate procedure of SAS to test for normality of the residuals and to see if residuals had homogenous variances.

Soybean phenological development stages were analysed with repeated measurement analysis separate by site-year. This analysis was conducted with SAS 9.4 (Cary, USA) and the Proc Glimmix procedure with a Poisson distribution and the residual option in the random statement (SAS Institute, 2017). The covariance structure was chosen based on the lowest

Akaike Information Criterion (AICC) value. The norm was type ANTE (1) that is meant for unequal sampling intervals. Deviations from this norm were: The analysis for early plant development stage for MacGregor 2015 used power covariance structure SP(POW). Mean separations between treatments were determined according to the Tukey-Kramer test with a probability level for significance of 0.05.

Daily accumulated GDH above 10 °C for the first ten days after planting were analysed with repeated measurement analysis separate by site-year. This analysis was conducted with SAS 9.4 (Cary, USA) and the Proc Glimmix procedure with a Poisson distribution and the residual option in the random statement (SAS Institute, 2017). The covariance structure ANTE(1) was used. Mean separations between treatments were determined according to the Tukey-Kramer test with a probability level for significance of 0.05.

Total accumulated GDH above 10 °C until 50% and 100% emergence were analysed with site-years combined with the Proc Mixed procedure of SAS 9.4 (SAS Institute, 2017). Both treatment and site-year were included as fixed effected in the model as the site-year effect and the interaction between site-year and treatment were of interest. Blocks were treated random effects in the model. Mean separation between treatments was determined using the Tukey-Kramer test with a probability level for significance of 0.05.

All graphs and figures in the results section were created with R cran (Version 3.2.3 2015-12-10) and ggplot2_2.2.1 (R Core Team, 2015). The 95% confidence interval for the emergence graph was created in ggplot2_2.2.1 using geom_smooth (method= “lm”).

3.5.2 Linear Regression

Linear regression analysis was conducted with R cran (Version 3.2.3 2015-12-10) with the base package lm. Assumptions of non-linearity of residuals (Residual vs. Fitted), normally distributed residuals (normal Q-Q), equal variances of residuals (scale-location) and influential outliers (residual vs leverage) were tested (Kim, 2015).

4 RESULTS AND DISCUSSION

4.1 Soil

4.1.1 Surface Residue Cover

Soil surface residue cover before planting in spring varied across corn residue management treatments. The lowest and highest values for residue cover occurred in strip till treatment when analyzing the zone of tillage in the planting row separately from the undisturbed zone in between the rows (Table 4.1). If residue cover is averaged over both the tilled and untilled zones in the strip till treatment, residue cover is not different from vertical till low disturbance. Vertical till high disturbance and double disc showed no significant differences between each other, but were significantly lower compared to vertical till low disturbance.

Vertical till low disturbance was a conservation treatment that was supposed to have high residue cover compared to vertical till high disturbance and double disc as conventional tillage treatments. Strip till showed the same mean residue cover as vertical till low disturbance but the distribution between these two treatments is different. However, strip till can still be considered as conservation treatment even though there are two distinct areas. Images from the different surface residue cover can be found in the appendix (see Figure 6.1, Figure 6.2, Figure 6.3, Figure 6.4).

Table 4.1: Effect of corn residue management treatment (Treatment) on percent residue cover before planting averaged over four site-years.

Treatment	Surface Residue Cover
	%
Double disc	29.7c
Vertical till high disturbance	26.6c
Vertical till low disturbance	64.6b
Strip till	62.9b
Strip till in row	4.4d
Strip till between row	94.7a
ANOVA	P>F
Source of Variation	
Treatment	<.0001 ***
Block (Site-year)	0.0713
CV, %	25.36

Means within a column followed by the same letter are not significantly different.

Similar residue cover ratings have been reported in the literature for strip till. In Minnesota, mean residue cover rating for strip till was 64% when analysed over both zones (DeJong-Hughes and Coulter, 2013). Vertical till low disturbance residue cover ratings ranged from 69 to 94% with one pass in Wisconsin (Klingberg and Weisenbeck, 2011) and from 50-90% for two passes in Minnesota and Kansas (DeJong-Hughes and Coulter, 2013, Presley, 2013). Residue cover ratings for double disc were 5.9% and 18.3% lower compared to research in Kansas (Presley, 2013) and research in Minnesota (Lueschen, et al., 1992), respectively. However, it is important to note that absolute differences between the values in this study and literature are not surprising as settings on the machinery, different soil types, corn yields and soil moisture at the time of operation will all have an influence on residue cover.

In summary, the hypothesis that surface residue varied among all tillage corn residue management treatments (Hypothesis I) was only true for some but not all of the treatments. There were no significant differences between double disc and vertical till high disturbance. Strip till showed significant differences between the tilled and not tilled part, as well as compared to all treatments when dissected into two distinct areas. Even though statistically significant treatment effects were shown, the dataset showed a relatively high CV of 25% indicating that there was a high variability relative to the mean of this dataset. This variability could be caused due to two reasons. Only one picture was taken per plot and the program that was used for the analysis included several steps that required subjective ratings.

4.1.2 Temperature

Soil temperature at planting depth (5 cm) and in the rooting zone (30 cm) varied across site-years. Differences in planting dates for each of the site years resulted in differences in minimum soil temperatures and soil temperature patterns at planting. Soil temperature will be discussed first on a descriptive basis by site-years, followed by statistical approaches to identify agronomically relevant differences among corn residue management treatments.

4.1.2.1 Winkler 2015

A cold weather period in early May in Winkler 2015 lowered the soil temperature for approximately 10 days and resulted in less variation in soil temperature at 5 cm below the surface after planting and rolling among corn residue management treatments. Soil temperature in 5 cm and 30 cm will be discussed for the first three days after planting and rolling, the first two month after planting and rolling and the period before and after planting and rolling with a focus on diurnal patterns as well as minimal and maximum temperatures.

The highest temperature in strip till, vertical till high and low disturbance in the first three days after planting was reached at 6pm on May 5th 2015 and was 18°C (Figure 4.1). At the same time strip till in the untilled zone and double disc were slightly colder than the other treatments at 15°C and 16°C, respectively. Differences among corn residue management treatments decreased, over the following three days. By 11pm on May 8th, there were no differences among treatments and all temperatures were at 7.5°C. This drop in temperature was induced by a 10-day cold period that started on May 5th 2015 (Figure 4.2). Temperature for the cool period at 5 cm was below 10°C for an extended period of time (Figure 4.2), which can cause soybean hypocotyl damage (Hobbs and Obendorf, 1972, Jones and Gamble, 1993). Soil temperature at 10°C is often used as critical threshold for soybean planting (Crop Chatter Manitoba, 2016, Manitoba Pulse and Soybean Growers, 2016, Miller, et al., 2002). Temperatures were close to 2°C and research showed that chilling injury can occur after 5 minutes at that temperature (Bramlage, et al., 1978). Soil temperature in the rooting zone at 30 cm below the surface during the first three days after rolling were constant and showed almost no diurnal swing. All corn residue management treatments were at 9°C.

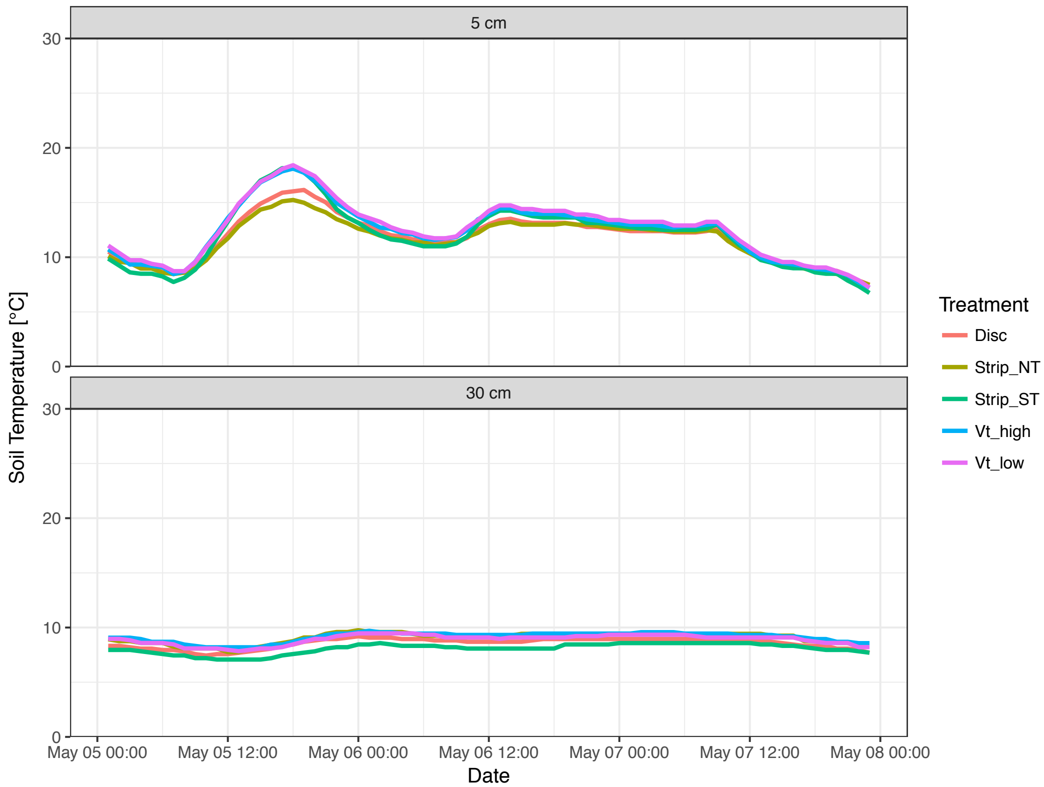

Figure 4.1: Soil temperature at 5 and 30 cm depths for the first three days after rolling on May 4th 2015 (planting May 02nd 2015) in Winkler 2015 for corn residue management treatments using double disc (Disc), strip till between row (Strip_NT), strip till in row (Strip_ST), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low).

Figure 4.2: Soil temperature at 5 and 30 cm depths for the first two months after planting (May 02nd 2015) in Winkler 2015 for corn residue management treatments using double disc (Disc), strip till between row (Strip_NT), strip till in row (Strip_ST), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low).

Temperature patterns changed after planting and rolling. The highest and lowest temperature per day before planting and rolling were observed in the strip till in the row treatment (Figure 4.4). For 6 hours during the day in the row of strip till, the temperature was 4-5°C warmer than double disc and vertical till high disturbance. At night-time strip till in the row was 1-2°C colder than double disc and vertical till high disturbance for three hours. This trend disappeared or changed after planting and rolling when the berm that was created by the strip till implement was flattened (see Figure 4.3 strip till before planting).

Figure 4.3:Tilled zone in strip till treatment had a berm before planting and rolling in Winkler 2015

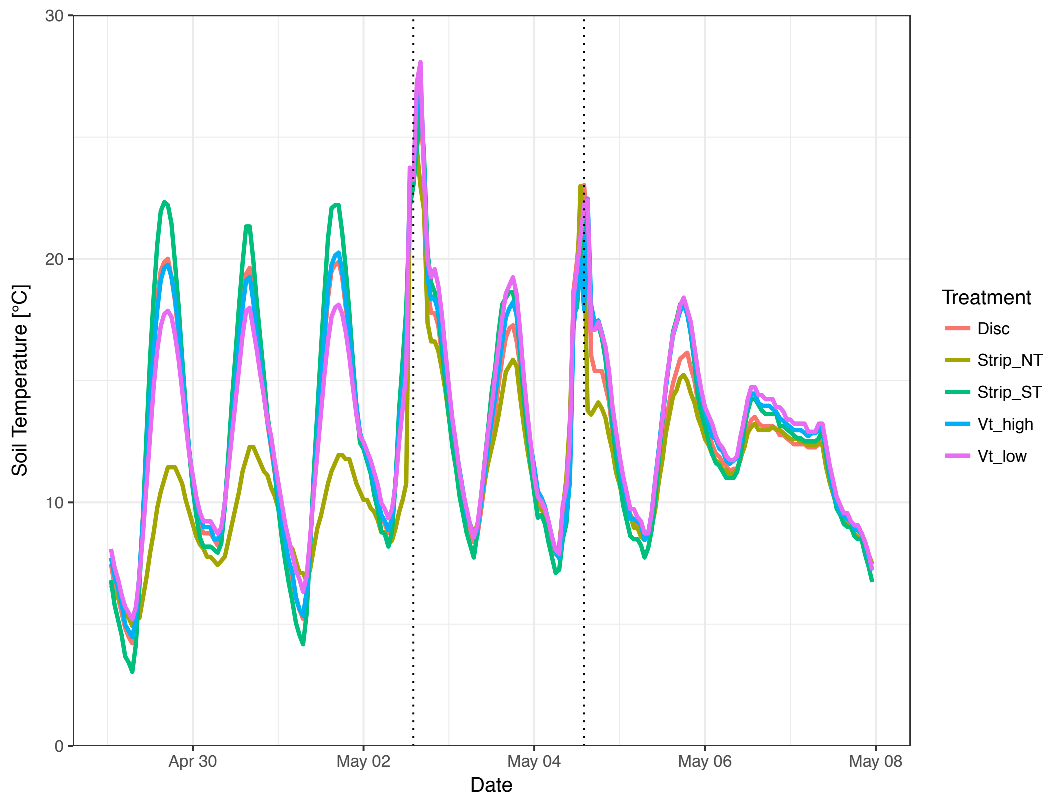

Figure 4.4: Soil temperature at 5 cm depth in Winkler 2015 before and after planting (May 2nd to 4th 2015, see dotted line) and rolling (May 4th 2015, see dotted line) for corn residue management treatments using double disc (Disc), strip till between row (Strip_NT), strip till in row (Strip_ST), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low).

Several reasons might have caused this change in temperature following planting and rolling. First, by flattening the berm, soil pores that are filled with air will be reduced. This increased bulk density made it harder for the air to infiltrate. However, in theory air has a very low thermal conductivity compared to soil and should have acted therefore as an insulation layer. Second, a round object (such as a berm) has a higher surface area than a flat object does. This leads to the potential of capturing more solar radiation per square meter and therefore it will warm up faster. Third, the higher bulk density might have led to higher soil moisture content. The wetter the soil, the less soil temperatures are fluctuating (Bristow, 1988, in Bullied, et al., 2012). Fourth, soil temperature sensors were pulled and replaced for planting and rolling and may therefore have been not replaced at the exact same depth. Rolling would have flattened ridges. Research showed that diurnal soil temperature fluctuation as well as actual soil temperature decreased with depth (Stull, 2012). Because the soil surface was flattened with the rolling operation, sensors were most likely placed lower above sea level than after planting and rolling because the soil.

Strip till between the row before planting and rolling was consistently colder than all other corn residue management treatments. After planting and rolling, all corn residue management treatments behaved more similar to strip till between the row. Bulk density will be also increased after rolling in vertical till and double disc as these treatments were not densely packed. This could have led to the smaller difference in soil temperature among strip till between the row and the other treatments.

4.1.2.2 MacGregor 2015

Daytime temperatures at 5 cm depth were above 15°C in MacGregor (Figure 4.5). Soil temperature for strip till in the row was slightly higher at 5 cm below the surface compared to all other corn residue management treatments. Standard error of the mean for soil temperature at 5 cm depth were as high as 0.76 (not shown) and suggests that there are no statistically significant differences among treatments, except strip till between the row and all other corn residue management treatments at daytime. Strip till between the row was consistently colder during the day compared to strip till in the row. Soil temperature at 30 cm depth was slightly lower compared to soil temperature at daytime in 5 cm depth. Soil temperature at 30 cm was consistently around 12°C. No differences in soil temperature were observed among corn residue management treatments at 30 cm depth.

Maximum soil temperatures of all corn residue management treatments were similar in MacGregor 2015 and Winkler 2015, but maximum soil temperature in MacGregor lasted for a longer period. Soil temperature at 5 and 30 cm were consistently higher at planting in MacGregor 2015 compared to Winkler 2015. However, soybean was planted almost a month later at this location and therefore avoided the 10 day cold period from May 5th 2015 that occurred at the Winkler 2015 site-year. With temperatures of 10°C overnight and daytime temperatures around 17.5°C at planting depth, this site-year showed similar temperatures to Winkler 2015 in the same time period (Figure 4.2, Figure 4.5).

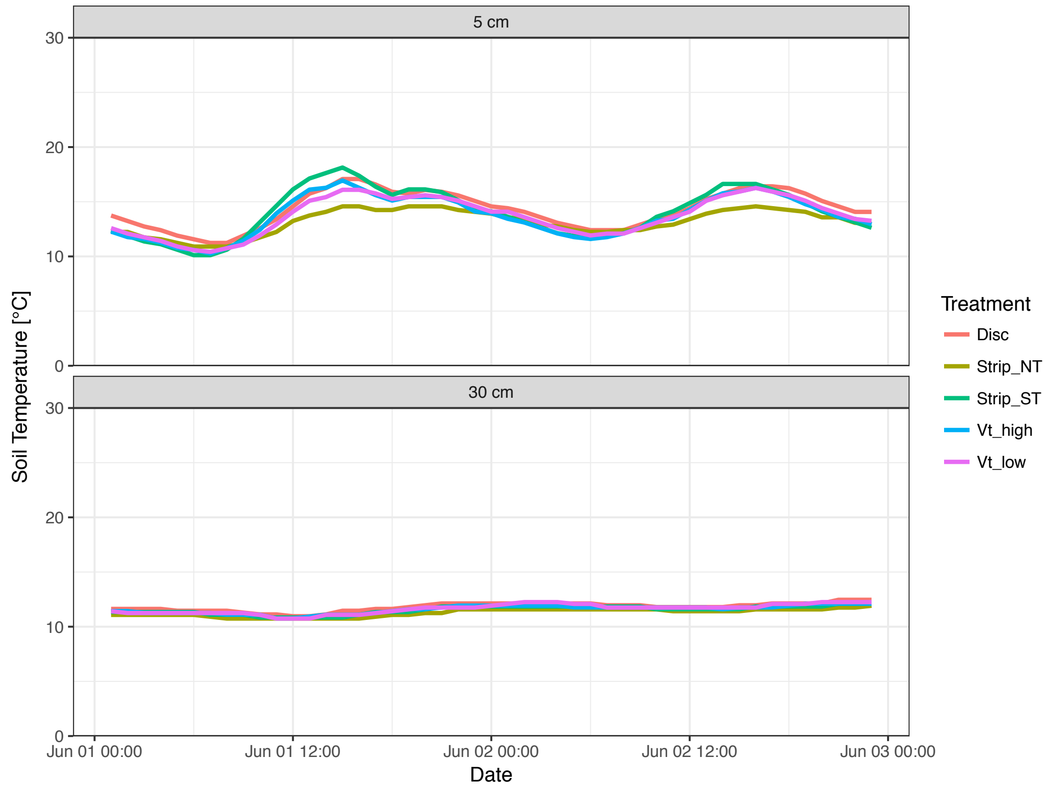

Figure 4.5: Soil temperature at 5 and 30 cm depths for first three days after planting (May 30th 2015) in MacGregor 2015 for corn residue management treatments using double disc (Disc), strip till between row (Strip_NT), strip till in row (Strip_ST), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low).

Rolling had no influence on temperatures in the strip till treatment at the 5 cm depth in MacGregor 2015 because the down pressure of the packer wheels on the planter flattened the berm. Strip till in the row, double disc and vertical till low disturbance treatments showed the same temperature day and night at 5 cm depth (Figure 4.6). Packer wheels from the planter had flattened the berm already at planting (May 30th 2015) (Figure 4.7). This means that the berm was flatened already before rolling occured. Unfortunately, the soil temperatures of treatments before planting were not measured because tillage treatments were setup in spring and the time between tillage and planting was short. It is unknown whether strip till treatments with a berm would have shown higher day and lower night-time temperatures in MacGregor 2015.

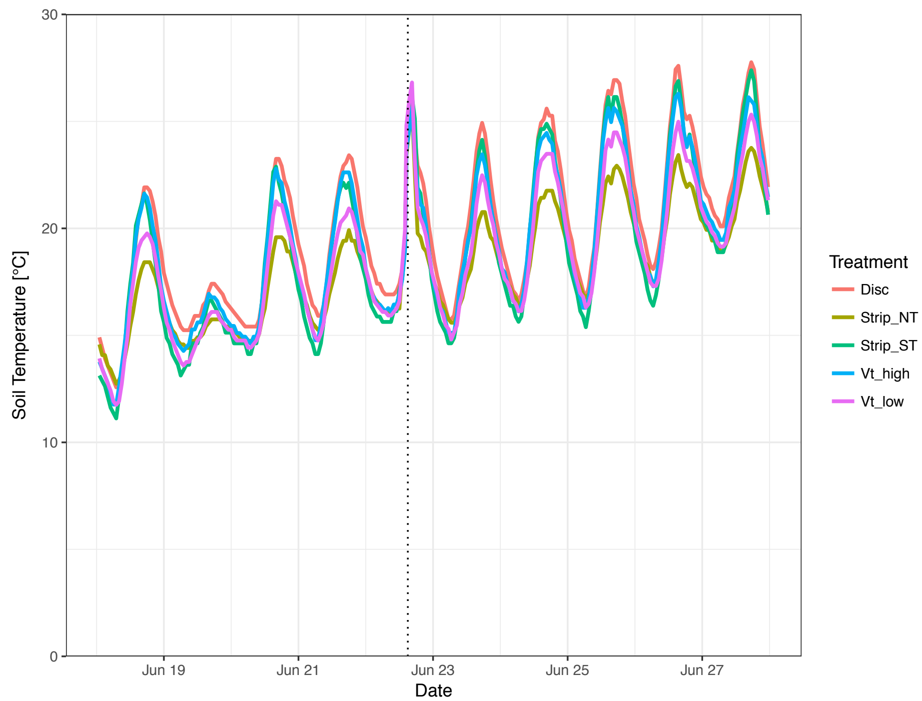

Figure 4.6: Soil temperature at 5 cm depth in MacGregor 2015 before and after rolling (June 22nd 2015, see dotted line) for corn residue management treatments using double disc (Disc), strip till between row (Strip_NT), strip till in row (Strip_ST), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low).

Figure 4.7: Packer wheels of the planter flattened the berm of the tilled zone in strip till in MacGregor 2015

4.1.2.3 MacGregor 2016

The site-year MacGregor 2016 showed higher soil temperature at 5 cm depth than the site-year MacGregor 2015. Daytime temperature at 5 cm depth was above 20°C in all treatments except strip till between the row. Temperatures at 5 cm depth ranged from 12.5° to 22.5°C in the first three days. This is slightly warmer than in MacGregor 2015, despite the fact that it was earlier in the year. Temperatures at 30 cm were around 13°C and were therefore similar to MacGregor 2015. Standard error of the mean indicated statistically significant differences in daytime temperature between strip till between the rows and all other treatments at 5 cm depth.

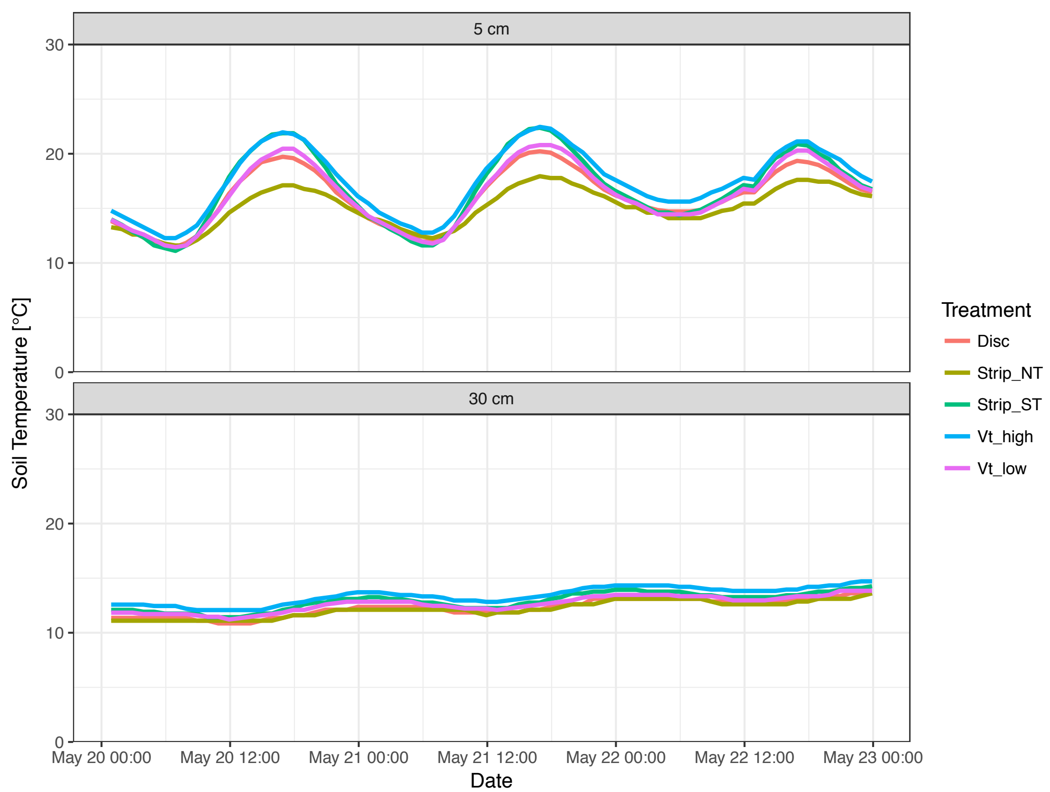

Figure 4.8: Soil temperature at 5 and 30 cm depths for first three days after planting (May 19th 2016) in MacGregor 2016 for corn residue management treatments using double disc (Disc), strip till between row (Strip_NT), strip till in row (Strip_ST), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low).

The down pressure on the soil during the planting operation influenced surface soil temperatures at MacGregor in 2016 in treatments strip till in the row and double disc. Soil temperatures at 5 cm depth before planting were warmest in the strip till treatment in the row and in the double disc treatment (Figure 4.9). This is a similar trend to Winkler 2015 where strip till in the row was warmest during daytime before planting and rolling. However, double disc behaved similarly to strip till in the row, which was not the case in Winkler 2015. The soil surface in MacGregor 2016 after double disc treatment was rough and uneven (Figure 4.10). It can be hypothesised that this treatment had a lower bulk density compared to the smooth surfaced vertical till treatments that had packers at the end of the machine. The bumpy surface of the double disc treatment acted similar to a berm in terms of capturing solar radiation. The double disc treatment would have had therefore similar soil characteristics than the berm in strip till. Double disc behaved therefore similarly to a berm. This may explain why soil temperatures trends for the strip till treatment in the row from Winkler 2015 are similar to the double disc and strip till in the row treatments in MacGregor 2016.

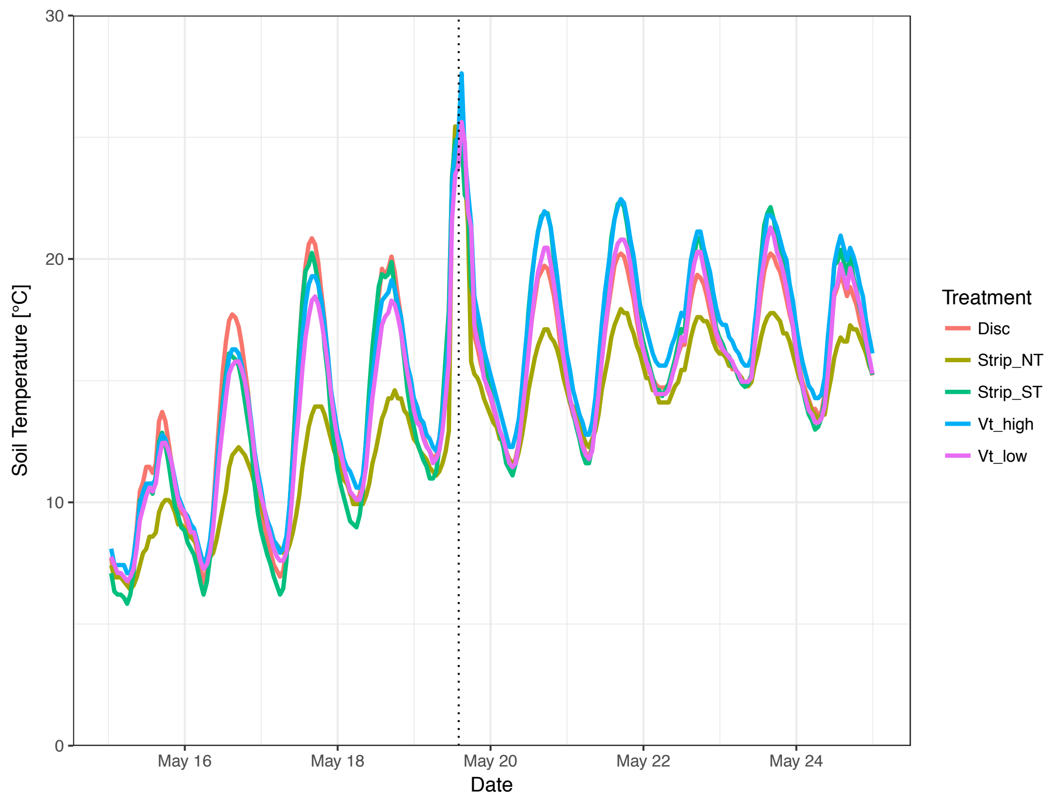

Figure 4.9: Soil temperature at 5 cm depth in MacGregor 2016 before and after planting (May 19th 2016, see dotted line) for corn residue management treatments using double disc (Disc), strip till between row (Strip_NT), strip till in row (Strip_ST), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low).

Figure 4.10: The double disc treatment at MacGregor in 2016 created a rough surface. This rough surface likely created a lower bulk density in the double disc treatment compared to the vertical till treatments that had packers at the end of the machine. It can be also be hypothesised that the bumpy surface of double disc acted similar to a berm in strip till in terms of capturing solar radiation.

4.1.2.4 Haywood 2016

In Haywood 2016 many rain events occurred throughout the season and led to equipment failure of the iButtons that were used for measuring soil temperature at 5 and 30 cm. Comparisons with at least three repetitions were possible for strip till between the row and in the row in 5 cm depth. Vertical till high disturbance and double disc treatments had only one and two repetitions that could be analysed at 5 cm depth, respectively. Useful data at 30 cm could not be collected in any of the corn residue management treatments. Statistical analysis in sections 4.1.2.6, 4.1.2.7 and 4.1.2.8 was still performed with the available data, but needs to be therefore looked at with caution because of the uneven number of replicates.

4.1.2.5 Trends across site-years

Strip till between the row seemed to be persistently colder around planting time than the other corn residue management treatments and was the only consistent pattern across the site-year. Trends in average surface soil temperature around planting time at 5 cm among treatments varied among site-years. Consistent trends among site-years were not observed. Differences among corn residue management treatments were small and most likely not biologically relevant.

Planting and rolling seemed to influence both maximum and minimum soil temperature patterns for all site-years. Strip till in the row in Winkler 2015 showed the warmest and coldest soil temperatures at 5 cm during day and night, respectively (Figure 4.4). After rolling, this effect disappeared and the treatment behaved similar to vertical till high disturbance and vertical till low disturbance corn residue treatments. MacGregor 2016 showed warmest day-time temperatures in strip till in the row and double disc treatments. Treatments were much closer together and the effect disappeared after planting (Figure 4.6) suggesting that a packer wheel from a planter can act similar to a rolling operation that flattens the soil surface and increases bulk density. The data indicated that absolute soil temperature differences at planting varied among corn residue management treatments (Hypothesis II), however differences are biologically not meaningful. As patterns varied over time and among site-years, differences should be integrated over time. An approach of accumulating soil temperature over a certain period is therefore discussed in the following section.

4.1.2.6 Daily Accumulated GDH above 10°C for the First Ten Days after Planting

Research has shown that temperature below 10°C can lead to soybean injury or delayed emergence (Hobbs and Obendorf, 1972, Jones and Gamble, 1993). Temperature accumulation above this critical threshold is therefore of interest for understanding the impact of residue management on soybean emergence.

The concept of growing degree hours (GDH) of soil temperature is not widely used compared to the concept of growing degree days for air temperature. Whereas growing degree days is based on air maximum and minimum temperature with a specific base temperature, the concept GDH is based on a continuous data set of soil temperature. It requires a continuous data set with hourly observations of soil temperature and does not include maximum and minimum temperatures. It has been used previously in research about stubble management for canola that looked at the effect on microclimate (Cardillo, 2014). Soil temperature fluctuated throughout a day in this experiment. A concept such as GDH that adds up time series observations is therefore needed when comparing to categorical variable such as surface residue cover.

Soybean emergence started within 10 days of planting in three out of four site-years (see Section 4.2.1). It is therefore of interest whether the corn residue management treatments accumulated different amounts of GDH per day, and if patterns over these 10 days changed. This analysis should help to see if corn residue management treatments varied in accumulated soil temperature at emergence in planting depth and ultimately evaluate Hypothesis II.

Daily accumulated soil temperature above 10°C showed no statistically differences among treatments double disc, vertical till low and high disturbance and strip till in the row in any site-years (Table 4.2).

Table 4.2: Effect of corn residue management treatment (Treatment) on daily accumulated soil temperature above 10°C at 5 cm for the first 10 days after planting over time (Days) with repeated measurements. Average daily accumulated soil temperature for treatments from the treatment least square means table are reported.

Treatment	**Winkler 2015 †**	**MacGregor 2015**	**MacGregor 2016**	**Haywood 2016 ‡**
Double disc	31.0	131.9a	124.0ab	117.3
Vertical till high disturbance	43.4	117.8a	142.9a	133.1
Vertical till low disturbance	43.4	114.8a	128.7ab	N/A
Strip till in the row	42.6	122.3a	132.2ab	135.5
Strip till between the row	13.2	97.0b	114.0b	122.0
ANOVA		P>F		
Source of Variation				
Treatment	0.1802	0.001***	0.0128*	0.2222
Days	<.0001***	<.0001***	<.0001***	<.0001***
Treatment*Days	0.0164*	0.0054**	0.0003***	0.0366*

† Excluding observations for May 10th and 11th for analysis due to convergence problems. No temperature was accumulated on those days above the critical value of 10°C. ‡ ‡Vertical till high disturbance observations only based on one logger. Means within a column followed by the same letter are not significantly different.

The only statistical differences were observed between strip till between the row and other corn residue management treatments in two out four site-years. In MacGregor 2015 strip till between the row showed significantly lower daily accumulated soil temperatures at 5 cm compared to all corn residue management treatments. Strip till between the rows would accumulate, on average 17.8°C per day less, compared to the treatments double disc, vertical till low disturbance, vertical till high disturbance and strip till in the row (p=0.001). On an hourly basis this is only 0.7 °C less compared to the other treatments. In MacGregor 2016 strip till between the row was significantly lower than vertical till high disturbance, but not significantly lower than the other corn residue management treatments (p=0.0128). Strip till in MacGregor 2016 accumulated 1.2°C less per hour compared to vertical till high disturbance. The main reason for differences between strip till between the row and the other corn residue management treatments is most likely due to lower solar transmittance and higher shortwave albedo. However, the differences need to be put into context. Research has shown that diurnal soil temperature fluctuation as well as actual soil temperature is highly dependent on depth placement of the sensor (Stull, 2012). A sensor placed in 3 cm compared to 2 cm showed lower soil temperatures of up to 4°C. The hourly differences of 0.7°C is therefore very small and one needs to ask the question if these differences were induced by slightly different placement of the sensors and if these differences are biologically meaningful.

However, the observations of lower accumulated soil temperature in strip till between the row indicated that a corn residue management treatment with no-till at all in Manitoba would likely negatively influence daily accumulated soil temperature at emergence in planting depth. This effect would have to be further investigated as one needs to keep in mind that the residue from the planting row gets pushed on to the no-till part of strip till which leads to higher residue cover in strip till between the row than in a complete no-till setting.

The daily accumulated soil temperatures varied significantly over time. In all four site-years a significant effect of days was observed. This means that the daily accumulated soil temperature varied significantly among these 10 days that were observed indicating that not every day accumulated the same amount of heat. This agrees with the qualitative description of soil temperature differences in previous sections (e.g. Figure 4.2, Figure 4.5, Figure 4.9), where major differences in minimum and maximum temperature between days were shown due to weather. However, the interaction between treatment and days is of interest.

In all site-years, analysis showed significant treatment by days interaction (Table 4.2). This is of great interest as it means that treatments did not behave the same over this 10-day period. An analysis of a single day is therefore not suitable without any further discussion as to why a particular day should be selected for analysis.

There are two main potential reasons for the change of patterns between treatments over time. First, soil temperature trends could vary between cold cloudy and warm sunny days.

Significant differences between residue cover in this experiment would have caused different solar transmittance and shortwave albedos. More residue leads to lower solar transmittance and higher shortwave albedo (Fabrizzi, et al., 2005, Horton, et al., 1996, Johnson and Lowery, 1985, Teasdale and Mohler, 1993) and ultimately lower soil temperature. This effect would be reduced on cloudy days compared to sunny days where more solar radiation reached the soil surface. In other words, the differences in temperature between treatments with more residue compared to one with less residue would be smaller on a cloudy day compared to a sunny day. On a sunny day, the treatment with less residue would benefit form the solar radiation and warm up quicker. Secondly, a significant interaction between soil temperature and soil moisture was reported (Erivelton, et al., 1999). Differences in soil moisture would influence the pattern of diurnal change in soil temperature.

Corn residue management treatments double disc, vertical till low disturbance, vertical till high disturbance and strip till in the row showed no significant differences between corn residue management treatments in terms of daily accumulated soil temperature in the first ten days at emergence at any site-year. The hypothesis that there are differences in daily accumulated soil temperature at emergence in planting depth (Hypothesis II) could therefore not be proven (Table 4.2). However, in two site-years strip till between the row accumulated significantly less soil temperature daily than other corn residue management treatments.

4.1.2.7 Relationship between Residue Cover and Total Accumulated GDH above 10°C for the First Ten Days after Planting

It was emphasised that that residue cover influences accumulated growing degree hours (GDH) above 10°C (Hypothesis III). To explore whether higher residue ground cover leads to lower accumulated soil temperatures at planting depth by the time soybean emergence occurs, a regression between residue cover and accumulated GDH above 10°C was conducted. When combining all site-years in the same analysis two distinct groups were present. The assumption underlying linear regression that residuals need to be normally distributed was therefore not met when including the site-year Winkler 2015 in the analysis (see Appendix 6.3.2). Site-years MacGregor 2015, Haywood 2016 and MacGregor 2016 Winkler 2015 accumulated above 1100 GDH in the first 10 days after planting while in the same period Winkler 2015 accumulated only 400 GDH (Figure 4.11, Figure 4.12). These low accumulated GDH were due to an extended cold period after planting (Figure 3.1). The site-year Winkler 2015 was therefore analysed separately from all the other site-years (Figure 4.12).

Residue cover had a negative influence on GDH. Regression analysis with three site-years (MacGregor 2015, MacGregor 2016 and Haywood 2016) combined showed that higher residue cover led to lower accumulated GDH (Figure 4.11). The slope was significantly different from zero ($p<0.0001$) and showed therefore a relationship between residue cover and accumulated GDH above 10°C. Even though intercept and coefficient were highly significant residue cover explained only 33% of the observed variation of accumulated GDH above 10°C. The high coefficient of variations in the observations for residue cover were caused due to two reasons. Only one picture was taken per plot and the program that was used for the analysis included several steps that required subjective ratings. Furthermore, soil temperature in Haywood 2016 had only one and two repetitions for vertical till high disturbance and double disc that could be analysed at 5 cm depth, respectively. These reasons could have led to this low adjusted R-squared value for this regression.

The equation for the three site-years combined (Figure 4.11) indicated that a residue cover increase of 10% would lead to a 21°C lower accumulated GDH over a 10 days period. This would mean that this treatment with higher residue cover would accumulate 2°C less on average per day. On an hour basis this would be only 0.08°C less. The total spread of the data is only 217°C over 10 days. On an hourly basis, this means that the corn residue management treatment with the highest residue cover is on average 0.9°C colder than the treatment with no residue cover. This is in agreement with the temperature graphs in previous sections that showed only small differences among treatments. Furthermore, the assumptions for this analysis were only met when excluding the site-year Winkler 2015. Therefore, one needs to keep in mind that the difference of 0.9°C was only observed when excluding a site-year.

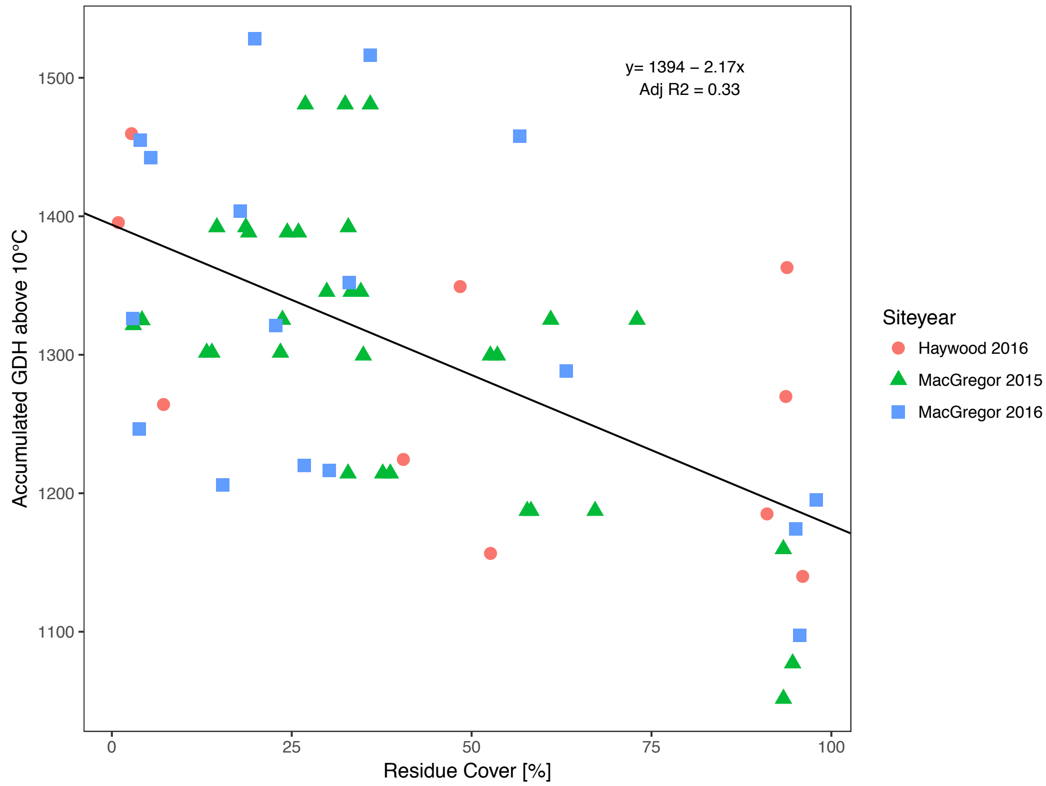

Figure 4.11: Influence of corn residue ground cover on accumulated soil growing degree hours (GDH) above 10°C for the first 10 days after planting in Haywood 2016, MacGregor 2015 and MacGregor 2016.

There was no relationship between residue cover and accumulated soil GDH at the site-year Winkler 2015 (Figure 4.12). Statistics showed a significant effect of the intercept ($p<0.0001$), but no significant effect of the slope coefficient ($p=0.129$). During the 10 days of this analysis the site-year Winkler 2015 experienced a cold period. Considering that Winkler 2015 accumulated no temperature above 10°C during three days (May 8th ,10th ,11th 2015) out of 10 days it is not surprising that the regression showed no relationship between the variables. Treatments did not have enough time to distinguish themselves from each other. An adjustment of the timeframe would be possible but not agronomically useful. The timeframe of 10 days was chosen as a soybean crop usually emerges within that period.

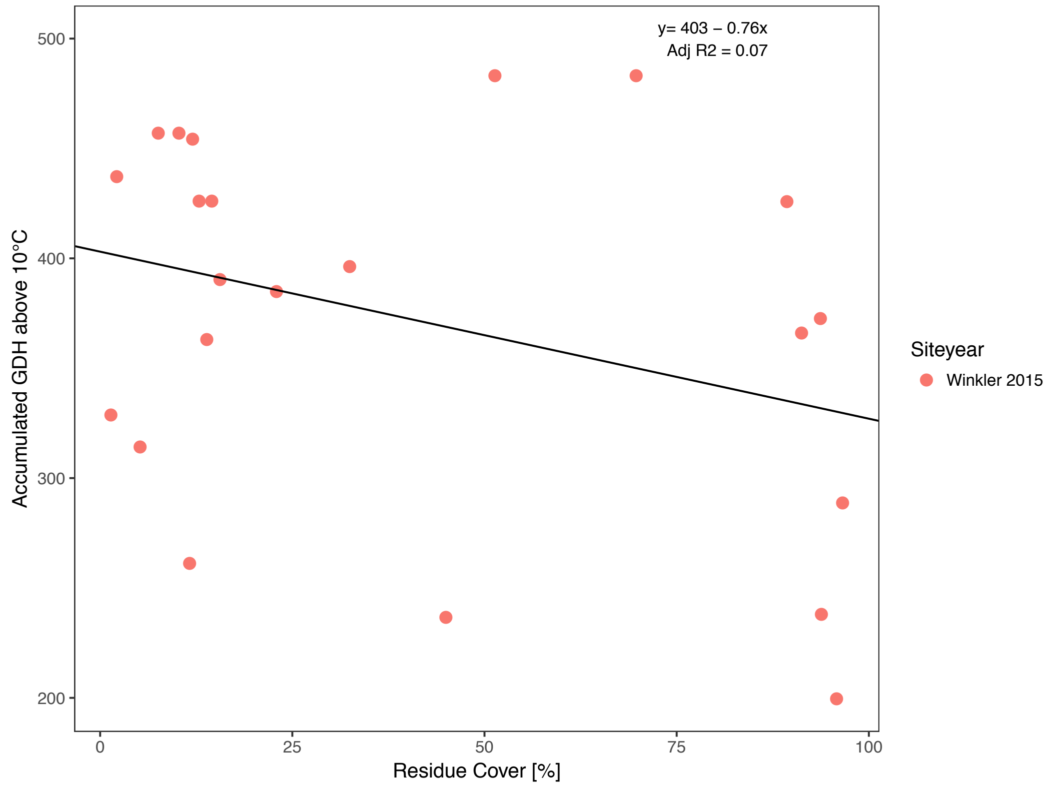

Figure 4.12: Influence of corn residue ground cover on accumulated soil growing degree hours (GDH) above 10°C for the first 10 days after planting in Winkler 2015.

Higher residue ground cover led to lower accumulated soil temperatures at planting depth by the time soybean emergence occurred in three out of four site-years. Winkler 2015 showed an extended cold period with many days accumulating no values. In cases like that, one might consider to adjust the threshold of 10°C to a lower value to accumulate soil temperatures or extending the period of 10 days. However, from an agronomic stand point it would be hard to justify. The hypothesis that higher residue ground cover leads to lower accumulated soil temperature at emergence in planting depth (Hypothesis III) was therefore proven in three out of four site-years.

4.1.2.8 Total Accumulated GDH above 10°C until 50% and 100% Emergence

Days to emergence for soybean varied significantly across site-years but not among corn residue management treatments (see Section 4.2.1). Site-year Winkler 2015, MacGregor 2015 and MacGregor 2016 needed 26, 10 and 13 days to reach 50% soybean emergence ($p<0.0001$) and 37, 18 and 34 to reach 100% soybean emergence ($p<0.0001$), respectively. As emergence did not vary among corn residue tillage treatments at any of these three site-years the days to 50% and 100% soybean emergence were the same among treatments at a particular site-year. As emergence did not vary among corn residue management treatments it is therefore of interest whether the total accumulated soil temperature varied among site-years. If the total accumulated sum of soil temperature at planting depth among corn residue management treatments would be the same among site-years a model to predict emergence based on soil temperature sum could be introduced. This was not a hypothesis of this thesis, however it seemed to be of interest to explore.

Total accumulated soil temperature at 5 cm depth showed no significant differences among corn residue treatments (Table 4.3). There were no differences in total accumulated soil temperature at 5 cm until 50% and 100% soybean plant emergence among all corn residue management treatments (Table 4.3). This finding disagrees with a corn residue study from Minnesota that found different tillage implements influenced days to 50% soybean emergence (Lueschen, et al., 1992). However, differences were rather small and inconsistent among years and the study did not include any soil temperature measurements. Of greater interest, however is that differences in total accumulated soil temperature in planting depth between site-years were much bigger relative to differences among residue management treatments.

Table 4.3: Effect of corn residue management treatment (Treatment) on total accumulated soil temperature at 5 cm until treatments reached 50% and 100% emergence based on site-years Winkler 2015, MacGregor 2015 and MacGregor 2016.

Factor	**Treatment**	**50% emergence**	**100% emergence**
		GDH	GDH
Treatment	Double disc	1577	3867
	Vertical till high disturbance	1692	4060
	Vertical till low disturbance	1599	3833
	Strip till in the row	1611	3897
Site-year	Winkler 2015	1860a	3430b
	MacGregor 2015	1325c	2841c
	MacGregor 2016	1673b	5490a
ANOVA		P>F	
Source of Variation			
Treatment		0.3340	0.2536
Site-year †		<.0001***	<.0001***
Treatment*Site-year		0.3767	0.2375
Block		0.4112	0.8048

Means within a column followed by the same letter are not significantly different.

The total accumulated soil temperature varied significantly among site-years. At 50% emergence, Winkler 2015 had accumulated 1860°C. This was significantly higher than MacGregor 2015 and 2016. This is interesting, as Winkler 2015 saw a cold period over a longer period of time at emergence and one might assume that Winkler 2015 would have had a lower total accumulated sum until reaching 50% of soybean emergence. Corn residue management treatments in Winkler 2015 needed on average 26 days until 50% emergence. In comparison, MacGregor 2015 and 2016 needed 10 and 13 days, respectively. This lead to a higher total accumulated soil temperature sum in Winkler 2015. In Winkler 2015, several days were observed that had temperatures under 10°C, which could have led to soybean damage (Hobbs and Obendorf, 1972, Jones and Gamble, 1993). This damage most likely delayed the emergence process.

Total accumulated soil temperature to reach 100% soybean emergence, varied among site-years as well. MacGregor 2016 had significantly higher accumulated temperatures until 100% soybean emergence compared to the other two site-years. MacGregor 2016 was a very wet site-year. Ponded water in the field during the emergence period in several areas throughout the field delayed emergence of some soybean plants. Therefore, it took on average all corn residue management treatments 34 days to reach 100% emergence compared to 18 and 37 in MacGregor 2015 and Winkler 2015, respectively.

This analysis indicated that a model to predict emergence purely based on total accumulated soil temperature is not feasible without including other factors. Factors such as chilling period that lead to delayed emergence or soil moisture content. The chosen threshold of 10°C could also be adjusted. Research has used 7.7°C as base temperature (Gauer, et al., 1982). Biological processes, such as emergence, are in general two to four times faster when the surrounding temperatures are increased by 10 units (Van't Hoffsch rule) (Vertucci and Roos, 1993). Therefore, higher soil temperature would have to be weighed exponentially higher when creating a model that would be linked to a biological process such as emergence.

Research does not agree on the effect of soil temperature on days to 50% and/or 100% emergence. Some literature showed no differences in phenological development and final emergence of soybean even when daily temperature reached 17°C and night temperatures were as low as 8°C in the laboratory (Helms, et al., 1996a). This stands in contradiction with another lab study that showed temperatures that ranged from 11.3/5.6°C day/night to 20.5/14.1°C day/night, exhibiting a decrease in emergence with lower temperatures. Every 1°C increase of average temperature was associated with a reduction of 1.92 days to attain 50% emergence. However, the same study also showed no reduction in total emergence despite different temperature treatments (Muendel, 1986). Further research for linking soil temperature to soybean emergence is needed.

4.1.3 Moisture

Soil moisture is important at the time of emergence and pod filling for soybean. Soil moisture at time of planting is critical at the depth where the seed is placed (5 cm). Soil moisture at emergence has been shown to have an optimum. Too much moisture can delay emergence (Muendel, 1986) whereas with too little moisture the seed will imbibe moisture but still fail to emerge (Helms, et al., 1996a). It was shown that when soil moisture was in an intermediate range, it had only a minor influence on days to emergence (Muendel, 1986) which was then mainly driven by temperature and planting date. Therefore, the following chapter looks at soil moisture at planting only descriptively to determine if the minimum moisture content needed for emergence was reached.

The minimum soil moisture threshold for seeds to fully emerge differs between soil types and crops. The minimum threshold for a soybean seed to emerge in this study was estimated based on the literature, as data for the exact soil type used in this study was not available. Each crop has been shown to have a different critical value of seed water content for germination (Hadas and Russo, 1974). For example, the minimum threshold of volumetric soil moisture for corn germination was 0.121 $m^3 m^{-3}$ for a clay loam and 0.070 $m^3 m^{-3}$ for a loamy sand (Cutforth, et al., 1985). Two site-years had a loamy sand and two site-years had a sandy loam. A sandy loam has an intermediate clay content compared to a clay loam and loamy sand. Research for soybean seeds in Fargo, ND showed that emergence was not delayed when volumetric soil moisture content was 0.091 $m^3 m^{-3}$ or greater on a clay loam soil (Helms, et al., 1996a, Helms, et al., 1996b). For the soils in this study (sandy loam and a loamy sand), the critical threshold would be lower when following the logic from the corn experiment. It is therefore assumed that a volumetric soil moisture content above 0.091 $m^3 m^{-3}$ would be sufficient for soybean emergence in this experiment.

4.1.3.1 Winkler 2015

Soil moisture content was sufficient for soybean emergence in Winkler 2015. All corn residue management treatments showed volumetric soil moisture content above the 0.091 m^3 m^{-3} threshold (Figure 4.13). In Winkler 2015 corn residue management treatments were applied in the fall. The standing stubble over winter in strip till between the row might have helped to capture more snow. In all other site-years no-tillage was done as the corn residue management treatments were set up in spring. Therefore there would be no differences in snow capture prior to applying tillage treatments in the spring. All differences in terms of soil moisture would be due to different soil drying. It can be therefore hypothesised that in site-years with spring applied treatments the differences between strip till between the row and the other corn residue management treatments would be smaller than for fall applied treatments Soil moisture content at 30 and 60 cm was the same for all treatments. Soils among corn residue management treatments were therefore the same deeper in the profile which becomes more important for roots later in the season.

Precipitation during the time period for the soil moisture graph illustrates its importance for inducing soil moisture differences. Accumulated precipitation in the two-month period was 200 mm with a total of 17 days where it rained. (Figure 4.14). Several rain events around 50 and 100% soybean emergence insured enough soil moisture for sufficient emergence.

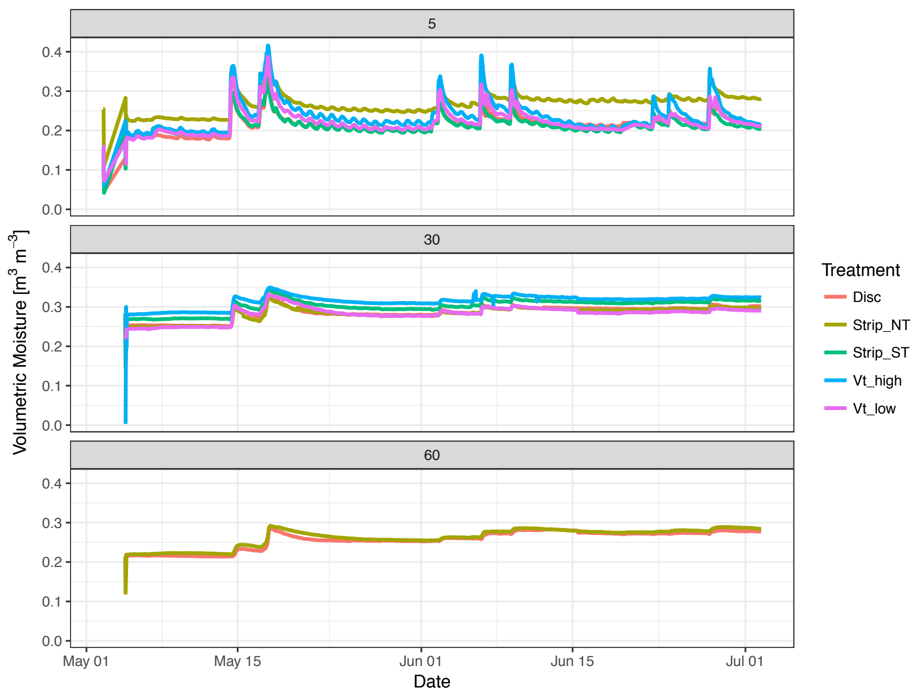

Figure 4.13: Volumetric moisture content [m^3 m^3] at 5, 30 and 60 cm depth in Winkler 2015 from May 2nd to July 2nd 2015 for corn residue management treatments double disc (Disc), strip till between row (Strip_NT), strip till in row (Strip_ST), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low).

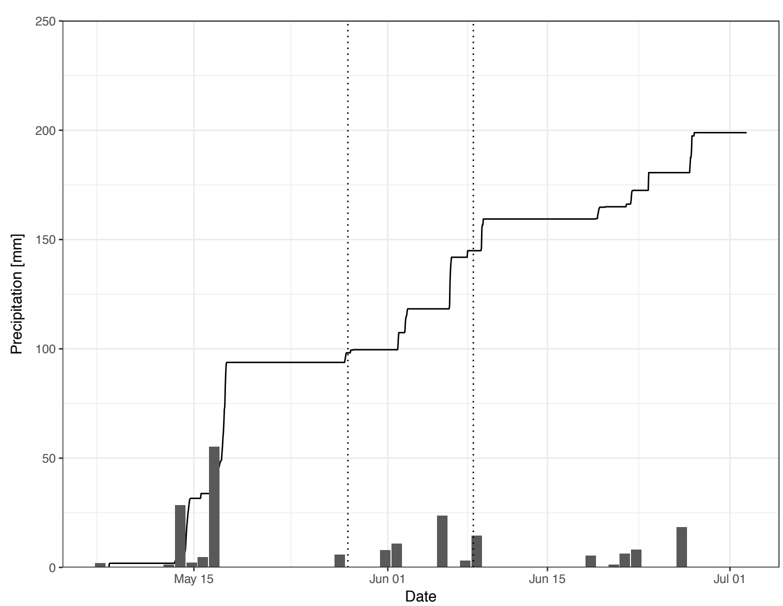

Figure 4.14: Daily and accumulated precipitation from May 2nd to July 2nd 2015 in Winkler 2015. Rain occurred on a total of 17 days during this period. Vertical dotted lines indicate the day of 50% and 100% soybean emergence.

4.1.3.2 MacGregor 2015

Measurements of soil moisture in MacGregor 2015 were not complete. Due to equipment shortage, MacGregor 2015 had only two repetitions at depths of 5, 30 and 60 cm at emergence. These limited repetitions per corn residue management treatment are important when considering the following discussion.

MacGregor 2015 exceeded the critical soil moisture threshold for soybean emergence (Figure 4.15) throughout the emergence period. Volumetric soil moisture contents were around 0.35 m^3 m^{-3} at planting and therefore sufficient for soybean emergence. Strip till in the row appeared to dry out slightly faster than all other corn residue management treatments. Otherwise residue management treatments were similar.

Soil moisture content at 30 and 60 cm with 0.4 m^3 m^{-3} were higher than Winkler 2015 and offered therefore more moisture for soybean later in the season.

Accumulated precipitation was 140 mm with 22 rain events for the first two months (Figure 4.16). Several rain events around 50 and 100% soybean emergence secured enough soil moisture for sufficient emergence.

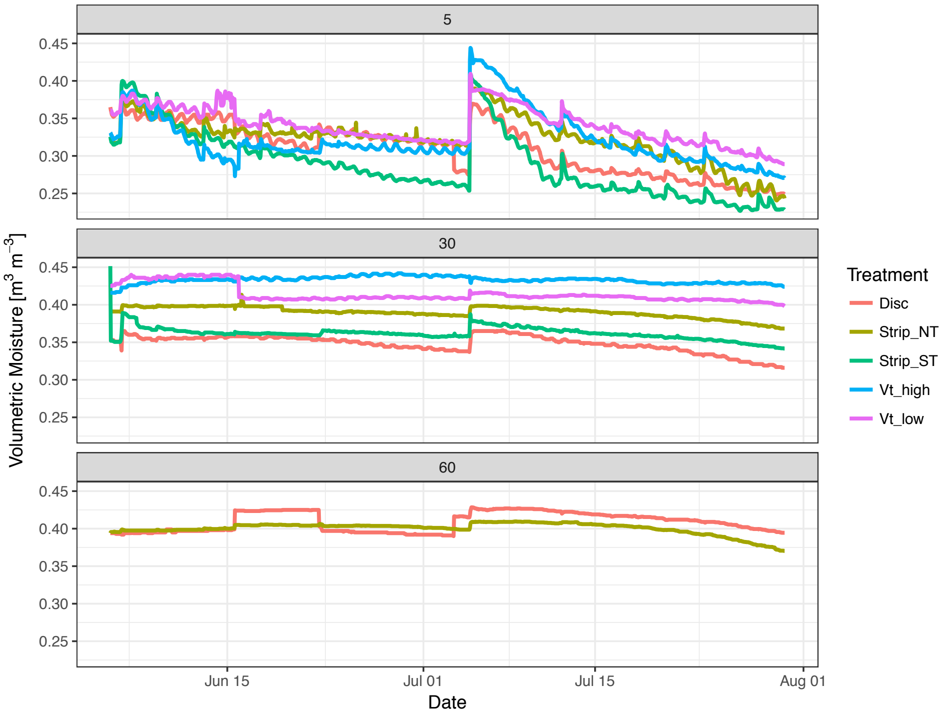

Figure 4.15: Volumetric moisture content [m^3 m^3] at 5, 30 and 60 cm depth from May 30th to July 30th 2015 in MacGregor 2015 for corn residue management treatments double disc (Disc), strip till between row (Strip_NT), strip till in row (Strip_ST), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low).

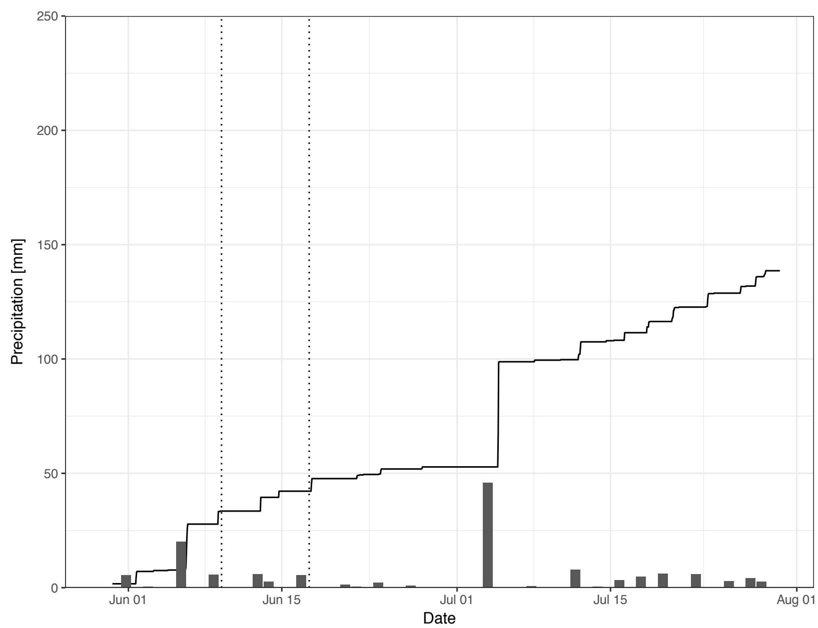

Figure 4.16: Hourly and accumulated precipitation from May 30th to July 30th 2015 in MacGregor 2015. Rain occurred on a total of 22 days in this period. Vertical dotted lines indicate 50% and 100% soybean emergence.

4.1.3.3 MacGregor 2016

Soil moisture content was sufficient for soybean emergence in MacGregor 2016 (Figure 4.17). Double disc seemed drier than all other corn residue management treatments for the first 6 days before several days of rain in mid May. Treatments reached 50% emergence on June 1st 2016 and by that time residue management treatments had all the same soil moisture content at 5 cm depth with the help of rain that occurred at the end of May (Figure 4.18).

Soil moisture at 30 cm was numerically higher in treatments vertical till high and low disturbance than in double disc, strip till between the row and strip till in the row. However, standard error of the means indicated no significant treatment differences. A major rain event on May 25th 2016 increased soil moisture by at least 10 m^3 m^{-3} and brought soil moisture levels deep in the profile (30 cm) similar to MacGregor 2015. Total accumulated precipitation in the first two months was 205 mm with 28 rain events during this time. Several rain events around 50 and 100% soybean emergence secured enough soil moisture for sufficient emergence.

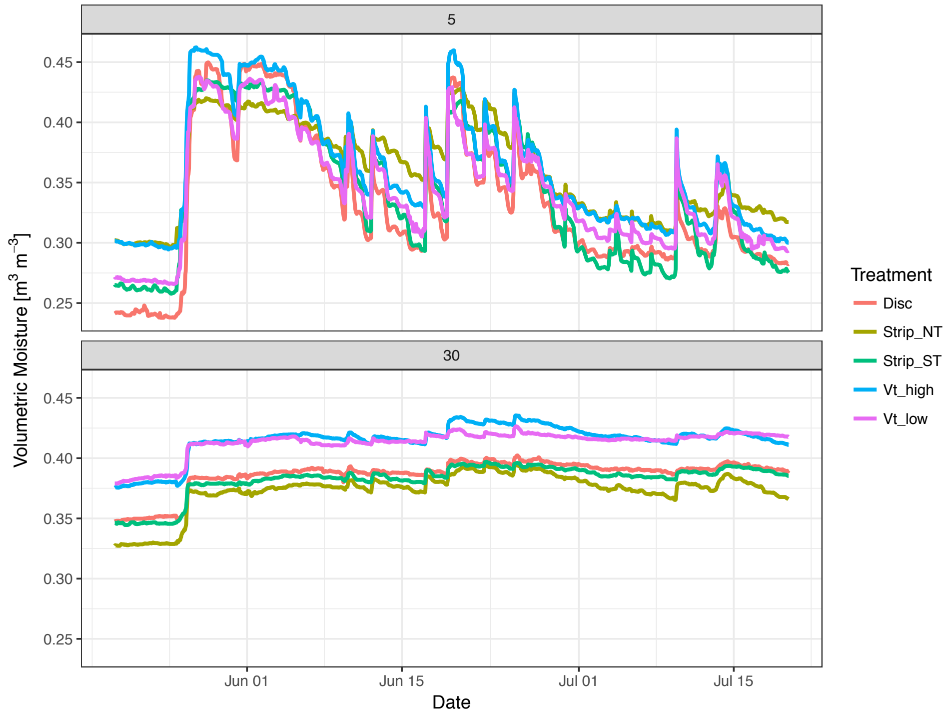

Figure 4.17: Volumetric moisture content [m^3 m^3] at 5 and 30 cm depth from May 19th to July 19th 2016 in MacGregor 2016 for corn residue management treatments double disc (Disc), strip till between row (Strip_NT), strip till in row (Strip_ST), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low).

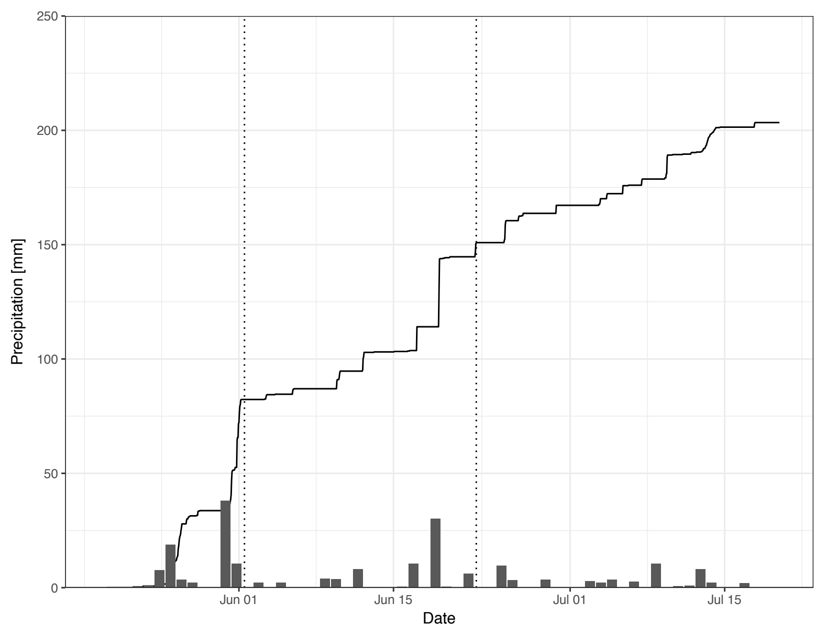

Figure 4.18: Daily and accumulated precipitation from May 19th to July 19th 2016 in MacGregor 2016. Rain occurred on a total of 28 days in this period. Vertical dotted lines indicate 50% and 100% soybean emergence.

4.1.3.4 Haywood 2016

Soil moisture content was sufficient for soybean emergence in Haywood 2016. Soil moisture content at 5 cm was between 0.15 and 0.2 $m^3\ m^{-3}$ for the first six days after soybean planting (Figure 4.19). This is similarl to Winkler 2015 and lower than the MacGregor 2015 and 2016 sites, however still higher than the required 0.091 $m^3\ m^{-3}$ threshold for soybean emergence. Treatments double disc and strip till in the row seemed to have lower soil moisture content at 5 cm depth compared to vertical till high disturbance treatments.

Soil moisture at 30 cm seemed to be similar among treatments strip till in the row, double disc and vertical till high disturbance. Strip till between the row seemed 0.05 $m^3\ m^{-3}$ wetter in the first 14 days and may have lost less water through transpiration than the other corn residue management treatments. After a several rain events at the end of May soil moisture levels in 30 cm were all at 0.35 $m^3\ m^{-3}$ in all corn residue treatments.

Total accumulated precipitation was just under 200 mm with 27 rain events (Figure 4.20). Several rain events around 50 and 100% soybean emergence secured enough soil moisture for sufficient emergence.

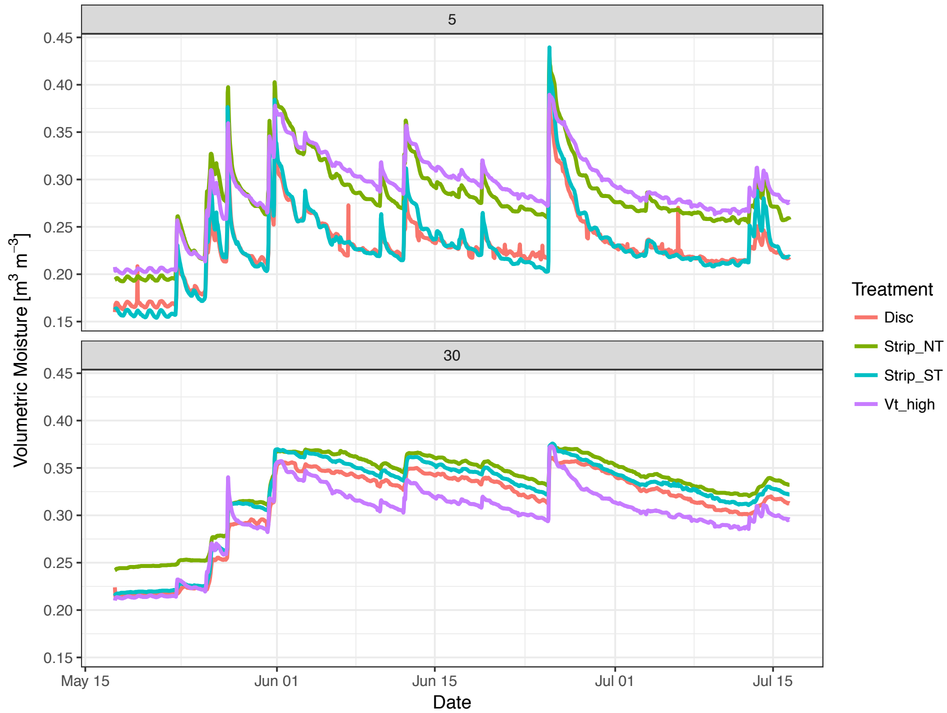

Figure 4.19: First two months of volumetric moisture content [m^3 m^3] at 5 and 30 cm depth from May 16th to June 16th 2016 in Haywood 2016 for corn residue management treatments double disc (Disc), strip till between row (Strip_NT), strip till in row (Strip_ST), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low).

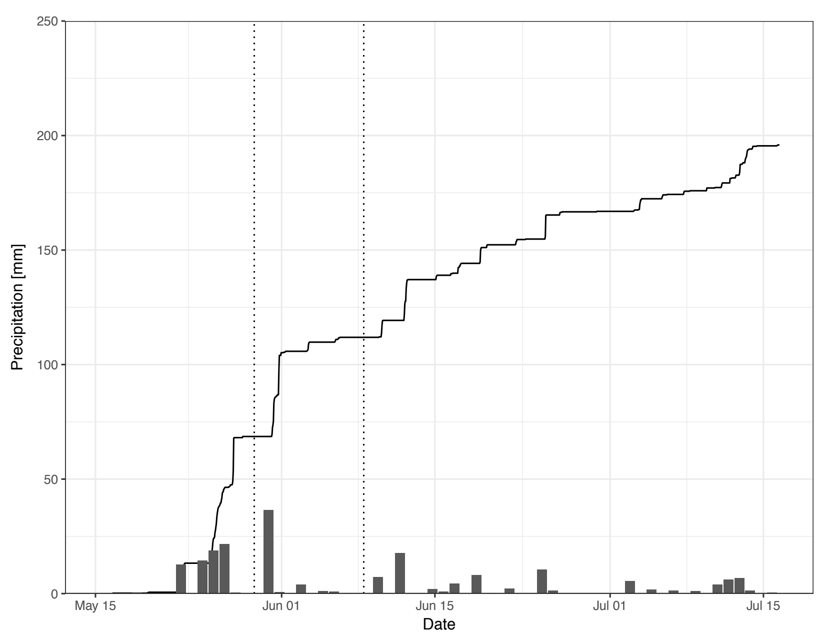

Figure 4.20: Daily and accumulated precipitation from May 16th to June 16th 2016 in Haywood 2016. Rain occurred on a total of 27 days in this period. Vertical dotted lines indicates 50% and 100% soybean emergence.

4.1.3.5 Trends across Site-years

Soil moisture content was sufficient at all site-years for emergence. Soil moisture levels were all above the critical 0.091 m^3 m^{-3} threshold at all site-years and in all corn residue treatments. Soil moisture was sufficient for soybean emergence at planting depth in all corn residue management treatments (Hypothesis IV). An initial hypothesis stated that with higher residue cover, soil moisture should also be increased. Descriptive analysis indicated that a high residue cover treatment such as strip till between row showed higher moisture contents over a longer period compared to all other corn residue management treatments only in two site-years (Winkler 2015, MacGregor 2016). Why this common observation could not be observed in MacGregor 2015 and Haywood 2016 is unclear. Strip till in the row on the other hand, with the lowest residue cover, showed lower moisture contents compared to vertical till high disturbance only in one site-year (Haywood 2016). In the three other site-years (Winkler 2015, MacGregor 2015, MacGregor 2016) strip till between the rows showed no differences compared to vertical till high disturbance. The initial hypothesis that with higher residue cover, soil moisture should also be increased could be therefore not be proven and further research is needed. Future research should also include statistics. One would have to find a statistical approach that uses repeated measurement analysis for timeseries data so that the entire emergence period could be analysed. It also should include precipitation as a covariate that influences soil moisture. Unfortunately, current repeated measurement models were not able to handle this large dataset.

4.2 Soybean

One of the main reasons for residue management is to prepare a seedbed for the following crop (Randall, et al., 2002). Crop residues can hinder seed-soil contact and therefore delay emergence of the following crop (Beyaert and Voroney, 2011, Markowski, 2013). Delayed emergence can lead to delayed flowering and an overall shorter growing period which ultimately affects yield. This thesis looked at corn residue management and its influences on soybean. The previous chapter focused on differences in soil temperature and moisture induced by the different tillage treatments (Chapter 4.1). The next chapter focuses on the test crop soybean and how it was influenced by these different corn residue management treatments.

4.2.1 Emergence (BBCH 0 to 14)

Corn residue management treatments influenced residue cover on the soil surface and therefore the seedbed for the following crop (see Section 4.1.1). These differences in seedbed preparation could have influenced soybean emergence. Soybean emergence is a process over time that can be looked at just graphically or can be analysed with repeated measurement analysis over time. The following section describes the emergence period, from time of seeding to first plants that emerged based on the emergence graph. The section after that analyses the emergence period from the day the first plants emerged until corn residue management treatments reached final plant population with repeated measurement analysis.

4.2.1.1 Period until First Soybean Emergence

Days until first soybean emerged out of the ground varied among site-years. First plants emerged around 8 days after planting in three out of four site-years (Figure 4.21). Only Winkler 2015 showed delayed emergence compared to all other site-years.

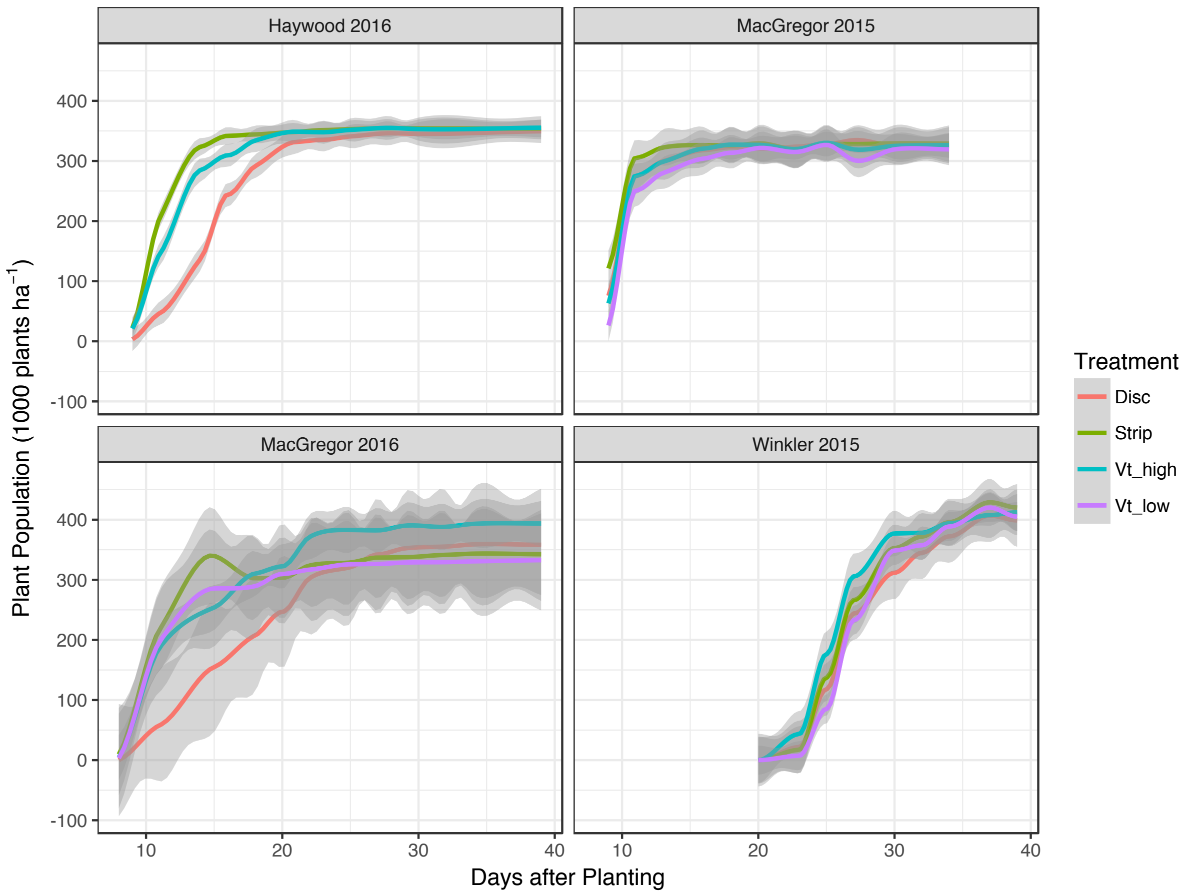

Figure 4.21: Emergence period with days after planting and plant population in Haywood 2016, MacGregor 2016, MacGregor 2015 and Winkler 2015 for corn residue management treatments double disc (Disc), strip till (Strip), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low). Grey area surrounding the line represents the 95% confidence interval.

In Winkler 2015 the corn residue management treatments emerged only after 20 days. This is an unusually long period between planting and emergence. Soil moisture, soil temperature or planting depth could have caused this delay. Soil moisture content at planting reached the minimal soil moisture threshold, however it was one of the driest site-years at emergence. Volumetric soil moisture content in Winkler 2015 was 0.2 m^3 m^{-3} and therefore the driest locations at emergence in this study (see Figure 4.13). However, the minimum soil moisture threshold of 0.091 m^3 m^{-3} (Helms, et al., 1996a, Helms, et al., 1996b) for emergence was therefore still reached and soil moisture was likely not limiting (see Figure 4.13).

Soil temperature was also low during soybean emergence at Winkler 2015. For several days in Winkler 2015, soil temperatures at night were below 10°C in all corn residue management treatments. These low temperatures could have led to chilling injuries and reduced hypocotyl growth rates which would ultimately delay emergence (Bramlage, et al., 1978, Hobbs and Obendorf, 1972, Jones and Gamble, 1993). Low soil temperatures at the beginning of May were associated with an early planting date as Winkler 2015 was planted the earliest (May 2nd 2015) of all site-years. A study in Lethbridge showed that an early planting date of soybean (May 22nd) needed 25 days to reach 50% emergence compared to 11 days when planted later (June 5th) (Muendel, 1986).

The interaction between soil moisture and temperature also suggested that the low soil temperature had influenced the emergence in Winkler 2015 (Table 3.3). A study showed that soil moisture had only minor influences on emergence when cold temperatures were present (Cutforth, et al., 1985). However, the moisture contents still needed to be sufficient when soil temperature is at 5°C, otherwise a decrease in survival and dry matter accumulation of the seedling was observed (Obendorf and Hobbs, 1970). As soil moisture was sufficient in Winkler 2015 emergence was likely influenced by the low soil temperatures.

Planting depth likely influenced days until first plants emerged in Winkler 2015. Planting depth in Winkler 2015 was the deepest of all site-years. Soybean were planted at a depth of 5.4 cm. Deeper seed placement delays emergence (Cox, 2016, Fehr, et al., 1973). This leads to the conclusion that the low soil temperature combined with a deeper seed placement caused the 20 days long period from planting to emergence in Winkler 2015.

4.2.1.2 Soybean Emergence Period and Final Plant Population

Soybean emergence over time was the same in all corn residue management treatments in three out of four site-years (Table 4.4). Site-years were analysed separately as repeated measurement analysis was not able to handle all site-years at the same time. Final plant population was 415,841 in Winkler 2015, 325,110 plants/ha in MacGregor 2015, 344,745 plants/ha in Haywood 2016, 355,798 plants/ha in MacGregor 2016. There were no-tillage treatment differences in soybean emergence over time due to no significant differences in daily accumulated soil temperature in the first 10 days after planting among corn residue management treatments. There were no differences in daily accumulated soil temperature in planting depth even though surface residue cover ranged from 4.4 to 64.6 % (section 4.1.1). Only Haywood 2016 showed significant differences among treatments in emergence over time (Table 4.4). This contradicts an older study conducted in Minnesota that found differences in soybean emergence over time for different corn residue management treatments (Lueschen, et al., 1992).

Table 4.4: Effect of corn residue management tillage treatments on soybean emergence over time (Days) with repeated measurement analysis in Winkler 2015, MacGregor 2015, MacGregor 2016 and Haywood 2016 for treatments double disc, vertical till high disturbance, vertical till low disturbance and strip till. Reported p-values are from ANOVA from repeated measurement analysis.

Effect	**Winkler 2015**	**MacGregor 2015**	**MacGregor 2016**	**Haywood 2016 †**
		P>F		
Treatment	0.1685	0.0707	0.3673	0.0006***
Days	<.0001***	0.2249	0.1805	<.0001***
Treatment*Days	0.8745	0.6392	0.5092	0.3715

†Based only on double disc, vertical till high disturbance and strip till. Due to equipment shortage no vertical till low disturbance treatment was set up at this location.

Haywood 2016 showed significant delayed emergence in double disc compared to strip till and vertical till high disturbance treatments. Soil temperature, soil moisture, or planting depth are three potential reasons why soybean in the double disc treatment emerged slower compared to the other corn residue management treatments. An incubation study with soybean grown at three different temperature regimes (17/8°C day/night, 21/12°C and 25/16°C) showed no significant differences in total emergence nor different development of emergence (Helms, et al., 1996a, Helms, et al., 1996b). These temperature regimes were chosen based on average temperature at different planting dates in Fargo, ND. Soil temperatures at Haywood 2016 in all corn residue management treatments were above 8°C and above 10°C at night during the first 20 days after planting. Two exceptions were vertical till low disturbance on the May 17th for one hour and strip till on May 18th for three hours. Furthermore, previous analysis in section 4.1.2.6 has shown no significant differences in daily accumulated soil temperature above 10°C among the corn residue management treatments in Haywood 2016. Soil temperature was therefore not likely the reason to cause these significant differences in emergence among treatments in Haywood 2016.

Volumetric soil moisture content above 0.091 m^3 m^{-3} was reported by Helms, et al. (1996a), and Helms, et al. (1996b) to be sufficient to fully emerge a soybean seed. Volumetric soil moisture content at Haywood 2016 during emergence was above 0.15 m^3 m^{-3} at all times in all treatments. Soil moisture in the double disc treatment was the same as the treatment strip till. Strip till seemed to be the one that emerged slightly faster than the other corn residue management treatments, not significantly though. Delayed soybean emergence due to differences in soil moisture content is therefore unlikely.

Delayed emergence in the double disc treatment at Haywood 2016 must likely come from differences in planting depth and not caused by soil temperature or soil moisture. Unfortunately, not enough observations were gathered for a statistical analysis on planting depth. However, visual observation confirms that double disc treatment in Haywood 2016 was the roughest corn residue management treatment by having many large soil pieces and an uneven surface (based on observation and see Figure 4.10). One could therefore assume that in the double disc treatment, a lower seed-soil contact or less uniform planting depth was achieved due to this roughness at planting. Less seed-soil contact has been shown to reduce emergence in soybean for treatments with similar soil moisture content (Hadas and Russo, 1974, Wagnerriddle, et al., 1994). Planting depth has been shown to negatively influence soybean plant stand early in the season even with ideal emergence conditions (Cox, 2016, Fehr, et al., 1973). However, final plant stand was the same for all corn residue management treatments in Haywood 2016 (not shown). Differences in yield would be therefore most likely be caused by a delayed emergence resulting in a shorter growing season and not by a lower plant population.

The double disc treatment in MacGregor 2016 showed also a rough surface. No statistical differences in emergence were found, however double disc seemed to have a slight lag in emergence as well (Figure 4.21). This supports the argument that soybean emergence in the double disc treatment was significantly delayed at Haywood 2016.

4.2.1.3 Early Soybean Phenological Development Stages from Emergence to Third Trifoliate Leaf (BBCH 0 to 13)

Differences in emergence can lead to differences in early soybean phenological growth stages. Early soybean phenological development stages showed significant differences among corn residue management treatments (Table 4.5). The early soybean phenological development stages showed similar trends as the plant population during the emergence period (Figure 4.21). Treatment differences in the early soybean phenological development stages were more distinct. Significant treatment effects early in soybean phenological development stages were observed (Table 4.5) in three out of four site-years.

Table 4.5: Effect of corn residue management tillage treatments on early soybean phenological development stages over time (Days) with repeated measurement analysis in Winkler 2015, MacGregor 2015, MacGregor 2016 and Haywood 2016 for treatments double disc, vertical till high disturbance, vertical till low disturbance and strip till.

Type III Test †	Winkler 2015	MacGregor 2015	MacGregor 2016	Haywood 2016 ‡
		P>F		
Treatment	0.9889	<.0001***	<.0001***	<.0001***
Days	<.0001***	<.0001***	<.0001***	<.0001***
Treatment*Days	0.0561	0.0059***	0.5450	<.0001***

† Covariance structure for Haywood 2016, MacGregor 2016, Winkler 2015 was first-order antedependence ANTE (1). MacGregor 2015 was power covariance structure SP(POW) ‡ Based only on double disc, vertical till high disturbance and strip till.

In MacGregor 2015 vertical till low disturbance showed significantly earlier phenological development stages than all other treatments over the first 39 days after planting. The same site-year showed significantly later soybean phenological development stages during the same time period in strip till compared to vertical till high and low disturbance but no significant differences from double disc treatment (Figure 4.22). Emergence (Figure 4.21) showed a similar pattern, however treatments differences were smaller compared to early soybean phenological development stages (Figure 4.22).

MacGregor 2016 and Haywood 2016 showed significantly earlier soybean phenological development stages in double disc compared to all other corn residue management treatments after 39 and 32 days, respectively (Figure 4.22). This agrees with the emergence data that showed a significant delay in emergence for double disc in Haywood 2016. The emergence data for MacGregor 2016 showed no significant differences among corn residue management treatments for emergence over time, however the double disc treatment seemed to have a slight lag in terms of plant population compared to all the other corn residue management treatments and therefore tends to agree with the early soybean phenological development stages.

The only site-year that showed no significant differences in early soybean phenological development stages among corn residue management treatments was Winkler 2015. This site-year showed no significant differences in early soybean phenological development stages in the first 58 days after planting among treatments (Table 4.5).

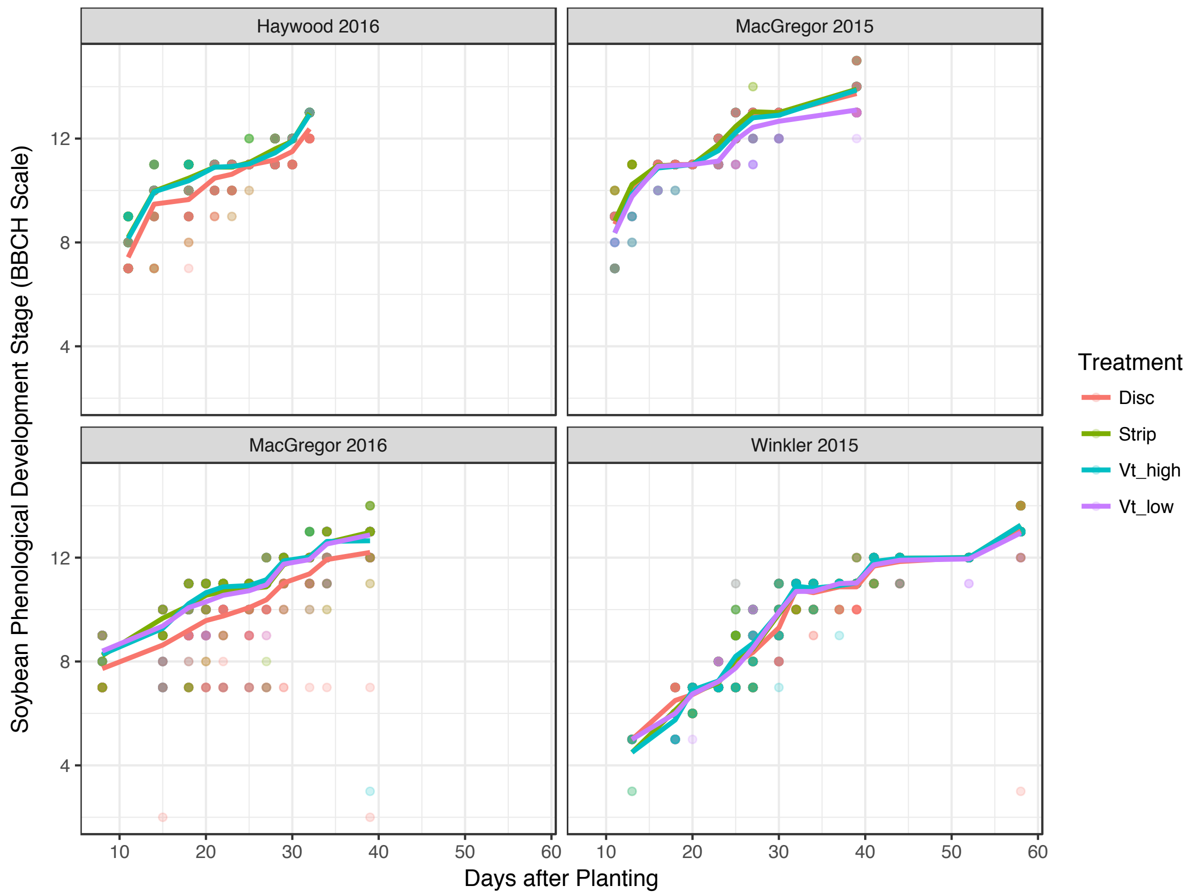

Figure 4.22: Early season soybean phenological development stages using the BBCH scale in Haywood 2016, MacGregor 2016, MacGregor 2015 and Winkler 2015 for corn residue management treatments double disc (Disc), strip till (Strip), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low). Dots are observed observations with fading of the colour when number of observations decreases. Stage 10= Cotyledons completely unfolded, Stage 12 = Trifoliate on 2nd node unfolded.

Early season soybean phenological development stages varied among site-years. BBCH stage 12 (equivalent to V2) was reached in Winkler 2015 after 40 days. This is 10 to 15 days later than in Haywood 2016 (10 days), MacGregor 2016 (30 days) and MacGregor 2015 (25 days). This is consistent with the emergence results where the site-year Winkler 2015 emerged

10 days later than all other site-years. The delayed emergence and delayed soybean phenological development stages created a potential for lower yield in Winkler 2015.

The hypothesis that emergence varied significantly among corn residue management treatments (Hypothesis VI) for emergence could not be proven. In three out of four site-years no significant differences in emergence were reported with repeated measurements. First plants emerged around 8 days after planting in three out of four site-years. Early soybean phenological development stage analysis showed no consistent effect of the different tillage treatments across site-years, as in some years vertical till low disturbance had earlier development stages, whereas in others double disc was had the lowest development stages.

4.2.2 Flowering (BBCH 60 to 69)

The phenological stages that follow after flowering are most critical for soybean yield (McWilliams, et al., 1999). The earlier all plants are flowering the higher the yield potential. It is therefore of interest to look at the flowering period and see if there were significant differences among these corn residue management treatments. Date of flowering has been shown to be dependent mainly on air temperature and photo period (Sinclair, et al., 1991). In theory, these different residue management treatments could create different microclimates and influence the air temperature (Sharratt, 2002).

Soybean flowering period showed significant differences among corn residue management treatments as well as different treatment patterns among site-years (Figure 4.23, Table 4.6, Table 4.7, Table 4.8 and Table 4.9).In two out of four site-years the percentage of plants that flowered were significantly different among treatments on a given day after planting (Table 4.6, Table 4.9). For example, in MacGregor 2015 at 39 days after planting, only 3% of the plants flowered in vertical till low disturbance compared to 28% in double disc, 43% in vertical till high disturbance and 46% in strip till (Figure 4.23, Table 4.6). Two days later, vertical till low disturbance caught up with double disc but not with vertical till high disturbance and strip till (Table 4.6). On day 44 after planting no significant differences among the treatments were detected. Vertical till low disturbance was therefore 2 days delayed in percentage of the plants that flowered compared to all other corn residue management treatments.

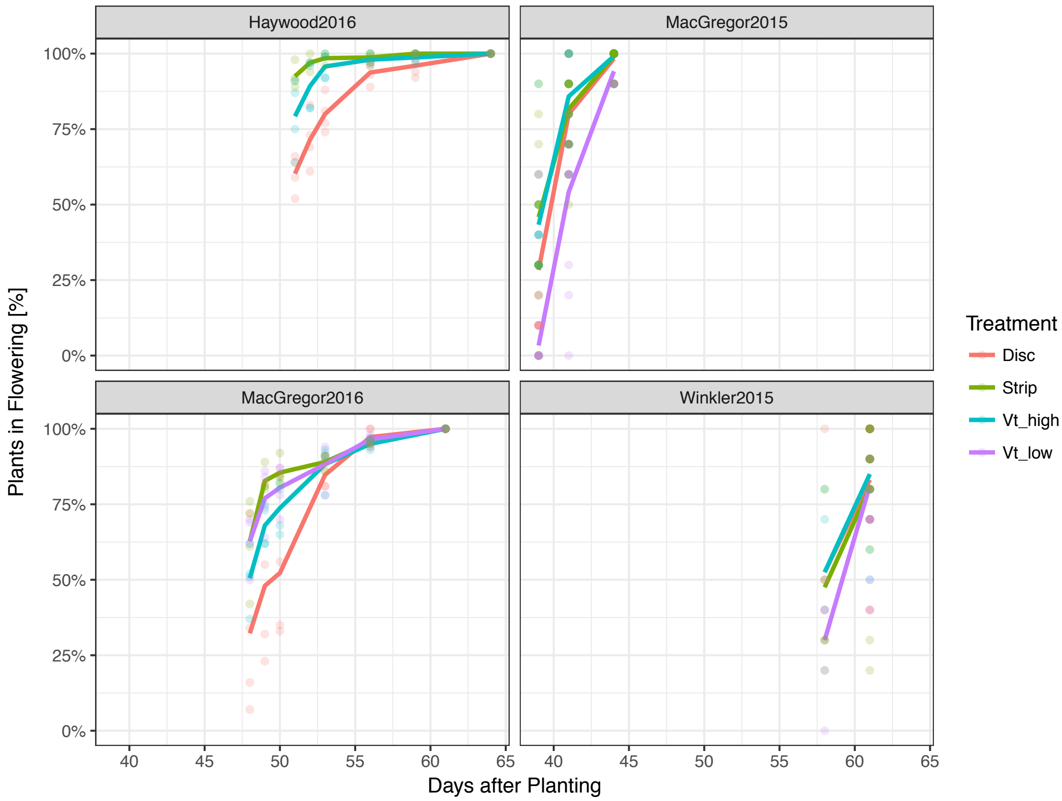

Figure 4.23: Percentage of plants that are flowering in Haywood 2016, MacGregor 2016, MacGregor 2015 and Winkler 2015 for corn residue management treatments double disc (Disc), strip till (Strip), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low). Dots are observations with fading of the colour when number of observations decreases. Number of plants observed ranged by location: Haywood 2016 N=72, MacGregor 2016 N=96, MacGregor 2015 N=144 and Winkler 2015 N=80.

Table 4.6: Effect of corn residue management tillage treatments on percentage of plants that are flowering with repeated measurement analysis over time (Days) in MacGregor 2015.

Treatment †	**Days after planting**		
	39	**41**	**44**
	---------------------%---------------------		
Double disc	28e	80dc	98a
Vertical till high disturbance	43e	86c	99a
Vertical till low disturbance	3f	54d	94a
Strip till	46e	82c	99a
ANOVA	P>F		
Treatment	<.0001***		
Days	<.0001***		
Treatment*Days	0.3685		

† Analysis based on 40 plants per plot. Means within a column followed by the same letter are not significantly different.

Winkler 2015 showed no significant differences among corn residue management treatments in terms of percentage of plants that flower on a given day. This was the first site-year where flowering data was collected. Differences among corn residue management treatments were apparent in the field with vertical till low disturbance behind, however no statistical differences were found when 10 plants per plot were tested. A power analysis on the same day with the collected data revealed that the number of observations needed to be increased to achieve significant differences among corn residue management treatments. In Winkler 2015, on day 58 after planting vertical till low disturbance showed lower percentage of plants that were flowering compared to all other corn residue management treatments (Figure 4.23). This was done on day 61 after planting, however at that point in time already 80% of the plants were flowering and there were no longer any differences among corn residue management treatments.

Table 4.7: Effect of corn residue management tillage treatments on percentage of plants that are flowering with repeated measurement analysis over time (Days) in Winkler 2015.

Treatment †	Days after planting	
	58	**61**
	------------------%------------------	
Double disc	47	83
Vertical till high disturbance	53	85
Vertical till low disturbance	33	81
Strip till	40	81
ANOVA	P>F	
Treatment	0.7392	
Days	<.0001***	
Treatment*Days	0.9079	

† Analysis on day 58 and 61 based on 10 and 40 plants per plot, respectively. Means within a column followed by the same letter are not significantly different.

Trends in 2016 were different than in 2015. In 2016 at both sites, soybeans in the double disc treatment flowered later than all other treatments, but only one site-year showed probability levels lower than 0.05 (Table 4.8). The MacGregor 2016 had a p-level of 0.0675 and was therefore not significant at the 0.05 level. On day 48, 49 and 50 after planting 20% fewer plants were flowering in double disc compared to all other corn residue management treatments. On day 53, differences among corn residue management treatments in percentage of plants that flowered were less than 5% and by this day in all corn residue management treatments more than 84% of the plants flowered.

Table 4.8: Effect of corn residue management tillage treatments on percentage of plants that are flowering with repeated measurement analysis over time (Days) in MacGregor 2016.

Treatment †	**Days after planting**				
	48	**49**	**50**	**53**	**56**
	---------------%---------------				
Double disc	32	48	52	84	97
Vertical till high disturbance	51	68	74	88	95
Vertical till low disturbance	63	77	81	88	97
Strip till	63	83	86	89	96
ANOVA	P>F				
Treatment	0.0675				
Days	<.0001***				
Treatment*Days	0.3685				

† Analysis based on 100 plants per plot. Means within a column followed by the same letter are not significantly different.

In Haywood 2016, on day 51 after planting significant differences were observed among treatments in percentage of plants that were flowering (Table 4.9). In the double disc treatment only 60% of the plants flowered compared to 79% and 95% in vertical till high disturbance and strip till treatments, respectively. Significant differences among corn residue management treatments were still present on day 52 after planting but there were no longer any differences among treatments on day 53.

Table 4.9: Effect of corn residue management tillage treatments on percentage of plants that are flowering with repeated measurement analysis over time (Days) in Haywood 2016.

Treatment †	Haywood 2016			
	51	**52**	**53**	**56**
	--------------%--------------			
Double disc	60d	72d	80b	94a
Vertical till high disturbance	79bd	89b	96b	98a
Strip till	93b	97b	99b	99a
ANOVA	P>F			
Treatment	0.0046***			
Days	<.0001***			
Treatment*Days	0.1204			

† Analysis based on 100 plants per plot. Means within a column followed by the same letter are not significantly different.

Significant treatment differences observed in phenological stages at emergence continued at flowering in all site-years. Vertical till low disturbance had a lower percent of plants that were flowering on a given day after planting in MacGregor 2015 and double disc showed lower percentages of flowering on a given day after planting in Haywood 2016 and MacGregor 2016.

Differences among site-years observed in days to emergence continued at flowering in terms of days to 95% plants flowering. Winkler 2015 showed a 12 day delay in emergence compared to all other site-years. Winkler 2015 did not reach 95% of plants flowering even after 61 days after planting. In MacGregor 2015 95% of the plants flowered already after 44 days. Haywood 2016 and MacGregor 2016 both needed 56 days after planting to achieve 95% of the plants flowering (Table 4.9). In other words, Winkler 2015 had a 12 day delayed emergence compared to all other corn residue management treatments and showed 5 (Haywood 2016 and MacGregor 2016) and 17 days to MacGregor 2015 delayed flowering. This difference could be due to soybean variety as they were not the same at all locations. However, this data indicated that the delayed start of the treatments in Winkler 2015, was still present at flowering. Research in the short growing season climate of Belgium showed negative correlation between yield and days until all plants were flowering (Aper, et al., 2016). An overall lower yield in Winkler 2015 would be therefore likely.

Corn residue management treatments significantly influenced the percentage of plants that flowered on a given day after planting and therefore delayed phenological development of the soybean. The hypothesis that tillage corn residue management treatments influenced soybean development stage of flowering (Hypothesis VI) was therefore proven. The next section will talk about whether these differences among corn residue management treatments in percentage of plants that were flowering on a given day after planting and therefore still existed in the phenological development of the soybean at maturity.

4.2.3 Pod filling and maturity (BBCH 75 to 100)

4.2.3.1 Late Soybean Phenological Development Stages

In the short growing season of Manitoba, an earlier maturing soybean that matures before the risk of frost increases late in the season is of advantage. It is therefore of interest to understand if the corn residue management treatments influenced the phenological development of soybean at maturity. However, staging late in the season is very subjective as it is only based on colour in the BBCH stage. Furthermore, the transition of pod colouring (Stage 80-89) and leaf colouring (Stage 90-100) is often not distinct and the two processes can occur at the same time. Varietal differences were observed as well as substantial differences soybean in phenological development stages within the same plots.

No significant differences in late season soybean phenological development stages were observed among treatments at three out of four site-years (Table 4.10). Differences in soybean phenological development stages that were present at flowering were no longer present at these late development stages. It seemed that the growing season conditions allowed the plants in certain treatments to hasten their development so that all the corn residue management treatments matured at the same time.

Table 4.10: Effect of corn residue management tillage treatments on late soybean phenological development stages over time (Days) with repeated measurement analysis in Winkler 2015, MacGregor 2015, MacGregor 2016 and Haywood 2016 for corn residue management treatments double disc, vertical till high disturbance, vertical till low disturbance and strip till.

Effect	**Winkler 2015**	**MacGregor 2015**	**MacGregor 2016**	**Haywood 2016 †**
		P>F		
Treatment	0.2006	0.1544	0.6196	0.0096**
Days	<.0001***	<.0001***	<.0001***	<.0001***
Treatment*Days	0.0108*	0.3526	0.5481	0.6887

† Based only on double disc, vertical till high disturbance and strip till.

The days from planting that was needed for soybean to start ripening their pods varied between years but not among treatments (Figure 4.24). Ripening of pods (BBCH stage 80 or equivalent to R7) started after 100 days in the site-years Winkler 2015 and MacGregor 2015 and after 106 days in Haywood 2016 and MacGregor 2016. Looking at all four site-years, the years seem to have a bigger effect than the actual treatments on the length of the season. In three out of four site-years no significant treatment effect was observed and therefore showed that the corn residue management treatments did not have any effect on late soybean phenological development stages.

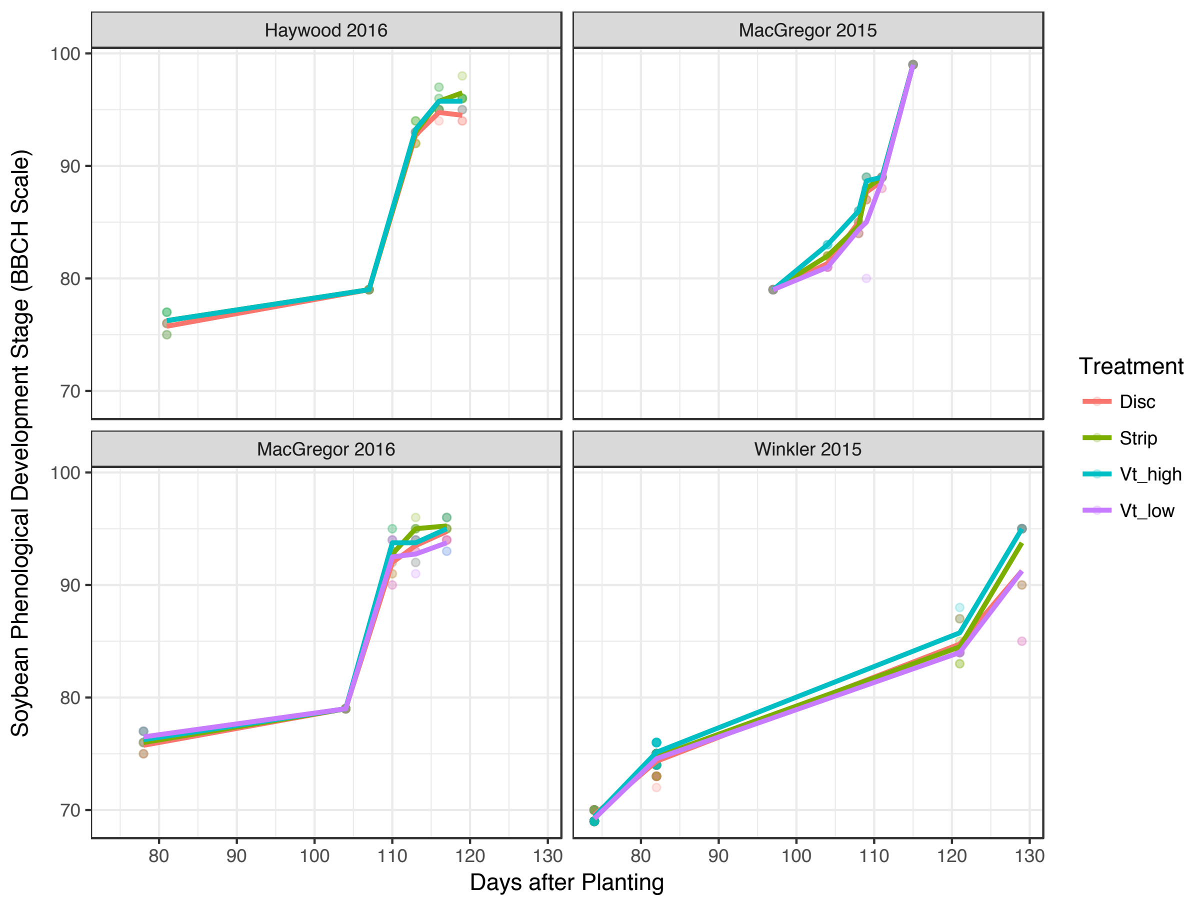

Figure 4.24: Late season phenological development stages of soybeans using the BBCH scale in Haywood 2016, MacGregor 2016, MacGregor 2015 and Winkler 2015 for treatments double disc (Disc), strip till (Strip), vertical till high disturbance (Vt_high) and vertical till low disturbance (Vt_low). Dots are observed observations with fading of

the colour when number of observations decreases. Stage 80 = First pod ripe, Stage 89 = Full maturity with all pods are ripe, Stage 95 = 50% of leaves discoloured or fallen, Stage 99 = Harvested Product.

Only one site-year showed significant treatment differences in late season phenological development stages. The only statistical differences among treatments in late season phenological development stage at a given time were found in Haywood 2016. In Haywood 2016, double disc treatment was significantly later in soybean phenological development stages than the vertical till high disturbance and strip till treatment. Double disc seemed to have a slight delay from the beginning of the season (Figure 4.21, Figure 4.22) and soybean phenological development stages were never able to catch up. Pictures of the soybean canopy in Haywood 2016 showed only minor differences in bean and leaf colour at those stages (Figure 4.25 and Figure 4.26). As mentioned earlier the staging of late soybean phenological development stages is very subjective as it is only based on colour in the BBCH staging guide. The significant differences in late season phenological development stages in Haywood 2016 should be therefore looked at with caution as the method of staging itself is challenging.


a)


b)


c)

Figure 4.25: No visible differences in late season soybean phenological development stages among corn residue management treatments (a=Vertical till high disturbance, b=Double disc, c=Strip till) 96 days after planting (September 12th 2016). Colour of leaves and pods are similar among treatments.

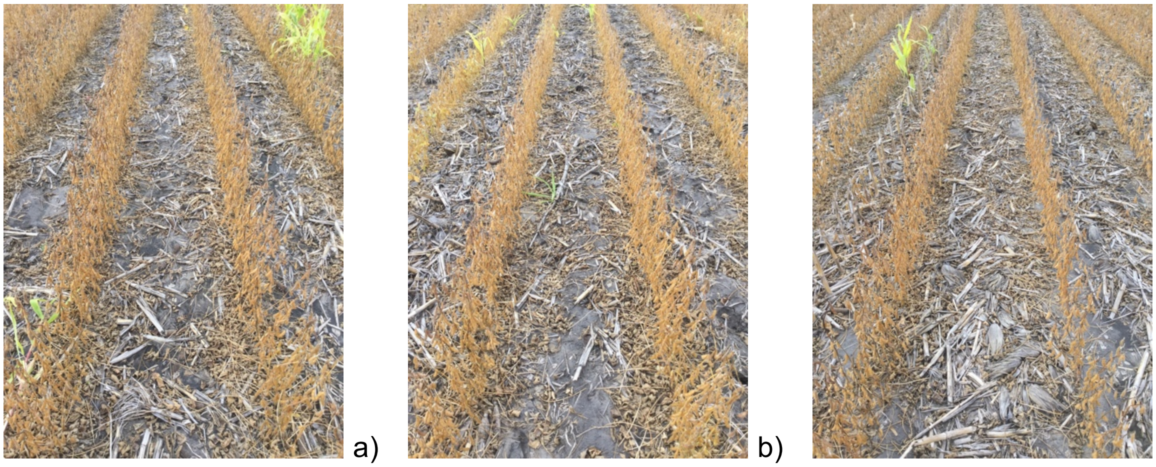
a) b) c)

Figure 4.26: No visible differences in late season soybean phenological development stages among corn residue management treatments (a=Vertical till high disturbance, b=Double disc, c=Strip till) 105 days after planting (September 21st 2016). All soybean leaves have fallen and pod colour is similar among all treatments.

4.2.3.2 Aerial imagery

Using aerial imagery in an on-farm trial setting with much variability within the plot is one method to overcome subjective visual ratings. Aerial imagery allows for the calculation of different indices of the reflected light by the crop and calculate values for an entire plot. This technique was only available in the 2016 growing season.

Haywood 2016 showed no significant differences among treatments in aerial imagery. Aerial imagery at pod filling development stage (BBCH stage 75 to 79) showed no significant differences in normalized vegetation index (NDVI) and normalized difference red edge index (NDRE) in Haywood 2016 (Table 4.11). This finding disagrees with the significant differences in the subjective soybean phenological development ratings that were observed in Haywood 2016. These late soybean phenological development ratings should therefore be looked at with caution and might have been only caused by the variability within the plot and the visual subjective rating.

Table 4.11: Effect of corn residue management treatment (Treatment) on normalized difference vegetation index (NDVI) and normalized difference red edge index (NDRE) in Haywood 2016 on August 10th 2016 when soybean were in pod fill stage with aerial imagery from a multispectral camera.

Treatment	**NDVI**	**NDRE**
Double disc	0.7916	0.4374
Vertical till high disturbance	0.8071	0.4416
Strip till	0.8166	0.4437
ANOVA	P>F	
Source of Variation		
Treatment	0.6054	0.7383
Block	0.0439*	0.0655*
CV, %	2.58	4.24

MacGregor 2016 showed significant differences among treatments in NDVI index but not NDRE index. Aerial imagery showed significantly lower NDVI values in MacGregor 2016 for vertical till low disturbance treatments compared to double disc and strip till treatments (Table 4.12). This finding contradicts previous research in Iowa that showed no significant differences in NDVI values at pod filling stages across different tillage treatments (chisel plough, fall and spring strip till) (Hatfield and Prueger, 2010). However, other research indicated that NDVI indices at pod filling stages should not be used (Rodriguez, et al., 2006). It was shown that NDVI can only be used up to a canopy cover of 90% (Rodriguez, et al., 2006). The research suggested that at pod filling a NDRE index is more accurate. The significant differences in NDVI among treatments in MacGregor 2016 should be therefore ignored and instead a NDRE index should be discussed.

NDRE showed no significant differences in MacGregor 2016 (Table 4.12). It can therefore be assumed that canopy density, water and nitrogen stress, were similar across treatments at stage 78 to 79 in the 2016 site-years (Rodriguez, et al., 2006). This finding corresponds with the findings from this study from the late soybean phenological development stages that there was no significant differences among treatments.

Table 4.12: Effect of corn residue management treatment (Treatment) on normalized vegetation index (NDVI) and normalized difference red edge index (NDRE) in MacGregor 2016 on the August 10th 2016 when soybean were in pod fill stage with aerial imagery from multispectral camera.

Treatment	**NDVI**	**NDRE**
Double disc	0.9097a	0.5000
Vertical till high disturbance	0.8916ab	0.5085
Vertical till low disturbance	0.8810b	0.4911
Strip till	0.9053a	0.5072
ANOVA	P>F	
Source of Variation		
Treatment	0.0430*	0.3783
Block	0.0019**	0.1187
CV, %	1.44	2.71

Means within a column followed by the same letter are not significantly different.

In conclusion, late soybean phenological development stages did not vary among corn residue tillage treatments in three out of four site-years. Aerial imagery in 2016 at pod filling showed no significant differences among treatments in NDRE as well. Visual ratings of development stages and aerial imagery of NDRE indicated that there were no differences in late soybean phenological development stages at maturing among corn residue tillage treatments (Hypothesis VI).

4.2.4 Soybean Growth Characteristics

Soybean growth characteristics such as plant height and lowest pod height varied significantly among corn residue management treatment. Plant height was affected by tillage treatments. Strip till had significantly taller plants than vertical till low disturbance and double disc but not compared to vertical till high disturbance (Table 4.13). The height difference was 2 cm and is therefore not of agronomic importance. Similarly, small differences were found among corn residue tillage treatments for lowest pod height.

To reduce harvest losses, lowest pod height is of great interest to farmers. Lowest pod height varied significantly among corn residue management treatments. The strip till treatment had significantly lower pods compared to all other corn residue management treatments. Strip till had pods that were 0.8 cm lower than vertical till low disturbance treatments. Considering that recent flex headers for combines will cut soybean plants 2-3 cm from the ground, the agronomic importance of these significant observed differences is minor.

Previous research has found a correlation between lowest pod height and plant height. Variety trial research in short growing season environment in Belgium showed that lowest pod height is positively correlated with flowering, plant height and maturity date for soybean in the earliest maturity group (Aper, et al., 2016). In contradiction to this research, the strip till treatment in this study did not show significantly earlier flowering across site-years. This stands therefore in contradiction to the previous research conducted by Aper, et al. (2016). Furthermore, a negative relationship between pod height to plant height was observed in this experiment which does not support the findings from the variety trials from Aper, et al. (2016).

It is unclear why significant differences among corn residue tillage treatments in lowest pod height were observed as many factors that are known to be influential can be eliminated. Previous research showed that plant population and planting date have influence on lowest pod height, however both of these factors were kept the same in this study. Low planting populations have been showed to reduce lowest pod height (Kandel, 2010) in North Dakota, but in this experiment final plant stand was the same across treatments. Additionally, plant height and pod height was shown to be influenced by planting date in North Dakota and Nebraska (Elmore, 1990, Kandel, 2010). However, in this experiment the planting date was the same among treatments at the site-years. This thesis found that soil temperature and moisture were similar among treatments. Differences in surface residue cover may have caused differences in reflectance of the light from the ground. Different spectra have been shown to influence growth characteristics of soybean. Unfortunately, reflectance of the different residue treatments were not measured and it can be therefore only hypothesized that this was the reason for the significant differences among corn residue management treatments. The residue might have caused this variability between plant and lowest pod height.

Table 4.13: Effect of corn residue management treatment (Treatment) on plant height, height of bottom of lowest pod averaged over all four site-years.

Treatment	**Plant height**	**Pod height**
	cm	cm
Double disc	71b	6.5b
Vertical till high disturbance	73ab	6.5b
Vertical till low disturbance	72b	6.9a
Strip till	74a	6.0c
ANOVA	P>F	
Source of Variation		
Treatment	0.0096**	<.0001***
Block (Site-year)	<.0001***	<.0001***
CV, %	10.45	27.44

† Based only on two locations: Haywood 2016 and MacGregor 2016. Means within a column followed by the same letter are not significantly different.

Significant differences in growth characteristics including plant and pod height were observed. The hypothesis that the intensity of tillage influenced soybean growth characteristics (Hypothesis VII) was therefore proven. Although these differences were statistically different, they are not agronomically important.

4.2.5 Soybean Yield

Grain yield showed no significant differences between corn residue management treatments (Figure 4.15). Average grain yield for all treatments and site-years was around 2811 kg ha^{-1} when adjusted to 13% moisture content. Statistical analysis indicated that there was no significant treatment by site-year interactions (p-value 0.6263) (see Appendix 6.3.1), therefore analysis for soybean yield were analysed with combined site-years. Associated coefficient of variation for grain yield was within acceptable range (CV 5 to 15%) for agriculture research (Bowman, 2001, Cochran, 1957, Gomez and Gomez, 1984) even though the experiments were conducted on-farm.

These findings agreed with many research papers that showed no significant differences for corn residue management for soybean production. Soybean yields in strip till and vertical till have been shown outside of the northern great plains not to yield higher than conventional tillage double disc in corn residue (Adee, 2015, Presley, 2013, VanDee, 2008). Non-peer-reviewed literature in Minnesota in the Northern Great Plains has showed no significant differences in soybean yield among different corn residue management implements. Strip till, vertical till high and low disturbance as well as chisel plough showed no significant differences in soybean yield (DeJong-Hughes and Coulter, 2013). Other non-peer-reviewed literature in Minnesota showed no significant differences in soybean yield between strip till and chisel plough, as well as no-till for corn residue management treatments (Stahl, 2011). This trial was only based on one site-year and needs to be looked at with caution. However, Stahl (2011) finding that no-till did not yield differently compared to conventional tillage systems is of great interest for no-till production in corn residue in Manitoba. This thesis indicated that soil temperature in a untilled part of the field (strip till between the rows) at planting depth at planting are lower and a delayed emergence could therefore occur resulting in lower yields in no-till.

Both of these research papers from DeJong-Hughes and Coulter (2013) and Stahl (2011) were conducted in Minnesota. The growing season in Manitoba is even shorter than in Minnesota and soil temperature could play a more important role as soybean are likely to be seeded into colder soils. Literature for corn residue management of soybean production in Manitoba was not found. This thesis has therefore a unique dataset that indicated no soybean yield differences among different tillage treatments exist north of Minnesota. It also indicated that soybean yield is not greatly influenced by contrasting tillage treatments like other research had found (Nowatzki, et al., 2011). It can be concluded that the soybean yield in corn residue for reduced tillage systems such as strip till and vertical till is the same than the standard tillage practice double disc in Manitoba on sandy soils.

Seed moisture content at harvest was influenced by corn residue management treatments. Seed moisture content at harvest varied significantly among treatments (Table 4.14) Strip till showed significantly lower moisture content (13.38%) compared to double disc (14.29%) and vertical till low disturbance (14.12%). The same trend was observed with plant height (see Section 4.2.4). The taller plants in strip till may have led to a faster dry down, because pods could have been further apart. Vertical till high disturbance was significantly lower moisture content (13.65%) than the double disc treatment.

Soybean grain oil and protein content were the same across treatments. No significant differences were observed. Oil and protein content was around 18.7% and 33.8%, respectively.

Table 4.14: Effect of corn residue management treatments on soybean grain moisture at harvest and soybean grain oil and protein content and soybean grain yield averaged over all four site-years.

Treatment	**Moisture at harvest**	**Oil**	**Protein**	**Grain yield†**
	%	%	%	kg ha^{-1}
Double disc	14.29a	18.75	33.69	2770.79
Vertical till high disturbance	13.65bc	18.67	33.83	2847.43
Vertical till low disturbance	14.12ab	18.73	33.88	2830.77
Strip till	13.38c	18.63	33.95	2794.91
ANOVA		P>F		
Source of Variation				
Treatment	0.0102*	0.4370	0.3779	0.6267
Site-year (Block)	<.0001***	<.0001***	0.0003**	<.0001***
CV, %	6.01	1.14	1.24	6.65

† Yield adjusted to 13% moisture content. Means within a column followed by the same letter are not significantly different.

No differences in grain yields were observed. The hypothesis that there are significant differences among corn residue management treatments in terms of soybean yield was therefore not proven (Hypothesis VII). However, the overall hypothesis of this thesis was to find out if strip till achieves the same yield than the standard tillage practice double disc but can outperform all other tillage treatments in the overall economics due to lower total costs for preparing a seedbed for soybean production. The hypothesis that there are no significant yield differences between the strip till treatment and the standard double disc treatment was proven. The next chapter will be addressing the economics behind the different tillage systems and therefore address the second part of the overall hypothesis. Even though no differences in yield were observed, a farmer is interested in the overall profitability of the tillage system to make an equipment purchase decision. Machinery data needs to be therefore included.

4.3 Economics

Decision making by farmers is often driven by economics. Highest yield is not anymore the only factor affecting management decisions; instead the overall economics of a production system is of interest. The previous section 4.2.1.2 showed no differences in final plant stand which means plant population is not affected by tillage systems. Section 4.2.5 showed no significant differences for soybean yield under different corn residue management practices and thus overall revenue from the soybean yield would be similar. In the experiments, management practices such as plant protection, fertilization and harvest were kept the same across all residue management treatments. Differences in economic return among different corn residue tillage treatments would be therefore only result from differences in the cost of tillage treatments. These costs would also include labor and time used to perform these tillage treatments.

The scope of this economic analysis is therefore only the cost of the different corn residue tillage treatments. It is important to note that a farmer would have to calculate an economic analysis for a minimum of one complete rotation period. This is especially important as certain machinery, such as strip till, cannot be used in crops grown on narrow row spacing, like wheat, and are therefore not used every year. In contrast equipment, such as double disc and vertical tillage could be used in all crops. However, this study was only conducted in one crop and therefore the gathered information in this study is not suitable to choose a multiyear economic analysis approach which has been done in the past (Meyer-Aurich, et al., 2006, Yin and Al-Kaisi, 2004).

Cost analysis is based on machinery performance measurements from both the tillage implement itself and the tractor (known also as power unit) that was used to pull the implement in the experiment. Measurements of operating speed (km h^{-1}) combined with implement width, lead to the working rate (ha h^{-1}) of the implement. Measurements of power requirement (kW m^{-1})

per meter of implement define the investment costs for purchasing a new power unit. Including but not limited this cost drives overhead (interest, insurance, housing) and operating costs (fuel, lubrication, repairs) of the power unit. Operating cost of the power unit is also influenced by fuel consumption ($l\ ha^{-1}$). Other measurements such as draft forces ($kN\ m^{-1}$) on the hitch from the power unit are not used for calculating cost but are of great interest for engineers to determine equipment wear and tear. Most of the information on these machinery performance measurements are available from the industry, however only limited independent research is available. Industry research is not unbiased because the same companies who producethis equipment also market and sell it. For this study, a side project was initiated together with Prairie Agriculture Machinery Institute (PAMI) in Portage la Prairie, MB that measured these machinery performance of four different tillage treatments in corn residue. Double disc, vertical till high disturbance, vertical till low disturbance and strip till were tested at two different locations. The following chapter presents the findings of these machinery performance measurements. These findings are then used to calculate overhead and operating costs for these implements and ultimately total costs. The last section presents the potential money and time savings for an average farm in Manitoba.

4.3.1 Machinery Performance Measurements

Machinery performance measurements were collected while conducting tillage operations in corn residue at two different locations (MacGregor and Beaver) that had two different soil types. The USDA textural class for the site at MacGregor was sand. The USDA textural class for the site Beaver was a loam. As these sites had contrasting soil types and likely different soil moisture content at time of tillage operation, the statistical analysis was done by site. Primarily, the analysis showed a significant treatment by site interaction for draft load, tractor requirement and fuel consumption (see Appendix 6.3.4). Measurements were taken for four tillage implements: double disc, vertical till high disturbance, vertical till low disturbance and strip till. All implements were pulled with the same power unit.

Work speed drives work rate and therefore operating and labour costs. Work speed varied significantly among tillage treatments ($p<.0001$) and soil types ($p<.0001$) (Figure 4.16). Implements are built to perform only at a certain speed range as otherwise the machinery starts to jump and the tillage performance is not as desired. The vertical tillage implement used for the vertical till low and high disturbance treatments could be operated at the highest speed compared to the other tillage treatments. Work speed off all tillage treatments was higher in MacGregor than in Beaver due to the different soil type and the response of the tillage equipment. All implements operated therefore faster in MacGregor on the sandy soils than in Beaver on the loamy soil. The work speed was 13.7 and 12.8 km h^{-1} for vertical till low disturbance and 14.0 and 13.1 km h^{-1} for vertical till high disturbance in MacGregor and Beaver, respectively (Table 4.15). Strip till was operated at 10 and 9.2 km h^{-1} and was therefore significantly lower than the vertical till implements. However, the slowest implement was double disc at both locations. Double disc was operated at 9.5 and 8.7 km h^{-1}. These different work speeds between the tillage treatments influenced work rates.

Table 4.15: Effect of tillage treatments on speed, work rate (100% field efficiency), draft load, tractor requirement and fuel consumption in MacGregor (sand) and Beaver (loam).

Treatment	Work Speed	Work Rate	Draft Load	Tractor Requirement	Fuel Consumption
	km h^{-1}	ha h^{-1}	kN m^{-1}	kW m^{-1}	l ha^{-1}
				MacGregor †	
Double disc	9.5c	7.7c	5.3b	14.3c	6.5b
Vertical till high disturbance	13.7a	12.5a	7.2a	27.5a	7.2a
Vertical till low disturbance	14.0a	12.8a	5.3b	20.7b	6.0c
Strip till	10.0b	9.1b	3.7c	10.3d	4.8d
Source of Variation					
Treatment	<.0001***	<.0001***	<.0001***	<.0001***	<.0001***
Block	0.8139	0.8139	0.0408	0.1442	0.0842
CV, %	1.91	1.96	1.82	3.41	1.67
				Beaver ‡	
Double disc	8.7d	7.1d	5.8b	14.2d	7.4
Vertical till high disturbance	12.8b	11.7b	7.0a	24.9a	7.8
Vertical till low disturbance	13.1a	12.0a	5.8b	21.0b	7.0
Strip till	9.2c	8.4c	7.1a	18.4c	7.7
Source of Variation					
Treatment	<.0001***	<.0001***	0.0049***	<.0001***	0.0832§
Block	0.8404	0.8363	0.3582	0.2748	0.3910
CV, %	0.90	0.9	4.65	3.67	4.44

†USDA textural class: sand, ‡ USDA textural class: loam, § automatic gear adjustment. Means within a column followed by the same letter are not significantly different.

Work rates are important to calculate the time requirements to perform corn residue management. The total time needed to perform corn residue management influences labour and operating costs of the tillage implements. Working rate is also influenced by the machinery width. In this experiment, all implements were 9.1 m wide except the double disc implement that was only 8.1 m wide. This smaller machinery width combined with the lowest work speed for double disc led to a working rate of only 7.7 to 7.1 ha h^{-1} with 100% field efficiency in

MacGregor and Beaver, respectively (Table 4.15). The 100% field efficiency defines instantaneous work rate in contrast to an average work rate accomplished over several hours. The work rate for the double disc treatment is more than 1.5 times lower than for vertical till high and low disturbance. Strip till showed significantly different working rates from both vertical till and double disc. The work rate for strip till covered 9.1 ha h^{-1} in MacGregor and 8.4 ha h^{-1} in Beaver and was therefore, between double disc and vertical till. Work rate and work speed at which these implements were operated are comparable with values in the literature. Working rate at 100% field efficiency for double disc was 6.5 ha $h^{-1}$and vertical till was 13.7 ha h^{-1} in the custom and rental guide for Manitoba (Government of Manitoba, 2017). This is slightly lower for double disc and slightly higher for vertical till compared to the measured data.

Draft load measurements are of interest for engineers for calculating wear and tear but are not important for operating cost calculations. Draft load varied significantly among all tillage treatments ($p<.0001$) and between the two soil types ($p<.0001$). Vertical till high disturbance had the highest draft load on the hitch compared to all other tillage treatments (Table 4.15). Over 7 kN m^{-1} were needed to pull this implement. The adjustment of the machinery to 0° angle (vertical till low disturbance) on the disc, reduced these requirements by almost 2 kN m^{-1}. In both soil types draft load for double disc was the same compared to vertical till low disturbance. However, in general draft loads were substantially higher compared to a study conducted on a Red River clay field in Manitoba. Chen, et al. (2005) showed for subsoiling and field cultivator draft forces lower than 2 kN m^{-1}. These implements were operated at a lower work speed (6.1 km h^{-1}), which can reduce draft loads and therefore explain these differences.

On the sandy site in MacGregor strip till showed almost half the amount of draft load on the hitch significant lower draft load compared to vertical till high disturbance. In Beaver, the draft load of strip till was the same as vertical till high disturbance. The higher silt and clay content of the loam in Beaver compared to the sand in MacGregor could have led to this difference. The shanks of strip till go to a depth of 15 to 30 cm. This deep tilling in heavier soil likely had a great impact on draft force, which was also found by Chen, et al. (2005) who looked at a field cultivator and subsoil implement in the Red River Valley in Manitoba. Furthermore, the soil in Beaver was wetter than MacGregor when tillage operations were conducted. Wetter soils amplify this effect even more. Unfortunately, no measurements of the soil moisture content were taken.

Measurements of power requirement (kW m^{-1}) per meter of implement width influence the investment for purchasing a new power unit and therefore the overhead costs. The tractor requirements for these different tillage implements are therefore of interest. The metric unit for power, the kW, converts into 1.341 horse power. Tractor requirement varied significantly between tillage treatments ($p<.0001$) and sites ($p=0.0009$) (Table 4.15). Work speed as well as draft load were driving power requirements of the power unit. The high work speed of the implement vertical till high disturbance combined with the highest draft load to pull the equipment resulted in the highest tractor requirement (27.5 kW m^{-1}) for vertical till high disturbance at MacGregor (Table 4.15).

Tractor requirements for a certain implement width varied among tillage treatments. A 9.1 m wide vertical till unit set for high disturbance (27.5 kW m^{-1}) would need at least a 250 kW (335.3 hp) tractor in a sandy soil at MacGregor. This matches the manufacture's recommendation and other literature from Kansas State University that suggested tractor requirements of 23 to 32 kW m^{-1} of implement width (Great Plains MFG, 2016, Presley, 2013). Double disc required significantly lower tractor requirements compared to vertical till units. Double disc used 14.3 kW m^{-1} in MacGregor and 14.2 kW m^{-1} in Beaver, respectively. A 9.1 m wide double disc implement would therefore require around a 130.1 kW (174.5 hp) power unit. However, a double disc used 1.4 times and a vertical till unit 2.7 times bigger power unit than a strip till unit in MacGregor on a sandy soil. Strip till in MacGregor used only 10.3 kW m^{-1} per meter of implement width. A 9.1 m wide strip till machinery would therefore use only a 94 kW (126.1 hp) tractor in a sandy soil. The draft load and tractor requirement for strip till on the loamy site at Beaver was higher relative to the other tillage treatments compared to the sandy site in MacGregor. This may be due to soil type and soil moisture. Strip till required almost as much power requirements as vertical till implements on the heavier and wetter soil in Beaver. Literature and manufacture industry suggest a power requirement of 11.7 to 29.4 kW m^{-1} for different strip till units, which is in accordance with measurements from this field trial (Haarberg, 2017, Nowatzki, et al., 2011). In other words, a bigger power unit is needed to run a vertical till implement than for a double disc implement. Farmers need to keep this in mind when considering changing from double disc to vertical till to manage corn residue.

Fuel consumption drives operating costs and are therefore of interest in this study. Fuel consumption varied between tillage treatments at MacGregor but not at Beaver. Significant differences between all tillage treatments were observed in MacGregor (Table 4.15). Vertical till high disturbance used 0.7, 1.2 and 2.4 l ha^{-1} more fuel compared to double disc, vertical till low disturbance and strip till, respectively (Table 4.15). Strip till used only 66% of the fuel compared to vertical till high disturbance. No significant differences were observed in Beaver. The lack of differences may have been due to the way the power unit was operated. In Beaver, the tractor operator used an automatic gear adjustment which led to switching gears within the same pass. This also influenced the variability of the draft load measurements. Every time the gear was switched, there was a small kickback on the draft load cell. This resulted in the highest observed coefficient of variations for the entire field trial for draft load and fuel consumption in Beaver (Table 4.15).

Tillage treatments showed significant differences in tractor requirement and draft load in both soil types (Hypothesis VIII). Significant differences in fuel consumption were found between the tillage treatments at the MacGregor location whereas in Beaver no significant differences were observed. The corn residue management trials in this thesis were all conducted on sandy loam and loamy sands. Work speed, work rate, tractor requirement and fuel consumption from the machinery measurements trial on the sandy soil (MacGregor) will be therefore used to calculate cost in the next section.

4.3.2 Cost of Tillage

Cost of tillage systems include financing cost such as depreciation, overhead and variable cost for the tillage implement as well as the power unit. Labour cost to operate the equipment needs to be included as well. To determine these costs machinery data from the field experiment was used in a excel spreadsheet from the University of Minnesota to calculate cost for the tillage implement as well as the power unit (Lazarus, 2016). The cost for one pass of tillage in corn stubble varied among tillage treatments (Table 4.16). The cost difference range for one pass on a hectare basis is Can$ 11 among tillage treatments. Double disc had slightly higher total costs than vertical till implements (Table 4.16). Double disc had low implement and power unit cost however due to the low work rate, labour costs are expensive. Vertical till high disturbance had slightly higher cost per hectare compared to vertical till low disturbance, mainly due to the requirement of a bigger power unit. Vertical till high disturbance had a higher power requirement per meter of implement width compared to vertical till low disturbance, where soil does not get disturbed as much. Strip till had the highest total costs on a per hectare basis. These high costs are driven by the high purchasing price (Can$ 216'720). At the same time, strip till had the lowest total power unit cost, as the least amount of kW m^{-1} were needed to pull the implement. Total cost of tillage operation in this analysis including power unit and labour might be over estimated, as Nowatzki, et al. (2011) in North Dakota showed total costs for strip till can be around Can$ 37.42 to 39.33 per hectare. However, all of this analysis is based on one tillage pass, and often corn residue management requires multiple passes.

To create a good seedbed for a subsequent crop, corn residue management requires multiple tillage passes. Double disc and vertical till required two passes for corn residue management. Strip till on the other hand can create a good seedbed in one pass and can therefore outperform all other treatments in terms of total costs. This difference resulted in cost saving of a least Can$ 25.71 per hectare when using strip till instead of the other tillage treatments for corn residue management. The results of this analysis agree with a three year on-farm study conducted by the University of Minnesota that showed that strip till can save up to Can$ 43.19 per hectare compared to disc ripping and chisel plowing (MSGA, 2015).

Total cost for tillage for corn residue management represented less than 10% of total crop production cost of soybean or less than 7% of total crop production of corn (Government of Manitoba, 2016f). Average crop production cost for soybean grown in Manitoba in 2016 was Can$ 846 per hectare and for corn Can$ 1,166 (Government of Manitoba, 2016f). The cost for tillage represented 5.6% to 9.4% of the total cost for soybean production and 4.1% to 6.8% of the total cost for corn production.

For corn residue management, strip till showed big cost saving compared to the other tillage treatments. Even though a high initial investment is required for strip till, operational costs can be saved as strip till is a one pass system. The overall hypothesis that strip till achieves the same yield as the standard tillage practice double disc but can outperform all other tillage treatments in the overall economics due to lower total costs for preparing a seedbed for soybean production was therefore proven. As strip till is a one pass system it also shows time savings. Time is key in the short growing season of Manitoba and is therefore discussed separately in the next section.

Table 4.16: Depreciation, overhead, operating and labour costs for implement and power unit for double disc, vertical till high disturbance, vertical till low disturbance and strip till for one and two passes in corn residue. In practice, corn residue management required one pass in strip till and two passes in double disc, vertical till low disturbance and vertical till high disturbance to achieve a suitable seedbed for subsequent crop planting.

Cost †	**Double disc**		**Vertical till high disturbance**		**Vertical till low disturbance**		**Strip till**	
	1 pass	2 passes	1 pass	2 passes	1 pass	2 passes	1 pass	1 pass
	Can$ ha^{-1}							
Implement depreciation	5.45	10.89	6.50	13.00	6.36	12.72	12.65	12.65
Implement overhead	4.13	8.26	4.93	9.86	4.82	9.65	9.59	9.59
Implement operating cost	3.85	7.70	2.31	4.61	2.26	4.51	8.94	8.94
Implement total cost	13.43	26.85	13.74	27.47	13.44	26.88	31.19	31.19
Power unit depreciation	6.74	13.48	6.43	12.86	6.18	12.36	3.45	3.45
Power unit overhead	6.26	12.52	5.98	11.95	5.74	11.48	3.21	3.21
Power unit operating cost	10.10	20.20	10.99	21.97	9.36	18.72	7.09	7.09
Power unit total cost	23.10	46.20	23.39	46.79	21.28	42.57	13.75	13.75
Labour cost	3.32	6.65	2.04	4.07	1.99	3.98	2.79	2.79
Total cost	39.85	79.70	39.16	78.33	36.72	73.43	47.72	47.72

† Based on the Machdata.xlsm excel spreadsheet from the University of Minnesota. Machinery details such as work rate, power requirement and fuel consumption were adapted according to machinery performance measurements conducted in the field. The custom rate and rental rate guide for field equipment from the Government of Manitoba was used to adapt the American spreadsheet to Manitoba conditions

4.3.3 Time for Tillage

Time is an important consideration that drives farmer’s decisions in Manitoba. The growing season length in Manitoba is short and days to perform field operations for residue management after a late season crop like corn are a scarce commodity.

Time that is needed to manage corn residue using tillage in order to create a suitable seedbed is dependent on work rate of the implement and the number of passes needed. The total time needed to perform tillage is based on the total farm size. The average farm size in 2011 in Manitoba was 459 ha (Statistics Canada, 2016). When a farmer purchases new equipment, he would try to use this equipment as much as possible. For calculation purposes, it is therefore assumed that the farmer would work their entire farm using the same tillage treatment compared in economic analysis. Based on experience, the average total farm size for Manitoba from Statistics Canada seems to be conservative for a grain farmer that would grow corn. However, 459 ha might represent the actual area that a farmer growing a significant amount of grain corn would seed in Manitoba. Unfortunately, no statistics are available to support that statement.

Based on the average farm size in Manitoba, strip till would save a farmer at least 27.4 hours of work compared to vertical till treatments in order to complete corn residue management (Table 4.17). Strip till would save a farmer 3.7 days of work compared to the conventional tillage method double disc over their entire farm. This is the result of a lower work rate for strip till compared to double disc and two passes needed for corn residue when using double disc. Strip till could therefore save a farmer Can$ 1,771 in labour costs compared to double disc (Table 4.17).

Total costs for tillage on an average farm size in Manitoba for corn residue management varied from Can$ 21,904 to 36,583. Double disc and vertical till units revealed Can$ 631 and Can$ 14,679 higher total costs on an average farm compared to strip till, respectively.

Table 4.17: Work rate of tillage implements at 80% field capacity and total time spent for tillage on an average sized farm in Manitoba (459 ha) assuming the entire farm will require corn residue management.

Treatment	**Work Rate**	**Labour cost for average farm †**	**Total cost for average farm**	**Total time for average farm †**
	ha/h	Can$	Can$	h
Double disc	6.14	3’051	36’583	152.5
Vertical till high disturbance	10.02	1’869	35’952	93.4
Vertical till low disturbance	10.24	1’829	33’705	91.4
Strip till	7.32	1’280	21’904	64

† Labour hours were assumed to be 102% of power unit hours as machinery needs to be maintained and prepared for field operation. During this time power unit is not running, but the worker still needs to be paid.

4.3.4 Summary of Costs and Time for Tillage

Strip till was shown to have the lowest total costs as well as showed the least time needed to perform corn residue management (Hypothesis IX). This was driven by completing tillage in one pass. Lack of differences in soybean yield led to the conclusion that differences in economic return are only based on tillage costs. These tillage costs were at least Can$ 25.71 per hectare lower in strip till compared to all other tillage treatments. However, when putting this number into perspective of the total production costs for soybean production, savings are not large. Total corn residue management costs represented less than 10% of the total soybean production costs (Government of Manitoba, 2016f). However, time savings from strip till were substantial.

Strip till showed time savings of up to 3.7 days compared to the standard tillage practice double disc. Assuming that a farm does not operate 24 hours per day, the days that are saved for performing tillage treatments are even more. To put this number into perspective a comparison to the average days needed to reach full maturity for soybean is helpful. On average a soybean crop requires 105 to 125 days to reach full maturity after planting (Manitoba Pulse and Soybean Growers, 2016). Most parts in the Red River Valley and the escarpment area in Manitoba show a frost free period of 115 to 125 days (Government of Manitoba, 2016a). This shows that growing soybean in this cold environment is on the edge of reaching maturity in time and delayed seeding due to tillage could lead to fall frost damage.

5 OVERALL DISCUSSION

This thesis was conducted to test four different corn residue management treatments on sandy soils in Manitoba. No information was available prior to this thesis that looked at the influence of different corn residue management treatments on soybean production in the cold environment of Manitoba. These trials were conducted on-farm and included information about the soil, soybean test crop, and overall economics of these different tillage treatments. This thesis has therefore a unique dataset for Manitoba and hopefully helps farmers in their decision making process.

During soybean emergence, surface (5 cm) soil temperature showed no differences among corn residue management treatments in total accumulated as well as daily accumulated soil temperature above 10°C at any site-year. This is surprising as surface residue cover varied significantly among corn residue management treatments and previous literature indicated surface residue cover highly influenced soil temperature (Horton, et al., 1996, Teasdale and Mohler, 1993). The minimal soil moisture threshold required for soybean emergence was reached in all corn residue management treatments at all site-years. Therefore, treatment effects of both soil temperature and moisture did not result in significant differences among corn residue management treatments in soybean emergence and final plant stand in three out of four site-years.

Early plant development stages varied among corn residue management treatments but trends were inconsistent and did not persist late in the season. In 2015, the vertical till low disturbance treatment and in 2016 the double disc treatment showed significantly later plant development stages compared to the other corn residue management treatments on a given day. These treatment differences continued at flowering. During the flowering period, a significantly lower percentage of plants were flowering on a given day in these treatments.

These differences among corn residue management treatments disappeared at pod filling and at final maturity. This was not surprising as previous literature indicated that soybean are mainly influenced by tillage only in their vegetative growth stages (Seddigh and Jolliff, 1984). The combination of aerial imagery and the visual ratings of the soybean crop led to the conclusion that there were no significant differences among corn residue management treatments in terms of late plant development stages. Aerial imagery was found to be a useful tool to accompany the visual ratings at the pod filling stage. However, further research is needed for ground truthing the NDVI and NDRE indices.

Several significant differences in soybean growth characteristics were observed, however differences were not agronomically meaningful. Plant height and pod height varied significantly among corn residue management treatments. Strip till had the tallest plants, but at the same time the lowest pods. Pod height differences among treatments were less than 0.9 cm and thus not agronomically important. The lowest pod heights of all corn residue management treatments were still high enough so that a commercial combine with a flexheader could catch the lowest pod. Power analysis suggested that many subsamples are needed to detect significant differences in lowest pod height in on-farm plots.

Pod height measurement methods were adjusted to be more meaningful for an on-farm setting. Disagreement in the method of where the lowest pod height measurement should be conducted arose. The literature suggested measuring the distance from the ground to the lowest node on the stem. This thesis measured the distance from the ground to the lowest pod as this determines whether or not the pod can be caught by the combine header. As research in agriculture is ultimately for farmers, the writer of this thesis believes that measurements of the lowest node should be complemented with a measurement of the pod length so that it can be determined where the bottom of the pod is or to measure the bottom of the pod.

Despite small early season differences in soybean phenological development stages among corn residue management treatments, soybean grain yield did not vary significantly among corn residue management treatments. These results agree with previous non-peer reviewed studies conducted on-farm (DeJong-Hughes and Coulter, 2013, Stahl, 2011). It can be concluded that there is no significant difference in soybean grain yield among double disc, vertical till high disturbance, vertical till low disturbance and strip till in a sandy soil. However, the trials of this thesis were only conducted for two growing seasons. Soil formation and soil food web are complex systems that occur over a longer period than this study investigated. The long term effect of these corn residue management treatments would therefore have to be further investigated (Fernández, et al., 2015). Furthermore, one needs to keep in mind that these experiments were conducted on coarse textured soils in the escarpment (former shoreline of Lake Agassiz) and Winkler area of Manitoba. Research on a heavy Red River Clay and or poorly drained soil is needed to make final recommendations for famers in Manitoba. Soil temperature and moisture could play a more important role with these soil types.

The economic analysis showed time and cost savings for strip till compared to the other tillage treatments. Soybean management practices were kept the same among treatments. Differences in economic return are therefore only driven by the cost of the different tillage systems as soybean test crop yields were the same. Strip till had a minimum of Can$ 25.71 per hectare savings compared to all other tillage treatments for corn residue management. These cost savings were mainly due to the need of only one pass for corn residue management in strip till. For an average size farm (459 ha) in Manitoba, strip till could therefore save a farmer Can$ 11,801 to Can$ 14,679 per year compared to other tillage systems if he had to conduct corn residue management on his entire farm. Furthermore, strip till as a one pass system showed time savings of 1.1 to 3.7 days compared to vertical till and double disc, respectively.

Corn residue was shown in previous studies to have a negative influence on the following crop and on soil temperature (Burgess, et al., 2002, Shen and Tanner, 1990). However, the present study showed that farmers have several effective tools for managing corn residue without compromising soybean emergence or soybean yield. Surface residue cover from corn influenced total accumulated soil temperature but the relationship was not strong (Adj. R^2 0.33). The relationship between residue cover and total accumulated soil temperature also only occurred if there was no extended cold period (i.e. 10 days) at emergence. The lack of strong relationship can be partly explained by a high variability of the surface residue cover measurements. Furthermore, the ground cover image analysis conducted with Assess 2.0 should include a standardized adjustment for light conditions so that parameters do not have to be adjusted for every single picture. Future research should also increase subsamples per plot to potentially reduce the impact of variability on the analysis.

The importance of soil temperature trends throughout a day was less than originally hypothesised. Soil temperature analysis should not be based only on an individual day as treatment trends varied among days. Repeated measurement analysis over several days showed that there is a significant treatment by days interaction. This is of great interest as it means that treatments did not behave the same over this 10-day period. An analysis of soil temperature for a single day is therefore not suitable without any further discussion as to why a particular day should be selected for analysis. This thesis therefore chose a more novel approach with accumulating soil temperature above a certain threshold temperature for the first 10 days after planting and the period from planting to 50% and 100% emergence. Daily and total accumulated soil temperature at emergence in planting depth did not vary among corn residue management treatments.

Soil temperature in a no-till setting might be lower and could reduce emergence of the subsequent crop. Two out of four site-years showed lower daily accumulated soil temperature in strip till treatment when measured between the row compared to the other corn residue management treatments where tillage was used. Whether a true long term no-till treatment would behave similarly would have to be further investigated as surface residue cover in strip till between the row is higher than in no-till as the residue from the seed row gets pushed in between the rows. The potential lower soil temperatures in no-till might be one of the reasons why there is low no-till adoption on heavy clay soil in the Red River Valley (Statistics Canada, 2011). Research for reduced tillage systems such as strip till on heavy clay soils is therefore needed and should be done in the near future.

This thesis has a unique dataset of continuous soil temperature and moisture for corn residue management treatments in the short growing season of Manitoba. However, statistical analysis for these time series datasets, such as repeated measurements analysis, were at its limits as many convergence problems occurred (Kiernan, et al., 2012). Other approaches such as moving average should be considered and explored for future research. These approaches should also include the known interaction between soil temperature and soil moisture. This might lead to a better estimation for building a model to predict 50% or 100% emergence based on soil temperature and moisture.

Reduced tillage systems have been widely shown to reduce the risk of soil erosion. Even though soil erosion was not measured in this thesis one can proceed on the assumption that reduced tillage systems such as strip till and vertical till low disturbance reduce the risk of wind and water erosion while still offering a good seedbed for soybean production.

On-farm research was required in this study as these vertical till implements cannot be operated at the right speed in a small plot setting. However, these large plots in on-farm trials required different methodology approaches such as aerial imagery analysis to be able to adequately represent the present variability in the field. On the other hand, this variability within a plot offers the unique possibility of spatially analysing data. Almost all commercial combines are now equipped with grain yield monitors. When calibrated properly, these grain yield monitor maps could be overlayed and analysed with many other spatial layers and potentially shed light on many unknown topics.

Collaborating with farmers and conducting on-farm trials has only advantages for the agriculture sector in its entirety. Academia can learn from farmers who have “boots on the ground” 365 days a year and bring knowledge from many generations before. Farmers can also learn from academia the importance of statistically verified difference and experiment methodology approaches. In addition the farmer can with moderate effort test what practices work and don’t work on his farm.

The overall hypothesis tested in this thesis was: strip till achieves the same yield as the standard tillage practice double disc but can outperform all other tillage treatments in the overall economics due to lower total costs for preparing a seedbed for soybean production. The results from the experiments in this thesis have proven this hypothesis to be correct. No significant differences in yield were observed between the strip till corn residue treatment and the standard corn residue treatment double disc. Cost analysis showed that the one pass treatment strip till has substantial lower cost compared to all other two pass treatments for preparing a seedbed for soybean after corn.

This thesis provided useful information about corn residue management for the short growing season of Manitoba. No literature and no best management practices had been identified for corn residue management for soybean production in Manitoba prior to this study. This thesis has therefore helped to overcome a lack of literature in this area. However, as mentioned earlier research on poorly drained and clay soils is still needed.

5.1 Recommendations for Farmers

Corn is a challenge in terms of residue management. However, the results of this study show that there are many options for managing corn residue to establish a good seed bed for soybean as a subsequent crop. These different options also mean that it is possible to reduce tillage on coarse textured soils in Manitoba despite the excessive amount of residue that is left after harvesting corn. These reduced tillage implements can save farmers money as well as mitigate the risk of wind and water erosion. It was shown that reduced tillage systems such as strip till can save a farmer money as well as time. The time aspect is of great interest in this short growing season region and should be included into equipment evaluations. Reduced long term loss of fertile topsoil could further justify the use of these implements by conserving soil resources and therefore saving money in the long run. Based on this research the following recommendations for farmers can be made:

- Soil temperatures were not lower with reduced tillage implements (vertical till and strip till) compared to standard double disc.
- No-till would likely result in lower soil temperatures at seeding compared to standard tillage practices.
- Reduced tillage treatments (vertical till and strip till) had the same soybean yields as the standard double disc treatment in sandy soils.
- All experiments were conducted on sandy soils. Further investigations are needed to evaluate these corn residue management strategies on poorly drained and heavy clay soils.
- Using a one pass system for corn residue management, such as strip till, on an averaged size farm in Manitoba could save a farmer up to 3.7 days of work and Can$ 14,679 in tillage costs per year compared to standard double disc.

- There is value to on-farm research. Participating in on-farm research allows you to find out what works on YOUR farm and gives researchers the chance to learn from your expertise.

6 APPENDIX

6.1 Residue Cover Pictures

Figure 6.1: Surface residue cover with corn residue was 30% during soybean emergence in the conventional tillage corn residue management treatment with two passes of a double disc in MacGregor 2016. The double disc had two sets of concave discs following after each other to assure a good mixture of residue into the soil. Photo Credit: Patrick A. Walther

Figure 6.2: Surface residue cover with corn residue was 27% during soybean emergence in the vertical till high disturbance corn residue management treatment with two passes in MacGregor 2016 (6° disc angle, concave

disc). The angle of the vertical till unit disc creates much more soil disturbance than in vertical till low disturbance. Photo Credit: Patrick A. Walther

Figure 6.3: Surface residue cover with corn residue was 65% during soybean emergence in the vertical till low disturbance corn residue management treatment with two passes in MacGregor 2016 (0° disc angle). Photo Credit: Patrick A. Walther

Figure 6.4: Surface residue cover with corn residue was 4% in the strip, 95% between the strips and 63% when analysed over the entire area during soybean emergence in the strip till corn residue management treatment with one pass in MacGregor 2016. Strip till uses tillage in only a small strip zone and leaves the area in-between the shanks undisturbed. Photo Credit: Patrick A. Walther

6.2 Statistical Sample Code

6.2.1 Sample Code for ANOVA with Proc Mixed Averaged over Site-year

```
dm'log; clear; odsresults; clear;';
Data data;
        Input  trtmnt $ block subsample depvariable  site-year $;
Datalines;

;
/*ods pdf file= "C:\SAS_Import\Yield Small Plot Winkler.pdf";*/



Proc Mixed Data=data Method=Type3;
 Title Moisture_Combined;                                                    /*!!!!!!!!Change
Title!!!!!!!!!!*/
 Class trtmnt block subsample site-year;                                     /*If variable
here not listed it is treated as continous variables*/
 Model depvariable= trtmnt /residual Outp=Resout;                    /*independent variables
trtmnt in ANOVA table*/
 Random block (site-year) ;
        /*Means blocks within site-year: Specifiy what should be random*/
 LSmeans trtmnt/pdiff          /*adjust=tukey if i want tukey*/;      /*LSD comes if i don't specify
"adjust=tukey", LSD is the most sensitiv, tukey kramer when unequal sample size*/
 ods output diffs=ppp lsmeans=mmm tests3=t3;



Proc Univariate Plot Normal Data=Resout;
 Var Resid;
Proc Plot data=Resout; Plot Resid*Pred=trtmnt; Plot Resid*trtmnt; Plot Resid*Block;
Proc Print;
Run;



data power; set t3;
    noncen=NumDF*FValue;
    alpha=0.05;
    Fcri=finv(1-alpha,NumDF, DenDF, 0);
    power=1-probf(Fcri, NumDF, DenDF, noncen);
run;proc print data=power;
run;
run;
%include 'C:\SAS_Import\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
 Run;


ods _ALL_close;
```

6.2.2 Sample Code for Repeated Measurement Analysis with Proc GLIMMIX

```
dm 'log; clear;odsresult; clear;';
ods graphics on;
data Gustavo_Raw;
        Input  DAYS ddmmyy8. TREATMENT $ BLOCK DEPTH  PLANTS_AC;
Datalines;


;

run;



title "Distribution of &Response from &DataToUse";
Proc univariate Normal data=Gustavo_Raw;
```

```
  VAR PLANTS_AC;
  histogram/normal(mu=est sigma=est color=BLUE l=1 w=2);
  QQplot / normal(mu=est sigma=est color=BLUE l=1 w=2);
  inset normal;
  run;

Proc GLIMMIX data=Gustavo_Raw plots=(residualpanel) IC=Q;
Title "Temperature_10days_Haywood2016_ANTE(1)";
  Class TREATMENT BLOCK DEPTH DAYS;
  model PLANTS_AC= TREATMENT|DAYS/ddfm=KR dist=poisson link=log;
  NLOPTIONS TECH=NRRIDG;/*to make the thing work if it doesnt work*/
  /*random BLOCK*TREATMENT;*/
  random DAYS/type=ANTE (1) residual  subject=BLOCK*TREATMENT;
  output out=pr student=sr resid=r ;/*  student=studentized residual resid=residual*/
LSMeans TREATMENT/ pdiff adjust=tukey lines ilink;
LSMeans DAYS/ pdiff adjust=tukey lines ilink;
LSMeans TREATMENT*DAYS/ pdiff adjust=tukey lines ilink;
  ods output diffs=diffs lsmeans=lsmeans;
  ods output FitStatistics=FitCS(rename=(value=CS))
               Dimensions=ParmCS(rename=(value=NumCS));
run;
```

6.2.3 Sample Code to Create Soil Temperature Graph in R cran and to Calculate Accumulated Soil Temperature above a certain Threshold

This is an R Markdown document. Markdown is a simple formatting syntax for authoring HTML, PDF, and MS Word documents. For more details on using R Markdown see http://rmarkdown.rstudio.com.

Activate library

library(ggplot2)

Import manipulated data

temp<-read.csv("/Users/Pat/Dropbox/University of Manitoba/Farming Systems Lab/Experiments - In the Field/Exp 33 - On Farm Corn Residue management/2014-15/Randy Froese/Temp/Temperature_Randy Froese_Winkler_COMBINED_2015.csv")

Make Date into usefull format

temp$Date < -as. POSIXct(temp$Date, format = "%d/%m/%y %H:%M")

Make Depth and Rep as factor

temp$Depth < -as. factor(temp$Depth) temp$Rep < -as. factor(temp$Rep)

Rename Levels of from factor Depth

levels(tempDepth)[levels(tempDepth)=="5"] <- "5 cm"

levels(tempDepth)[levels(tempDepth)=="30"] <- "30 cm"

Choose Period: One day after planting for three days

tempsub <- subset(temp, Date>"2015-05-04 24:00:00" & Date < "2015-05-07 24:00:00")

#Winkler2015

Creating Graph with geom_line

```
  h<-ggplot(tempsub, aes(x=Date , y=measurement, colour=Treatment))
  h+#geom_line(aes(x=Date, y=measurement, colour=Treatment), na.rm=T)+
    stat_summary(aes(colour=Treatment), fun.y=mean, geom="line", size=1.1)+
    #stat_summary(fun.data=mean_sdl, geom = "errorbar")+
    #geom_point(alpha = 1/5, aes(x=Date, y=measurement, colour=Treatment), na
.rm=T)+
    #geom_smooth(span=0.3 , aes(x=Date, y=measurement, colour=Treatment), na.
rm=T)+
    #stat_smooth(method=lm, aes(x=Date, y=measurement, colour=Treatment), na.
rm=T)+
    facet_wrap(~Depth, ncol=1)+
    #geom_point(alpha = 1/5, aes(x=Date, y=measurement, colour=Treatment), na
.rm=T)+
    xlab("Date")+ylab("Temperature")+
    theme_bw()+
    ylab( expression(paste("Soil Temperature [°C]")))+
    scale_y_continuous(expand = c(0, 0), limits = c(0, 30))
    #geom_vline(xintercept = as.numeric(as.POSIXct("2016-05-19 14:00:00")), l
inetype=3)
    #geom_vline(xintercept = as.numeric(as.POSIXct("2015-05-04 14:00:00")), l
inetype=3)
    #ggtitle("Temp_MacGregor2016_First Month_seperate")+
    #ggsave("Temp_MacGregor2016_Seeding_5 days before and after_0to25_only5cm
.pdf", width=8, height=6, dpi=300) #width=8, height=6
```

Basetemperature 10°C, set all values to 0 if lower than 10°C

```
  library(dplyr)
  tempsub$gdd10 <- tempsub$measurement - 10
  tempsub$gdd10[tempsub$gdd10 < 0] <- 0
```

Summarise by Day

```
  gdd10<- tempsub%>%
  group_by(Date = as.Date.character(Date), Treatment,Rep,Depth)%>%
  summarise(sum = sum(gdd10))
```

Write CSV in R

```
  #write.csv(gdd10, file = "/Users/Pat/Dropbox/University of Manitoba/Farming
Systems Lab/Experiments - In the Field/Exp 33 - On Farm Corn Residue manageme
nt/Haywood2016_sum_10days.csv")
```

Double check with plot

```
  o<-ggplot(gdd10, aes(x=Date , y=sum, colour=Treatment))
  o+#geom_line(aes(x=Date, y=cumsum, colour=Treatment), na.rm=T)+
    stat_summary(aes(colour=Treatment), fun.y=mean, geom="line", size=1.1)+
    stat_summary(fun.data=mean_sdl, geom = "errorbar")
```

Cumulate sum over entire period

```
    gdd10csum<- gdd10%>%
    group_by(Treatment,Rep,Depth)%>%
    mutate(cumsum = cumsum(sum)) %>%
    arrange(cumsum)
```

6.3 Statistical Output

6.3.1 Results for ANOVA Analysis with Site-year Interaction for Soybean Yield

```
dm'log; clear; odsresults; clear;';
Data data;
        Input  trtmnt $ block depvariable  site-year $;
Datalines;
Vt_high 1       2179.05762      Wink15
Disc    1       2175.695875     Wink15
Vt_low  1       2202.987308     Wink15
Strip   1       2166.461904     Wink15
Vt_low  2       2234.284225     Wink15
Vt_high 2       2242.552862     Wink15
Strip   2       2321.284375     Wink15
Disc    2       2307.218918     Wink15
Vt_high 3       2324.137395     Wink15
Strip   3       2226.013168     Wink15
Disc    3       2252.715616     Wink15
Vt_low  3       2223.048316     Wink15
Vt_low  4       2329.018465     Wink15
Disc    4       2374.431081     Wink15
Strip   4       2364.551899     Wink15
Vt_high 4       2510.66893      Wink15
Vt_low  1       2791.124506     Mcg15
Disc    1       .       Mcg15
Vt_high 1       3099.543539     Mcg15
Strip   1       2891.478232     Mcg15
Vt_low  2       3056.534073     Mcg15
Vt_high 2       3214.619005     Mcg15
Strip   2       2878.640555     Mcg15
Disc    2       2901.354643     Mcg15
Strip   3       2781.607727     Mcg15
Vt_low  3       2898.083668     Mcg15
Vt_high 3       3027.60696      Mcg15
Disc    3       3031.024124     Mcg15
Vt_high 1       2993.436058     Hay16
Vt_high 1       2827.192506     Hay16
Disc    1       2650.402751     Hay16
Disc    1       2578.528977     Hay16
Strip   1       2587.805835     Hay16
Strip   1       2426.402339     Hay16
Disc    2       2800.389175     Hay16
Disc    2       2545.983045     Hay16
Vt_high 2       2642.141069     Hay16
Vt_high 2       2770.644151     Hay16
Strip   2       2631.761547     Hay16
Strip   2       2931.535282     Hay16
Vt_high 3       3109.705252     Hay16
Vt_high 3       3104.573315     Hay16
Disc    3       3056.435977     Hay16
Disc    3       3033.248861     Hay16
Strip   3       3092.789694     Hay16
Strip   3       2982.939633     Hay16
Strip   4       3206.875182     Hay16
Strip   4       3097.042216     Hay16
Vt_high 4       2651.763357     Hay16
Vt_high 4       2932.089128     Hay16
Disc    4       2499.829296     Hay16
Disc    4       2623.278879     Hay16
Vt_low  1       3544.559092     Mcg16
Vt_high 1       3656.999177     Mcg16
Disc    1       3509.927141     Mcg16
Strip   1       3009.103632     Mcg16
Vt_low  2       3234.009081     Mcg16
Strip   2       2922.2558       Mcg16
Vt_high 2       2938.693758     Mcg16
Disc    2       3076.953606     Mcg16
Vt_low  3       3164.214325     Mcg16
Vt_high 3       3473.16503      Mcg16
Strip   3       3413.001496     Mcg16
Disc    3       3283.715621     Mcg16
Vt_high 4       2477.908491     Mcg16
```

```
Disc    4       3153.79609      Mcg16
Vt_low  4       3385.386939     Mcg16
Strip   4       3247.010809     Mcg16
;
/*ods pdf file= "C:\SAS_Import\Yield Small Plot Winkler.pdf";*/

Proc Mixed Data=data Method=Type3;
 Title Combined_Yield kg/ha;                                                              /*!!!!!!!!Change
Title!!!!!!!!!!!*/
 Class trtmnt block site-year;                                            /*If variable here not listed it
is treated as continous variables*/
 Model depvariable= trtmnt | site-year /residual Outp=Resout;                              /*independent
variables trmtnt in ANOVA table*/
 Random block ;                                                                                   /*Means
blocks within site-year: Specifiy what should be random*/
 LSmeans trtmnt/pdiff           /*adjust=tukey if i want tukey*/;       /*LSD comes if i don't specify
"adjust=tukey", LSD is the most sensitiv, tukey kramer when unequal sample size*/
 ods output diffs=ppp lsmeans=mmm tests3=t3;



Proc Univariate Plot Normal Data=Resout;
 Var Resid;
Proc Plot data=Resout; Plot Resid*Pred=trtmnt; Plot Resid*trtmnt; Plot Resid*Block;
Proc Print;
Run;



data power; set t3;
    noncen=NumDF*FValue;
    alpha=0.05;
    Fcri=finv(1-alpha,NumDF, DenDF, 0);
    power=1-probf(Fcri, NumDF, DenDF, noncen);
run;proc print data=power;
run;
run;
%include 'C:\SAS_Import\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
 Run;


ods _ALL_close;
```

Combined_Yield kg/ha

The Mixed Procedure

Model Information	
Data Set	WORK.DATA
Dependent Variable	depvariable
Covariance Structure	Variance Components
Estimation Method	Type 3
Residual Variance Method	Factor
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
trtmnt	4	Disc Strip Vt_high Vt_low
block	4	1 2 3 4
site-year	4	Hay16 Mcg15 Mcg16 Wink15

Dimensions	
Covariance Parameters	2
Columns in X	24
Columns in Z	4
Subjects	1
Max Obs Per Subject	68

Number of Observations	
Number of Observations Read	68
Number of Observations Used	67
Number of Observations Not Used	1

Type 3 Analysis of Variance								
Source	**DF**	**Sum of Squares**	**Mean Square**	**Expected Mean Square**	**Error Term**	**Error DF**	**F Value**	**Pr > F**
trtmnt	3	55607	18536	Var(Residual) + Q(trtmnt,trtmnt*site-year)	MS(Residual)	49	0.40	0.7543
site-year	3	7428954	2476318	Var(Residual) + Q(site-year,trtmnt*site-year)	MS(Residual)	49	53.31	<.0001
trtmnt*site-year	8	286685	35836	Var(Residual) + Q(trtmnt*site-year)	MS(Residual)	49	0.77	0.6294
block	3	248089	82696	Var(Residual) + 16.333 Var(block)	MS(Residual)	49	1.78	0.1632
Residual	49	2276135	46452	Var(Residual)	.	.	.	.

Covariance Parameter Estimates	
Cov Parm	**Estimate**
block	2219.06
Residual	46452

Fit Statistics	
-2 Res Log Likelihood	729.3

AIC (smaller is better)	733.3
AICC (smaller is better)	733.5
BIC (smaller is better)	732.1

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
trtmnt	3	49	0.39	0.7597
site-year	3	49	53.44	<.0001
trtmnt*site-year	8	49	0.78	0.6263

Least Squares Means						
Effect	**trtmnt**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
trtmnt	**Disc**	2803.88	61.9724	49	45.24	<.0001
trtmnt	**Strip**	2784.24	57.8269	49	48.15	<.0001
trtmnt	**Vt_high**	2860.74	57.8269	49	49.47	<.0001
trtmnt	**Vt_low**	Non-est	.	.	.	.

Differences of Least Squares Means							
Effect	**trtmnt**	**_trtmnt**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
trtmnt	**Disc**	**Strip**	19.6446	77.8534	49	0.25	0.8018
trtmnt	**Disc**	**Vt_high**	-56.8608	77.8534	49	-0.73	0.4686
trtmnt	**Disc**	**Vt_low**	Non-est	.	.	.	.
trtmnt	**Strip**	**Vt_high**	-76.5055	74.5958	49	-1.03	0.3101
trtmnt	**Strip**	**Vt_low**	Non-est	.	.	.	.
trtmnt	**Vt_high**	**Vt_low**	Non-est	.	.	.	.

Combined_Yield kg/ha

The UNIVARIATE Procedure

Variable: Resid (Residual)

Moments			
N	67	**Sum Weights**	67
Mean	0	**Sum Observations**	0
Std Deviation	188.626745	**Variance**	35580.049
Skewness	-0.2636633	**Kurtosis**	1.77177847
Uncorrected SS	2348283.23	**Corrected SS**	2348283.23

Coeff Variation	.	**Std Error Mean**	23.0444246

Basic Statistical Measures			
Location		**Variability**	
Mean	0.0000	**Std Deviation**	188.62675
Median	-28.5267	**Variance**	35580
Mode	.	**Range**	1191
		Interquartile Range	217.77627

<table>
<tr><th colspan="5">Tests for Location: Mu0=0</th></tr>
<tr><th>Test</th><th colspan="2">Statistic</th><th colspan="2">p Value</th></tr>
<tr><td>Student's t</td><td>t</td><td>0</td><td>Pr > |t|</td><td>1.0000</td></tr>
<tr><td>Sign</td><td>M</td><td>-2.5</td><td>Pr >= |M|</td><td>0.6254</td></tr>
<tr><td>Signed Rank</td><td>S</td><td>-1.5</td><td>Pr >= |S|</td><td>0.9926</td></tr>
</table>

Tests for Normality				
Test	**Statistic**		**p Value**	
Shapiro-Wilk	**W**	0.970743	**Pr < W**	0.1153
Kolmogorov-Smirnov	**D**	0.071561	**Pr > D**	>0.1500
Cramer-von Mises	**W-Sq**	0.059826	**Pr > W-Sq**	>0.2500
Anderson-Darling	**A-Sq**	0.460438	**Pr > A-Sq**	>0.2500

Quantiles (Definition 5)	
Quantile	**Estimate**
100% Max	533.8153
99%	533.8153
95%	288.8349
90%	229.4523
75% Q3	105.4042
50% Median	-28.5267
25% Q1	-112.3721
10%	-209.3553
5%	-225.1257
1%	-656.7291

0% Min	-656.7291

Extreme Observations			
Lowest		**Highest**	
Value	**Obs**	**Value**	**Obs**
-656.729	65	267.337	55
-429.734	34	288.835	43
-268.330	33	292.384	62
-225.126	49	339.285	47
-221.629	51	533.815	54

Missing Values			
Missing Value	**Count**	**Percent Of**	
		All Obs	**Missing Obs**
.	1	1.47	100.00

Combined_Yield kg/ha

Obs	Effect	NumDF	DenDF	FValue	ProbF	noncen	alpha	Fcri	power
1	trtmnt	3	49	0.39	0.7597	1.174	0.05	2.79395	0.12186
2	site-year	3	49	53.44	<.0001	160.326	0.05	2.79395	1.00000
3	trtmnt*site-year	8	49	0.78	0.6263	6.201	0.05	2.13399	0.31676

Combined_Yield kg/ha

Effect=trtmnt Method=LSD(P<.05) Set=1

Obs	trtmnt	Estimate	Standard Error	Letter Group
1	Vt_high	2860.74	57.8269	A
2	Disc	2803.88	61.9724	A
3	Strip	2784.24	57.8269	A
4	Vt_low	.	.	

6.3.2 Results for Assumptions for Regression Analysis

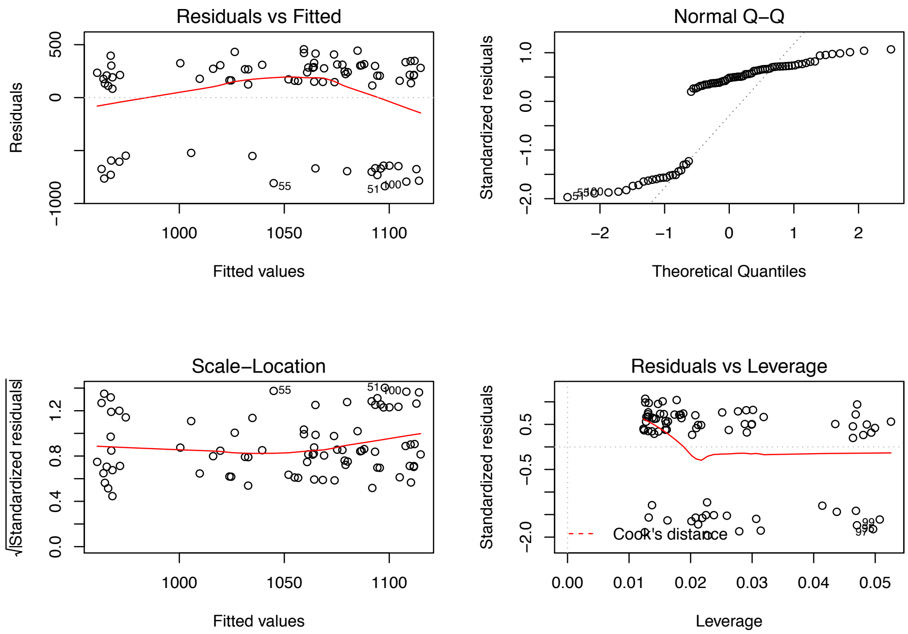

Figure 6.5: Assumptions for linear regression in residue cover vs accumulated GDH above 10°C. Theoretical quantiles vs standardized residuals indicated that residuals are not normally distributed when including Winkler 2015 in the analysis.

6.3.3 Results for Pods per Plant in 2016

One part of yield components are the amount of pods per plant. There were no significant differences among treatments in pods per plant in Haywood 2016 and MacGregor 2016. Potential yield differences would be therefore not be caused by plant population (see Section 4.2.1) nor number of pods. Yield differences could be only created in different number of seeds per pod or heavier seeds.

Table 6.1: Effect of tillage treatments on plant height, height of bottom of lowest pod and pods per plant for all four site-years.

Treatment	Pods per plant †
Double disc	25.7
Vertical till high disturbance	24.8
Vertical till low disturbance	26.3
Strip till	25.3
ANOVA	P>F
Source of Variation	
Treatment	0.7980
Block (Site-year)	<.0001***
CV, %	27.20

† Based only on two locations: Haywood 2016 and MacGregor 2016. Means within a column followed by the same letter are not significantly different.

6.3.4 Results from ANOVA for Machinery Performance Measurements

Table 6.2: Effect of tillage treatments in corn residue (treatment) and soil type (site) on work speed, work rate, draft load, tractor requirement and fuel consumption at the sandy site MacGregor and the loamy site Beaver.

Source of Variation	Work Speed	Work Rate	Draft Load	Tractor Requirement	Fuel Consumption
	km h^{-1}	ha h^{-1}	kN m^{-1}	kW m^{-1}	l ha^{-1}
Treatment	<.0001***	<.0001***	<.0001***	<.0001***	<.0001***
Site	<.0001***	<.0001***	<.0001***	0.0009**	<.0001***
Treatment*Site	0.8568	0.6568	<.0001***	<.0001***	<.0001***
Block	0.8089	0.8189	0.8840	0.7319	0.5089

6.4 Screenshot from Machdata.xlsm Spreadsheet

Machinery costs were calculated with a spreadsheet from the University of Minnesota (Lazarus, 2016). Following is a screenshot of the spreadsheet used for corn residue management treatments double disc and vertical till low disturbance.

Farm Machinery Economic Cost Estimation Spreadsheet (MACHDATA.XLS)

(Enter comments here if desired)

The yellow cells are for data input.

GENERAL PARAMETERS	Scenario 1			Scenario 2			
Labor Rate $/hr	$20.00			$20.00			
Interest Rate, % of average investment	6.5%			6.5%			
Insurance Rate	1.00%			1.00%			
Fuel price, $/gallon	$3.52			$3.52			
Lubrication cost, % of fuel	10%			10%			
Storage Cost/Sq. Foot of Space	$0.0000			$0.0000			
Inflation Rate, % per year	0.0%			0.0%			

INFORMATION ON THE IMPLEMENT, ATTACHMENT OR SELF-PROPELLED MACHINE

	Tandem Disk 26.5 Ft Fold			Vt_low 30 Ft Fold			
Implement Type	Select an implement if you would like to insert default data into scenarios 1 or 2 as a starting point for calculating costs for your own equipment						
Acres per hour	15.2	acres/hour		25.3	acres/hour		Field Capacity in Acres per Hour
Enter Description of the Implement, if Desired							
Implement's Age Now, if Used	0			0			
Hours Previously Used, if Known							
Expected Years Owned	12.0	years		12	years		
Age at Trade-in, Years	12			12			
Acres the Implement is Used On Per Year	2'275	acres		2'531	acres		
Times Over Each Acre Per Year	1			1			
Annual hours of use	150	hours		100	hours		
Estimated Accum. Hrs at Trade-in	1'800	2'000	Hrs Est Useful Life	1'200	2'000	Hrs Est Useful Life	
Current Purchase Price or Value	$78'300	90%	of list	$101'700	90%	of list	
Current List Price of Comparable Machine (new)	$87'000			$113'000			
Trade-in Value	Default CHF18'106	$18'106	(at 12 years old)	Default CHF23'517	$23'517	(at 12 years old)	
Type of Machine	Tandem disk harrow			Tandem disk harrow			
Annual Repairs & Maintenance	Default CHF3'545	$3'545		#VALUE!	#VALUE!		
Storage Shed Space Required, sq ft	280			280			

TRACTOR OR POWER UNIT INFORMATION

Enter Additional Description, if Desired	175 HP MFWD Disc			254 HP MFWD Vt_low			
PTO Horsepower	175			254			
Fuel gallons/Tractor HP/hr	0.0752	(gal/hr =	13.2	0.0802756	(gal/hr =	20.4	
Self-prop implement fuel/acre, gallons	-			-			
Machine's Age, if Used (Enter "0" for New)	0			0			
Expected Years Owned	12	years		12	years		
Estimated Years Old at Trade-in	12	Years Old		12	Years Old		
Annual Hours of Use	400	12'000	Hrs Est Useful Life	400	12'000	Hrs Est Useful Life	
Hours Previously Used, if Equipped with Tach	0			0			
Accumulated Hours at Trade-in	4'800			4'800			
Current Purchase Price or Value	$296'000	90%	of list	$452'900	90%	of list	
Current List Price of Comparable Machine (new)	$328'889			$503'222			
Trade-in Value	Default CHF97'434	$97'434	(at 12 years old)	Default CHF149'08	$149'081	(at 12 years old)	
Type of Tractor or Power Unit	Two wheel drive tractors, u			Two wheel drive tractors, ur			
Annual Repairs & Maintenance	Default CHF0	$0		Default CHF6'763	$6'763		
Storage Shed Space Required, sq ft	250			250			

							Results
Implement cost:	$/Year	$/hour of implement operation	$/Acre	$/Year	$/hour of implement operation	$/Acre	Implement ownership costs:
Implement depreciation	$5'016	$33.44	$2.20	$6'515	$65.15	$2.57	Depreciation
Implement overhead							Overhead:
Interest	$3'296	$21.97	$1.45	$4'281	$42.81	$1.69	Interest
Insurance & Housing	$507	$3.38	$0.22	$659	$6.59	$0.26	Insurance & Housing
Total implement overhead	$3'803	$25.36	$1.67	$4'940	$49.40	$1.95	Total implement overhead
Total implement ownership	$8'819	$58.80	$3.88	$11'455	$114.55	$4.53	Total implement ownership cost
Implement operating cost:							
Fuel and lubrication	$0	$0.00	$0.00	$0	$0.00	$0.00	
Repairs & maintenance	$3'545	$23.63	$1.56	$2'311	$23.11	$0.91	
Implement total cost:	$12'364	$82.43	$5.43	$13'766	$137.66	$5.44	
Power unit cost:							
Power unit depreciation	$16'547	$41.37	$2.73	$25'318	$63.30	$2.50	
Power unit overhead							
Interest	$13'324	$33.31	$2.20	$20'387	$50.97	$2.01	
Insurance & Housing	$2'050	$5.12	$0.34	$3'136	$7.84	$0.31	
Power unit total overhead	$15'374	$38.44	$2.53	$23'524	$58.81	$2.32	
Power unit total ownership	$31'921	$79.80	$5.26	$48'842	$122.10	$4.83	
Power unit operating cost:							
Fuel and lubrication	$20'382	$50.96	$3.36	$31'580	$78.95	$3.12	Fuel and lubrication
Power unit repairs & maintenance	$0	$0.00	$0.00	$6'763	$16.91	$0.67	Repairs & Maintenance
Power unit total operating	$20'382	$50.96	$3.36	$38'343	$95.86	$3.79	Total Operating Cost
Power unit total costs:	$52'304	$130.76	$8.62	$87'185	$217.96	$8.61	Total Power Unit Cost (w/o labor)
Total power unit cost using this implement	$19'614	$130.76	$8.62	$21'796	$217.96	$8.61	Using this implement
Use-related power unit cost using this implement	$13'849	$92.32	$6.09	$15'915	$159.15	$6.29	
Labor cost:	$3'060	$20.40	$1.34	$2'040	$20.40	$0.81	Operating cost:

		Total Costs:		Per year	Total Costs:		
	Per year	Per hour	Per acre		Per hour	Per acre	
Implement	$12'364	$82.43	$5.43	$13'766	$137.66	$5.44	Implement
Power Unit (using this implement)	$19'614	$130.76	$8.62	$21'796	$217.96	$8.61	Power Unit (using this implement)
Labor cost:	$3'060	$20.40	$1.34	$2'040	$20.40	$0.81	
Total cost:	$35'038	$233.59	$15.40	$37'602	$376.02	$14.86	Total
Use-related cost:	$25'469	$169.80	$11.19	$26'781	$267.81	$10.58	

6.5 PAMI Report

Project No. 22314
Date: April 18, 2016
Portage la Prairie, MB

Final Report

Measurement Report for “Comparing Soybean Residue Management Techniques on five farms in Manitoba”

For:
Manitoba Agriculture, Food and Rural Development

PAMI
Innovative Solutions for Agriculture and Beyond

Project No. 22314
Date: April 18, 2016
Portage la Prairie, MB

Final Report

Measurement Report for "Comparing Soybean Residue Management Techniques on five farms in Manitoba"

Jay Mak, E.I.T.
Project Leader

Lorne Grieger, P.Eng.
Project Manager,
Agricultural R&D

Acknowledgement

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Table of Contents

1. Executive Summary

Producers in Manitoba are faced with many challenges: growing new high value crops, ever-changing weather patterns, and on-going operation practices. Like all corporations, the decisions will affect their day-to-day operations along with any financial implications. One of those decisions is how they will invest time and resources to incorporate crop residue with varying tillage methods for the following growing season.

The partnership project with MPSG, MCGA, farmers in Manitoba, University and Prairie Agricultural Machinery Institute (PAMI), were to:

(1) Evaluate soybean and corn residue management strategies on-farm with field scale tillage equipment in a range of soybean growing areas across Manitoba,
(2) Provide information on power requirements of various tillage implements to growers,
(3) Conduct research that provides useful information to farmers for making sound agronomic decisions about crop and land management,
(4) Build a team of partners with complimentary skills for on-farm soybean research in Manitoba, and
(5) Engage farmers in the research process and teach them how to conduct research that is practical and reliable.

PAMI measured the power requirements for the various tillage implements, which consisted of the minimum horsepower, fuel consumption, draft force requirements and the ground speed. The four different types of tillage methods included;

- conventional discs (D),
- vertical tillage (VT),
- high speed discs (HSD) and,
- strip till (ST).

The equipment evaluated was tested using the manufacturer's recommended settings and a single pass of a conventional disc was used as a standard practice in comparing the work rate and the fuel consumed.

Soil Type	Sand		Loam	
Settings	Work Rate (ac/hr.) [%]	Fuel Consumption (US gal/acre) [%]	Work Rate (ac/hr.) [%]	Fuel Consumption (US gal/acre) [%]
D – 1st pass	19.0 [100]	0.69 [100]	17.4 [100]	0.79 [100]
D – 2nd pass	18.4 [97]	0.64 [92]	-	-
VT-0°-1st pass	31.6 [166]	0.65 [93]	29.6 [170]	0.74 [94]
VT-6° - 1st pass	31.0 [163]	0.78 [112]	28.9 [166]	0.83 [105]
VT-0°- 2nd pass	31.3 [165]	0.72 [104]	-	-
HSD	25.6 [135]	0.87 [126]	-	-
ST	22.6 [119]	0.52 [74]	20.9 [120]	0.82 [104]

The producers' economic interests on the various tillage implements would include how much time could be saved and the amount of energy saved per unit area. A higher work rate would save more time, while a lower fuel consumption would lower the operational costs.

2. Project Objective and Set-up

Farmers throughout Manitoba are investing resources and time incorporating crop residue using varying amounts of tillage to prepare the field for the following season. With new high value crops such as corn and soybeans being introduced to Manitoba, producers have to adapt different management strategies that could meet the ever-changing market demands. Strip till and vertical tillage have been used successfully in other soybean growing regions, such as North Dakota and Minnesota, but are not widely adopted in Manitoba.

The proposed project was a partnership between MPSG, MCGA, farmers in Manitoba, the University of Manitoba, and Prairie Agricultural Machinery Institute (PAMI). The project objectives were to (1) evaluate soybean and corn residue management strategies on-farm with field scale tillage equipment in a range of soybean growing areas across Manitoba, (2) provide information on power requirements of various tillage implements to growers, (3) conduct research that provides useful information to farmers for making sound agronomic decisions about crop and land management, (4) build a team of partners with complimentary skills for on-farm soybean research in Manitoba, and (5) engage farmers in the research process and teach them how to conduct research that is practical and reliable.

PAMI's objective was to provide information on the power requirements, which included the minimum horsepower, fuel consumption, draft force requirements and the ground speed of the various tillage implements. Two sites with different soil textures were measured using four types of tillage methods, which included vertical tillage, strip till, high speed discs and conventional discs (**Figure 1**). The details of each implement are listed in **Table 1**.

Great Plains [Vertical Tillage]

Landoll [High speed disc]

Orthman [Strip till]

Summers [Diamond Disk]

Figure 1. Types of implement equipment evaluated.

Table 1. Implement details.

Manufacturer	Model Number	Width	Category
Great Plains	Turbo-Max 3000 TM	9.1 m (30 ft.)	Vertical Tillage (VT)
Landoll	7831-25	7.6 m (25 ft.)	High Speed Disc (HSD)
Orthman	1tRIPr 12 row	9.1 m (30 ft.)	Strip Till (ST)
Summers	Diamond Disc	8.1 m (26.5 ft.)	Conventional Disc (D)

2.1 Equipment Settings and Field Set-up

The equipment settings, speeds and depth of each implement were determined based on the manufacturer recommendations (**Table 2**). The power requirements were measured for a total of seven treatments listed from A-G to provide information on the different tillage practices. Each treatment was replicated with three passes, up to 0.8 km (½ mile) per pass, at each site. However, only the steady state results at the desired speeds were taken into consideration.

Table 2. Equipment manufacturer's recommended settings.

Equipment	Settings	Depth	Speed
Great Plains (VT)	A. 1 pass at 0° gang B. 1 pass at 6° gang C. 2nd pass with 0° after the 6° pass	7.6-10.2 cm (3-4")	14.5 km/hr. (9 mph)
Landoll (HSD)	D. 1 pass	7.6-10.2 cm (3-4")	13.7 km/hr. (8.5 mph)
Orthman (ST)	E. 1 pass	15.3 cm (6")	10.5 km/hr. (6.5 mph)
Summers (D)	F. 1 pass G. 2nd pass	5.1-10.2 cm (2-4")	9.7 km/hr. (6 mph)

One site was a USDA Textural class: "Sand" (92% sand, 6% silt, and 2% clay) near MacGregor, MB and the other site was classified as "Loam" (50% sand, 32% silt, and 18% clay) near Beaver, MB. The average steady state pass at MacGregor was 0.5 km (0.3 mile), while the average pass was 0.3 km (0.2 mile) at Beaver, MB. The difference in trial lengths were due to field availability and soil conditions found at each site. The 2nd pass treatments were monitored to represent the 2nd tillage pass in spring after the 1st till during the fall. However, the results are for reference only because the 2nd pass was performed on the same day and will not have the same effect as tilling the soil after several months have passed with the freeze-thaw cycle. The trials were performed on October 29, 2015 in Macgregor, MB and November 9, 2015 in Beaver, MB.

2.2 Measurement Equipment

The equipment used to measure the power requirements consist of several components connected to the John Deere 9510R [510 hp] tractor (**Figure 2**). The PAMI "load cart" was connected on the tractor drawbar, in front of the implement to measure the draft load requirements for each trial. A GPS tracking device was installed inside the tractor cab to monitor the speed of operation, duration of the field pass, and the travel path. Lastly, the data from the load cart, GPS tracking device and the tractor CAN bus readout was recorded on the SOMAT/EDAQ data acquisition system (**Figure 3**). The fuel consumption was recorded from the manufacturer's CAN bus read-out, which was not third-party calibrated for this trial.

Figure 2: Tractor and load cart set-up.

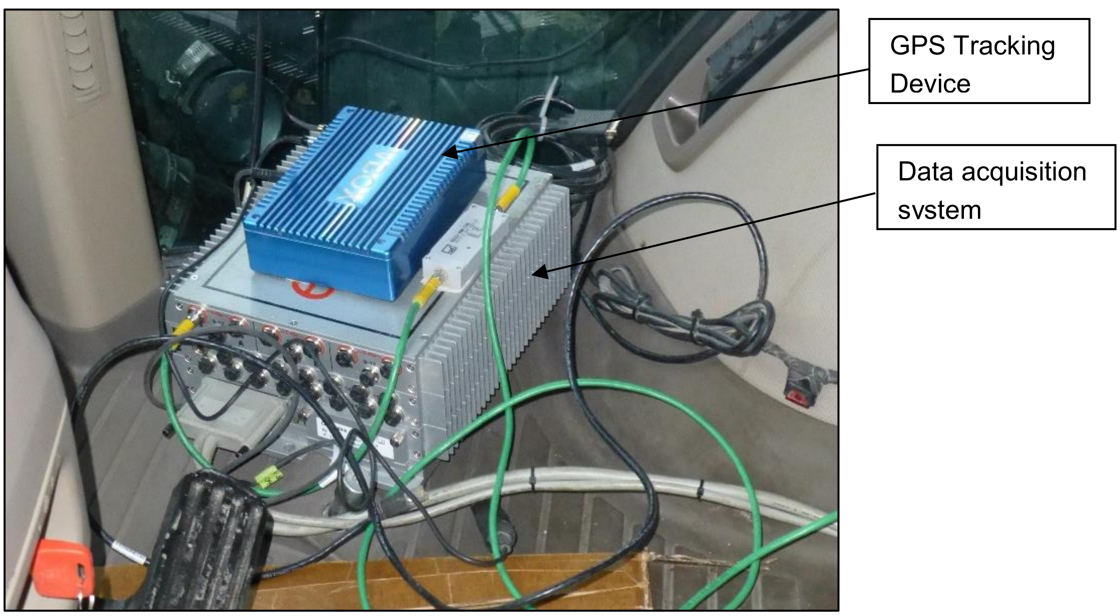

Figure 3: Data acquisition system and other instrumentation.

3. Results

The average tillage speeds, work rates, draft loads, tractor power requirements, and fuel consumptions are summarized for each site in **Table 3** and **Table 4**. Refer to the **Appendix** for imperial units. The raw measurements were converted to a unit width and area for comparison, due to the varying implement widths and speeds between the different equipment.

To compare the work rate and the fuel consumption, a single pass with a conventional disc was used as a standard practice. The other treatment results were compared to the conventional disc to determine what are the potential costs or savings.

Table 3. MacGregor Results (Sand).

Settings	Speed (km/hr.)	Draft Load (kN/m)	Tractor Requirement (kW/m)	Work Rate (ha/hr.) [comparison ratio]	Fuel Consumption (L/ha) [comparison ratio]
D – 1st pass (Standard)	9.5	5.3	14.0	7.7 [100%]	6.5 [100%]
D – 2nd pass	9.2	4.4	11.2	7.4 [97%]	6.0 [92%]
VT-0°-1st pass	14.0	5.3	20.6	12.8 [166%]	6.0 [93%]
VT-6° - 1st pass	13.7	7.2	27.5	12.5 [163%]	7.3 [112%]
VT-0°- 2nd pass	13.9	6.0	23.1	12.7 [165%]	6.7 [104%]
HSD	13.6	7.9	29.9	10.4 [135%]	8.2 [126%]
ST	10.0	3.7	10.3	9.1 [119%]	4.8 [74%]

Table 4. Beaver Results (Loam).

Settings	Speed (km/hr.)	Draft Load (kN/m)	Tractor Requirement (kW/m)	Work Rate (ha/hr.) [comparison ratio]	Fuel Consumption (L/ha) [comparison ratio]
D – 1st pass (Standard)	8.7	5.8	14.2	7.1 [100%]	7.4 [100%]
D – 2nd pass	-	-	-	-	-
VT-0° - 1st pass	13.1	5.8	21.0	12.0 [170%]	7.0 [94%]
VT-6° - 1st pass	12.8	7.0	24.9	11.7 [166%]	7.8 [105%]
VT-0° 2nd pass	-	-	-	-	-
HSD	-	-	-	-	-
ST	9.3	7.1	18.3	8.5 [120%]	7.7 [104%]

The economic factors of interest for the producer would be the time saved in the fields and the energy consumed per unit area. The higher work rate, determined by the speed and implement width, would allow a producer to finish tilling their fields in less time. Generally, the vertical tillage and the high speed discs offered higher speeds and work rates compared to the conventional disc and strip till. From these trial results, a producer may be able to save up to 70% on the cultivation time with a faster tillage implement compared to a conventional disc. However, the higher speeds would increase the minimum tractor power requirements to pull the implement. Therefore, a producer would require a larger investment on the capital and maintenance cost of a larger tractor. Refer to the Manitoba Agriculture, Food and Rural Development's "Farm Machinery – Custom and Rental Rate Guide" for more information.

Lastly, a lower fuel consumption rate would reduce the operational cost of tilling the fields with the selected tractor and implement. The results showed that the fuel consumption would vary based on the implement and the soil type. However, the trial results indicated that the strip till could save up to 26% of the fuel compared to a conventional disc on a sandy soil. These results were measured with the John Deere 9510R and they should only be used for comparison in this trial and not as an absolute result. When using a different tractor and set-up, the results will vary.

Another area of interest that was beyond the scope of this project was to capture the amount of useful work put into the soil. The work done by the different types of equipment would disturb the soil structure and profile through various soil properties, which ultimately affects the agronomic impact at the end of the season and the long-term soil health.

Appendix

Results (Imperial units)

Table 1. MacGregor Results (Sand).

Settings	Speed (mi/hr.)	Draft Load (lbf/ft.)	Tractor Requirement (HP/ft.)	Work Rate (ac/hr.) [comparison ratio]	Fuel Consumption (US gal/acre) [comparison ratio]
D – 1st pass (Standard)	5.9	363.9	5.7	19.0 [100%]	0.69 [100%]
D – 2nd pass	5.7	300.0	4.6	18.4 [97%]	0.64 [92%]
VT-0° - 1st pass	8.7	364.2	8.4	31.6 [166%]	0.65 [93%]
VT-6° - 1st pass	8.5	495.1	11.3	31.0 [163%]	0.78 [112%]
VT-0°- 2nd pass	8.6	411.4	9.4	31.3 [165%]	0.72 [104%]
HSD	8.5	542.2	12.2	25.6 [135%]	0.87 [126%]
ST	6.2	254.8	4.2	22.6 [119%]	0.52 [74%]

Table 2. Beaver Results (Loam).

Settings	Speed (mi/hr.)	Draft Load (lbf/ft.)	Tractor Requirement (HP/ft.)	Work Rate (ac/hr.) [comparison ratio]	Fuel Consumption (US gal/acre) [comparison ratio]
D – 1st pass (Standard)	5.4	400.4	5.8	17.4 [100%]	0.79 [100%]
D – 2nd pass	-	-	-	-	-
VT-0° - 1st pass	8.1	394.9	8.6	29.6 [170%]	0.74 [94%]
VT-6° - 1st pass	8.0	479.6	10.2	28.9 [166%]	0.83 [105%]
VT-0°- 2nd pass	-	-	-	-	-
HSD	-	-	-	-	-
ST	5.7	488.2	5.0	20.9 [120%]	0.82 [104%]

Useful Conversions

1 mi = 1.60934 km

1 ac = 0.404686 ha

lbf = 4.44822 N

1 ft. = 0.3048 m

1 HP = 0.7457 kW

1 US gal = 3.78541 L = 0.8327 Imp gal

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