A look at the impact of a controlled traffic farming system on crop yields and soil physical properties on a newdale clay-loam and beresford silty-clay soil located in south-western manitoba

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A Look At the Impact of a Controlled Traffic Farming System on Crop Yield and Soil Physical Properties on a Newdale Clay-Loam and Beresford Silty-Clay Soil Located in South-Western Manitoba.

By

Adam Gurr

A creative component submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Agronomy

Program of Study Committee:
Richard M. Cruse, Major Professor
Mark E. Westgate

Iowa State University
Ames, Iowa

2018

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I also want to salute my father Barry for helping to run some of the traffic simulations and affording me the opportunity to carry out a project like this on our farm. To my brother in-law Stephen I will forever be grateful for your help in conducting traffic simulations, collecting yield data and for the patience and interest you showed late into the fall of 2016 as we sampled soil and conducted infiltration tests in my plots. To my mother Carolyn and my mother and father in-law’s Marie and John many thanks are due for the child care you provided when it was most needed.

To Iowa State University and in particular Dawn Miller and the rest of the staff in the Distance program in Agronomy I need to extend my gratitude for the opportunity to broaden and develop my agronomic understanding from my home in Rapid City, Manitoba. To Dr. Richard Cruse, my Major Professor I am indebted for your guidance over the course of this lengthy project and for seeing me through to the finish.

In closing I would also like to acknowledge Marla Riekman from MAFRD for the use of the laboratory facilities at the Ian N. Morrison Research Farm; Dr. Tim Chamen of CTF Europe and Dr. Jeff Tullberg from the University of Southern Queensland for providing feedback on my initial experimental design and for providing advice and recommendations for sampling procedures and finally the Miller, Green and Nevin families for allowing us to sample their fields in the fall of 2016 as part of our soil sampling program.
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1. Introduction

Soil compaction can be defined as a reduction in porosity or an increase in bulk density resulting from external or internally applied forces (Alakukku, Laura, 2012). It is regarded with soil erosion, as the costliest and most serious environmental problem caused by conventional agriculture (FAO, 2003). Globally it is estimated that about 4% of agricultural lands or 64 million hectares are affected by compaction, with the majority of this associated with vehicular traffic (Flowers and Lal, 1998). The negative effects of soil compaction have been reported on nearly every continent in the world (Hamza and Anderson, 2005) and these effects have been shown to persist, especially at depth for periods of many years (Alakukku, 1996; Radford et al. 2007; Lowery and Schuler 1994; Logsdon et al. 1992; Hakansson et al. 1988).

One of the primary concerns in crop production relating to soil compaction is its potential to reduce profitability through reduced yields, reduced quality and/or increased costs of production (Hakansson et al. 1988). Many different field crops grown around the world have displayed the potential for yield loss associated with machinery induced compaction (Chamen, 2011; Hakansson 1988; Hakansson and Reader 1994). In addition to reduced yields, compaction can also have many negative effects on the environment; affecting the atmosphere, surface waters, ground waters and soil resources (Soane and van Ouwerkerk, 1995).

Fig. 1: A conceptual diagram showing the major pathways whereby compacted soil conditions may influence components of the environment. Adapted from Soane and van Ouwerkerk, 1995.
Many changes occur to a soil when compactive forces are applied resulting in adverse effects on soil properties (Hamza and Anderson, 2005; Hakansson, 1988) and it is these effects that ultimately lead to the negative impacts on crop production and the environment. Soil bulk density is an important indicator of soil compaction (Hamza and Anderson, 2005) and is defined as the dry weight of soil per unit volume. As a soil is compacted, bulk density increases and at some point it can impair root growth as well as air and water movement through the profile (A. Alaoui et al. 2011; Pierce et al. 1983). Soil porosity decreases as bulk density increases. Soil texture and structure will influence the size, number and interconnectedness of the soil pores (McCauley et al.). The macropores, which are critical to air and water movement into and through the soil profile, are most affected by machinery induced compaction (A. Alaoui et al. 2011). Air filled pore space levels above 10% have been shown to be critical for crop growth and compaction will increase the days at which air-filled pore space is below this critical level (Pierce et al. 1983). Compaction will also affect the number of days in which a soil is above critical levels of water filled pore space; levels greater than 60% are considered an important factor in N₂O emissions (Antille et al. 2015). Soil compaction has been shown to decrease the rate at which water infiltrates a soil (Hamza and Anderson, 2005; Soane and van Ouwerkerk, 1995; Hakansson et al. 1988). This needs to be considered as water that does not enter the profile can move off the landscape causing water induced soil erosion, sedimentation and pollution of surface waterways (Soane and van Ouwerkerk, 1995; Chamen, 2011; Tullberg et al. 2007).

So while machinery induced compaction has many negative effects associated with it, it is something that currently cannot be avoided in the production of crops. So the question then becomes how is this problem best managed? The most common solution is tillage at various
depths and intensities, but tillage is costly, is not a permanent solution, can lead to soil degradation and is simply not an option in conservation tillage systems. Controlled traffic farming on the other hand offers growers a permanent solution to the problem of machinery induced compaction. Controlled traffic farming (CTF) is a farming system built on permanent wheel tracks where the crop zone and traffic lanes are distinctly and permanently separated (Taylor, 1983). In a CTF system a condition more favorable for crop growth is created in the crop zone by the removal of traffic and a soil condition more favorable for trafficking is created in the permanent traffic lanes. By moving to a CTF system the effects that traffic can have on the soil is permanently removed from up to 85% of the field area, where as in random traffic systems (RT) upwards of 45% of the field area may be trafficked annually in no-till or 100% with many conventionally tilled systems. Even in no-till systems if traffic is not controlled, trafficked area may approach 100% after only two seasons.

There have been many benefits associated with the adoption of CTF systems. Improvements in soil bulk density, porosity, water infiltration and reductions in runoff and water erosion potential are common benefits (Gutu et al. 2015; Chamen 2011; Li et al. 2007; Tullberg et al. 2007). CTF also has the potential to reduce greenhouse gas emissions; more specifically N₂O (Ruser et al. 2006; Antille et al. 2015; Tullberg et al. 2018) and to a lesser extent CO₂ and CH₄ (Antille et al. 2015; Chen and Yang 2015; Tullberg et al. 2018). CTF has been demonstrated to reduce fuel consumption by reducing draught requirements and improving tractive efficiency (Chen and Yang 2015; Tullberg 2000). Crop yields have also been shown to respond positively to CTF (Tullberg et al. 2007; Godwin et al. 2015; Chamen 2011), which is a very important part of the consideration to adopt a CTF system due to its impact on profitability. In Chamen’s PhD dissertation (2011), he provides a graph to illustrate crop response to CTF.
systems around the world. The numbers in brackets behind each crop listed denotes the number of research results from which data were taken.

![Graph showing % increase in yield compared with RTF for various crops](image)

**Fig. 2:** The average yield benefit from controlled traffic farming versus random traffic farming. Data from Chamen (2011)

In our region of south-western Manitoba, traffic induced soil compaction has gained much attention in recent years due to a series of wet seasons. In fact we have been in a wet cycle for the better part of two decades, so there has been ample time for growers and agronomists to observe the harmful effects that heavy machinery can have on soils in the region. Area growers commonly attempt to control sprayer traffic with the adoption of auto-steer and a precision GPS signal like RTK. On our farm, we moved to a complete CTF system in 2012 after first starting with drill and sprayer traffic in 2011. Benefits such as higher yields, improved timeliness of field operations and improvements to soil health seemed clear to us so there has been no regrets associated with use of this system.
Despite the many benefits associated with a CTF system, adoption rates in Manitoba and across Western Canada are low, estimated to be at only 150,000 acres out of a total of 60 million acres (S. Laroque, personal communication, April 6, 2018). One of the factors potentially impacting adoption is a lack of data that defines CTF benefits under Western Canadian conditions. This reality is part of what motivated me to undergo this project on our farm. The objective of this study was to determine the impact of a controlled traffic farming system on crop yield and soil physical properties on a Newdale clay-loam and Beresford silty-clay soil located in south-western Manitoba.

2. Materials and Methods

2.1 Site description

The experiment was conducted on a field-scale at two different sites in the region of south-western Manitoba, Canada. One of the sites is located near the city of Brandon (49°50’0”N, 99°57’0”W) and will be referred to as the ‘Brandon site’. The other site is located near the town of Rapid City (50°7’14”N, 100°2’14”W) and will be referred to as the ‘Rapid City’ site. The two sites are located 15 miles apart. The Brandon site had been in a continuous crop, random traffic no-till system for 28 years and the Rapid City site for 16 years prior to the commencement of this study. Both fields were converted to a 40ft. no-till CTF system in the spring of 2012. Traffic simulations were conducted at both sites beginning fall of 2013 and continued until spring of 2016 (see sec 2.3 for a detailed description of the traffic simulations). Grain yield was measured over the course of three seasons beginning in 2014 and finishing in 2016. In the fall of 2016, water infiltration tests were conducted and the soils sampled for bulk density.
The soil at the Brandon site is comprised mainly of the Beresford Series and to a lesser extent the Janick. The Beresford is an imperfectly drained Gleyed Rego Black Chernozem that was developed on a thin mantle of loamy lacustrine sediments (L, CL) over strongly to very strongly calcareous, loam to clay loam glacial till of shale, limestone and granitic origin. Topography is nearly level, runoff is slow and permeability is moderately slow to slow. The Janick series is similar in many respects to the Beresford except that it occurs in the well-drained portions of the landscape and is classified as an Orthic Black Chernozem; it formed on clayey lacustrine deposits (C, SiC) rather than loam. The soil at the Rapid City site consists primarily of Newdale soils, which are an Orthic Black Chernozem on moderately to strongly calcareous, loamy (L, CL) morainal till of limestone, granitic, and shale origin. The Newdales are moderately well to well drained and occur on mid to upper slope positions of undulating to hummocky landscapes. Surface runoff is moderate to moderately rapid and permeability is slow. (Manitoba Soil Survey No. 30 and D65)

Table 1
Soil characteristics at the experimental sites. Adapted from Canada – Manitoba Soil Survey No. 30 (1976) and D65 (1988)

<table>
<thead>
<tr>
<th>Soil</th>
<th>Depth</th>
<th>pH</th>
<th>Slope (%)</th>
<th>CEC (meq/100g)</th>
<th>SOM (%)</th>
<th>Plastic Limit (%)</th>
<th>Liquid Limit (%)</th>
<th>Ksat (cm/hr)</th>
<th>Shrink/swell potential</th>
<th>Particle Size Distribution (%)</th>
<th>Bulk Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beresford</td>
<td>0-6&quot;</td>
<td>8.0</td>
<td>0 - 2</td>
<td>29.7</td>
<td>5.5</td>
<td>27</td>
<td>45</td>
<td>3</td>
<td>high</td>
<td>22 39 39</td>
<td>1.08</td>
</tr>
<tr>
<td></td>
<td>6-18&quot;</td>
<td>8.3</td>
<td></td>
<td>45.0</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newdale</td>
<td>0-6&quot;</td>
<td>7.8</td>
<td>2 - 5</td>
<td>33.2</td>
<td>6.6</td>
<td>26</td>
<td>46</td>
<td>3</td>
<td>moderate</td>
<td>30 36 24</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td>6-18&quot;</td>
<td>8.2</td>
<td></td>
<td>50.7</td>
<td>2.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The climate in this region of Canada is classed as sub-humid, cool continental. Due to its location at the center of the continent, summer temperatures are higher and winter temperatures cooler than the world average for this latitude. Average precipitation for this region is 470mm, with 100mm coming as snow in the winter months.

2.2 Experimental Layout

Four blocks with two treatments each were established at both sites in the fall of 2013. Plot dimensions were 120ft x 2000ft. The two treatments were CTF and simulated RT. Site selection of the plots within each field was guided by historical yield maps and done so as to avoid having drainage issues in a wet season influencing our results. The first plot at both sites started at the north end of the fields and the treatments were then applied in an alternating arrangement moving south; the Brandon site had the RT treatment applied in plots 1, 3, 5, and 7 and the Rapid City site had the RT treatment applied to plots 2, 4, 6, and 8.

Fig. 3: Plot layout at Brandon site

```
<table>
<thead>
<tr>
<th>Block 1</th>
<th>Block 2</th>
<th>Block 3</th>
<th>Block 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>RT</td>
<td>CTF</td>
<td>RT</td>
<td>CTF</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>RT</td>
<td>CTF</td>
<td>RT</td>
<td>CTF</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```
2.3 Traffic and cropping management

The RT treatment consisted of traffic treatments applied both spring and fall at timings which coincided with typical traffic dates for the region. Simulations were performed with a self-propelled sprayer, Class 9 combine on tracks, tracked tractor pulling a grain cart, and a larger tracked tractor that is used to pull our air drill (Table 2). The amount of area trafficked with each unit was roughly equivalent to the area typically trafficked in this region with each unit during a growing season. The simulations were also performed in the same location each year; this was done to facilitate a more accurate sampling program at the completion of the study. All simulations were applied outside of the time where crop was growing on the plots. We know that there is crop loss associated with driving heavy equipment over top of a growing crop and it was not the intent of this study to try and quantify what this type of yield loss might be.
Table 2
Equipment used to impose traffic on the RT plots and total plot area trafficked annually with each unit

<table>
<thead>
<tr>
<th>Machinery type</th>
<th>Tracks or Tires</th>
<th>Highest Axle load (lbs)(^1)</th>
<th>Approximate Total weight loaded (lbs)(^1)</th>
<th>Area trafficked/season (%)</th>
<th>Approximate ground contact pressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caterpillar MT 865</td>
<td>Tracks</td>
<td>25,000</td>
<td>50,000</td>
<td>38</td>
<td>6</td>
</tr>
<tr>
<td>Claas Lexion 760TT with 42ft. Honeybee draper header</td>
<td>Tracks</td>
<td>34,600</td>
<td>57,545</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>CaseIH 4420 sprayer</td>
<td>Tires</td>
<td>15,207</td>
<td>30,400</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>Caterpillar MT 765(^2)</td>
<td>Tracks</td>
<td>18,445</td>
<td>29,750</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Parker 750bus grain cart</td>
<td>Tires</td>
<td>26,450</td>
<td>30,780</td>
<td>7</td>
<td>50</td>
</tr>
</tbody>
</table>

\(^1\) Sprayer, Combine and Grain cart were approximately half full when imposing traffic
\(^2\) Caterpillar MT 765 was used to pull the grain cart so it did not traffic any additional area

Table 3
Calendar date for traffic simulations with corresponding soil volumetric water content (VWC %) at time of traffic

<table>
<thead>
<tr>
<th>Brandon</th>
<th>Traffic Timing</th>
<th>2013 VWC %(^1)</th>
<th>2014 VWC %</th>
<th>2015 VWC %</th>
<th>2016 VWC %</th>
<th>2016 VWC %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvest</td>
<td>Sep-22, Oct-24</td>
<td>40%</td>
<td>40%</td>
<td>42%</td>
<td>29%</td>
<td>40%</td>
</tr>
<tr>
<td>Fall</td>
<td>Oct-31, May-14</td>
<td>32%</td>
<td>42%</td>
<td>Oct-29</td>
<td>48%</td>
<td>Apr-22</td>
</tr>
<tr>
<td>Spring</td>
<td></td>
<td></td>
<td></td>
<td>Oct-01</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Harvest</td>
<td>Oct-07, Oct-24</td>
<td>40%</td>
<td>40%</td>
<td>Sep-01</td>
<td>38%</td>
<td>Oct-15</td>
</tr>
<tr>
<td>Fall</td>
<td>Oct-31, Jun-02</td>
<td>40%</td>
<td>40%</td>
<td>Nov-02</td>
<td>42%</td>
<td>May-05</td>
</tr>
<tr>
<td>Spring</td>
<td></td>
<td></td>
<td></td>
<td>May-05</td>
<td>34%</td>
<td>May-15</td>
</tr>
</tbody>
</table>

\(^1\) Estimated based on recorded rainfall between August and October of 2013
Fig. 5: Random traffic plot plan with location of traffic type and time of year traffic was applied, 80% of plot area received traffic

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Harvest</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>TrAM</td>
<td>TrAM</td>
<td>TrAM</td>
<td>TrAM</td>
</tr>
<tr>
<td>TrAM</td>
<td>TrAM</td>
<td>TrAM</td>
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<tr>
<td>TrAM</td>
<td>TrAM</td>
<td>TrAM</td>
<td>TrAM</td>
</tr>
</tbody>
</table>

= Sprayer
- = Grain Cart
= Tractor
= Harvester

Fig. 6: Controlled traffic plot plan, 15% of plot area received traffic

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Harvest</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>TrAM</td>
<td>TrAM</td>
<td>TrAM</td>
<td>TrAM</td>
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<td>TrAM</td>
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<td>TrAM</td>
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<tr>
<td>TrAM</td>
<td>TrAM</td>
<td>TrAM</td>
<td>TrAM</td>
</tr>
</tbody>
</table>

- = Tractor
= Harvester
Fig. 7: Pictures of equipment used during traffic simulations. (A) 865 Challenger used for spring and fall tractor traffic (B) 4420 CaseIH sprayer (C) Challenger 765 and 750 bus grain cart (D) Claas Lexion 760TT combine harvester. (A. Gurr, 2018)

Both sites were managed in the same manner in which the field containing the plots was managed; cropping choice was dictated by crop rotation. Seeding was performed with a Seedhawk no-till air drill which places seed and fertilizer together in one pass, row spacing is 12”. Inter-row seeding was performed with the aid of RTK guidance.
Fig. 8: Picture of Canola inter-row seeded into wheat stubble (A. Gurr, 2018)

Fig. 9: Picture of Seed-hawk air drill inter-row seeding wheat into canola stubble (A. Gurr, 2018)
Table 4
Crop rotation at Brandon and Rapid City sites

<table>
<thead>
<tr>
<th>Site</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandon</td>
<td>Canola</td>
<td>Wheat</td>
<td>Canola</td>
<td>Soybeans</td>
</tr>
<tr>
<td>Rapid City</td>
<td>Wheat</td>
<td>Canola</td>
<td>Oats</td>
<td>Canola</td>
</tr>
</tbody>
</table>

2.4 Equipment and Measurements

2.4.1 Soil Moisture

Soil moisture content was measured with a FieldScout TDR 300 soil moisture meter from Spectrum Technologies Inc.; the meter was equipped with 8” probes. Soil moisture readings were measured prior to traffic simulations; the volumetric soil moisture value reported for each date was an average of 50 measurements taken across the plot area.

Fig. 10: Picture of TDR 300 soil moisture probe (A. Gurr, 2018)
2.4.2 Yield Measurements

Plot yields were measured with a grain cart scale. The harvester made three passes within each plot to harvest the entire plot area and remained on the permanent tramlines at all times.

2.4.3 Bulk density and Water infiltration

At the completion of the study we sampled soil at both sites for bulk density in the 0-3” depth. The bulk density rings were 3” in diameter. The CTF plots were sampled at 10 random locations with measurements taken from the main tram line, intermediate tram line and the untrafficked area. The RT plots were sampled at five random locations within the plots with measurements taken from sprayer, spring and fall tractor, harvester and grain cart tracks as well as the untrafficked area within the RT plot. We also sampled selected neighboring RT fields. Soil samples were oven dried for 48 hours prior to weighing to obtain oven dried weights.

Water infiltration was measured at the same locations within each plot that bulk density samples were taken. A single-ring infiltrometer, 6” in diameter was used to conduct the infiltration tests. We measured the time it took for 1” of water to infiltrate soil within the ring; if there was water remaining in the ring after 30 minutes then we ended the test and recorded the time as 30+. If the first inch of water infiltrated prior to the end of the 30 minute period then we would add an additional inch of water and record the time it would take for the second inch to infiltrate. In the case of the untrafficked soil we would on some occasions apply up to five inches of water because the infiltration rates were so rapid, in doing this we were able to come up with a steady-state value for each site on the untrafficked soil. The time between the final traffic date on a particular treatment and our sampling date varied from a low of one month to a high of 14 months; Table 5. In addition to sampling the CTF and RT plots, we also sampled two neighboring RT fields at each site for bulk density and time to infiltrate 1” of water. When
sampling these RT fields we avoided obvious traffic lanes and focused on areas of the field that appeared to be well-drained.

Table 5
Time (months) between most recent traffic date and soil sampling date

<table>
<thead>
<tr>
<th></th>
<th>S</th>
<th>GC</th>
<th>C</th>
<th>T Fall</th>
<th>T Spring</th>
<th>IT</th>
<th>MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandon</td>
<td>5</td>
<td>13</td>
<td>13</td>
<td>12</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Rapid City</td>
<td>6</td>
<td>14</td>
<td>14</td>
<td>12</td>
<td>6</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

S = sprayer
GC = grain cart
C = combine
T Fall = fall tractor
T Spring = spring tractor
IT = Intermediate tramline
MT = Main tramline

Fig. 11: Picture of single-ring infiltrometer at the Rapid City site (A. Gurr, 2018)
2.5 Statistical Analysis

Yield data were analyzed with a two-tailed paired-t test. Infiltration tests, bulk density, WFPS and porosity were all analyzed as randomized complete block designs. LSD was calculated in all cases and differences were considered significant at P <= 0.10.

2.6 Growing season rainfall

Published literature suggests that it is often during the extremes of precipitation, i.e. too wet or dry, that yield losses associated with compaction show up. In two out of the three years that yield data were collected, growing season precipitation could be characterized as being relatively extreme for this region. In 2014 April – October rainfall was 160% of normal and then during the 2015 growing season, rainfall amounted to only 68% of normal. In the final year of the trial seasonal rainfall was 124% of normal. During the 2014 season extremes of both were experienced in successive months as June rainfall totaled 358% of normal and then July only amounted to 35% of normal.

Fig. 12: Distribution of growing season rainfall for the years 2014 – 2016; data comes from the Environment Canada weather station at Brandon, Manitoba.
3. Results

3.1 Crop Yield

Mean crop yields for the Brandon and Rapid City sites are presented in Tables 6 & 7. The only site year where yields between CTF and RT were significantly different was at the Rapid City site in 2016. There was a general trend towards higher yields at the Rapid City site in all years of the trial, but at the Brandon site this was not the case.

Table 6
Mean crop yield (bushels/acre) for CTF and RT treatments at the Brandon site

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
<th>CTF</th>
<th>RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Wheat</td>
<td>89a</td>
<td>87.8a</td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>Canola</td>
<td>55.5a</td>
<td>55a</td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Soybeans</td>
<td>50.4a</td>
<td>51.3a</td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same letter are not significantly different at (P<0.10)

Table 7
Mean crop yield (bushels/acre) for CTF and RT treatments at the Rapid City site

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
<th>CTF</th>
<th>RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Canola</td>
<td>50.2a</td>
<td>49.2a</td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>Oats</td>
<td>133.2a</td>
<td>130.6a</td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Canola</td>
<td>57.1a</td>
<td>55.5b</td>
</tr>
<tr>
<td></td>
<td>LSD</td>
<td>0.7</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same letter are not significantly different at (P<0.10)
3.2 Water Infiltration

Results of our infiltration testing for both the RT and CTF plots at each site are contained in Tables 8 & 9. In all cases CTF had a profound effect on infiltration rates. Differences were also noted between traffic type and intensity. A value of 1800 indicates that the test was ended after 30 minutes and water remained in the infiltration ring.

Table 8
Time (seconds) to infiltrate 1” of water in the CTF plot
N = 10

<table>
<thead>
<tr>
<th></th>
<th>CTF</th>
<th>IT</th>
<th>MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandon</td>
<td>82a</td>
<td>1800b</td>
<td>1800b</td>
</tr>
<tr>
<td>Rapid City</td>
<td>19a</td>
<td>1662b</td>
<td>1800b</td>
</tr>
</tbody>
</table>

CTF = untrafficked plot area
IT = intermediate tramline (1-2 annual equipment passes)
MT = main tramline (4-6 annual equipment passes)

Means followed by the same letter are not significantly different at (P<0.10)

Table 9
Time (seconds) to infiltrate 1” of water in the various traffic treatments contained within the RT plot and neighboring RT fields
N = 5

<table>
<thead>
<tr>
<th></th>
<th>S</th>
<th>GC</th>
<th>C</th>
<th>T Fall</th>
<th>T Spring</th>
<th>CTF</th>
<th>R1</th>
<th>R2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandon</td>
<td>1800c</td>
<td>1548c</td>
<td>906b</td>
<td>276a</td>
<td>687b</td>
<td>151a</td>
<td>1731</td>
<td>1210</td>
</tr>
<tr>
<td>Rapid City</td>
<td>1620c</td>
<td>1800c</td>
<td>799b</td>
<td>1458c</td>
<td>922b</td>
<td>63a</td>
<td>920</td>
<td>882</td>
</tr>
</tbody>
</table>

S = sprayer
GC = grain cart
C = combine
T Fall = fall tractor
T Spring = spring tractor
CTF = Untrafficked plot area
R1 = neighboring random traffic field 1
R2 = neighboring random traffic field 2

Means followed by the same letter are not significantly different at (P<0.10)
3.3 Bulk Density, Porosity, Water-filled pore space

Tables 10 & 11 contain the results of sampling we conducted for bulk density, porosity and water-filled pore space for both the RT and CTF plots at our two sites. CTF consistently produced the lowest bulk density and water-filled pore space and the highest porosity values.

Traffic type and intensity influenced the results of these tests.

Table 10
Bulk density, porosity and water-filled pore space in the CTF plot

<table>
<thead>
<tr>
<th>Brandon</th>
<th></th>
<th>MT</th>
<th>IT</th>
<th>CTF</th>
<th>LSD P&lt;0.10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bulk Density (g/cm³)</td>
<td>1.29a</td>
<td>1.22b</td>
<td>1.04c</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Porosity (%)</td>
<td>51a</td>
<td>54b</td>
<td>61c</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>WFPS (%)</td>
<td>72.3a</td>
<td>70.4a</td>
<td>48.7b</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Rapid City

|            | Bulk Density (g/cm³) | 1.27a | 1.2b  | 0.96c | 0.05       |
|            | Porosity (%) | 52a  | 55b  | 64c  | 2          |
|            | WFPS (%)     | 74a  | 57b  | 43a  | 4          |

CTF = untrafficked plot area
IT = intermediate tramline (1-2 annual equipment passes)
MT = main tramline (4-6 annual equipment passes)
Means followed by the same letter are not significantly different at (P<0.10)

Table 11
Bulk density, porosity, and water-filled pore space in the RT plot

<table>
<thead>
<tr>
<th>Brandon</th>
<th></th>
<th>S</th>
<th>GC</th>
<th>C</th>
<th>FT</th>
<th>ST</th>
<th>CTF</th>
<th>R1</th>
<th>R2</th>
<th>LSD P&lt;0.10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bulk Density (g/cm³)</td>
<td>1.21d</td>
<td>1.15c</td>
<td>1.10c</td>
<td>1.05a</td>
<td>1.10b</td>
<td>1.06a</td>
<td>1.07</td>
<td>1.05</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Porosity (%)</td>
<td>54a</td>
<td>57b</td>
<td>59bc</td>
<td>60c</td>
<td>58bc</td>
<td>60c</td>
<td>60</td>
<td>60</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>WFPS (%)</td>
<td>62d</td>
<td>55bc</td>
<td>55.8c</td>
<td>50.7ab</td>
<td>49.8a</td>
<td>48.7a</td>
<td>63.7</td>
<td>60.3</td>
<td>4.9</td>
</tr>
</tbody>
</table>

Rapid City

|            | Bulk Density (g/cm³) | 1.04ab | 1.15c | 1.15c | 1.10bc | 1.09bc | 0.97a | 1.02 | 1.10 | 0.09       |
|            | Porosity (%) | 60bc  | 57a  | 57a  | 58ab  | 59ab  | 63c  | 62   | 58   | 3          |
|            | WFPS (%)     | 54b  | 58b  | 55b  | 55b   | 54b   | 45a  | 51   | 59   | 8          |

S = sprayer
GC = grain cart
C = combine
T Fall = fall tractor
T Spring = spring tractor
CTF = untrafficked plot area
R1 = neighboring random traffic field 1
R2 = neighboring random traffic field 2
Means followed by the same letter are not significantly different at (P<0.10)
4. Discussion

4.1 Crop Yield

There have been many studies conducted around the world, which have shown the potential for CTF to improve crop yields (Tullberg et al. 2007; Godwin et al. 2015; Chamen 2011). At the Brandon site we did not observe a yield benefit to CTF after four seasons. The soil at the Brandon site appears to be quite forgiving when it comes to traffic induced compaction. During wet seasons, one can often observe traffic lane yellowing across local fields in areas when the soils are waterlogged, but as the soil dries the yellowing quickly disappears along with any evidence of traffic patterns; crop growth in the traffic lanes appear unaffected. At the Rapid City site we observed a small, but consistent trend towards higher yields for CTF and in the final year of the study it was statistically significant. The Newdale soils at the Rapid City site are less forgiving when it comes to compaction then the Beresford soils at Brandon. Quite often the season long evidence of compaction can be observed on the Newdale, in particular if it has been wet during seeding. In all three years of the study we could observe the effects of tramline compaction on the Newdale soil, whereas this was rarely the case on the Beresford soil.

Fig. 13: Tram line compaction on Newdale soil (A. Gurr, 2018)
There are several reasons that could be used to possibly explain why the yield responses were small at best in this trial. Some of it will no doubt have to do with experimental design as it is a real challenge to effectively test CTF, especially on a field-scale due to equipment challenges, cost and logistics. In the materials and methods section this was briefly mentioned that all traffic simulations were performed outside of the actual cropping season, meaning once the crop season commenced the entire plot area was managed as CTF. There are several sources of crop loss that can be associated with vehicular traffic in our region, these include compaction resulting from spring seeding and field preparation.

Fig. 14: Compaction in soybean (l) and wheat (r) from spring seeding and field preparation (A. Gurr, 2018)

Crop loss from uncontrolled sprayer traffic, which is common on today’s farms, which do not typically use tramlines or RTK GPS signals for repeatable traffic passes.

Fig. 15: Uncontrolled sprayer traffic in wheat displaying obvious crop impacts (A. Gurr, 2018)
Yield and/or quality loss from uneven emergence resulting from vehicle traffic can often be observed. This can pose a challenge to fungicide application and harvest timings among other things.

**Fig. 16:** Various types and timing of traffic affecting canola development (A. Gurr, 2018)

All of the above mentioned sources of yield loss that can result from traffic can be greatly reduced or even eliminated inside of a CTF system, but we were not attempting to include these in the trial work we conducted.

Another explanation could be related to the length of the study period and the fact that we did not perform any deep loosening prior to commencement of the study to try and remove any pre-existing compaction that may have been present at each site. It has been well-established in the literature that the effects of soil compaction can persist for periods of many years, particularly at depths beyond the plough layer (Alakukku, 1996; Radford et al. 2007; Lowery and Schuler 1994; Logsdon et al. 1992; Hakansson et al. 1988). In a study conducted by Hakansson and Reeder
(1994) the compacted soil profile was divided into three layers; plough layer, upper part of the subsoil and the deeper part of the subsoil. The authors were able to show not only the persistence of compaction from high-axle load traffic, but they also highlighted that the persistence varies depending on depth and that even in the plough layer this effect can persist for upwards of 5 years on a clay-loam soil; 10 years in the upper part of the subsoil and that the effect is essentially permanent in the deeper part of the subsoil, Figure 16. So perhaps given that the study period was only 4 years, it was not a long enough period for natural processes like freezing and thawing, wetting and drying and the activity of earthworms to entirely remediate the effects of pre-existing compaction resulting from a generation of random traffic with high axle-load equipment.

Fig. 17: Schematic diagram showing the compaction contributions to subsequent crop yield reductions as a function of compacted soil layers caused by high axle-load traffic. The magnitude and persistence of the individual components vary considerably between soils. The diagram illustrates the situation for a clay loam soil. Adapted from Hakansson and Reeder, 1994.
One final but important consideration with regards to yield is the concept of a soil’s critical stress level, which is defined as the stress that a soil can withstand at a given water content without enduring soil structural damage (Gelder et al., 2006). When forces are applied that exceed the critical stress level it is thought that harmful effects such as aggregate destruction occur, which can in turn lead to crop yield loss. If loads are kept below the critical stress level then it is thought that the more serious effects of compaction can be avoided. In the case of this study the stresses applied by our various traffic treatments may not have been enough to cause soil structural damage.

4.2 Water Infiltration

Improvements to water infiltration associated with a move to CTF systems are a common theme around the world (Gutu et al. 2015; Chamen 2011; Li et al. 2007; Tullberg et al. 2007) and our experience was no different. At both sites we saw large differences in infiltration between trafficked and untrafficked soil. This came as no surprise when we were testing the CTF plots because our comparison was the CTF tramlines, which had not only received multiple passes over the course of the four seasons, but had also, received recent traffic during harvest, so the compaction was fresh. This was not the case in the RT plots, where our sample sites only received a single pass per season and in the case of the fall tractor and harvest traffic 13-14 months had passed from when the final simulations were performed and our sample dates. In order to locate the simulated area in the RT plots, we had to count seed rows, using our tramlines as reference points, otherwise there was no indication that traffic had occurred. Once we tested infiltration however it was clear where we had driven and where we had not over the course of the study. Statistically significant differences were noted between CTF and our various RT
treatments in all cases except for fall tractor traffic at the Brandon site. We also noted differences in traffic type at both sites.

In addition to sampling our RT and CTF plots, we also sampled two neighboring RT fields at both sites. When we were choosing sample sites in the RT fields we avoided fresh or obvious traffic lanes and poorly drained portions of the fields. It was interesting to note the large differences between the RT sites and the CTF soil in our plots, keeping in mind that between 25 and 40% of these fields contained recent traffic from harvester, grain cart, tractors and sprayers and these areas were not sampled for infiltration; essentially our sample sites in the RT fields represented the best that these fields had to offer.

When we were measuring infiltration in the untrafficked soil at both sites we applied additional inches of water to see where the infiltration rates would stabilize. On the Newdale it was at about 300 seconds and on the Beresford it was 430 seconds. What made this all the more remarkable was the soil moisture conditions in the fall of 2016. Between August and October we received 10” of relatively slow gentle rain, which meant that the soil profile was at or above field capacity. On a Newdale soil at field capacity, we could infiltrate 5” of water in 19 minutes. We conducted over 150 infiltration tests in the fall of 2016 and while the traffic effect was obvious on this important soil property it also became clear to us that there was a biological component to this. Whenever we would remove an infiltration ring from trafficked soil and flip it upside down, you could observe the number of earthworm channels present in the sample. Where the soil was more intensively trafficked there were fewer channels; in some of the RT treatments where infiltration did occur there appeared to be more earthworm activity as evidenced by the number of holes. The CTF samples were so porous that when we removed the infiltration rings from the soil, there was no soil remaining in the rings. We felt that the
impressive infiltration rates in the CTF soil could be explained by enhanced earthworm activity and the continuous pore space they will have created from the surface to depths deeper in the profile. When traffic is applied to the soil not only will this continuous pore space be interrupted, but earthworm activity will be hindered, preventing them from restoring these important networks to their pre-compacted states for periods of several years (Radford et al., 2001; Capowiez et al., 2012).

4.3 Bulk Density, Porosity, Water-filled pore space

Bulk density, porosity and water-filled pore space (WFPS) are three soil physical properties that often come up in discussions relating to CTF and/or soil compaction (Hamza and Anderson, 2005; McCauley et al.; Antille et al., 2015). In the case of all three we saw improvements with CTF relative to our main and intermediate tramlines, our RT treatments and the neighboring RT fields we included in our sampling program. Of particular importance from a climate change perspective were the values for WFPS. As expected, the CTF tramlines returned the highest values for WFPS, but the differences could still be observed in our RT treatments and the neighboring RT fields. This is important because it suggests that even a single pass/season is enough to increase the risk of N loss from a soil when it is wet. (Ruser et al. 2006; Antille et al. 2015) both mention WFPS levels of 60% as being a critical level with regards to N$_2$O emissions and in spite of the fact that our sampling took place up to 9 days after the most recent rain event, several of the samples exceeded or approached this critical level. In the case of the RT fields we sampled, one must recall that we did not sample wheel tracks or poorly drained portions of the fields, which comprised upwards of 40% of the field area in some cases. Our CTF treatments consistently had the lowest values for WFPS and in most cases these differences were statistically significant.
In the case of bulk density, the differences were once again most pronounced when comparing untrafficked soil in the CTF plots to the tramlines. The RT treatments also tended to have higher bulk density values than the untrafficked soil, but they were also lower than the CTF tramlines in all cases. This data displays the obvious impact of traffic on bulk density, but it also highlights the fact that given time these soils have the potential to return to their pre-compacted state once traffic is removed for a period of time.

5. Conclusion

This 4-year study investigated the effect that a controlled traffic farming system could have on crop yield and soil physical properties on a Beresford and Newdale soil in south-western Manitoba, Canada. Based on the data we collected we were able to conclude the following:

1. Controlled traffic had no effect on crop yield on the Beresford soil, and showed only a modest improvement to crop yield on the Newdale (2%).
2. Controlled traffic resulted in significant improvements to water infiltration on both soils.
3. Controlled traffic improved soil bulk density, total porosity and water-filled pore space on both soils in the areas without traffic.
4. Traffic type and intensity influenced infiltration, soil bulk density, total porosity and water-filled pore space on both soils.
References


