

Controlled Traffic Farming

Final Report
Nuffield Study Tour



By Steve Larocque | March 2012
2007 Canadian Nuffield Scholar

Sponsors



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Foreword

When I applied for the Nuffield Scholarship in 2007, my intention was to investigate new precision technologies that would help Western Canadian farmers generate higher yields and improve profitability. My travels took me to Australia, New Zealand, Brazil, Mexico, United States, Eastern Canada and the United Kingdom. Little did I know I would stumble upon one of the most revolutionary farming systems since no-till and pioneer the very first controlled traffic farming system in Western Canada.

During the 13 weeks I travelled, I logged 68,000 air miles, spent 134 hours in the air, waited 52 hours in 34 airports and drove 6 mini buses and 5 rental cars. I rushed home from the middle of Brazil while on the Global Focus Tour to be present for the delivery our first child born 15 weeks early on March 28th, 2008. Our sweet, strong daughter hasn't looked back since those long drama-filled days in intensive care.

This report is a snap shot of what I have learned about controlled traffic farming and its fit in Western Canada. I hope you enjoy reading it as much I enjoyed experiencing it.

Acknowledgments

I would like to thank my wife Vanessa for all her encouragement, love and support everyday and during my time away from home. My successes are a direct reflection of her sacrifice. I am also grateful for Vanessa's parents, Sam and June Currie, for looking after my family while I was away and for their never ending love and support. I am truly blessed. I cannot forget



to thank my brother-in-law, Mitch Currie, who bought into this crazy idea called controlled traffic farming whole heartedly along with Sam so that we could spend hours together ripping apart our equipment and welding it back together.

To Nuffield Canada, thank you for awarding me such a prestigious and life changing scholarship. I am now a better father, businessman and advocate of agriculture because of this experience. Also, to Jim Gelch for organizing the global focus tour and allowing us to rub shoulders with senators, ambassadors and leading edge farmers from around the world.

Sincere thanks to the hospitable strangers and fellow Scholars who invited me into their homes to share their knowledge about their farm and passion for the business. Thank you for the warm meals, inspiring conversations and most of all for your friendship.

Thank you to my generous sponsors: Nuffield Canada, Syngenta, Bayer CropScience, Advanced Leadership and Management Development Program, FarmTech, Alberta Barley Commission, Arysta LifeScience and Deer Valley Implements. You made this experience possible and I am deeply indebted.

Abbreviations

bu/ac = bushels per acre
T/ha = tonnes per hectare
NDVI = normalized difference vegetative index
CTF = controlled traffic farming
RTK = real time kinematics

Note: All dollar amounts are in Canadian dollars unless otherwise stated.

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Executive Summary

In an effort to achieve greater farm profitability in Canada, the evolution of 21st century agriculture can be described as “bigger is better”. Today’s philosophy is to reduce operating costs by gaining economies of scale while using current farming practices across more acres of land. However, continuing to farm with the same management practices over a larger land base simply adds more risk and not necessarily profit. Bigger is not better, better is better. I believe that controlled traffic farming offers the potential to generate higher returns to Western Canadian grain farmers on less land base with less risk.

Approximately 70% of Western Canadian farms have adopted direct seeding as part of their farming system. This farming system can see up to 50% of each field covered by wheel traffic each year during seeding, spraying and harvest activities. As equipment sizes have grown, so have equipment axle loads and with it, the potential for compaction. Controlled traffic farming is a system that seeks to minimize the damaging effects of compaction by concentrating wheel traffic to a small area of the field. This paper will address the effects of wheel traffic, compaction and how controlled traffic offers a solution.

Benjamin Franklin once said the definition of insanity is doing the same thing over and over and expecting a different result. We cannot continue the same farming practices on a larger scale and expect different results. Successful Canadian farms of the future will embrace controlled traffic and take production and profitability to a new level.

Introduction

Objectives

The key objectives of my Nuffield Scholarship were:

- To investigate the concept of controlled traffic farming (CTF).
- To discover the benefits of CTF.
- To visit CTF farms and document the equipment used and modifications made.
- To determine if CTF has a fit in Western Canada.

Key findings

- Converting to controlled traffic farming doesn't have to happen overnight. You can move to CTF over time as you begin to match up equipment widths and axle widths. Nobody says you have to flip a switch and change instantly.
- CTF equipment setups don't have to be expensive. Many of the farms I visited invested less than \$15,000 initially and some took a few years to change over as cash flow allowed.
- You don't have to be completely rigid about CTF. For example, if you have to veer off of a tramline to unload during harvest because you can't make it to the end of the field, then jump off and unload. The extra wheel tracks caused by leaving the tramline to unload add up to a very small percentage across the farm.
- CTF opens up a world of precision applications such as inter-row seeding to inter-row spraying herbicides, on-row spraying of fungicides and insecticides, in-crop fertilizer banding, and strip till banding fertilizer in the fall.
- CTF initiates spatial awareness. With the aid of application and yield mapping you can begin to uncover the variables that reduce yield in your cropping system. Once

you reduce the randomness of input over lap and under lap, you can start to extract valuable yield data because the placement of inputs is so precise.

- CTF improves the timeliness of input applications. We all know how important timing is in farming. With CTF, growers can get on the field sooner after a rain than conventional farming systems. Improving the timeliness of seeding, spraying and harvest can generate big returns.
- CTF reduces fuel use by 30 to 50%, with big savings during harvest. Compare for example, a loaded combine weighing in excess of 60,000 lbs driven across a soft field and driven on a set of hard packed tramlines. Needless to say, the reduction in fuel use would be significant.
- On farm research becomes easier and the data collected more valuable with CTF. The pass to pass accuracy in a CTF system allows you to apply treatments and collect yield data knowing exactly how many rows you treated and how many rows you harvested. It eliminates the randomness like input overlap and harvest under lap that skews yield data.

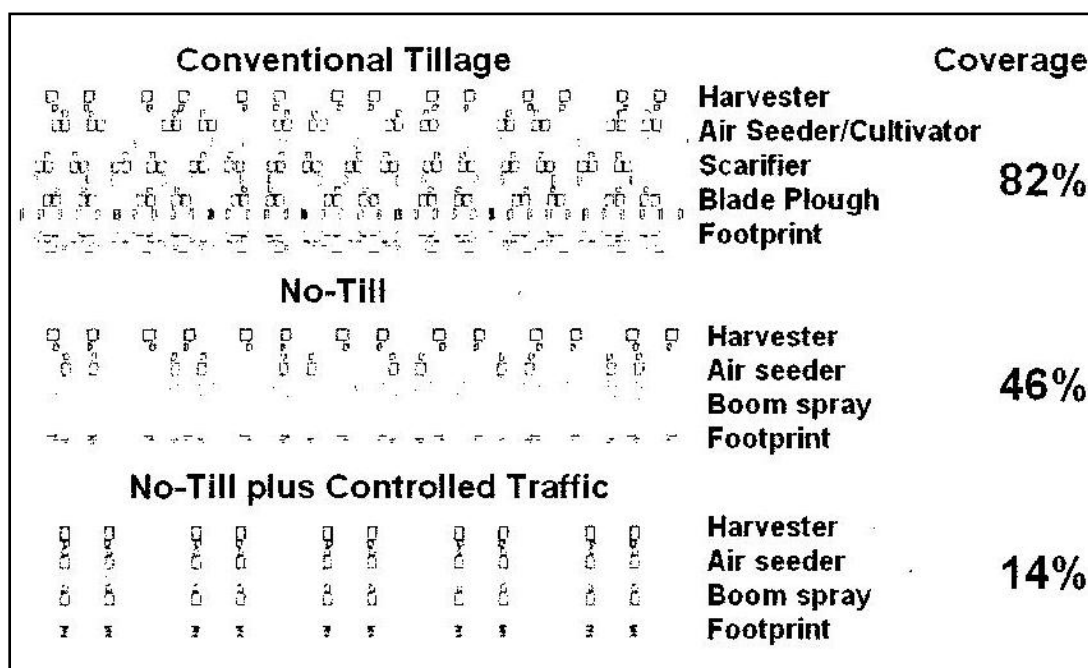
Recommendations

1. Farmers must begin to evaluate axle loads and the potential for wheel track compaction in their own farming system.
2. Researchers and farmers must put aside assumptions and speculation about compaction and begin addressing the issue through research and on-farm experimentation.

Chapters

What is Controlled Traffic Farming?

Controlled traffic farming is a crop production system that seeks to minimize compaction from wheel traffic by restricting all equipment to permanent traffic lanes. The goal is to restrict wheel traffic to the least possible area within each field so crops can grow in uncompacted seedbeds. This is accomplished by matching up all equipment widths and axle widths so every farming activity travels down the same path each year. The result is a reduction in inputs (time, fuel, and machinery), an increase in efficiency (moisture, nutrients, and sunlight) and an increase in output (yield).



Graph 1. Wheel track coverage of conventional tillage, no-tillage and controlled traffic. Source: Walsh (1998) in Rainfed Farming Systems¹

Direct seeding systems can see up to 50% of each field covered in wheel traffic from seeding, spraying and harvest activities. Graph 1, above, compares the percentage of wheel traffic covering each field in conventional tillage, no till and controlled traffic no-till. (Direct seeding and no-till have the same level of equipment traffic, they differ in soil disturbance only). Switching to a no-till controlled traffic system can reduce equipment traffic by 32% when compared to straight no-till.

To take it a step further, Photo 1 illustrates how equipment can be modified to travel down the same path each year; a 4WD tractor on singles with 121.5-inch axle widths pulling a 30-foot air drill and tow behind air tank. Each tire except for the outside castor wheels follow down the same set of permanent tram lines each year. The combine and sprayer also travel down the same tram lines. The air drill and combine are 30 feet wide and the sprayer is 90 feet wide. This is our own controlled traffic system and has brought the amount of wheel traffic down to 16.6% from 46%.



Photo 1. Our 4WD tractor and air drill are modified to travel on permanent tram lines. Source: S. Larocque

The weight of equipment has increased dramatically over the last ten years which has added to the potential for compaction issues. Chart 1, below, illustrates the approximate weight of a given set of John Deere equipment. Machines like combines, sprayers, grain carts and air carts weigh in excess of 18,000 kg and upwards of 25,500 kg in the case of the 9770 combines. Taking into account mismatched equipment widths, some areas of the field will see two to three passes with equipment carrying over 20,000 kg.

CTF Field Vehicles (12.0m System)	Approx Machine Mass (kgs)
9770 Combine/ MWF Draper (12.0m)	25,500
1910 Air Cart (430 Bu)	21,000
Grain Cart (22,000 litre)	20,000
4930 Sprayer (120ft Boom)	18,100
8365R Tractor (3.0m Tread/Singles)	14,000
1890 No-Till Disc Drill (12.0m)	10,200
1870 No-Till Hydraulic Bar (40ft)	8,000

Chart 1. Approximate machinery weights. Source: John Deere

When you consider covering 50% of a field every year with wheel traffic and combine that with heavier axle loads, the potential for compaction in Western Canada is significant. Furthermore, extreme or abnormal weather events contribute negative effects. Over 10

million acres in Western Canada received above average precipitation in early 2011 putting 15% of the acres in Western Canada at risk of serious compaction issues. I will make the case that compaction negatively impacts yields, maturity and profitability and controlled traffic offers a solution.

Making the Case for CTF in Western Canada

The debate about the effects of compaction is an intense one. Many people feel that compaction due to wheel traffic does not pose a threat to crop production in Western Canada. Some argue that the freeze thaw cycle removes compaction or that our soil types simply are not prone to compaction or that organic matter acts like a sponge to buffer the effects of potential damage from wheel traffic. Unfortunately, these arguments are fundamentally speculation because there is no scientific research to support the claim that compaction does not pose an issue in Western Canada. The same could also be said for my position so let me set the stage with visual examples.

As an agronomist, I manage close to 35,000 acres of crop land that spans a dozen soil types and three soil zones within a 100 km radius near Calgary, Alberta. Every year I see wheel track issues caused by equipment traffic early in the growing season, typically the wettest time of year. Depending on the equipment width and tire size, the area covered by wheel

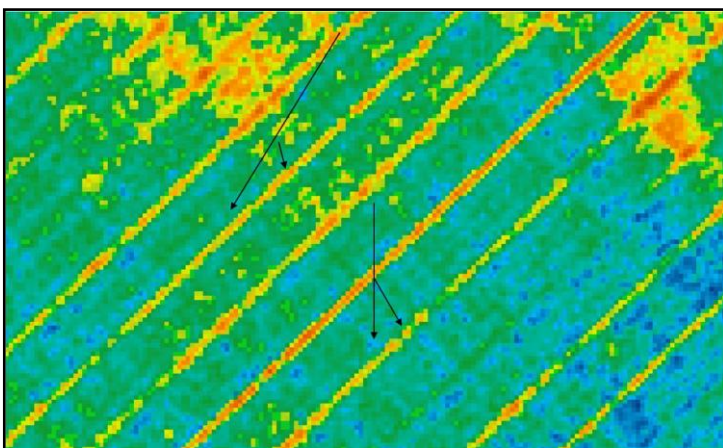


Image 1. Red and yellow coloured areas indicate a reduction in vegetation caused by machinery. Source: Precision Agronomics Australia.

traffic could reach between 20% and 30% on a field before the end of June given two passes with the sprayer and one pass with the air drill all. This is what concerns me and what the research community needs to begin looking at. It is very difficult to see a 10, 20 or 30% yield reduction in any crop by assessing it visually on-site.

Quenten Knight, from Precision Agronomics Australia based out of Esperance, WA showed me how he captures wheel track damage using high resolution NDVI imagery. At 1 metre resolution the imagery has the power to capture differences in vegetation from a magnified level. Shown in Image 1 (previous page), the red and yellow coloured lines running northeast and southwest spaced 56 feet apart indicate a reduction in vegetation and yield potential. In this case, it was the air cart behind the drill that was causing enough compaction to reduce crop growth. The damage was not visible to the human eye and could only be picked up using high resolution imagery. This example literally opened my eyes to the potential for unseen compaction issues in our soils.

Photos 2 and 3 below were taken near Drumheller and Three Hills, AB in 2007 and 2010, respectively, on a clay loam and heavy clay soil. Notice the pattern of the late blooming canola; it follows wheel traffic from seeding. In both cases, the bloom stage was delayed and finished blooming later than the rest of the field. Unfortunately, in common scenarios like these, once all the petals drop the visual difference in crop growth is undetected and all is forgotten. What about the impact on yield and maturity? The answer is unknown because it has never been studied in Western Canada. The wheel tracks showing in Photo 2 were of a Case STX 425 quad track pulling a 40-foot 1830 hoe drill with a John Deere 1910 tank, a very common set up.



Photo 2. Near Drumheller, AB, mid-August 2007, a canola field on heavy clay soil.
Source: S. Larocque



Photo 3. Near Three Hills, AB, August 2010, a canola field on clay loam soil. Source: S. Larocque

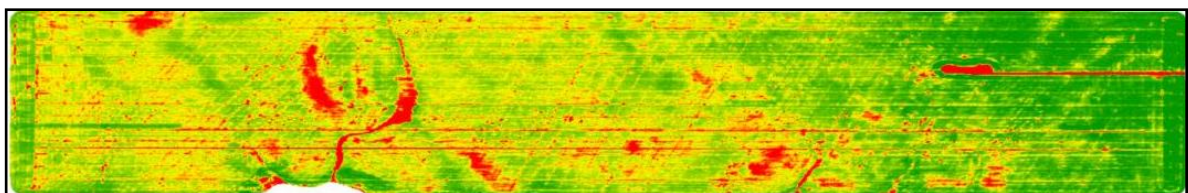
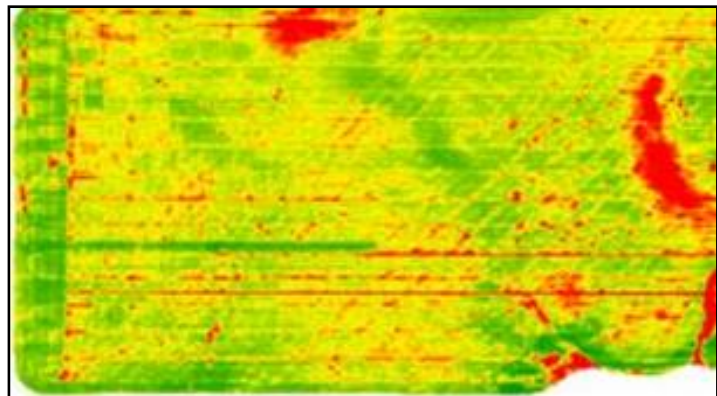
The effects of wheel track damage in an emerging wheat crop from a John Deere 1910 430 bushel tow behind air tank is shown in Photo 4. The plants inside the wheel tracks were struggling to emerge and would have had decreased yield and delayed maturity. The effected area works out to 8.3% on this field; so before the crop has even begun to tiller, yield potential has been lost.



Photo 4. Late plants emerge in wheel tracks near Drumheller, AB. Source: S. Larocque

The images below show a 1metre resolution NDVI photo of wheat in 2007. The crop was harvested with John Deere combines in a NE/SW direction in 2006. In Image 2 there are noticeable lines running on a diagonal in a NE/SW direction. These red and yellow areas indicate a reduction in crop growth and yield potential. This is one of my favourite visuals because the research community has told us our soils are not prone to compaction and the freeze-thaw cycle removes most of the harvest compaction. With imagery like this, it clearly indicates that equipment traffic is impacting crop growth and yield. The question is to what degree.

Image 3 (bottom), and Image 2 (right) of a wheat field at 1metre resolution. NDVI photos taken at Doug Clemens' farm near Mossleigh, AB in 2007. Source: D. Clemens



In 2010 my family and I converted our equipment to begin controlled traffic farming on a 3:1 30-foot system. We farm near Drumheller, AB, an area known for heavy clay soils with high magnesium levels that swell when wet and crack when dry. They are very similar to the soil

types I saw on farms in Queensland, New South Wales and Victoria, AUS. In the first season, after one pass with the air drill there were cracks within the tram lines but nothing outside of them (Photo 5). Cracks throughout the field were a common occurrence before but not since wheel traffic was confined to permanent tram lines which cover 16% of the total field area.

There are countless examples of wheel track damage and compaction issues across many soil types and soil zones. The most significant damage is the wheel traffic created at the beginning of the growing season during seeding and spraying, normally the wettest time of year. As identified previously with the 1 metre resolution NDVI imagery, harvest traffic is also having an impact on crop yield in spite of the freeze-thaw cycle. I am convinced that wheel traffic negatively impacts crop growth in Western Canada. I am also convinced that controlled traffic farming provides a solution to minimize the effects and has a fit in Western Canadian production.



Photo 5. After just one pass with the seed drill, soil cracks are confined to tram lines, August 2010. Source: S. Larocque

The Economic Impact of Compaction

There has been very little research on the economic impact of compaction caused by wheel tracks in Canada. The majority of research on compaction has been done in Eastern Canada on corn and soybeans but nothing to date in wheat, barley or canola. In an attempt to provide some examples of revenue loss from compaction I've included research in this report from North America, anecdotal findings from close to home, and some personal observations made in Australia to bring perspective to the potential economic impact across Western Canada.

Yield loss measured in sprayer tracks

On a trip to Horsham, Victoria in 2009 I had a visit with long-time CTF farmer, Robert Ruwoldt, and his agronomist, Andrew Newall. They showed me a picture (Photo 6) of a yield

monitor recording the yield loss which occurred in lentils from two passes with the John Deere self-propelled sprayer. The soil type was a 2:1 self-mulching red clay loam soil. The yield loss suffered in the area around the wheel tracks was 12 to 15%. Also, the sprayer tracks affected the adjacent four rows, not just the trampled row. The two yellow lines in the picture indicate a 12% reduction in yield every 90 feet which is the length of the high clearance sprayer. They found similar results in barley as well.

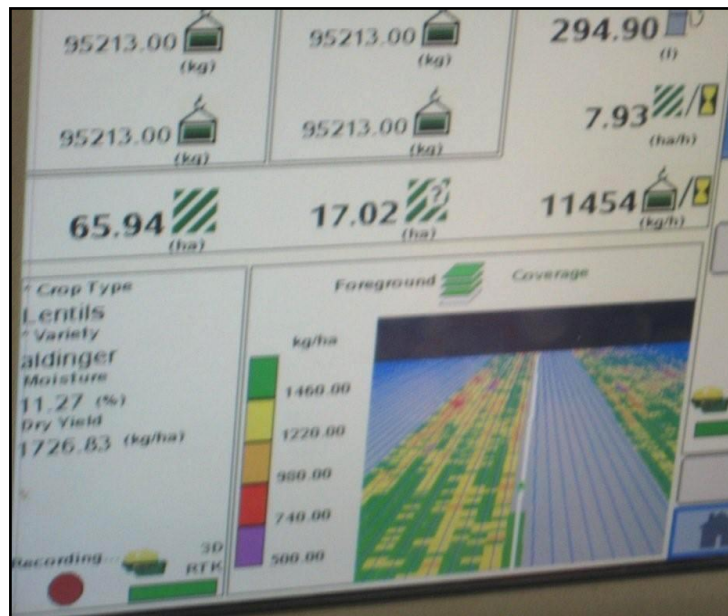


Photo 6. Yield variability from compaction is noticeable on the yield monitor. Source: A. Newell

The economic loss calculations are as follows:

Lentil yield loss: $1,600 \text{ lbs} \times 12\% \times \$0.25/\text{lb} = \$48.00/\text{acre}$

Malt barley yield loss: $65 \text{ bu}/\text{ac} \times 12\% \times \$5.00/\text{bu} = \$39.00/\text{acre}$

In this example, the yield loss caused by sprayer wheel tracks resulted in a \$39.00 to \$48.00 per acre revenue loss.

Revenue loss from protein decrease

Research completed in Grand Forks, North Dakota found a significant decrease in wheat protein when comparing compaction caused from a spring activity to a spring and fall compaction event with an uncompacted check². The results (Chart 2) showed a 0.7% decrease in wheat protein from one single spring compaction event. An example of the ensuing economic loss is calculated below:

Treatment	% Protein
Non-compacted	13.6
Spring compacted	12.9
Fall and Spring compacted	12.7

Chart 2. Timing effect of compaction on percent wheat protein in Grand Forks, ND. showed compaction decreased wheat protein. Source: Voorhees *et al.* (1985)

Wheat revenue loss:

$$50 \text{ bu/ac} \times (0.7\% \text{ protein} \times \$0.46/1\% \text{ protein CWB PRO}) = \$16.10/\text{ac}$$

In this example, a one-time spring compaction event could lead to a \$16.10 per acre loss from a reduction in wheat protein. Considered on a larger scale with 25 million tonnes of wheat produced in Western Canada, the potential revenue loss from compaction at these values would be \$293,000,000.00.

Yield loss in sprayer tracks

Photo 7, right, shows wheel track damage from a high clearance sprayer and the resulting delay in maturity. Both fields are located near Three Hills, AB. A typical high clearance sprayer in this area would have 12- inch wide tires and 90-foot booms, which covers roughly 3% of the entire field. The loss calculations below follow the equation $\% \text{ loss} \times \text{bu/ac} \times \$/\text{bu}$.



Photo 7. High clearance sprayer tracks in barley (top) and wheat (bottom) caused maturity delays. Source: S. Larocque

Wheat revenue loss:

$$3\% \times 50 \text{ bu/ac} \times \$6.50/\text{bu} = \$9.75/\text{ac}$$

Malt barley revenue loss:

$$3\% \times 80 \text{ bu/ac} \times \$5.00/\text{bu} = \$12.00/\text{ac}$$

In this example, the potential yield loss from wheel track damage in wheat is \$9.75 per acre and \$12.00 per acre for malt barley. Any way you look at it, wheel track damage from in-season herbicide and fungicide applications cost producers money every year.

It's dangerous to assume that our soils have the right buffering capacity to withstand the effects of wheel traffic when there are examples of damage every year. I would argue that with the right axle load and the right soil moisture at the right time, any field has the potential to compact, even in Western Canada. Using these examples, you could easily argue the economic losses to farms in Western Canada would be in the hundreds of millions each year.

Understanding Soil Compaction

Soil compaction occurs when soil particles are pressed together, reducing pore spaces between them. Compaction is significant to crop production because it impedes root growth, reduces soil oxygen, water holding capacity and the amount of soil roots can explore. The effect of compaction in dry years, for example, can lead to stunted, drought stressed plants and in the absence of timely rains, yield losses may be worsened. The chart below shows the area of soil beneath the surface where compaction occurs.

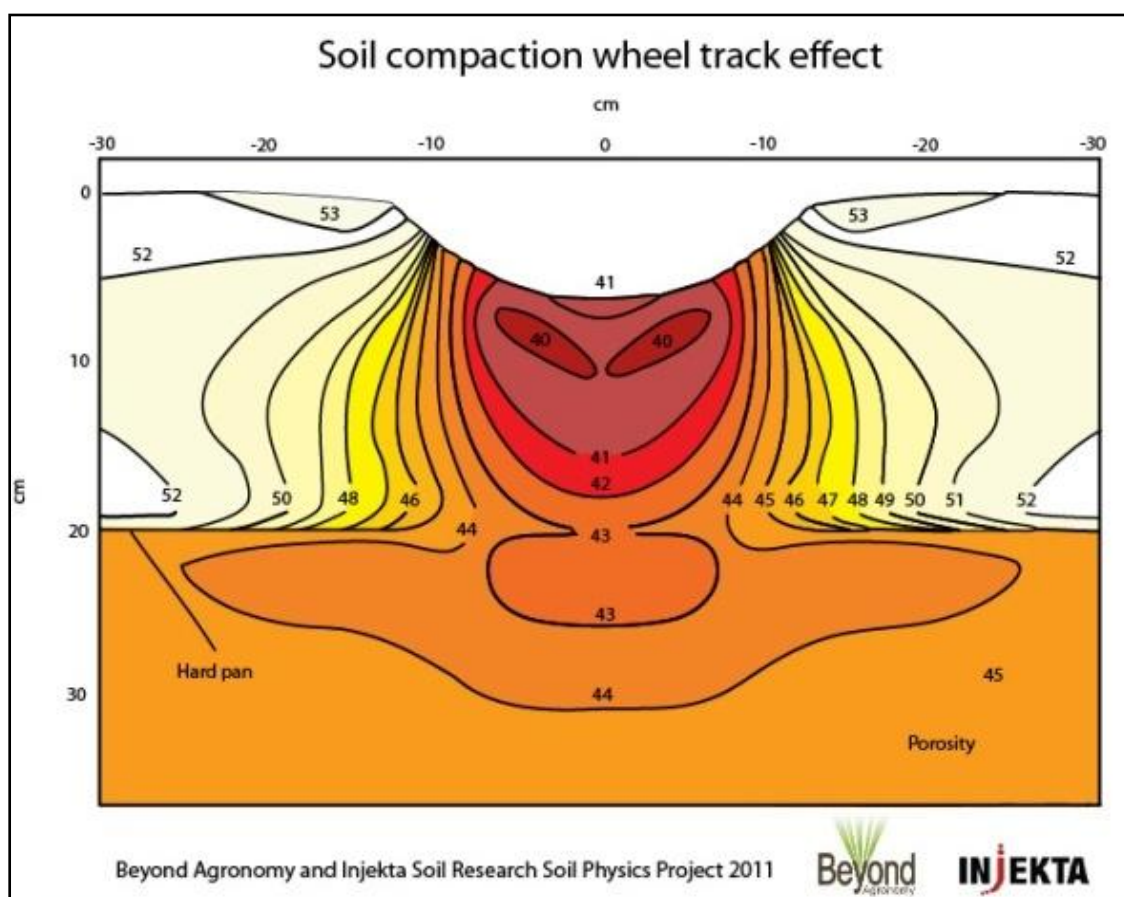


Chart 3. The impact of a wheel track on the surrounding soil. Source: Injekta

The effects of compaction during wet years stems from a decrease in soil aeration. With reduced aeration soils are more prone to flooding which reduces oxygen available to the plant and increases denitrification (the loss of nitrate nitrogen to the atmosphere). Also, reduced soil aeration forces plants to expend more energy taking up potassium and slows overall plant metabolism. Plants with weak metabolism are at risk to disease. Ultimately, in a dry or wet year, compaction has the potential to reduce yield.



Photo 8 (left). Latex paint on untracked area. Photo 9 (right). Latex paint on tracked area, after one pass of a field sprayer. Source: R. Ruwoldt

The photos above show the differences in an untracked area versus one sprayer track on a sandy soil in a continuously cropped field. The producer poured latex paint on the soil in two different areas to illustrate the point. Photo 8 shows where the paint moved uniformly downwards through the soil. In Photo 9, the paint moved laterally across the wheel track until it reached soil structure with less resistance and then moved downward. It is a misnomer to think that only clay soils are subject to compaction. All soil types are susceptible to compaction under the right conditions.

The effects of axle load on compaction

It's logical that as axle weight and soil moisture increases the depth of compaction increases, as illustrated in Chart 4 (following page). Axle loads greater than 10 tons (approximately 9,000 kg) on wet soils can compact to depths of 24 inches². If you recall Chart 1 of the approximate weights of John Deere equipment, nearly every implement and machine would carry axle loads much greater than 9,000 kg. The axle load on high clearance sprayers can be deceiving as well given their typical weight of about 20,000 kg. Depending on the weight displacement, upwards of 60% of the load might be transferred on to the rear axles. For example, on an 18,000 kg sprayer 10,800 kg would be placed on the rear axles.

The debate between tracked and wheeled units

There is an ongoing debate about the use of track machines versus wheeled units as a measure to reduce compaction. Studies on the Claas Terra Trac system at Cranfield University showed that tracked machines compact less than wheeled units³. Graph 2 below

shows a comparison of the level of compaction created at each depth from large Metric 900/60 tires versus Claas's Terra Trac system. Notice that tracks compact less than tires but the fact remains that both systems cause compaction.

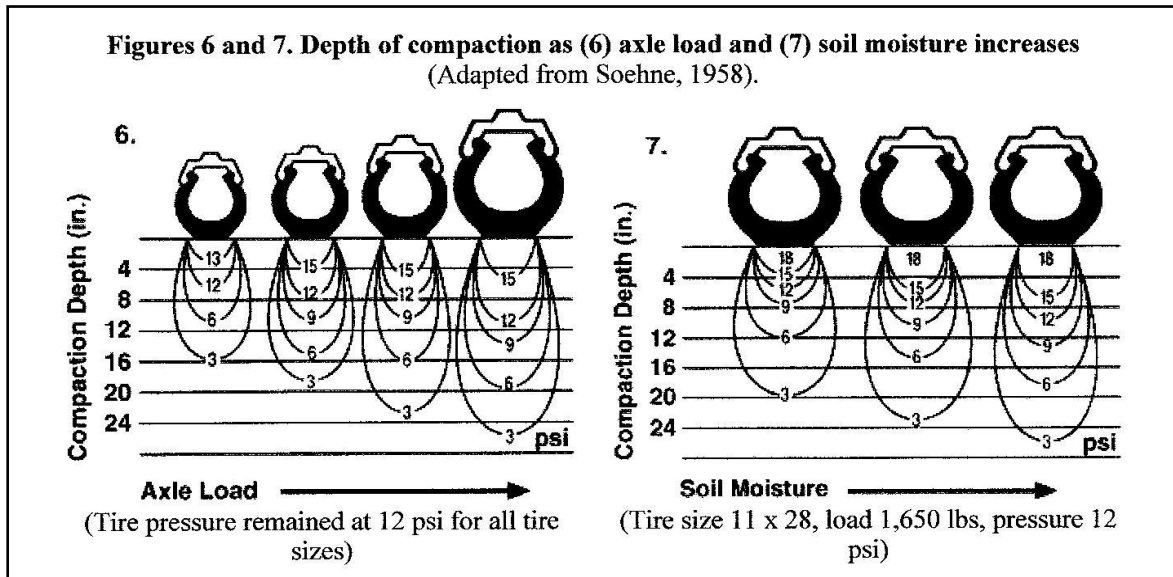
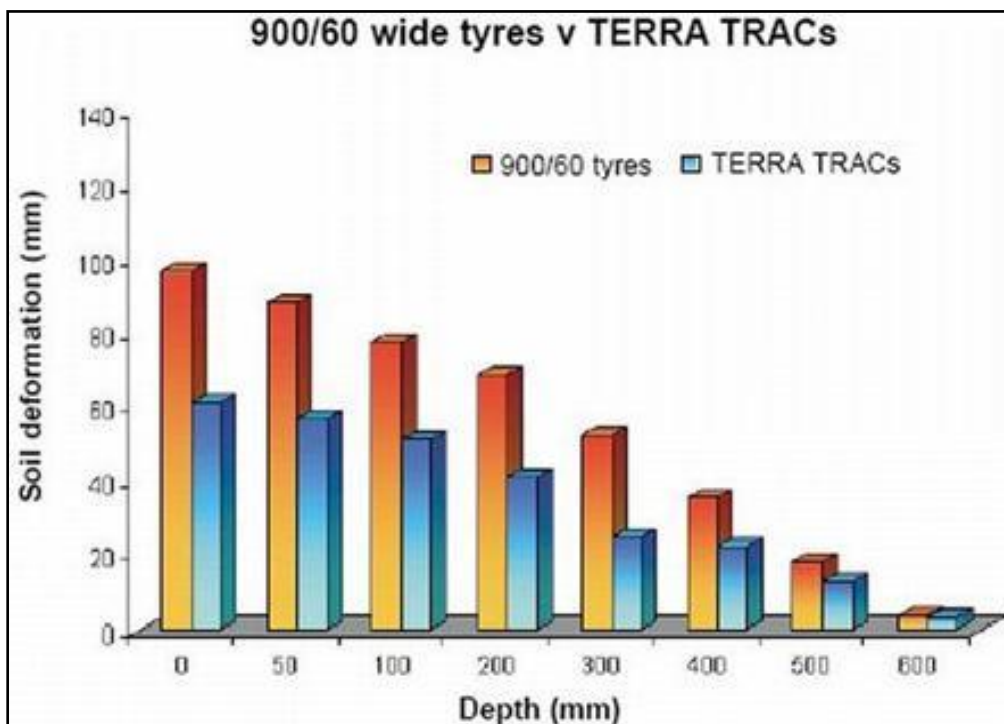


Chart 4. The effect of heavier axle loads with increasing soil moisture. Source: University of Minnesota Extension



Graph 2. Compaction comparison studies by equipment manufacturer Claas indicate both track and tire systems cause soil compaction. Source: Claas

Many of today's equipment in Western Canada carry heavy axle loads that increase the risk for compaction under the right conditions. Compaction is a relevant and significant issue in Western Canada and can be alleviated with controlled traffic farming systems. As you will read, controlled traffic farming offers more than a reduction in compaction; there are many tangible benefits that occur subsequent to improving soil health.

Benefits of Controlled Traffic Farming

Yield improvements

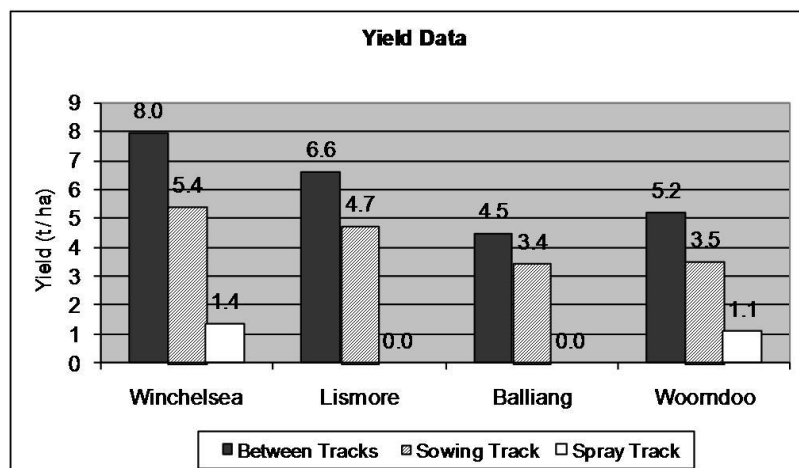
Controlled traffic farming has shown yield increases across a variety of crops and soil types. Tullberg (2001) found yield increases were significantly greater in drought conditions⁴. Yield advantages may be due to improvements in soil quality such as structure, porosity, and water holding capacity.

Anecdotally, all of the producers I visited in Queensland, AUS mentioned sorghum yields had doubled since they had implemented CTF 10 to 15 years earlier.

Wheel tracks early in the season can cause significant yield losses. Graph 3 compares the yield loss occurring inside the wheel tracks from a seeding and spraying application to an untracked area. The results showed 48% reduction in yield inside the wheel tracks from the compaction created at seeding⁵. The yield loss created by sprayer tracks ranged from 68% to 100% less than the untracked areas.

Germination and emergence

It makes intuitive sense that a seed planted into compacted soil versus uncompacted soil has a better chance at germination and emergence. Research from DPI in Geelong, AUS confirmed



Graph 3. An Australian study showed a 48% yield reduction in wheel tracks made at seeding time at four different locations. Source: Department of Primary Industries, Geelong, AUS

this by comparing germination counts inside wheel tracks from seeding and spraying activities to areas with no wheel tracks. The results of the study showed a 50% increase in germination and emergence from areas with no wheel traffic compared to areas with wheel traffic created at seeding⁵. The difference between germination and emergence between sprayer tracks and non-wheeled areas was even greater.

Improved field efficiency

The potential for increased field efficiency would differ with every farm depending on what type of technology and equipment is currently used. CTF requires the use of RTK guided autosteer for sub-inch pass to pass accuracy which significantly improves overlap at seeding and spraying and underlap at harvest. Case studies by Robertson *et al.* (2007) indicated a 10% savings being typical from reduced overlap and spray application⁶. From our own experience, moving from no technology in the combine to full RTK guided autosteer we picked up a 20% gain in efficiency from eliminating underlap and having the cutter bar on the combine 99% full on each pass.

Improved timeliness of field activities

A large contributor to the success of the system is the improved timeliness of farming operations, as in Bowman (2008)⁷. I have travelled to Australia three times and have witnessed extremes in drought and flooding. During the floods of 2010, Robert Ruwoldt, of Victoria demonstrated what a CTF system can provide in a record wet year. At harvest time, I watched Robert and his crew pull off 1,000 tonnes of canola while his conventional no-till neighbours took in one tenth of that. The hard packed tram lines enabled Robert to travel over the ground without getting stuck; he harvested \$600,000 worth of canola while his neighbours spent most of their time pulling their combines out of the mud. The benefits of improved traffic ability from CTF holds true for seeding, spraying and harvest. Timing is everything in farming and hard packed tram lines allow farmers to get on their fields sooner than conventional no till farms, especially after heavy rainfall.

Improved water infiltration rates

Soil porosity has been shown to improve when converting from straight no-till to CTF and no-till. It is estimated that 90% of the damage from wheel traffic occurs on the first pass⁸ and almost 100% of each field is covered in wheel traffic every two to three years in a no-till system. Confining wheel traffic to tram lines allows the soil to recover from previous wheel

track damage subsequently improving soil porosity. The increase in soil porosity allows more water to percolate into the soil profile at a faster rate when compared to straight no-till. Studies from Li *et al.* (2007) found a 57% increase in water infiltration potential when comparing zero-till to CTF⁹. This means less run off occurs and 57% more water becomes available to the crop.

The next example shows the power of CTF systems to absorb water into the soil profile. During a December 2010 visit to Robert Ruwoldt's farm near Horsham, Victoria we arrived after five inches of rain had fallen during the week, contributing to the 16-inch total for the month. The area was flooding and some fields were completely under water. Photo 10 shows the difference in water infiltration on the headland where traffic is heavy and inside the field where the tram lines run. Notice how the water ponded along the headlands and not inside the field. This was incredible to see first hand.



Photo 10. Water ponded along headlands in CTF field. Source: S. Larocque

Increased nutrient use efficiency

It is well documented that soils with restricted aeration have a greater potential to lose nitrogen as a gas (N₂O) compared to well aerated soils. This is significant in a no-till system where nitrogen is placed at a shallow depth at seeding. Ball *et al.* (2008) suggests that most denitrification occurs in the top 10 cm of the profile¹⁰. If nitrogen is placed into compacted soil with a rainfall event following, the risk of loss is significant. Some research suggests that CTF leads to a 15% increase in nitrogen use efficiency by reducing the potential for loss.

In the case of phosphorus and potassium efficiency, University of Minnesota research found a 19% decrease in P and K uptake in corn from the compaction caused by one wheel track¹¹. The effects were reduced over a five-year period when no wheel traffic was applied to the field. I would argue that in a no-till system, 90% to 100% of every field would be covered in wheel tracks every two years leaving very little time for the soil to recover. Even with organic matter acting like a sponge, soil can remain compressed for several days after seeding which leaves room for denitrification to occur.

Reduction in greenhouse gasses

CTF improves soil structure and porosity as previously mentioned. Better soil structure creates an environment favourable for gaseous exchanges. In moist compacted soil, anaerobic conditions cause nitrous oxide and methane production increase. Rochette *et al.* (2008) noted that nitrous oxide and methane emissions increased by 20% to 40%¹². Literature also demonstrates that nitrous oxide emissions can increase significantly when no-till systems are applied to soil with poor internal drainage. In the context of the emerging carbon markets around the globe, CTF provides an opportunity to sell the offsets generated from the potential for methane and nitrous oxide avoidance.

Reduction in fuel use

It is difficult to find scientific research on the level of fuel reduction experienced with CTF. Anecdotally, from the more than 40 CTF farms I visited many producers noted a 30% to 50% reduction in fuel use compared to their conventional no-till systems. One of the ways fuel reduction occurs is by operating smaller equipment: a 350 hp 4WD traded for a 200 hp front wheel assist, a 40 or 50-foot air drill downsized to 30 or 25 feet. The biggest reduction in fuel comes from the reduced rolling resistance from driving on packed tram lines compared to softer no-till ground. A good way to picture it is to think of the energy required to pedal a bicycle on pavement versus the energy required to pedal on a gravel road. It simply takes less energy to drive equipment down hard packed tram lines compared to conventional no-till fields, which leads to less fuel consumption.

Reduces weed germination

There is well documented research on the importance of seed to soil contact in field crops to obtain optimum germination and emergence. Unfortunately, the same can be said for weed seeds. The picture to the right (Photo 11) shows a set of wheel tracks from a self-propelled sprayer in a CTF system where the operator



Photo 11. Wild oats found only in sprayer tracks. Source: R. Ruwoldt

decided to jump off the tram lines and head for an approach. Wild oats germinated from the seed to soil contact caused by the sprayer tires. There had not been wild oats in this field for years yet one pass with the sprayer and weeds jumped at the opportunity to grow.

Reduced pesticide costs

Anecdotal evidence suggests a 10% to 25% reduction in pesticide and crop protection costs in a CTF system. First, crops are more competitive in the CTF system from a reduction in abiotic stress caused by compaction or poor soil structure. RTK GPS has allowed farmers to apply pesticides more accurately and efficiently, avoiding overlap. CTF also allows for inter-row seeding which places crop between last year's stubble rows, the area where weeds typically grow. There is an opportunity for on-row spraying of fungicides and insecticide with shroud sprayers which reduces the amount of pesticide that needs to be applied. Shroud sprayers provide a means to spray less expensive herbicides like glyphosate between the rows in uncompetitive crops like pulses.



Photo 12 (top). A chaff cyclone mounted on a combine drops weed seeds onto tram lines in Photo 13 (bottom). Source: S. Larocque, Q. Knight

Another weed control benefit of running tram lines is the ability to capture weed seeds in the chaff and drop them in the tram line. Photos 12 and 13 above are from Mark Wandel's farm near Esperance, WA. Mark uses a chaff cyclone attached to the combine to capture weed seeds, specifically annual ryegrass within the chaff and drop them on to the tram line. This enables him to go back and spray out the tram lines with glyphosate to control the ryegrass. The system has dramatically reduced herbicide resistance, herbicide costs and increased yields from reduced weed pressure. I can see a system like this as a great fit in Southern Alberta to control Japanese brome and Downey brome weed seeds.

Reduced disease incidence

A four-year study in England by Bayles *et al.* (2008) found that 99% of ergot infections were found on late tillers in wheat¹³. When counting ergot bodies, 82% of the ergot was found along wheel tracks compared to inside the field where no wheel tracks existed. Also, of those areas infected with ergot 99% were found on late tillers. Wheel tracks delay maturity and increase late tillering in cereals, specifically wheat. Controlled traffic farming provides a

means of reducing the damage caused by wheel tracks and the subsequent increase in late tillers.

Increased accuracy of seeding implement

The improvement in surface soil structure from CTF reduces the likelihood of machines shifting off course. Most air drills will skew side to side a few inches because of changes in soil bulk density as tynes rip through the soil. Once the soil bulk density evens out across the surface, air drills will be less likely to drift off course from changes in soil resistance across the tool bar. Also, the use of RTK GPS guidance provides sub-inch pass to pass accuracy as well as repeatability, year over year.

CTF Equipment Set Ups

The goal of any CTF system is to minimize the amount of traffic across each field by selecting the right equipment set up. The CTF farmers that I interviewed found that a 3:1 system works best. A 3:1 CTF system would have a 30-foot air drill, 90-foot sprayer and 30-foot header. This would put a set of tram lines every 30 feet across a field. The most common 3:1 systems in Australia are 30, 35 and 40 feet wide. A 35-foot system would have a 35-foot drill, 105-foot sprayer and 35-foot header. A 40-foot system would have a 40-foot drill, 120-foot sprayer and 40-foot header. The area confined to wheel tracks in 3:1 systems of these widths are 16%, 14% and 12%, respectively.

There are producers who chose to match economies of scale with CTF by using a 2:1 system. One example of a 2:1 system is a 60-foot air drill combined with a 120 or 90-foot sprayer and a 30-foot header. The 3:1 system gives up less area to tram lines compared to a 2:1 system but offers increased efficiency from larger seeding and spraying equipment. Choosing a 2:1 versus a 3:1 system is completely up to the individual. There is no right or wrong in this case.

Getting started with CTF

The limiting factor when determining the width of the CTF system to be designed is the capability of the combine to spread residue evenly across the width of the cut. In a permanent CTF system, residue must be reliably spread across the complete width of the header to avoid

nutrient loading, and variability in soil moisture and temperature over time. For instance, spreading residue across 75% of a 30-foot cut will lead to uneven crop stands over time. Loading 75% of the area with residue and starving the other 25% causes varied nutrient, moisture and temperature distribution across the field creating a wavy, uneven crop stand over time. Every CTF farmer will tell you to start at the header and work backwards when designing a CTF system.

Harvest equipment

There are a few things to consider when setting up harvest equipment on CTF. The first as previously mentioned is the ability of each combine to spread residue across the width of the cut. Whether you design a 30, 35 or 40-foot CTF system, residue must be spread evenly across the width of the combine. The second thing to consider is the actual width of the cutter bar on each header model. For example, a straight cut header might be advertised as 30 feet wide, but in reality, the knife may only measure 29 feet across. In our own situation, we bought a 30-foot AGCO straight cut header that had a knife measuring 29 feet 8 inches. Had we not modified the drill width from 30 feet shank to shank, we would have left a 4-inch strip unharvested on every pass across every field.



Photo 14. Spreading chaff across the entire width of the header is important. Source: R. Ruwoldt

Most combines have a standard 3.6-metre or 136.9-inch axle width but can be brought down to 120-inches by swapping the rims so the dished side faces inwards. No modifications to the axles are necessary. A commonly chosen tire size is the 800/65R32 which is 30.5 inches wide. The 20.8-inch size is an option which would theoretically reduce the machine's footprint. However, those who have tried them were very disappointed in wet years because of the deep ruts cut into the tram lines.

Tractor configurations

I found it interesting that the majority of CTF farmers I met in Australia owned front wheel assist tractors instead of 4WD's. There has been a shift away from 4WD's to FWA's due to the lower horsepower requirement when pulling a 30 or 40-foot drill in soil that has less draft

from years of CTF. In fact, most FWA's were in the 180 to 200 hp range. Conversely, a 350 hp tractor is considered small in Western Canadian terms with many upwards of 425 or 550 hp pulling air drills just 10 or 15 feet wider.



Photo 15 (left). JD 7030 with cotton reels. Source: S. Larocque. Photo 16 (right). John Deere cotton reel kit. Source: John Deere

The front and back axles on all FWA's need to be modified to fit a CTF system. Whether it's a 3-metre axle width or 120-inch axle width, extensions are necessary on both axles. I found 7R and 8R series John Deere tractors were the most popular on CTF farms in Australia. The following specifications are for a JD 7030 with cotton reels shown in Photo 15:

- 1150 front axle with 12 bolt hub, with or without Triple-Link Suspension.
- No frame ballast (Cast ballast can be used on rear axle and liquid in front tires).
- No front hitches, loaders, implements, or spray tanks of any kind allowed.
- Part number for cotton reels: RE267658 3-metre axle width.

The cost for a pair of cotton reels on the front axles in Australia was roughly AUS \$5,000. Some producers built their own for AUS \$2,000 to AUS \$2,500.

The next example is a JD 8R series tractor:

- ILS or 1500 Series axle for single front tires only.
- 120 mm rear axle.
- No front hitches, loaders, implements, or spray tanks of any kind allowed.
- Tractor ballast must not exceed 14,900 lb static scale weight on the front axle.
- Part number for cotton reels: RE267658 3-metre axle width.

The alternative to cotton reels is axle extensions, which requires the axles to be cut and steel extensions welded in. Photo 17 shows a seamless extension which stretched the axle width on the New Holland FWA to 3-metre centres. The work was done by C & C Machining from Brisbane who build and warranty front axle extensions. Their web address is <http://www.candemachining.com.au/>. They have built axle extensions for customers in Australia and the USA. Costs per axle range from AUS \$4,000 to over AUS \$25,000.



Photo 17. Custom axle extension by C & C Machining, Brisbane. Source: S. Larocque

Setting up 4WD's

John Deere tractors seem to be very popular with CTF farms and likely because they have inboard planetaries. Some older model Case and New Holland 4WD's have outboard planetaries, making axle extensions impossible. I did see one NH TJ 325 on single tires in Queensland, AU but I also noticed leaks on every wheel seal. On our own farm, we converted a Steiger PTA 325 with outboard planetaries to run on singles. We removed the tires, rims and spacers, cut the spacers and wheel bolts down to size and welded the two rims together, shown in Photo 19 below. We placed bias ply 23.1-34 tires with 20 psi on the outside rims which allowed us to carry 30,000 lbs on 4 tires. The cost to retrofit the Steiger was approximately \$1,800 plus labor.



Photo 18 (left). Retrofitted 4WD on singles. Source: S. Larocque. Photo 19 (right). Welded rims. Source: S. Larocque

Tracked machines for CTF

In my travels I visited some farms with large tracked machines like the Caterpillar MT series that come factory with 120-inch centers. The larger horsepower tractors like the Caterpillar MT 865 series and the John Deere 9530T series were typically used in 2:1 CTF systems where a 60-foot air drill would be pulled along with a 400 to 500 bushel air tank. The tracks on the larger machines remained at 30 inches wide while the 8000 series tractors had 16 to 18-inch tracks and were typically used in 3:1 systems with a 30-foot drill.

Air drills

Air drill setups for controlled traffic are relatively simple. There are numerous drill makes and models used in CTF systems. The key is to be sure the centre shank to centre shank measurement across width of the drill fits inside the cutter bar width on the combine.

Depending on the row spacing, a 30-foot drill for example, may only be 29 feet from centre shank to centre shank. In our case, the 30-foot drill was actually 29 feet from centre shank to centre shank so the seed rows fit comfortably inside the 29-foot 8-inch AGCO header and no unharvested check strips were left at harvest.

The one recommendation I did get from a long-time CTF farmer who used a 3-point hitch on his drill was to use a floating hitch. There is a lot of stress placed on the mounting brackets of the 3-point hitch when driving down rutted tram lines as the tractor is fighting to stay in the tram lines while the drill is pulling the opposite direction. This creates undue stress and wears out pins and hinge points. A floating hitch provides the flexibility a drill needs to move back and forth.

Hitch designs for inter-row seeding

CTF provides a great opportunity to inter-row seed each year with the simple design of an offset hitch on the drill and air tank. Inter-row seeding requires the drill to shift side to side but the tractor and air tank must stay stationary to remain in the tram lines. Photo 20 below, is of a 7.5-inch offset hitch Robert Ruwoldt designed for his air drill which he simply unbolts and flips over each year to seed between 15-inch rows. Photo 21 is of our own 6-inch offset hitch designed to allow the air tank to remain in the tram lines while shifting the drill side to side each year on 12-inch row spacing.



Photo 20 (left). 7.5-inch offset drill hitch. Source: S. Larocque. Photo 21 (right). 6-inch offset air tank hitch. Source: S. Larocque

Grain cart set ups and auger extensions

The easiest set up for harvest equipment to unload on the go is to design a 30-foot CTF system. Most new model combines require a 2.5-foot extension on the unload auger to enable unloading into the grain cart on the next tram line. For 35 or 40-foot wide headers, an auger extension is required on the combine as well as an extension table on the grain cart. Three examples of modifications made to fit 30-foot, 35-foot and 40-foot wide CTF systems are given below.

30-foot CTF system The 30-foot system of Robert Ruwoldt’s in Photo 22 shows the combine unloading on the go into the grain cart driving on the next tram line. The 2.5-foot extension auger easily reaches into the centre of grain cart.



Photo 22. Source: R. Ruwoldt

35-foot CTF system Additional modifications are needed to unload grain on a 35-foot system as shown in Photo 23 of a farm in Queensland. There is a 2.5-foot extension on the combine auger plus a hopper and conveyor extension mounted on the side of the grain cart to bring grain into the centre of the cart.



Photo 23. Source: T. Neale

40-foot CTF system Photo 24 shows a 40-foot system on a South African farm. There is an auger extension plus a large hopper and auger mounted on the side of the grain cart. This system is especially difficult when you're trying to "thread the needle" so to speak and be on target.



Photo 24. Source: T. Neale

Proposed Australian CTF standard

Considering the significant variance in axle widths from equipment manufacturers, the Australian farm industry has come up with a proposal to standardize equipment to suit controlled traffic farming. Australia has a 30% adoption rate of CTF so the demand for such a standard has grown. I anticipate the time when there will be a North American standard as well. This is the outline of the proposed standard:

Purpose

This standard is intended as a guide for equipment manufacturers to facilitate dimensional compatibility of equipment to be used in controlled traffic farming where precise dimensional matching is essential.

Track Width Standard:

- The track width (centre to centre of vehicle track) of tractors, self-propelled sprayers, harvesters and all other in-field vehicles should be 3.0 metres (118.1 inches).
- All towed and self-propelled machines with load bearing wheels (eg. seeder bars and air carts/bins, spreaders and boom sprayers) should have single wheels spacing in increments of 3.0 metres (118.1 inches).

Working Width Standard:

- Preferred machine working widths should be in increments of 3.0 metres (118.1 inches). For example, 6.0 metres (236.2 inches), 9.0 metres (354.3 inches), 12.0 metres (472.4 inches), and so on.

Converting to Controlled Traffic Farming

Tim Neale of Precision Agriculture in Queensland, Australia has been helping farmers convert to CTF for over ten years. I was fortunate to have his assistance in configuring our machinery. I've included his step by step planning process he recommends to producers before converting their farming system to controlled traffic.

12-Month Planning Process to Move to CTF

By Tim Neale

1. Calculate the approximate coverage of wheel tracks in current random system to the planned CTF system.
 - a. Zero-till about 40-60% of field
 - b. Conventional/minimum-till > 85% of field
 - c. Zero-till CTF <16% of field
2. Develop a 5 to 10-year plan.
 - a. Think ahead to what you want to do in the future.
 - b. How many acres do you want to be farming in 5 years?
 - c. What are the time critical activities or how much needs to be achieved in a set timeframe?
3. Are the axles strong enough on your current tractor to go to 3 metres or 120 inches? Both front and back need careful consideration. For example, the rear axles on FWA tractors should be a minimum diameter of 100 mm . This is only a rule of thumb as some 90 mm axles have worked, some have failed. Best to be safe than sorry.

4. Decide on imperial or metric measurements early and put everything on the same system (eg. row spacings, spray nozzles, wheel track width, etc.)
 - a. 3 metres is 118.1 inches, not 120 inches so stick to 120 inches for Canada.
 - b. You may have to make the row spacing fit the tramlines; it depends on the seeder configuration and manufacturing method (welded supports, etc. in the way).
5. Decide on row spacings and tramline width. I suggest not planting the tramlines, but in some areas they do.
6. Is the combine at 3-metre or 120-inch track width or can it be adjusted? Some combines, as well as some sprayers, cannot come in to 120 inches.
7. Decide on combine header width; combine needs to match the system from the start.
 - a. Match other implement widths to combine header width or multiples of it.
 - b. For example, if the header is 30 feet wide you could go with a 30 or 60-foot seeder.
8. Modify air cart, sprayer and other equipment.
 - a. Match to header (multiplies of it).
 - b. Multiples of 3:1 are ideal for sprayer to seeder widths.
9. Choosing tire sizes
 - a. 500 mm or 19.68-inch track favored. Twenty inches is recommended for wheel track width to reduce the amount of track erosion.
 - b. Ensure very large sprayers are purchased with wider tires, 20 inches preferably.
 - c. Combine tires
 - Duals just spread the compaction damage.
 - Higher tire pressures cause surface damage.
 - Deep compaction is done by axle load – tire width makes little difference.

10. Examine ways to improve efficiencies on the farm.
 - a. Field/farm layout
 - b. Topographic maps
 - c. Location of roads on ridges/removal of grain
 - d. Roads to improve truck “flow” through the farm, which minimizes trucks turning in the field
 - e. Length of runs based on header width, box capacity, average yield, etc.
 - f. Water, drainage, erosion to minimize concentration and water logging
 - g. Agronomic improvements to match new soil conditions

Frequently Asked Questions

What about the yield loss in tram lines?

Many people ask how much yield is lost in the area given up to permanent tram lines. The closest figures to date suggest there is no reduction in yield from the area given up inside the tram line. Research on wheat and lentils in Australia showed no decrease in yield from unsown tram lines due to the “edge effect”. The rows adjacent to the tram lines can see up to a 180% increase in yield due to less competition for moisture, nutrients and sunlight. Overall, any potential yield loss given up from unplanted tram lines are more than compensated for by the increase in yield from the edge effect and the increased yield on the rest of the field.

Doesn't the freeze-thaw cycle take care of compaction?

There is a common misconception that the freeze-thaw cycle in Western Canada alleviates compaction. In reality, only the top 2 to 3 inches experience more than one freeze-thaw cycle per year which is necessary to break up compaction. The compacted soil below the top few inches will typically see one freeze and one thaw. Research conducted at Lamberton, Minnesota showed that nine years of cropping and annual freezing and thawing did not remove a compacted soil layer at the bottom of the plow furrow in a clay loam soil².

How do you address wheel ruts?

Tram lines are not a no-maintenance system. In fact, wheel ruts need to be repaired every so often not unlike a random traffic system that needs repair after harvest. Heavy rutting in the

tram lines can be repaired with a tram line renovator, an innovation developed in Australia (Photo 25). The tram line renovators hook to a 3-point hitch. There are three disks positioned on each side of the tram line which bring soil back into the ruts, which is firmed with a rolling basket and then smoothed with tyne harrows. Grizzly, a company from Victoria, AUS builds award-winning tram line renovators. Their web address is <http://www.grizzly-engineering.com.au>.



Photo 25. Grizzly Wheel Track Renovator.
Source: J. Bruggencate

Is deep ripping an equal solution?

Deep ripping has been touted as the solution to alleviate soil compaction. I have to agree with CTF farmer Robert Ruwoldt when he says, “Why create the problem in the first place?” Deep ripping can be beneficial in some cases but it is not a long-term economical or agronomic solution. The benefits may be an increase in yield but it comes at a cost of \$68 to \$75 per acre including rental, tractor and labour. Deep ripping is a slow process, 5 to 12 acres per hour is common. Faster travelling speeds with non-inversion deep rippers leads to soil admixing of the A, B or C horizons. Sometimes there are no immediate results as plants and soil take time to adapt to the disturbance.

Impediments to Adoption in Western Canada

Adoption of permanent controlled traffic systems in Canada will be met with resistance. The reasons may include the following:

- There is an assumption by farmers and researchers that compaction is not a problem therefore why change current practices.
- Most equipment manufacturers have varying sizes of wheel track and working widths, making it difficult to match all equipment.

- RTK GPS is a relatively small market in Canada right now. The availability of wireless RTK may not be available to producers in certain areas and the expense may be prohibitive.
- There is very little technical support to help producers understand how to choose the right CTF system.
- There is a false assumption that CTF is risky and takes a great deal of capital to convert equipment.

Conclusion

The impact of equipment traffic on crop growth and maturity has largely been ignored in Western Canada. The assumption that our soils are immune to compaction or that natural processes work to alleviate the damage caused by wheel traffic is dangerous. On average up to 25% of our fields are covered in wheel traffic during the growing season and up to 50% throughout the year. How can we rely on speculation and assumptions when others around the world are realizing tremendous gains from minimizing wheel traffic through CTF? The combination of CTF and direct seeding stands to revolutionize farming systems in Western Canada.

Signs of wheel traffic damage present themselves throughout the year in Western Canada. This paper outlined local examples where canola was blooming in the wheel tracks or where maturity was delayed from late herbicide and fungicide applications. The wrong tractor and air tank set up can also have an impact on yield and maturity. The effect of harvest traffic on crop yield was identified through 1metre resolution NDVI imagery. Equipment traffic can also impact wheat protein and lead to reduction in gross revenue.

The benefits of CTF extend far beyond a simple reduction in compaction. Producers have realized significant increases in moisture use efficiency with cases of 300% yield gains during drought years. Research has shown 30% to 50% reductions in fuel use from less horsepower requirements. Controlled traffic farming can reduce nitrous oxide emissions, a significant greenhouse gas, by 15% according to research. CTF improves the timeliness of crop production allowing producers to get on the field sooner after a rainfall compared to

conventional no-till systems. There is an improvement in water infiltration along with a reduction in weed germination, pesticide use and disease pressure. A CTF system also provides an opportunity to employ more precision applications like inter-row seeding, inter-row shroud spraying, on row fungicides and insecticide spraying, strip-till banding and in-crop fertilizer side dressing.

Choosing the right CTF system requires forward planning but does not need to occur overnight. Many producers move towards CTF over time by matching up axle widths and equipment widths as budget and time allow. To begin the process there are simple steps you can follow to avoid costly mistakes as outlined in this paper. Many producers have chosen the 3:1 CTF system but in Western Canada, a 2:1 system with economies of scale would work very well. The key is to start the measuring process at the combine to determine its ability to spread residue across the width of its cut. Always work backwards from the combine and header when designing a controlled traffic system.

Ultimately, the potential benefits realized from CTF are hard to ignore. The combination of CTF and direct seeding has the potential to generate large returns to Western Canadian farms in three ways: 1) increased efficiency, 2) increased yield, and 3) a cost reductions. CTF offers ways to reduce the impact of excessively wet and excessively dry years creating more financially stable farms in Western Canada. Progressive, early adopters will overcome the unforeseen challenges and develop CTF systems that fit Western Canada much like the movement of direct seeding over 30 years ago. The precise placement of inputs, timeliness of applications and the reduction in costs will set these farms apart from their peers. In my opinion, controlled traffic farming will revolutionize Western Canadian farming.

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Additional Resources

Controlled Traffic Farming sites

Controlled Traffic Farming Alberta: <http://canola.ab.ca/ctfalberta.aspx>

Controlled Traffic Farming - <http://www.ctfsolutions.com.au/>

Tramline farming systems: technical manual

http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/land/cult/bulletin4607_comp_lete.pdf

Controlled Traffic Farming- UK/Europe

<http://www.controlledtrafficfarming.com/content/default.aspx>

Australian CTF Association

<http://www.actfa.net/index.html>

GRDC Controlled traffic farming road beds and root beds

http://www.grdc.com.au/director/events/factsheets.cfm?item_id=4824D94996A6A10EA8108A83C59300FB&pageNumber=8

Precision Agriculture

<http://www.precisionagriculture.com.au/controlled-traffic-farming.php>

Controlled traffic farming Alberta

www.controlledtrafficfarming.org

The Mitchell Farm- CTF in USA

<http://www.mitchellfarms.com/2008/01/12/controlled-traffic-farming-ctf/>

Southern Farming Systems

http://www.sfs.org.au/cb_pages/control_traf_farm_con_bu.php

CTF videos

CTF in Alberta at harvest- interview with Steve Larocque

<http://youtu.be/3Tdx7-Y4Dno>

CTF in action in Alberta- interview with Steve Larocque

http://originals.farm.tv/post/92/controlled_traffic_farming_3.html

CTF Alberta July 29 field day near Morrin, AB

http://originals.farm.tv/post/75/controlled_traffic_farming.html

YouTube- Controlled Traffic System (4.0 metres)

<http://youtu.be/NqcAf8QBibQ>

YouTube- Grain cart with loading table in Australia

http://www.youtube.com/watch?v=1CJKcgYA_k&feature=related

YouTube- Harvest on the Mitchell Farm <http://youtu.be/f-jLyEcwZPA>

YouTube- Inter-Row Spraying Sorghum <http://youtu.be/jFUbtXIoP30>

YouTube- New Holland CR9090 OptiSpread http://youtu.be/eFbb9N8Z_Ok

YouTube- Reichhardt PSR Sonic Sensor Guided Steering <http://youtu.be/8RE7jISHeMs>

YouTube- Harvesting on Controlled Traffic http://youtu.be/7Yc66o_8crg

YouTube- Harvesting on tram lines <http://youtu.be/8hzf4JM0Ovc>

Soils and Compaction

Soil compaction- Minnesota

<http://www.extension.umn.edu/distribution/cropsystems/components/3115s01.html>

GRDC deep ripping factsheet

http://www.grdc.com.au/uploads/documents/GRDC_DeepRipping_6pp_.pdf

South Australian soil structure module

http://bettersoils.soilwater.com.au/module6/6_2.htm

Mapping Soils with a Penetrometer

<http://www.soils.wisc.edu/extension/wcmc/proceedings01/Rooney-etal.PDF>

Compaction of 'heavy' soils by cropping traffic and estimated benefits of tramline farming

http://www.grdc.com.au/director/events/researchupdates.cfm?item_id=AC901FBEED33A1ED463040662A556858&pageNumber=49

Soil Compaction: Causes, Concerns and Cures

<http://www.soils.wisc.edu/extension/pubs/A3367.pdf>

Effect of soil compaction on root growth and crop yield in Central and Eastern Europe

http://www.ipan.lublin.pl/artykuly/international_agrophysics/IntAgr_2003_17_2_61.pdf

Economics of CTF

CTF Australian economics calculator

http://soilquality.org.au/calculators/controlled_traffic

Yield loss from combine wheel ruts

<http://www.agprofessional.com/cornrc.php?id=1308080&page=5>

Assessing the whole-farm benefits of Controlled Traffic technology
http://www.regional.org.au/au/asa/2010/crop-production/precision-agriculture/6960_kingwell.htm

Equipment: Toolbars, Openers, Applicators

Fertilizer Opener, Fertilizer Coulter
http://www.dawnequipment.com/Fertilizer_Applicator.html

Low-disturbance NH3 Openers NH3 applicators
http://www.agriculture.com/products-classifieds/product-reviews/crops/fertilizers/Lowdisturbance-NH3-Openers_414-ar5566

Moore built Toolbars
<http://www.moore-built.com/index.php>

Row Crop Cultivators and Planter Toolbars Wil-Rich
<http://www.bigironequipment.com/wilrich-rowcropcultivators.php>

Tilco shielded sprayers
<http://www.tilco.com.au/products/rowcrop/shldsprayers.htm>

Twin Diamond Industries
<http://twindiamondind.com/equipment.php>

Amity tramline system for spraying - <http://www.amitytech.com/tramlines>

Equipment: Fabrication, wheel kits, axle extensions

Adjustable Track Tractor for Zero Compaction Farming
<http://www.wipo.int/patentscope/search/ja/WO2008109089>

John Deere controlled traffic spacer extension kits
http://salesmanual.deere.com/sales/salesmanual/en_NA/tractors/attachments/wheels_and_tire_s/comm_wloo_ctf_spacers.html?sbu=ag&link=prodcat

John Deere 8345RT axle extension kits
http://salesmanual.deere.com/sales/salesmanual/en_NA/tractors/attachments/undercarriage_and_tracks/8030t/8030t_option_code_9134_wide_midroller.html?sbu=ag&link=prodcat

Stevenson wheels and rims
<http://www.stevensonwheel.com/products.php?fnc=view&id=24>

Header Equipment John Deere & MidWest Fabrication Pty Ltd
http://www.deere.com/en_AU/equipment/ag/combindes/platforms/midwest/index.html

Unverferth wheel and hub extensions
<http://www.umequip.com/wheels/dual-and-triple/extension/>

C&C Machining and Engineering- axle extensions
http://www.candcmachining.com.au/c_and_c_tractor_extensions.php

Stewart Steel combine auger extension kits
<http://www.stewartsteel.com/ag/extender.html>

CTF Australia Trip- Peter Gamache, Project Lead CTF Alberta

CTF Australia Tramlines
<http://picasaweb.google.com/105641866059022155818/CTFTramlines?authkey=Gv1sRgCPbFxdkrcuEqQE#5553211372737424002>

CTF Australia Wheel Extensions
http://picasaweb.google.com/105641866059022155818/CTFWheelExtensions?authkey=Gv1sRgCKXG4N6_2tCQ4gE

CTF Australia Weed Control
<http://picasaweb.google.com/105641866059022155818/WeedControl?authkey=Gv1sRgCMqTnqek3tnidw>

CTF Harvester, Auger extensions, grain carts
<http://picasaweb.google.com/105641866059022155818/HarvestAugerExtensionsChaserBins?authkey=Gv1sRgCLXHvqrj5rHhJA>

CTF Australia Seeding/Fertilizing
<http://picasaweb.google.com/105641866059022155818/SeedingFertilizing?authkey=Gv1sRgCLucjseSzcSu7wE>