CONTROLLED TRAFFIC FARMING TECHNICAL MANUAL

NACC
Managing Natural Resources

CARING FOR OUR COUNTRY

NORTH STIRLINGS PALLINUP NATURAL RESOURCES

GOVERNMENT OF WESTERN AUSTRALIA
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Authors

Bindi Isbister[1], Paul Blackwell[2], Glen Riethmuller[2], Stephen Davies[2], Andrew Whitlock[3] and Tim Neale[3]

[1]North Stirlings Pallinup Natural Resources [2]Department of Agriculture and Food, Western Australia, [3]precisionagriculture.com.au

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1. INTRODUCTION

Controlled Traffic Farming (CTF) is:

'a crop production system in which the crop zone and the traffic lanes are distinctly and permanently separated. In practice it means that all implements have a particular span, or multiple of it, and all wheel tracks are confined to specific traffic lanes.' (Baker and Saxton 2007).

This separates the paddock into two zones:

1) root bed—soft uncompact soil for growing crop or pasture

2) roads (permanent traffic lanes or wheel tracks)—firm compact lines for running machinery on (at least for wheel loads greater than about one tonne).

Benefits include higher crop income from greater yield and better grain quality and improved input efficiency from less overlap, better access for in-crop operations and less fuel use from running on firm tracks. CTF also generates agronomic opportunities such as inter-row sowing, shielded or banded spraying, relay planting and easy on-farm trials. Higher crop income comes from better access to crop nutrients and water, as well as greater potential to compete with weeds and minimise invasion of root diseases.

A primary motivation for the development of CTF systems has been the negative effects of subsurface compaction on crop production. Subsurface compaction from cropping traffic is essentially a consequence of the need for greater efficiency in the industrial production of grain, especially in the rain-fed dryland cereal production in southern Australia. In these farming systems the profit margins are often small or negative, thus the scale of operation needs to be very efficient to minimise overhead costs. Efficiency is improved by using high capacity equipment which sows, spreads or sprays materials over as much area as possible in the available time, as well as removing the products as fast as possible with high capacity transport. Such high capacity equipment is usually as wide or as high carrying capacity as possible and thus relatively heavy; some of the most recent models of air carts on the world market in 2013 are more than 70 tonne loaded.

A guidance system is required to set up evenly spaced permanent traffic lanes. The more accurate the guidance system, the more benefits can be gained from a CTF system, therefore currently best the guidance system for good repeatability is real time kinematic (RTK) GPS autosteer accurate to +/- 2 cm. It is not essential to have +/- 2 cm guidance, however, experience of broadacre farmers in Australia has shown that lower accuracies are not quite good enough when you want to precisely place inputs such as sow on or off the rows. There are mechanical options for guidance that may be better suited to smaller scale and low tech operations. Marker arms are still commercially available, though not so readily purchased nowadays in Australia.

Another term that has been commonly used is 'tramline farming'. Controlled traffic farming and tramline farming have been used interchangeably in Australia. Controlled traffic farming is now the more broadly used term world wide for a system with permanent traffic lanes. Tramlining in Europe refers to seasonal wheel tracks that are commonly used for spraying and are usually replaced each year. The terminology used in this manual is based on terms most used in Western Australia. See the Terminology box or Glossary for other options. CTF is just one aspect of a farming system. To achieve maximum benefits, CTF should ideally include stubble retention, a minimum or no-till cropping system and sound agronomic practices. As well as obtaining benefits of improved soil health with no-till, good stubble cover, good soil management practices and well-designed paddock layouts reduce the risk of CTF failure due to erosion.

Accurate driving and matching machinery widths for a CTF system are very complimentary for precision farming methods for zone management and variable rate applications of inputs. CTF is generally included under the common 'umbrella' of 'precision agriculture'. Grower experience has often shown the benefits of a strategy that first applies a CTF system to the farm, to remove and control subsurface compaction constraints. Variable amounts of deep soil ameliorants (for example, lime or gypsum) may also be applied at that stage, as required. When these major constraints have been rectified, variable rates of nutrients can be appropriately applied to best economic and environmental effect.

As CTF involves matching of all machinery widths and tracks and its efficient operation in already formed paddock shapes, it can rarely be adopted in one season, particularly as farms often have a plethora of machines with varying operating widths. It is recommended a plan be developed for investment.

See Figure 1.1 for steps to implement a CTF system. Many growers have been using partial CTF where the header or some spreading operations or a contract self propelled sprayer do not fit the whole system. Such partial options still provide some benefits and may be more cost effective for some environments and farm budgets. It is important to review the plan as time goes on to optimise profitability and sustainability.

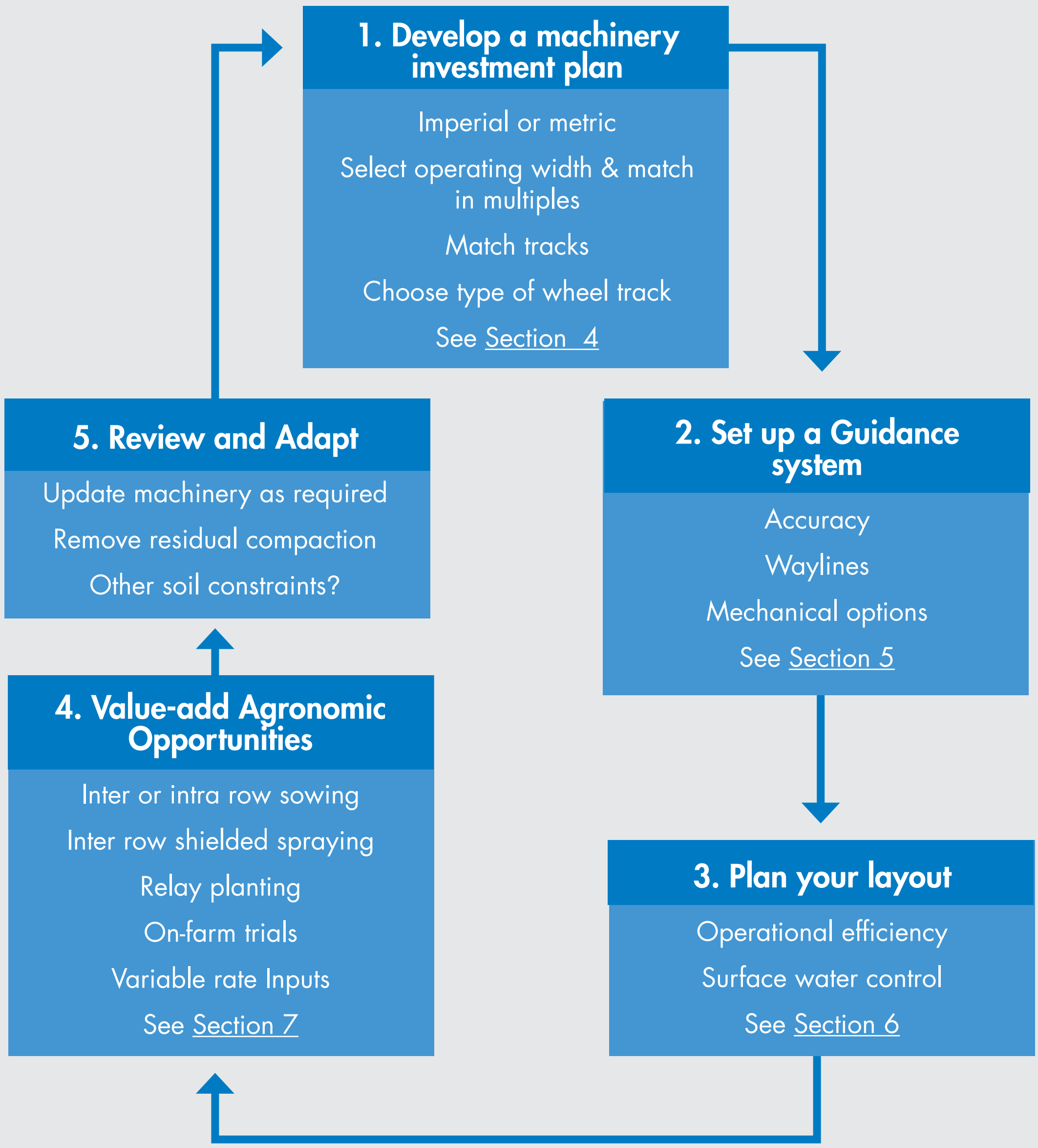


Figure 1.1 Steps to implement a controlled traffic farming system.

This manual focuses on developing a CTF system in Western Australia, however it contains information from research and on-farm development of CTF elsewhere in Australia, including the benefits of CTF, compaction identification, machinery options, layout planning and experiences of CTF farmers to help develop a CTF system to suit each farm. There is not one set recipe and the cost of conversion varies greatly depending on the machinery already on-farm. These principles may also be applicable to other farming systems of like scale in other parts of the world.

As with many collections of technical advice specific recipes for specific locations are not presented. Instead this manual explains the principles behind the processes causing the problem and the guidelines on which the possible solutions are based. Once farmers and land managers are armed with this understanding they can often implement the appropriate solutions for their landscape and circumstances that are unique.

Talking to CTF farmers who have already been through the process is invaluable particularly to overcome challenges and avoid mistakes, as chances are they have made them or can suggest a solution.

CTF Terminology

Terminology used in this manual is based on terms most commonly used in Western Australia. The principles of CTF are the same no matter where you farm. The following list of terms used in this manual and their names in other parts of Australia or the world will allow you to use information from a range of sources.

header = harvester = reaper (in South Australia) = combine harvester in UK and USA

seeder = bar (in Western Australia) or airseeder or planter in eastern Australia

seeding combine = small gravity fed seeder

sprayer = boomspray

wheel track = tramline (permanent) = permanent traffic lane = wheelway

2. BENEFITS, COSTS, PROFIT AND CHALLENGES

Many Western Australian CTF farms have been successfully running for over 10 years now; there have been very few cases of well-converted farms with the original owner going back to uncontrolled traffic. The growers with well-established CTF systems increasing appreciate the benefits of their systems although some are often frustrated by various subsoil constraints and a need to improve seeding and harvesting capacity. This sustained use of CTF seems to come from the benefits eventually outweighing the costs and a capacity and determination to overcome technical challenges.

This chapter provides some detail of known benefits and costs of CTF in Australia and some calculations of profitability. We also identify some known CTF constraints and possible solutions. See Table 2.1, on the following page, for a summary of the benefits and associated risks.

2.1 Benefits

Benefits from CTF can be broadly viewed as either economic (improved profit for grain growing) or environmental (better condition of the soil water and atmosphere). In reality the two are closely interdependent but not all benefits are easily expressed in financial terms. The technical challenges in CTF also need careful consideration, as well as a realistic understanding of how the estimated benefits can help finance the costs of CTF in a planned transition.

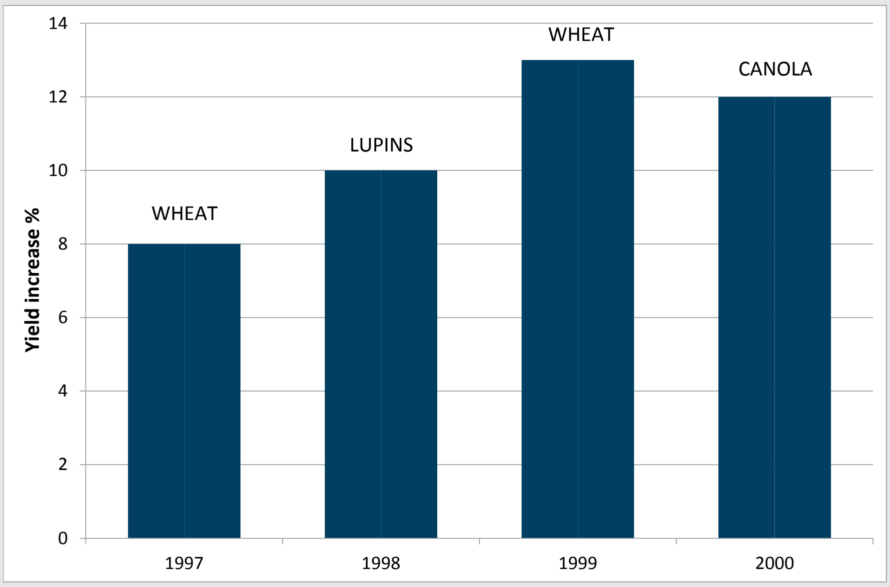
2.1.1 Economic benefits

Increased grain yield and quality*

CTF provides better and more uniform crop growth and yield. Grain quality is also improved with trials showing less screenings in cereals and more oil in canola. Although cereals often have lower protein; this can be expected due to the higher yield and larger grain size grown with the same amount of nitrogen. Measured and calculated yield benefits are about two to 16 per cent, depending on soil type and local climate (Table 2.2, Figure 2.1). Measurements on some representative soil types in Western Australia generally showed an average of 10 per cent grain yield increase after the year of establishment if deep ripping had been used, however duplex soils are poorly represented in studies.

*When subsoil constraints have been rectified sufficiently

Figure 2.1 Grain yield increases with controlled traffic on deep yellow sand at Mullewa. Growing season rainfalls were 229, 291, 369 and 123 mm respectively. Yield included the area of bare tramlines. The CTF system used 90 ft farm sprayer, 30 ft farm header and a 30 ft research seeder with a 150HP tractor. The normal traffic system used the 50 ft farm seeder with a larger tractor. The whole paddock was deep ripped in the first year. For CTF, two ripper tines were lifted to form firm tramlines.



	1997	1998	1999	2000
Yield No CTF (t/ha)	2.41	1.1	2.45	0.95
Yield CTF (t/ha)	2.8	1.21	2.77	1.06

Table 2.1 Summary of CTF benefits. (Yellow shading indicates conditions where benefits are more common.)

		Benefits	Risks	Solutions Tested and untested
	Rainfall	High: Sand, Loams & clays; Low: Sand, Loams & clays		
	Soil types			
Economic Benefit	Production	better yield & grain quality*	poor grain in wheelways (green)	block sections of knife on harvester?
Economic Benefit	Costs	reduced by less overlap better fertiliser efficiency (less leaching or waterlogging) lower power requirement for tractors, less capital investment.	drivers may be not available for multiple units at seeding	start earlier with some dry seeding
Economic Benefit	Safety	less driver fatigue using autosteer and better back care on smooth tracks	loss of freehand driving skills with autosteer/ loss of GPS signal	outside laps are often free hand or use wake up alarms
Economic Benefit	Weed control	better crop competition, better use of inter-row methods, weed disposal on wheel tracks # more timely spraying in wet	poor nutrient distribution from burned swath as difficult to move harvester	perhaps move swath (not harvester) or put chaff & weed seeds on wheeltrack #
Economic Benefit	Trafficability	less rolling resistance and fuel use better floatation and less sinkage in wet	rough riding when mustering livestock	muster with six wheel motor bikes?
Economic Benefit	Soil amelioration	easier cropping after deep cultivation between wheelways and longer lasting effect of treatment compatibility with raised beds	get bogged if driving off wheel tracks	use experienced drivers
Economic Benefit	Agronomy	oppportunity for relay planting of crops or pastures & deep ripping between wide rows of crop	large soil clods	use a shallow leading tine ripper
Environmental Benefit	Water erosion	better infiltration reduces water erosion risk	water erosion in concentrated flows when downhill	plan surface water control to prevent water shedding and run on
Environmental Benefit	Wind erosion	better more even crop growth and stubble cover	wind erosion of bare wheelways on hilltops	seed wheel tracks or chaff on wheel tracks
Environmental Benefit	Leaching	reduced by better root growth and nutrient interception	more salt buildup	be careful on salt affected soil
Environmental Benefit	Ecosystem services	more macrofauna (earthworms) more macrofauna (ants and termites)	tillage can reduce macro/micro fauna	use no-till
Environmental Benefit	Green house gas emissions	less CO_2 from less fuel use less emission due to less waterlogging and denitrification	none	

* perhaps less protein in some circumstances

in some situations for example if herbicide resistant radish is present chaff carts may be a better strategy

Table 2.2 Measured and calculated yield benefits of CTF for a range of soil types and regions.

Soil type	Yield increase (%)	Details
Deep sands	10–13	WA, four year farm scale trial, deep yellow sand CTF after deep ripping 10–13% yield increase and better grain quality the year after the year of establishment (Figure 2.1) (Webb et al. 2004)
Duplex sandy gravel	6–9	WA, 430 mm growing season rainfall, sandy gravel estimated 6% yield improvement without deep ripping estimated 9% yield improvement with deep ripping (Blackwell et al. 2004 a)
Loams	9	WA, 426 mm growing season rainfall, loam soil CTF after deep ripping estimated 9% yield improvement (Blackwell et al. 2004)
	2–7	Roseworthy, South Australia, red loam 6 years of CTF without deep ripping 2–7% increased crop yield of barley, wheat and beans (Ellis et al. 1992)
Clays	2–11	WA, 280 mm and 206 mm growing season rainfalls, clay soils estimated 2 and 8% yield improvement respectively without deep ripping estimated 11 and 9% with deep ripping (Blackwell et al. 2004)
	16	University of Queensland, Gatton, self-mulching clay up to 16% improvement in crop yield (Tullberg et al. 2001; Yuxia et al. 2001)

Reduced fuel use from smoother running

Spending less money on fuel is the CTF benefit most growers find as soon as they get their system going. Improved fuel use efficiency comes from machinery running on firm compact wheel tracks with less rolling resistance and wheel slip compared to running on softer soil. Twenty-five per cent reduction in fuel use has been measured in CTF systems with no-till farming in Western Australia. When combined with fertiliser savings from less overlap from guidance, this could translate to 200 tonnes of greenhouse gas avoided for every tonne of improved grain production (Blackwell et al. 2004 b). Queensland research has shown up to 50 per cent less fuel use when CTF is used on clay soils (Tullberg 2000).

Improved operator health

CTF farmers often report smoother running along firm wheel tracks. This improves driver comfort, especially when spraying and spreading, and can conserve back health to enable a longer time in farming. However, additional care must be taken in most CTF paddocks for rougher travel when spraying on the second lap around headlands where the permanent wheel tracks are often not so well defined. Also tracked tractors for spraying on hard wheel tracks can sometimes encourage severe vibrations. However, such generally smoother running with CTF systems is a good complement to less driver fatigue from the use of autosteer.

Better yield from timely crop protection and harvest in very wet soil conditions

Reports are very common of CTF farmers being able to spray their paddocks when their non-CTF neighbours cannot and being able to harvest when non-CTF neighbours are sitting frustrated in the shed or trying to free a bogged header from a wet paddock in a wet harvest. It is difficult to put exact dollar values on such advantages, but in extreme cases it may be the difference between making a profit or a loss from cropping!

Reduced input costs from less overlap

CTF improves cropping efficiency (if a suitable guidance system is not already established) because a guidance system is used to set up evenly spaced wheel tracks across a paddock. The overlap savings of seed, fertiliser, herbicide and fuel will vary depending on the accuracy of the guidance system used and the shape of the paddock. Savings of three per cent using marker arm systems to 10 per cent using +/- 2 cm RTK GPS autosteer systems have been found (Webb et al. 2004). The use of highly accurate guidance systems is increasingly common in broadacre cropping systems with about 70 per cent of farmers using autosteer in 2013. However, as the benefit of compaction control is much greater than the savings of overlap, it is even more beneficial to develop a CTF system.

More efficient working of paddocks

Many growers find that CTF systems provide much easier working of paddocks. Some of this is from the simplicity of straight line working, although there are a few growers who have developed their own racetrack (round and round) CTF system. Racetrack CTF is more difficult to apply to autosteer but seems to have its own unique advantages which are retained from older systems of paddock working in uncontrolled traffic; offset equipment and one sided unloading can be used easily and empty travel distance to reload when spaying or spreading can be less. Bochtis et al. (2010) show that distance travelled in CTF using longest side can be greater than uncontrolled traffic due to longer pathways when travelling empty to a loading point when spraying or spreading. For harvesting, the run length needs to be worked out carefully as high yield crops may be better with shorter runs. Unloading tracks are often established across wheel tracks of long paddocks.

Better fertiliser use efficiency*

When fertiliser is used more efficiently, more grain is grown for the same amount of fertiliser per millimetre of growing season rainfall. Alternatively, less fertiliser may be needed to grow the same yield for the same amount of growing season rainfall. This seems to be due to better soil health, which fosters increased beneficial microbial nutrient transformations, such as mineralisation of nitrogen, and fewer detrimental microbial nutrient transformations, such as denitrification. Better soil health of soils under CTF seems to come from more porous and easily drained soil decreasing the frequency and duration of waterlogging, as well as encouragement of soil macrofauna (worms, ants and termites). Evans et al. (2011) found CTF and no-till in a low rainfall loam encouraged activity of termites and led to better yield, most likely from nitrogen fixed by nitrogen-fixing bacteria in the termite gut. Abundant termite activity has been observed on well-established CTF farms on sand and loam in the low rainfall north-eastern wheatbelt and abundant earthworm activity has been observed on a well-established high rainfall farm on clay soil near Esperance. Detailed studies of soil biology effects of CTF and no-till treatments to a vertisol in south-east Queensland found CTF could increase abundance of earthworms, mites and springtails by 160 per cent, 40 per cent and 40 per cent respectively, compared to wheeled treatments (Table 2.3). The combination of reduced denitrification loss as nitrous oxide (Tullberg et al. 2011), and reduced loss of nutrients in run-off (Masters et al. 2008) together with reduced leaching and improved soil biological activity might account for the anecdotal claims of enhanced yields from reduced nutrient input.

Table 2.3 Tillage and traffic impacts on the abundance of soil macrofauna in south-east Queensland (mean values from 13 sampling dates over two years in grain cropping). (Source: per.comm Jeff Tullberg 2013).

Number per m^2 from 150 mm cube samples				
Soil macro-fauna	Wheeled		CTF	
	Tilled	No-till	Tilled	No-till
Earthworms (Oligochaeta)	15	44	39	115
Mites (Acarina)	457	537	631	794
Springtails (Collembola)	91	339	191	417

*When subsoil constraints have been rectified sufficiently

Better water use efficiency*

This may occur in CTF due to easier root exploration of the soil and better interception of available water. CTF farms in Western Australia have shown water use efficiencies better than 20 kg/mm. Peak infiltration rates (Li et al. 2009) and plant available water capacity (McHugh et al. 2009) in CTF were 40 to 50 per cent greater in Queensland clay soils.

Reduced capital cost, depreciation and better use of tractor capital

Firm wheel tracks and soft soil enable better traction and less draft for the same seeding or tillage operation; thus lower horsepower tractors, such as front wheel drive tractors, can be used. Tracked tractors can take advantage of this because they have a higher tractive efficiency than a wheeled tractor, which may need duals or triples to provide the same draft. The lower capital cost of a smaller horsepower tractor will provide benefits of lower depreciation cost and a better fit to other on-farm operations (such as spraying, spreading and pulling chaser bins) than a larger horsepower tractor. This benefit has often been included in CTF farms in eastern Australia and more Western Australian farmers are becoming aware of it and using lower powered tractors. See Case Studies 8.4 and 8.10.

2.1.2 Environmental benefits

Environmental benefits are difficult to quantify, but may affect a farm budget. Interestingly, all environmental benefits of CTF correspond with economic benefit to the grower (Tullberg 2013).

Less greenhouse gas emission

There can be less fossil fuel consumption by cropping with CTF (see Reduced fuel use in section 2.1.1, Economic benefits), and therefore, less carbon dioxide emission from a farm. Nitrous oxide and methane formation in oxygen deprived waterlogged conditions are less on a CTF farm with better soil health than a non-CTF farm on the Darling Downs in Queensland, if subsoil constraints have been sufficiently rectified (Tullberg et al. 2011). Thus there may be less greenhouse gas emissions from soil on CTF farms, but this has not yet been assessed in Western Australia.

Less nutrient leaching, especially from deep sandy soils

Less subsoil constraint for root growth on sandy soils will enable better interception of leaching nutrients by roots. This may enable some additional fertiliser efficiency to further reduce input costs. The benefit may only be in the vegetative growing season of the crop, and so summer leaching or leaching during extreme rain events would not be reduced.

Reduced water erosion risk

Sufficient anchored ground cover is a primary requirement for reduction of water erosion risk by increasing the erosive resistance of the soil surface to overland flow. Overland flow of water is encouraged by poor infiltration. The good condition of CTF soils, if subsoil constraints have been sufficiently rectified, improves infiltration of large rainfalls and can minimise run-off; see the 'Management of surface water for CTF Technical Manual' (link in section 9) for more details.

Masters et al. (2008) demonstrated significant reductions in nutrient loss in run-off under CTF. This work was carried out in canefields, but nutrient loss is likely to be directly proportional to run-off in any crop.

2.2 Costs

The initial costs of setting up a CTF system in Australia are generally estimated to be under $40 000 (McHugh et al. 2004; Tullberg et.al. 2007). However, costs are very dependent on individual farm situations. Some indications of actual costs are shown in the case studies (section 8), but they are often not recent costs.

Modifications of machinery and replacements

Some cropping equipment will fit better than others and some machinery will be closer to needing replacement than others. On-farm costs of modifications on Western Australian farms have ranged from $2000 to $10 000 (Webb et al. 2004).

Farm layout

To improve efficiency of working up and back some changes to layout may be needed to be accounted for, such as modifications to surface water control structures, fence removal, removal of rock heaps and other obstacles. Many of these changes may have already been made when straight-line autosteer was adopted.

*When subsoil constraints have been rectified sufficiently

Subsoil tillage and amelioration

Where soil types are responsive to amelioration, this will be an additional cost that will add value to a farm CTF system (unless subsoil constraint management has already been planned and CTF will be integrated with it). Initial deep cultivation costs can be relatively easily estimated from known evidence, but the fuel estimates may be reduced for the area of permanent wheel tracks, which may not be treated (for example in modified deep ripping or spading). There are also avoided costs to consider, the longer period before deep cultivation will be needed again, due to less subsurface compaction by traffic. Recultivation may only be required from eventual settlement under wetting and drying and flooding (see section 11 Technical note 1) or electrochemical instability and the need for deep incorporation of gypsum (Hamza and Penny 2002). Recent farm observations on some deep sands have found the benefits of deep ripping persisting for at least ten years on a fully matched CTF farm.

Improved guidance

If autosteer or a suitable equivalent, has not been adopted this may be an additional cost to include.

2.3 Profit

With a good plan, and advice from a suitable source, a cost to transition can be estimated. When this planned cost is integrated with estimated benefits over the transition period there may be a confident calculation of the possible pay-back time for assumed growing seasons and prices.

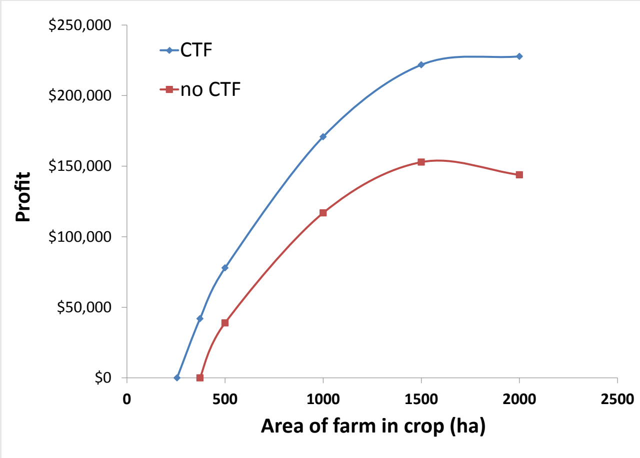
The common experience of many CTF farm conversions has been that the costs have been lower than anticipated and the benefits often very encouraging (especially when combined with suitable subsoil constraint management strategies).

General assistance to provide more confidence in CTF adoption can come from whole farm economic models of farm profitability, or more simplified analysis of possible income from improved yield and the possible pay-back time.

2.3.1 Whole farm economic modelling

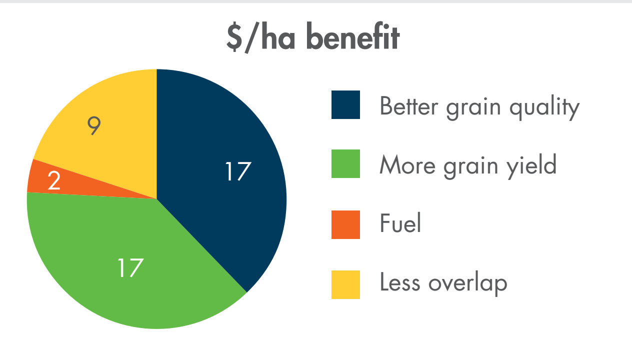
Economic modelling by Kingwell and Fuchsbichler (2011) has shown estimated profits of a mixed enterprise farm greater than 2000 ha with a range of soil types in the Western Australian central wheatbelt increasing with use of CTF (Figure 2.2). Farm profit from moving to CTF in the dry season of 2012 was $36/ha if autosteer was already being used and $45/ha if autosteer had yet to be adopted (Blackwell et al. 2013). The analysis is based on figures from trial results; a conservative five per cent grain yield increase, 2.5 per cent shift to better grade APW quality grain worth $275 per tonne and 10 per cent reduction of inputs and conservative conversion costs. This assumed a $35 000 investment, relatively high for a 2000 hectare farm. This cost included a two centimetre accuracy GPS unit transferable across equipment and modification costs for machinery axles and widths if not already matching. Using the same calculations for moving to CTF if autosteer was already adopted estimated profits were $60 per hectare for a two tonne per hectare average year and $120 per hectare for a four tonne per hectare average year.

Figure 2.2 Effects of CTF on profit on a WA central wheatbelt farm with 35 per cent deep sands, 35 per cent loamy duplex and 30 per cent clay soils and conservative yield responses to CTF on the soils of 5, 7 and 9 per cent respectively.



The trial results and the economic analysis are based on CTF systems where the residual soil compaction between the wheel tracks is removed when the system is first established. Seventy five per cent of the benefit comes from improved grain yield and quality (Figure 2.3).

Figure 2.3 Dollar value that the various components contribute to the overall $45/ha benefit of CTF for a low yielding 1.2 t/ha wheat crop (Blackwell et al. 2013).



2.3.2 Simplified analysis of costs, benefits and pay-back time

The possible number of years it will take to pay back a loan to convert to CTF has been calculated using estimated yield benefits from CTF. Yield benefits were calculated by comparing on-farm measurements of yield on deep ripped sand, which was subsequently compacted by cropping operations, with yield estimates from a complementary CTF system on deep ripped sand. This gave an estimated yield benefit ranging from about five to 10 per cent (Blackwell et al. 2013). Figure 2.4. shows the estimated time to pay back appropriate conversion costs for these cases and fixed per cent yield benefits. The estimated payback time is approximately halved when benefits for improved grain quality and less fuel use are included, despite the previous adoption of autosteer.

2.4 Challenges

As CTF involves a shift in mind-set and change in machinery and farm layout that are key components of farm operations, there can be some challenges to consider. Potential solutions to many these challenges are discussed in relevant sections of the manual and have been noted in the case studies. Challenges may include:

- seeding and harvesting capacity, see section 4.2.4 Bigger machinery is better: or is it?
- high cost of changes in some cases (depending on current machinery and changeover preferences)
- spreading widths (especially lime and straw), see section 4.2.3 Options for modifying machinery width
- burned windrows leading to uneven distribution of nutrients, see section 4.2.3 Options for modifying machinery width
- wheel track sinkage and erosion, see section 4.4.2 Wheel track maintenance
- staff and consultant training to stay driving on the wheel tracks
- guidance compatibility between brands and drift between seasons, see section 5 Guidance systems.

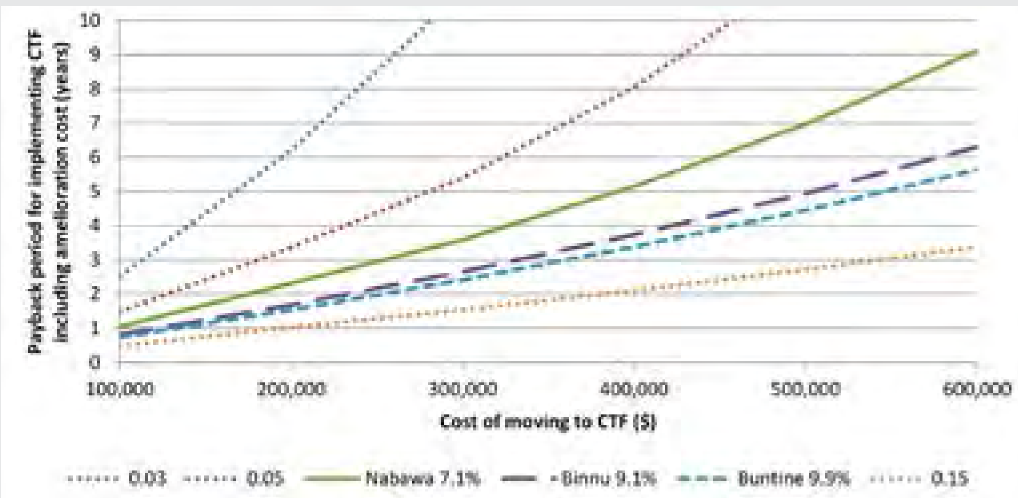


Figure 2.4 Repayment time for conversion costs to CTF for 2,800 ha of wheat each year in the Northern Agricultural Region of WA, including setting up the system with deep-ripping or other soil amelioration techniques. Different per cent yield benefits are shown; including a line for three farm sites. Calculations are based on 2 t/ha without CTF and at $250/t for wheat and 8.5 per cent interest rate for the investment. (Blackwell et al. 2013).

3. SUBSURFACE COMPACTION: IDENTIFICATION AND ALLEVIATION

Heavy agricultural machinery, especially in moist soil conditions, can induce significant deformation to the soil subsurface, inducing compaction detrimental to profitable crop production and the environment.

3.1 The processes of compaction

Cropping machinery is a major cause of subsurface compaction (that is, below a depth of about 10 cm); however, loosened subsurface soils can also be compacted from natural processes of wetting and drying. Soil flooding and instability from sodicity are the main causes for serious subsurface compaction by wetting and drying (see section 11 Technical note 1). The soil formation history can also be the cause of some compact layers too hard or deep to fix (see section 11 Technical note 2).

3.1.1 Increased bulk density and reduced porosity

Compaction is the change of a soil volume by compression and shear forces to increase bulk density and decrease porosity—the air is squeezed out of larger soil pores. Shear forces are caused by the traction forces of wheels and tracks and are mainly confined to the surface soil. Compression forces affect surface and subsurface soil and have the greatest influence on soil that is moist and soft. More detail is provided in section 11 Technical note 3. Some detail of effects of poor soil macroporosity on soil health and plant production is explained in section 11 Technical note 4 and in Davies and Lacey (2011).

3.1.2 The impact of farm vehicles

The severity of surface and subsurface compaction is related mainly to the ground contact pressure and axle load of wheels and tracks. Tracked vehicles generally have a lower average ground pressure than wheeled tractors, but there can be high-pressure peaks below each idler on the bogey, and there tends to be a large peak at the rear end of the track when the tractor is working in high draft conditions. The largest peak for a tracked machine can be as much as two to three times the calculated average pressure under a track. The main benefit of tracks appears to be better traction, and more efficient use of engine power.

Once compaction has occurred in moist soil conditions, subsequent passes of the compacting force will only marginally increase the amount of compaction; 80 to 90 per cent of the surface and subsurface compaction occurs during the first pass. The amount of compaction tends to decrease as forward speed increases.

Subsurface compaction is controlled more by total axle load rather than surface pressure under a tyre or track. **Larger axle loads = more subsurface compaction**. A rough 'rule of thumb' is that the peak compressive force below a tyre or track is at a depth of half the width of the tyre or track. The greater the axle load the greater the depth and magnitude of subsurface compaction. Machinery sizes are increasing as growers seek improved cropping efficiency; therefore, axle loads are increasing and compaction severity and depth is also increasing. This is likely to result in subsurface soil being compacted to depths beyond 40 cm (Figure 3.1). This increased subsurface compaction largely goes unnoticed and conventional methods of amelioration, such as deep ripping, may not have sufficient working depth to remove such very deep compaction.

3.2 Identification of subsurface compaction

Take care not to waste your money on ineffective deep cultivation; investigate if subsurface compaction or other constraints are present and consult local research for effectiveness of treatment.

Controlled traffic farming systems are a very effective way of avoiding further subsurface compaction problems from cropping traffic in the crop production zone. Most of the crop production benefits are gained if inherited compaction in the paddock is ameliorated, but some paddocks may have insufficient subsurface compaction problems to justify the costs of amelioration, for example, paddocks with little cropping history and on soil types such as gravels, which carry machinery loads by stone to stone contact. There may be, and often are, additional subsurface constraints which still restrict soil exploration even when the profile has been mechanically decompacted.

Subsoil constraints are often more difficult to identify than topsoil influences on crop performance and poor topsoil growth conditions may also mask the influence of poor subsoil growth conditions; thus a poorly germinated and fertilised crop may not reveal additional limitations to growth from subsoil conditions. Many subsoil growth issues are only clearly expressed when the crop is well managed in relation to topsoil conditions.

Paddock symptoms can reveal subsurface compaction problems. Knowledge of the cropping and tillage responses of a paddock can often provide evidence for possible negative effects of crop growth and grain yield, for example:

- Dry topsoil and moist subsoil after a relatively poor yield and a dry finish to the season suggests there have been insufficient roots at depth to extract water.
- Deep working points at seeding that bring large dense clods of soil to the surface is often evidence of a dense compacted layer in the subsoil.
- Difficulty for tines to penetrate and increased draft force of the tractor, especially when working across previous directions of cropping, indicate compact subsurface zones in the paddock.
- Linear patterns of delayed flowering (green strips), particularly in broadleaf crops such as lupin can be a useful indication of subsurface compaction effects on crops.
- Having 1-in-20 to 1-in-50 individual plants performing a lot better than the rest of the crop is a very common symptom of subsurface compaction. Those better plants have found old root channels and so enjoy better nitrogen and sulphur nutrition than the rest of the crop because they have deeper roots. This effect is obvious early in the growth before stem elongation and even after then it might still be visible.
- Deformed and bent roots of individual plants in poorer growth areas (dig up to examine), especially in canola, can be strong evidence for subsurface compaction.

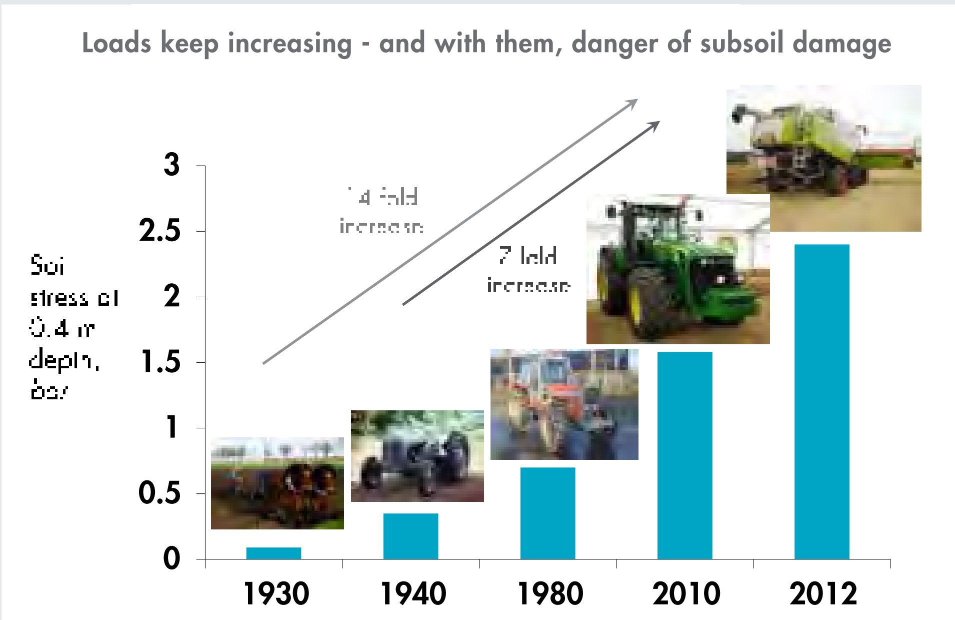


Figure 3.1 Historical increase of subsoil stress with increasing weight of farm machinery in Europe; conservative in comparison to the effects on Australian dryland farming soils! (Source: Tim Chamen, controlledtrafficfarming.com).

3.2.1 Crop growth and flowering patterns

Poor growth and yield in wheel tracks from a wet harvest or a change of direction in seeding may be readily visible to the experienced eye in the earlier parts of the growing season (Photo 3.1). In many seasons and circumstances, linear patterns of delayed flowering, especially green strips in lupins and canola, reveal delayed growth and development due to subsurface constraints from compaction; often zones about 3 m wide on the same spacing as the seeder, especially on sandplain (Photo 3.2). Growth patterns from windrow burning should not be confused with patterns from compaction. Patterns of growth from windrow burning are usually lines of better growth at spacing equivalent to the harvester that formed the windrows. Zones of poor growth from cropping traffic patterns can also be revealed with the help of Normalised Difference Vegetation Index (NDVI) images and infrared images (Bakker & Poulish, 2009).

Photo 3.1 Crop health patterns from soil compaction by heavy wheeling on a shallow duplex soil in a wet year.

Photo 3.2 Canola crop flowering on the left where the green stripes are normal traffic and on the right with more even crop growth is controlled traffic.

3.2.2 Soil strength

Penetrometers can help find detail of subsurface compaction—but don’t forget to DIG!

Penetrometers are metal cones pushed into the soil to mimic stresses experienced by root growth. They can be simple metal rods that rely on the feel of the user to identify changes in pressure, or have a pressure gauge attached (Photo 3.3).

Photo 3.3 Handheld pentrometer with pressure gauge and GPS logger attached (Source: Paul Blackwell, DAFWA).

The soil strains from the expansion ahead of the cone are a close parallel to the soil responses around an expanding and penetrating root tip. However, the exploration of macropores and micropathways of least resistance are beyond the ability of a penetrometer cone to detect, therefore, soil structural conditions more complex than sands, are poorly reflected in the moist soil strengths measured by a rigid cone penetrometer.

The effects of compaction on root growth in sandy soils, as measured by cone resistance, are summarised in Figure 3.2, which relates published data on root growth and penetrometer resistance to a general guideline on the influence of soil strength on root growth of cereals.

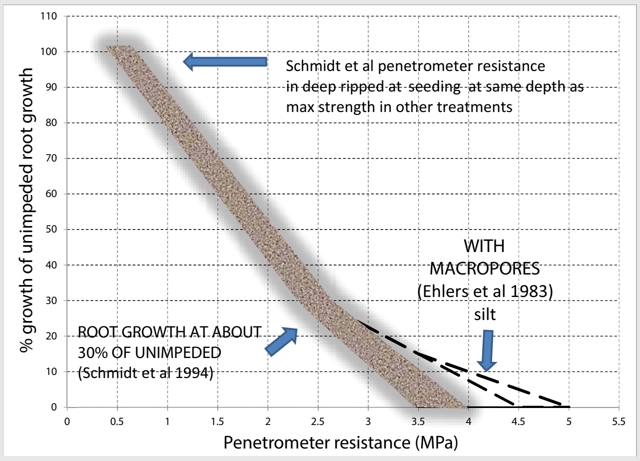


Figure 3.2 A general guide to the relationship between penetrometer resistance and root growth from research investigations and observations mainly in Western Australia. The most relevant published sources are noted. Macropores can enable penetration of a hard layer, but may not help exploration of the soil between them.

Penetrometer measurements, usually in the crop row, should be taken when the whole profile is at field capacity (for sand, approximately 24 hours after a soaking rain or a flood irrigation of 50 to 100 mm; soils with higher clay content may need more time to drain). The best time of the year for the compaction measurement is the winter because the whole profile is usually wetted up and early crop root growth can also be examined. If the soil is too wet and of high clay content, strength can be underestimated because the moisture lubricates the penetrometer movement and the soil behaves as a liquid. If the soil is too dry, compaction could be overestimated because roots will be able to penetrate the soil when it gets wet. The idea behind using the penetrometer at field capacity is that this is the best-case scenario for roots. Hopefully, the soil will be at field capacity at various times during the growing season. During these periods, roots will be able to penetrate soil that has low penetration resistance. Penetration resistance will increase when the soil dries out, and root growth can then be expected to be limited. However, when the moisture content of the soil increases again, penetration resistance will decrease, and root growth will resume.

If penetration resistance is very low, seed-to-soil contact is likely to be poor due to excessive air pockets (soil that has been deep cultivated may need to be packed to get good seed-to-soil contact at seeding).

3.2.3 Soil structure

Often the best method of assessing root growth in subsoil is visual assessment of root distribution in pits, following careful preparation of the pit face. Physical limitations can sometimes be seen as in Photo 3.4.

Photo 3.4 Compacted subsoil layer in a loamy earth near Mukinbudin. Note the distinctive upper and lower boundaries of the compacted layer, blocky structure and fractures, which are preferred pathways for roots to grow (Source: Stephen Davies, DAFWA).

Common symptoms of subsurface compaction are: platy structures with horizontal orientation of peds, blocky structures with sharp linear edges and roots flattened between the faces of such dense soil shapes or massive layers of low porosity, sometimes with plant roots growing horizontally above them. Often root growth proliferates above a restricting layer and roots may be thickened or contorted at the interface (Photo 3.4). Root growth through such layers may be restricted to cracks and channels left by worms or roots. If root depth or quantity is seen to be limited, biological or chemical causes, or limitations due to water must be considered as well as strength. Visual soil investigation methods such as Visual Soil Assessment (VSA) bioagronomics http://www.bioagrinomics.com/visual-soil-assessment.html and SOILpak http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/127274/Soil-examination-and-structural-rating.pdf provide more quantified and well-developed techniques for more detailed investigations of visible soil and root symptoms of soil compaction.

The pit method is laborious, destructive, and not easily replicated so it is often impractical on a large scale. Pits can be used on a miniature scale by excavating blocks of undisturbed soil to about 20 cm depth for a greater number of observations.

3.2.4 Root symptoms

Roots that have suffered from mechanical growth restrictions due to compact soil usually show typical features of:

- enlarged and distorted root tips (Photo 3.5)
- flattened roots between faces of dense soil (see Photo 3.4)
- roots growing down macropores, but not through the main body of the soil

Roots mechanically impeded or restricted by aluminium toxicity can show similar symptoms.

Photo 3.5 Washed roots of lucerne excavated from a very compacted sandy soil with little root penetration below 30 cm depth (as indicated on the included scale). Note the enlarged root tips and distorted growth compared to the roots at 25 cm and one root which has explored a path through the decayed remains of a previous larger root (Source: Jeremy Lemon, DAFWA).

3.2.5 Possible confusion of compaction with other subsoil constraints

Maximum rooting depth can also be restricted by extreme acidity or alkalinity, aluminium toxicity, nutrient deficiencies, salinity, sodicity, a high or fluctuating water table and low oxygen levels. Anaerobic (anoxic) conditions due to deoxygenation and prolonged waterlogging restrict the rooting depth as a result of the accumulation of toxic levels of hydrogen sulphide, ferrous sulphide, carbon dioxide, methane, ethanol, acetaldehyde and ethylene, which are by-products of chemical and biochemical reactions. Subsurface acidity and aluminium toxicity of sands and salinity and boron toxicity and high pH in clays are typical of such additional constraints in Western Australia.

Nutrient toxicities and soil pH extremes can be identified by soil testing to depth 0–10 cm, 10–20 cm and 20–30 cm. Soil samples can be sent to an accredited soils laboratory for soil analysis, which is the most accurate approach for assessment of soil pH and specific nutrients. Alternatively, soil pH can be assessed in the field using handheld pH meters or can be estimated using universal pH indicator sprayed onto soil pit faces (Photo 3.6) or using pH test kits. Universal pH indicator, or pH test kits give a colour-based indication of an acidic or alkaline layer and are typically only accurate to 0.5 of a pH unit but are sufficient to indicate the presence of an acidic or alkaline layer.

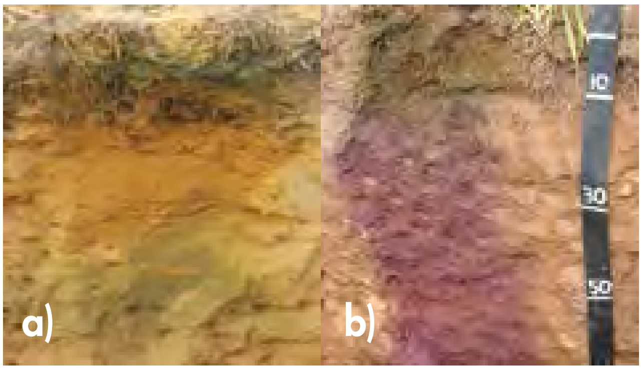


Photo 3.6 Soil profile pit faces that have been sprayed with universal pH indicator. a) shows a deep sand profile near Miling WA and demonstrates a subsurface acidic layer, stained orange in colour, indicative of a soil pH less than 4.5 and b) shows a duplex profile near Cadoux, WA with an alkaline clay subsoil, stained purple in colour, indicative of a soil pH greater than 8. Colours from the universal pH indicator on moist soil give a guide only and soil samples would need to be measured in a soil analysis laboratory or with a portable pH meter to get an accurate measure of the soil pH. (Source: Stephen Davies, DAFWA).

High boron, sodicity (dispersive soil) or salinity are sometimes associated with strongly alkaline clay layers in the subsoil. Boron in soil needs to be measured in a laboratory or inferred by toxicity symptoms on susceptible plants (Lacey and Davies 2009 DAFWA Farmnote 388/2009). Dispersive sodic soils can be assessed with dispersion tests or by using laboratory analysis for exchangeable sodium percentage or sodium absorption ratio (Davies and Lacey 2009 DAFWA Farmnote 386/2009). Salinity can be assessed by measuring the electrical conductivity (EC) using a portable meter or lab analysis. Portable pH and salinity meters are commonly available from suppliers of scientific and environmental assessment equipment. More information on these additional subsoil constraints can be found here: www.liebegroup.org.au/factsheets/

Such visual observations and measured explained above provide strategies more likely to evaluate the most cost effective management solutions for the current farm business. Soil, root and crop examination and the use of test strips of possible solutions are often the most effective general strategy. See section 7.5 On-farm trials.

3.3 Alleviation

3.3.1 Mechanical

Mechanical reversal of subsurface compaction is provided by a range of deep tillage techniques including deep ripping (or subsoiling), deep ploughing, inversion (mouldboard) ploughing, spading and delving. Table 3.1 is a summary of some of the important features of many current methods and their capacity to decompact subsurface soils. Davies and Lacey (2011) give more technical details of deep ripping, inversion ploughing and spading. Hamza and Penny (2002) provide more detail on the value of additional chemical stabilisation of gypsum-responsive subsoils when deep ripping.

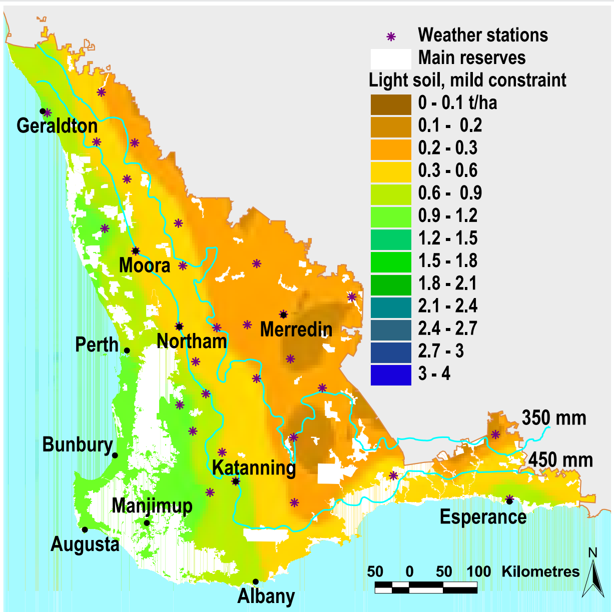
Table 3.1 Summary of mechanical methods to remove compaction

Method	Maximum depth of loosening	Technical improvements	Ease of mixing soil ameliorants	Key value
Deep working seeding points	About 20 cm (~ 9 inches) using narrow knife points	Tungsten carbide attached all the way up the point for reduced wear	Some mixing possible with degree dependent on soil type and moisture content, working speed and tine spacings	Partial decompaction without a separate operation; deep working points can be put on selected tines each year and rotated to reduce total draft impact in a given year
Deep ripping	1 m or more with sufficient traction, tine breakout and winged points# (about 50cm with largest current farm equipment)	Wings on points or tine legs and shallow leading tines* or discs to allow deeper effective working	Comparatively poor with single tines at the same depth	More commonly available, relatively lower operating costs for the same depth of working, deeper loosening
Inversion ploughing	About 35 cm	Relatively few for deeper loosening but share angle needs attention to maintain depth	Relatively effective; can result in deeply buried layers with minimal mixing through disturbed profile	Burial of topsoil, organic matter, nutrients and weed seeds if skimmers are used
Rotary spading	About 40 cm when combined with deep ripping	Stronger and deeper working spades	Very good	Incorporation of clay, especially old ineffective claying; lime into acidic subsoils
Delving	Perhaps 0.5-1 m depending on design and draft	Closer spaced narrow legs may reduce clod size	Can be very good	Cost effectiveness for depth of loosened (not cultivating all the soil); capacity to lift subsoil clay into sandy topsoils and create sand seams into subsoil clay layers

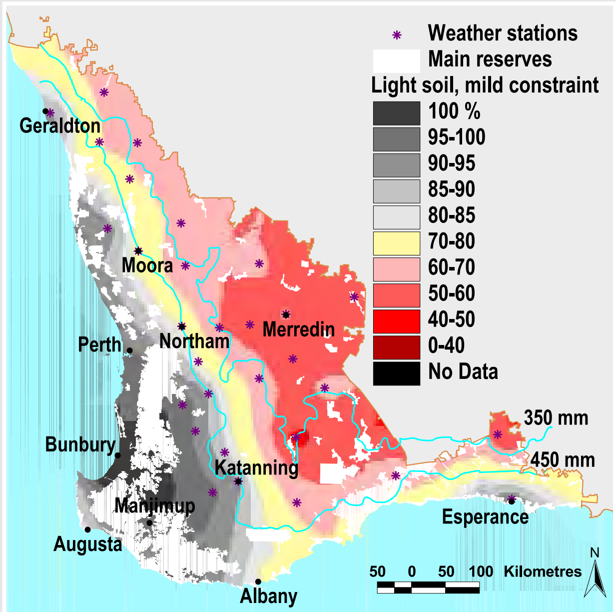
*Hamza et al. (2011) #Forestry and mining rippers

General predictions to responses to deep ripping and the reliability of the response have been investigated by recent modelling. Figure 3.3 shows the analysis for one soil type in Western Australia (loamy sand, distribution shown in Figure 3.4). Poor response to deep ripping in the modelling is due to terminal drought from the larger biomass using too much water in drier seasons. Poor responses to deep ripping can also be caused by digging too deep below the critical depth where the soil does not break out and poor penetration of a hard layer, as well as the presence of another subsoil constraint.

Figure 3.3 a) Loamy sand response to removal of a mild subsoil constraint from compaction and/or acidity (root growth rate reduced by 80%), and b) probability of a positive yield response to deep ripping and/or lime incorporation during a period of 1957–2006 (right) (Source: Farre et al. 2010).



a)



b)

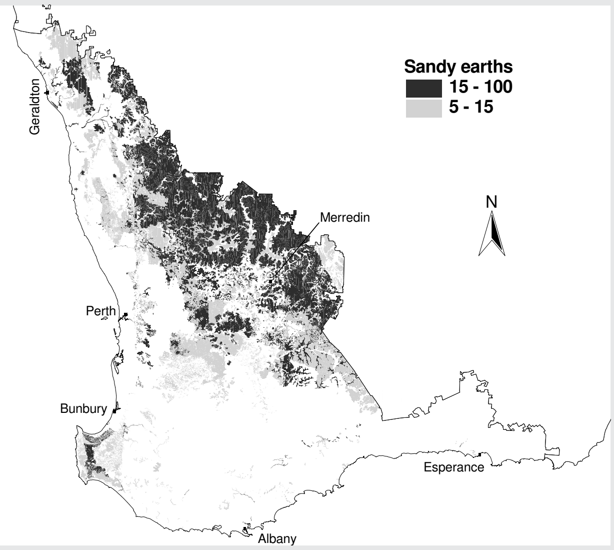


Figure 3.4 The actual distribution and percent of the landscape of loamy sand soils in the Western Australian south west land division which should give the modelled yield responses shown in Figure 3.3 (Source: http://grains.agric.wa.gov.au/node/sandy-earths).

3.3.2 Natural forces

Shrink and swell (especially by cracking clays), biological activity of roots (especially woody species), burrowing of soil animals (especially earthworms, ants and termites) and chemical stabilisation of soil by components of organic matter can all contribute to improving soil condition and help to alleviate compaction. Unfortunately such responses are not as rapid as mechanical loosening, but may be very cost effective in the long term, especially on some clay soils. Radford et al. (2007) show that severe compaction of a cracking black clay in Queensland by 10 tonne axle loads can be ameliorated naturally in five years.

Evidence of CTF allowing improvement of soil structure by natural processes has been shown by Ellis et al. (1992). The avoidance of heavy wheelings enabled soil macropores (cracks and tunnels from soil animals and roots) to increase within six years, allowing better infiltration of water into the soil (Figure 3.5).

Some grower experience with difficult subsoils seems to show that progressively deeper digging with points at seeding, encouragement of increased soil organic matter and use of lime or gypsum or both can provide a more cost effective improvement than deep cultivation or organic matter improvement and use of ameliorants alone. On-farm evaluation of deep ripping across different soil types or combinations of soil amelioratants may be helpful before rolling out an amelioration program across the whole farm. For further advice on designing on farm trials see section 7.5.

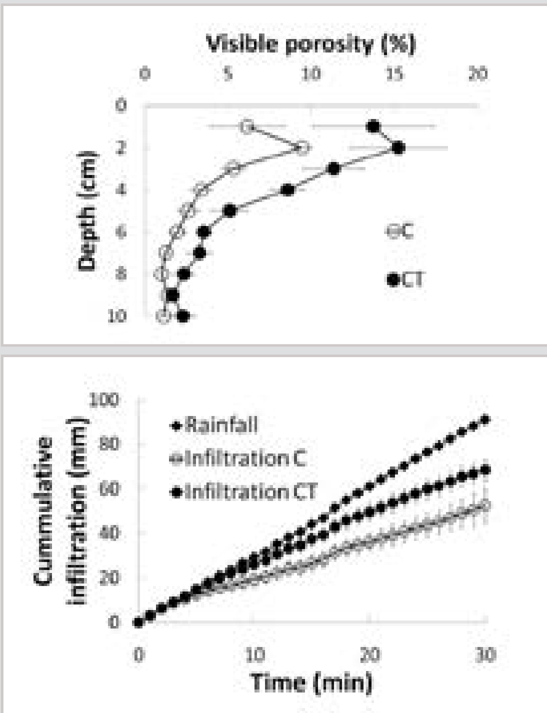


Figure 3.5 Visible soil porosity (top) and surface water infiltration (bottom) after six years of CTF (CT) or uncontrolled traffic (C). Error bars are one standard deviation. (Source: Ellis et al. 1992).

3.4 Integration of compaction management into CTF

General grower experience and on-farm trials indicate that:

1) Clay soils that have shrinking and swelling characteristics can repair themselves over time by the natural shrinking and swelling process that occurs as a result of rainfall patterns and improvements to soil health (especially the activity of earthworms, ants and termites) if wheeling is removed/confined to permanent traffic lanes (Photo 3.7).

Photo 3.7 Evidence of increased earthworm activity after 10 years of CTF on a mallee clay soil in Esperance (Source: Quenten Knight, Precision Agronomics Australia).

2) Deep rippers and spaders can be modified to deep cultivate between permanent wheel tracks when or after a CTF system has been established (Photo 3.8). Tines or spades are removed from the wheel track zone in the first pass and any uncultivated ground between the first passes is treated in a second pass with the tines or spades replaced and perhaps outside tines or spades removed to fit the width.

Photo 3.8 Ripping from the wheel tracks with tines on the wheel tracks removed.

Soils with high nutrient exchange capacity, such as clays and gravels, will not need as much depth or rooting volume as sands, which have low nutrient exchange capacity; therefore, plants can grow on shallower soil and above a compaction layer, especially if rainfall is frequent enough. This is illustrated by the modelled crop response in the Figure 3.6.

Estimating the value of a deep cultivation may be improved with analyses such as in Figure 3.6. Yields from deep sands are more sensitive to shallow root depth than loams. Restriction of root depth to 60 cm in deep sand leads to a yield penalty of 1 t/ha. Loams and clays can hold more water and nutrients, so may require less depth than sand to supply a crop the expected water from the rainfall received.

With assistance from the guidelines and information above, growers and consultants should be able to assess the severity of subsurface compaction, and any other constraint, in a paddock. The suggested strategies will then hopefully lead to the most cost effective and sustainable management of the soil within a planned CTF system.

3.5 Further reading on compaction

Davies, D L & Lacey, A 2011, *Subsurface compaction—a guide for WA farmers and consultants*, Bulletin 4818, Department of Agriculture and Food, Western Australia.

Hamza, MA & Anderson, WK 2005, 'Soil compaction in cropping systems: a review of the nature, causes and possible solutions', *Soil and Tillage Research* vol. 82 pp. 121–145.

Hall, D, Lemon, J, Oliver, Y, Gazey, C, Davies, S, Russell, C & Whitham, N 2009 *Managing south coast sandplain soils to yield potential*, Bulletin 4773, Department of Agriculture and Food, Western Australia.

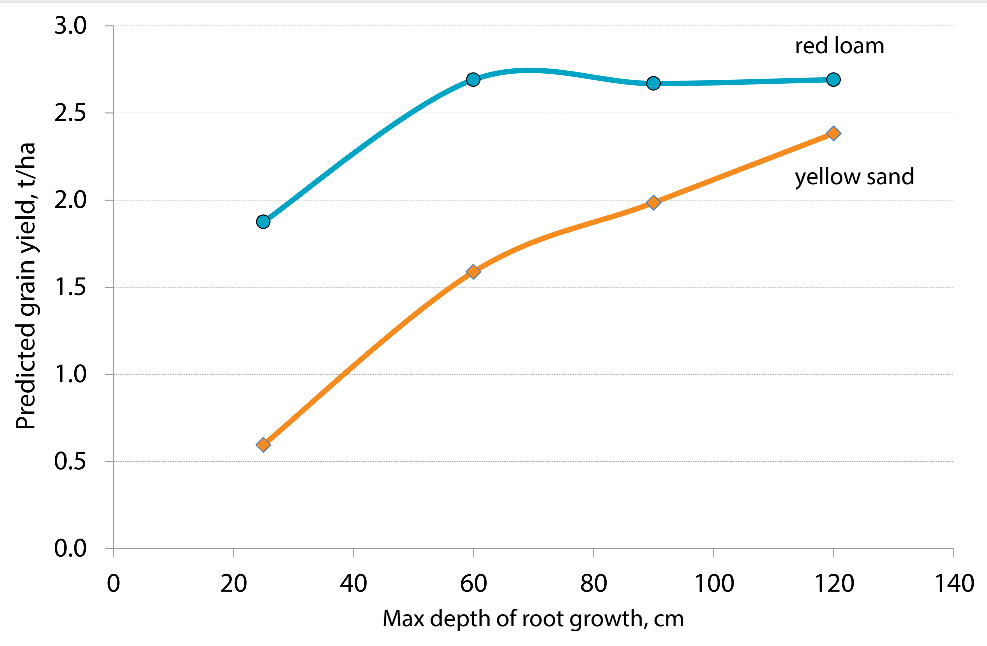


Figure 3.6 Yield effects of the depth of root growth limitation for wheat on a red loam and a deep yellow sand in the 2005 growing season at Mingenew in the Northern Agricultural Region modelled in yield prophet.

4. MACHINERY MATCHING

Ultimately all machinery wheel tracks should match to confine the wheels of all heavy machinery to permanent traffic lanes, however larger headers, off-set fronts or airseeders wider than 12 m can make matching difficult. To make the process of converting to CTF manageable, developing a machinery investment plan to enable changes within the farm budget is recommended. This may be a plan over a few years. Estimated benefits can help plan pay-back times of foreseen costs.

Steps to develop a machinery investment plan are:

1. Decide on imperial or metric measurement (this applies to machines and row spacing).
2. Select an operating width and match in multiples (multiples of 9 or 12 m are most common).
3. Match the tracks (for wheels or tracks with more than a one tonne load). Work off header size as it is the most limiting. Ensure machines can go to 3 m wheel centres.
4. Choose the type and width of wheel track you want to leave (fuzzy, bare, etc).

Before getting out the gas axe to modify machinery widths or axles, experience has shown it is better to **measure twice and cut once!** (Photo 4.1 & 4.2). In particular, make sure you check the actual cutting width of the header and set the bar width accordingly to avoid leaving unharvested rows of crop.

Photo 4.1 Measure your machinery carefully (Source: Tim Neale, precisionagriculture.com.au).

Photo 4.2 A useful way to measure your wheel track width is to do it in the paddock (Source: Tim Neale, precisionagriculture.com.au).

4.1 Decide on imperial or metric measurement

Many of the early controlled traffic farming adopters have discovered 9 m is not 30 ft. A 30 ft header front is 9.14 m, a 40 ft header front is 12.2 m, and therefore it is easiest to choose one or the other measurement to use to avoid miscalculating.

Australian built sprayers are often in metric with 50 cm nozzle spacing, so matching to an imperial seeder can be a challenge. Sprayers imported from the United States of America may be imperial or metric.

Converting the sprayer to imperial 20 inches (50.8 cm) may be cheaper than converting headers or seeders. For soil-applied herbicides on wider rows of crop, the best nozzle position is either on top of, or central between, the previous stubble rows to reduce herbicide losses on the standing stubble. Nozzles located directly over the crop row also enables band spraying of in-crop sprays for some crops.

A smart approach is to work on metric for the bar and sprayer and imperial on the header for example 12 m bar, 36 m boomspray and 40 ft header front (12.2 m). That way you always have a little overlap on the header to make sure all crop goes in the front.

4.2 Select an operating width and match in multiples

The ideal machine work to from, as a base, is the header. The header is one of the heaviest machines used in farming operations, with a full capacity of approximately 10 t of grain. It also can have the widest wheelbase and widest tyres. Track width is usually about 3.05 m (10 ft) and some new models cannot be modified less than this. Some may argue that compaction does not occur at harvest when the soil is usually dry, but it only takes one wet harvest for the residual compaction to have a lasting effect for many years and loose sands can compact at depth when dry at the surface but still moist at depth. Research in eastern and Western Australia, and from around the world, has found harvest compaction may cause 15 to 24 per cent yield penalty, in the order of $120 to $350 per hectare in the wheeled zone, depending on yield potential and current grain prices (Neale 2012).

4.2.1 Seeding or harvesting operating widths less than 12 metres

The easiest machinery width ratio to operate, especially for spraying, is an odd numbered ratio: 3:1 for common broadacre machinery, but 5:1 can work well with narrow seeders, such as a seeding combines of about 3 to 5 m in smaller scale operations (Figure 4.1). A 3:1 ratio works very well for smaller broadacre operating widths, for example:

a. 9.1 m (30 ft) header front, 9.1 m airseeder bar, 9.1 m spreading and 27.3 m sprayer

b. 12 m header front, 12 m airseeder bar, 12 m spreading and 36 m sprayer

c. 12.2 m (40 ft) header front, 12.2 m bar, 36.6 m sprayer.

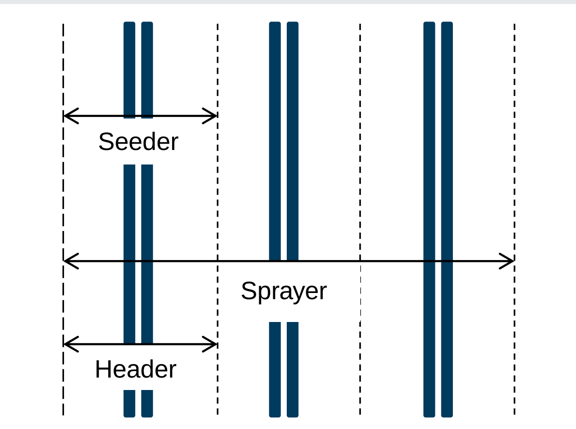


Figure 4.1 3:1 seeder bar/header to sprayer ratio.

4.2.2 Seeding operation widths greater than 15 metres (50 feet)

Larger airseeder widths of greater than 50 ft are harder to match headers and sprayers at a 3:1 ratio because such wide headers and sprayers may be unavailable, unaffordable or just too impractical to operate on some farms. For larger machinery, a 2:1 matching ratio is an option.

The 2:1 sprayer: airseeder bar ratio can be tricky on the edge of the paddock but can be done by shutting off sections of the sprayer (Figure 4.2). Consider how many sections would be ideal when upgrading your sprayer.

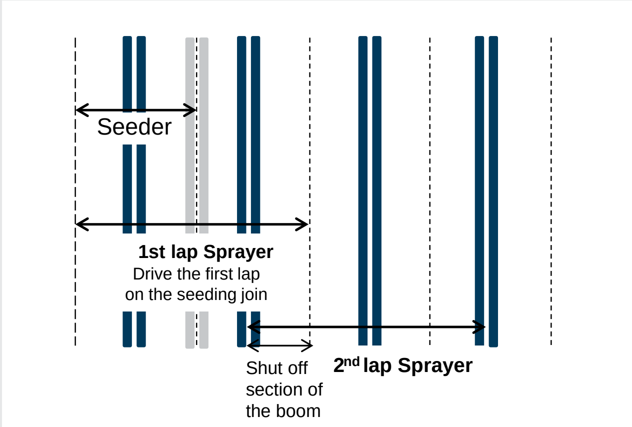


Figure 4.2 2:1 seeder to sprayer matching ratio (Source: Western Australian Agriculture Authority).

An alternative to shutting off sections of the boom is to make spraying wheel tracks in the wings of the airseeder bar and drive down the seeding joins on 'wing wheel tracks'. This can be effective if you have a 17.6 m bar, 35 m sprayer and a 9.1 m harvester. Some farms have developed this idea very successfully with 18 m wide bars. Alternatively, Figure 4.3 shows a compromise at the edge of the paddock to allow normal use of wheel tracks after the first pass with the sprayer.

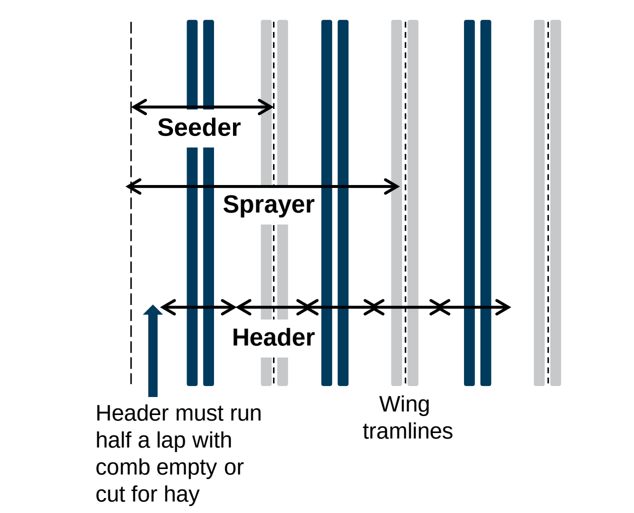


Figure 4.3 2:1 seeder to sprayer matching ratio including the header, for example, 18.2 m seeder, 27.3 m sprayer, 9.1 m header (Source: Western Australian Agriculture Authority).

Another option proposed for larger seeders is to match the header in multiples of the sprayer 3:1 and the seeder to the sprayer 2:1. For example, 40 ft header, 120 ft sprayer and 60 ft seeder. In this way the seeder will run on wheel tracks every second run (Figure 4.4). This does mean there will be a compromise at the edge of the paddock: either the seeder double seeds half a width on the second run or the header and boomspray do part passes. Some airseeders may have section control to avoid double seeding. Alternatively, you could skip over to the fourth header wheel track after the first seeding run and then fill in the second run with only a slight overlap.

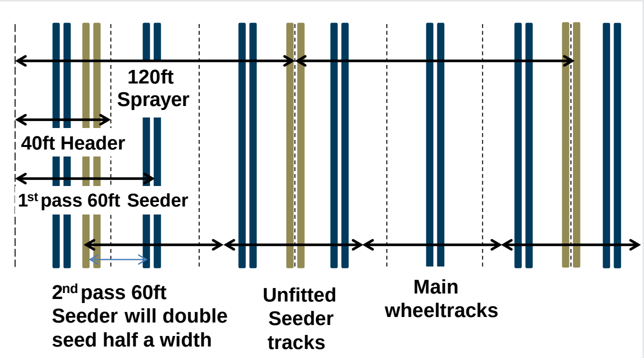


Figure 4.4 Matching of a header and boomspray 3:1 and boomspray to seeder 2:1.

4.2.3 Options for modifying machinery width

(exert from Webb et al. 2004)

Boomspray

Changing the width of a boomspray may be as simple as adding a tap or clamp to reduce the spraying width or small extensions to increase it. If increasing boom width significantly, ensure the pump has enough capacity and the boom is strong enough.

Airseeder

It may be possible to remove tines or discs to reduce the width or extend the frame to add more tines or discs with frame extensions.

Header front

Wider harvester fronts are normally offset to assist unloading. Centred fronts are required for the best wheel track layouts. It is possible to have an offset header front modified to centred mounted, however this can be very costly so most farmers opt to change the header front.

There are now centred belt front harvester fronts available up to 18 m. However, to unload into a chaser bin on the run, the auger may need to be lengthened or extensions added to the chaser bin. Prices vary depending on width, platform type and options required. For example, a 12.5 m centred draper front with a batt reel begins at approximately $110 000 plus GST (2013 price www.midwest.net.au/platforms.htm).

Spreading straw evenly across the full operating width becomes challenging even at 12 m with a strong cross wind. Different harvesters use different methods of straw spreading with varying degrees of evenness. There are various after market devices that can be attached to the back of the header such as the MAV™ straw spreader that can spread straw to 12.4 m. One suggestion to avoid uneven distribution of nutrients from straw is to harvest in-between normal wheel tracks, on a 'Clayton's wheel track', only in a dry harvest with high stubble (straw) levels, since this will put some nutrients where the residue is the least. Another technical possibility to avoid nutrient concentration by windrow burning is to move the swath, but not the header. This may be achieved by a swath chute hung offset to put the swath on opposite wheel tracks in alternate seasons, or preferably a conveyor, as used for some chaff carts, to place the swath either side of the harvester centre line and eventually even out the distribution of nutrients from swath burning in an integrated weed management system.

Deep ripper

Some increase of deep ripping width, for the same tractor power, may be possible when tines are lifted or removed from where the wheel tracks are needed. Matching the ripper to a wider airseeder may also be possible by using guidance to rip with two lifted tines where the wheel tracks go (in the central part of the airseeder width), then modifying the width of the ripper and dropping the two lifted tines to rip the miss between. For example, for a 12 m seeder and a 9 m ripper, the ripper first runs on guidance at 12 m spacing with the two tines lifted for the unripped wheel tracks, then the two tines are lowered, the ripper folded to rip three metres and the gaps between the first runs are ripped out. Some are using ripping tines at 50 cm spacing to fit between 25 cm rows, which allows a wider ripper to be pulled.

Spreader

Adjust the throwing distance of the spinners, which is often difficult beyond 18 m. Otherwise, change to an air spreader system with suitable ease of loading. Contract spreader trucks for limesand may be always incompatible with a farm CTF system; putting at least one wheel on the most convenient permanent wheel track may be the most feasible strategy; this also provides better traction and guidance for the truck.

Spreading widths for different inputs may not match well for systems based on multiples greater than 9 m, particularly for soil ameliorants, for example, lime where 8–9 m is the recommended spreading width, for all but the latest spreaders, and many ameliorants can spread to greater widths than others. It is important to check the evenness of spreading across the nominated width. High resolution biomass imagery has identified striping patterns in crop biomass that on close examination have been related to uneven spreading width (Figure 4.5). In this example, of a 12.2 m system where the fertiliser is spread at 36.6 m, closer investigation of striping in the biomass imagery determined that the spreader was putting more on the outside two seeder runs than the middle run. This caused a 13 per cent yield decrease in the middle seeding run, which is a significant cost in a 4.5 t/ha wheat yield across the farm (personal communication Andrew Whitlock).

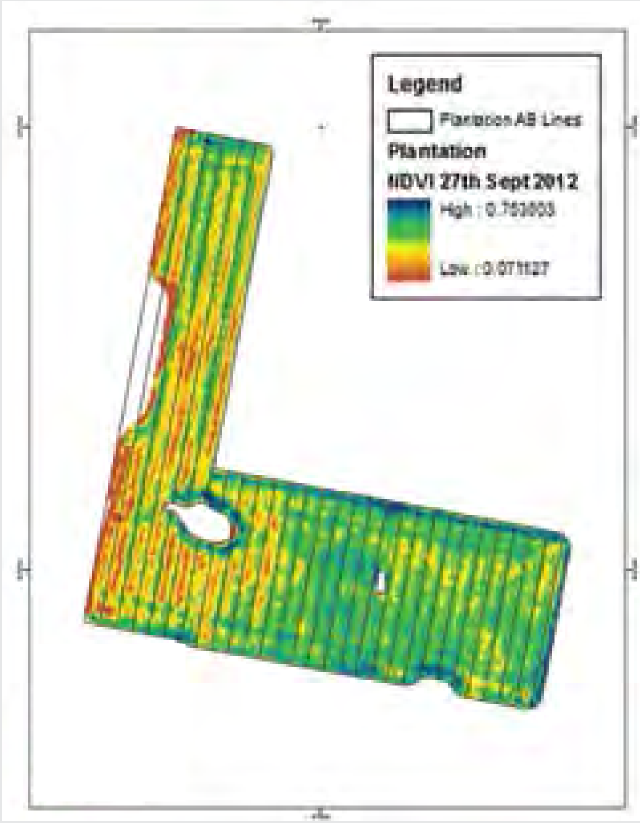


Figure 4.5 High-resolution biomass shows striping due to poor spreader efficiency. Red colour indicates low biomass to blue colour that is high biomass. (Source; Andrew Whitlock, precisionagriculture.com.au).

A compromise for the spreader in a 12 m system may be to use partial spread on 9 m and every third run will be on a permanent wheel track (Figure 4.6).

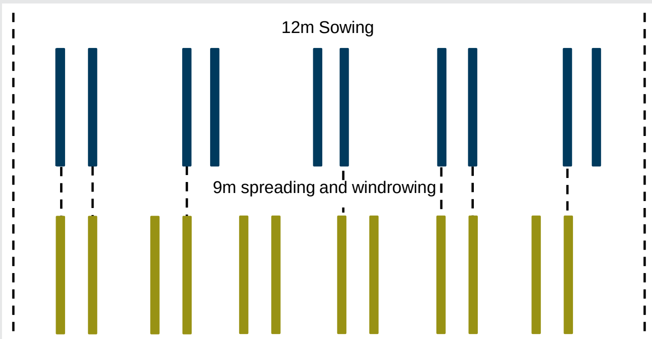


Figure 4.6 Spreading on 9 m in a 12 m system.

4.2.4 Bigger machinery is better: or is it?

Balancing traffic control with operational efficiency

Matching machinery for dryland cropping can be challenging as the desire to get as much seed in as quickly as possible is increasing in lower rainfall areas where the seeding window with good moisture conditions is narrow. Airseeder bars greater than 60 ft wide are being included in the farming system, making matching to other widths difficult.

It is difficult to provide suggestions for all cropping situations because at the detailed level, all farms are individual, and all financial circumstances and farm skills are unique. There are also many farms constrained by financial or other circumstances with little opportunity to significantly convert to CTF. Despite this, there may still be opportunities for all farms to improve their traffic control and minimise compromise of operational efficiency.

Traffic control priorities (with use of autosteer):

1. Ensure season-to-season traffic does run in the same place
    a. Use the same A–B lines for different operations (for example, seeding and spraying) to avoid making extra residual compaction, see section 5.2
    b. Plan to match the seeding, spreading and spraying traffic as well as possible; they are most likely to run over moist soil, and spraying is the most frequent in-crop traffic.
    c. Try to match the wheel track of the air cart to the seeding tractor, especially the inner dual. Air carts tend to make the most compaction at seeding due to high axle loads and the common use of single wheels.
    d. Consider using a 'three wheel' wheel track if the sprayer and seeding tractor do not have matching tracks, at least one sprayer wheel runs on a seeding tractor wheel track and one wheel mark from spraying will be avoided.
    e. Attempt to get some of the spreader traffic on some of the spraying and seeding wheel tracks for some of the passes, by careful choice of spreading widths.
2. When seeder width is increased, change the sprayer boom width to match two or three times the seeder width. This will keep more cropping traffic controlled and improve seeding efficiency. The paddock has more spraying traffic than seeding or harvesting traffic in most seasons.
3. When header front width is increased, try and match some of the header tracks to existing wheelings from spraying and seeding.
4. Move chaser bins onto header tracks (at least one wheel), especially when loading, if possible.
5. Use deep working points on the seeder, but not where the sprayer will run, to break out as much the residual compaction as possible; this may need progressively deeper working.
6. Select contractors who can fit your system and ensure that they understand why you are in a CTF system so they don't drive anywhere.

Seeding efficiency priorities

1. Quantify where the inefficiencies are occurring in the seeding operation. Is it opener type, bin capacity, refill time, staff issues, etc?
2. Try to improve daily seeding rate first by increases of speed (say with discs), perhaps by changes of row spacing and openers too.
3. Consider getting a bigger capacity air cart and faster loading systems before increasing seeder width. Try to double seeder width to allow refitting onto wheel tracks or existing wheel marks.

It is possible to increase the seeding capacity of a 12 m seeder to equal an 18 m system by increasing speed and capacity (Blackwell et al. 2013). Capacity at seeding can be increased by increasing forward speed, air cart capacity or loading rate when filling (Figure 4.7).

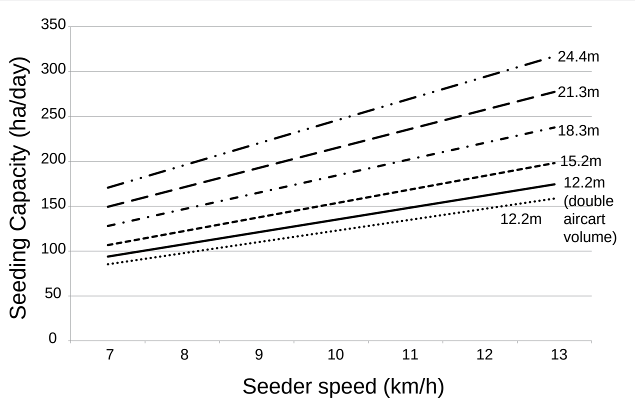


Figure 4.7 Calculated effect of seeding speed and seeder width on seeding capacity 10 h/day and 100 per cent seeding efficiency. Doubled air cart size assumes a current downtime of 20 minutes to prepare for refill and restart seeding. The number of refills is halved, giving 50 per cent less time when not seeding or loading (from Blackwell et al. 2013).

Other strategies used by growers include:

- Widen row spacing and use twin or fuzzy rows of crop to allow the seeding speed to increase, for example, 15 inch row spacing could increase speed by 20 per cent.
- Plan to eventually double the bar width, for example, 30 ft to 60 ft or 40 ft to 80 ft, to retain compatibility with existing permanent wheel tracks.
- Increase seeder width by 1.5 times so every second run fits permanent wheel tracks, for example, 40 ft to 60 ft.
- Run two seeders with smaller tractors to also reduce your capital depreciation and improve flexibility of tractor use.

Harvesting efficiency priorities

1. The main priority seems to be to use the widest front possible and travel as quickly as the threshing efficiency allows.
2. Use a chaser bin, which can increase harvest capacity by around 30 per cent.
3. Use of a 'mother bin' can also improve harvest efficiencies.

There do not seem to be many operational features that can be changed to improve harvesting efficiency and maintain the same harvesting width when a chaser bin is used to unload on the run. However, attention to run length can reduce the dead run time for chaser bins having to go all the way to the end before coming back on the next run.

Consider combinations of the main priorities to enable the most benefit at least cost.

Longer term strategies

Each farm and circumstance will be different, but it may be possible to use the above strategies for short term benefits of compaction control and still have a medium to long term plan to modify track widths and operating width to enable more and more of the heavy loads to stay on permanent wheel tracks in transition toward a complete CTF system.

4.3 Match the tracks

Wheel track spacings are commonly 3 m or 2.2–2.4 m. Three metres is around the ideal spacing as this will incorporate the header. Headers on dual tyres don't match as well as headers on rubber tracks. There is an increasing range of machinery that can come from the factory set at 3 m. It is important to check that the machinery can be modified to have a wheel track of 3 m. Be aware that not all manufacturers will warrant machinery modified to 3 m so check the warranties for each machine and follow the appropriate occupational health and safety standards. Wheel tracks of 2.2 m are usually used in systems that only match the seeder and the sprayer. While this is a great start, with experience, CTF farmers have found they will eventually move out to 3 m to include the header and wish they had started from there. Remember that wheel tracks can be changed. The residual subsurface compaction will need to be removed mechanically on most Australian soil types.

4.3.1 Options for modifying wheel tracks out to 3 m

(exert from Webb et al. 2004)

Boomspray

It may be possible to move and strengthen the axles. Hydraulically adjustable axles (2–3 m) that will extend or retract the axle for more convenient road travel are commercially available. Alternatively, change the sprayer, especially to a self-propelled model if moving to 3 m wheel tracks. Widening the wheel tracks to 3 m on boom sprays is usually fairly straight forward, and most farmers do their modifications themselves.

Tractor (spraying, seeding and spreading)

- Use manufacturer's adjustments.
- Extend and strengthen axles.
- Use 'cotton reels' to extend front wheel assist axles.
- Change to a tracked tractor with row-crop settings for a 3 m wheel track (normally done at the factory–there is limited option for aftermarket changes).

See Photos 4.3, 4.4 and 4.5.

Photo 4.3 Warranted front-end extension (Source: Tim Neale, precisionagriculture.com.au).

Photo 4.4 Cotton reels have been used to extend the axles to 3 m on this JD4250MFWD (Source: DAFWA Bulletin 4607 Webb et al 2004).

Photo 4.5 New Holland Front Wheel Assist on 3 m with cotton reels (Source: Tim Neale, precisionagriculture.com.au).

It is better to extend (cut and weld) the axles because farmers who have used cotton reels to extend their front axles have reported increased wear on the wheel bearings and king pins, which sometimes leads to axle failure. However, if the tractor is needed for other purposes such as mowing, the ease of removing the cotton reels to narrow the track is an advantage.

It is reasonably easy to find an engineering/fabrication firm that will make spacers for front ends of Front Wheel Assist tractors, however more advanced modifications (such as cutting and welding of axles) are highly specialised. The only company we are aware of is C&C Machining & Engineering in Toowoomba, Queensland (Photo 4.6 and 4.7).

Photo 4.6 C&C Machining & Engineering axle modification (Source: Tim Neale, precisionagriculture.com.au).

Photo 4.7 C&C Machining & Engineering axle modification spacer on certain John Deere tractors (Source, Tim Neale precisionagriculture.com.au).

Seeding tractor

Duals can be removed within manufacturer's specifications to allow singles on 3 m centres. In some cases dual or triple tyres may still be required in the early stages of establishing permanent wheel tracks to help provide enough traction for deep ripping through the existing compaction. The additional wheels may also be needed for flotation in other parts of the seeding program. To confine most of the compaction to the main wheel tracks if the spacing is 2 m, increase the pressure in the inner dual tyres and reduce it in the outer tyres. The outer tyres then cause less compaction outside the wheel track and can improve flotation when off the track, such as on end workings, like trainer wheels on a child's bicycle. Be careful not to reduce the pressure in the outer tyres too much and cause tyre damage. Minimum tyre pressure specifications must be observed and the combined pressures must be sufficient to carry the total load.

In 3 m wheel track systems, often the outer dual is on the wheel track and inner off but tractor warranty might be affected by low inner and high outer tyre pressures. One grower in Western Australia successfully fitted undersized outer duals to his seeding tractor with modified rims, which avoided all the problems of under inflation mentioned above and the outer wheel barely touched the soil in normal CTF operations, just provided extra floatation in areas with extreme sinkage. The same principle should be able to be applied to spraying and spreading equipment for wet conditions on boggy areas and headlands and avoid some wheel track rutting. Photos 4.8 and 4.9 are examples of seeding tractors modified to 3 m wheel track.

Photo 4.8 John Deere tractor on 3 m (Source: Andrew Whitlock, precisionagriculture.com.au).

Photo 4.9 4WD Case on 3 m (Source: Tim Neale, precisionagriculture.com.au).

Photo 4.10 John Deere tracked Tractor on 3 m (Source: DAFWA).

Air-seeder carts

Modification of airseeder carts to 3 m is normally straight forward, and most farmers do these themselves. There have been instances of failures, so if unsure engage an engineering firm.

Spreader

The axles of the spreader could be modified using cotton reels or old truck rims or by extending the axles for 3 m tracks (Photo 4.11).

Photo 4.11 The spreader is mounted on an old truck axel extended to 3 m. Modifications to vehicle axles may require risk assessment on farm and recertification for road use (Source: Webb et al. 2004).

Harvester

It is difficult to change the axle of a harvester so most other machines must be modified to match it. The front wheels could be rotated on some older model harvesters. Access to grease points behind the wheels may be reduced on some models. The general rule to modifying harvester tracks is that the front wheels are set at their minimum track and the rear wheels follow within the wheel marks of the front wheels.

Chaser bins

Axles can be widened to fit wider wheel tracks, but the main difficulty is unloading the harvester while both are on adjoining wheel tracks. Rob Taylor of Dalby, Queensland has a catching hopper on the side of his chaser bin and a cross auger to distribute the load evenly (Photo 4.12a and b).

Old PTO headers can be converted into chaser bins that fit a 3 m track. The header auger must then be long enough to reach. For example, a 9.1 m harvester front can unload into a chaser bin on adjacent wheel tracks with a 6.7 m auger. Auger extensions are available for most headers to unload into a chaser bin from the wheel tracks (Photo 4.13 and 4.14).

Photo 4.13 Auger extended to allow unloading on the wheel tracks (Source: DAFWA Webb et al 2004).

Photo 4.14 Auger extension (Source: Tim Neale, precisionagriculture.com.au).

There are a number of companies now offering chaser bins that can gather on 12 m CTF or even wider. These include Dunstan, Oztec, Finch, and White. Options include a basic slide on the side of the bin and bubbler augers inside the bin, through to fast moving rubber belts at the top of the machine. Auger extensions are also available for most headers.

Photo 4.12 a) Catching hopper and cross auger on the chaser bin to allow unloading from the wheel tracks; b) Catching hopper on the chaser bin (Source: Rob Taylor).

4.4 Choose the type of wheel track you want to leave

There are three commonly used options for wheel track design (Photo 4.15 a, b and c).

The original CTF wheel tracks used in Queensland and Northern NSW were left bare by removing the tines behind the wheels. Research has shown that the overall yield increase of the crop growing in un-compact soil and the higher yielding edge rows from better access to nutrients more than compensate for missing one or two rows of crop. However, many growers have found that bare wheel tracks can lead to severe erosion and weed control problems.

In areas, especially on sandy soils, where there is risk of weeds developing herbicide resistance, shallow seeding the wheel tracks is a safer strategy. Herbicides like trifluralin, used to control ryegrass, require some cultivation to activate. It may be that over time, as the wheel tracks harden and become a hostile environment for growing crop or weeds, the tines can be lifted and bare tracks left in a zero till system with insignificant weed seed burial.

If in-crop guidance is needed for machinery that does not have autosteer with a sown wheel track then a central guide row can be left by moving two centre tines closer together or further apart (see the Barber Case study in section 8). Leaving the tines down for the first few years of working in a controlled traffic layout may also help to smooth the old workings, evening out the paddock to reduce wear and tear on machinery from rough running.

Another option for a permanent traffic lane if weeds are a concern and some in-crop guidance is desired, is to leave a 'fuzzy' track. Fuzzy wheel tracks, as described in Webb et al. 2004, are made by rolling topdressed seed into the wheel track with one of the following wheels of the seeder. The seed and fertiliser is sprayed from hoses taken out of the seeding boot in the wheel track zone and strapped to the frame about 800 mm above the ground. The wheel rolls them in and a broad green band of crop is formed. This can be distinguished from the sown rows next to it and followed for spraying and spreading on the appropriate seeder laps. Lugged tyres are better for 'planting' this topdressed seed. Trifluralin and drought can be a problem with this method. The risk of crop damage from trifluralin is increased because of lack of incorporation and survival of ineffectively planted seeds on the soil surface will be reduced by drought due to poor germination in dry soil. Fuzzy wheel tracks are easily seen in cereals but can be hard to distinguish in crops with a dispersed canopy such as canola.

A problem that may be found with sown or fuzzy wheel tracks is delayed crop development leaving green heads in the wheel track zones. Some have suggested putting shields on the harvester knife where the wheel track is to avoid harvesting poor quality grain.

Most growers in broadacre areas of Western Australia are now sowing their wheel tracks in cereals and some keep them bare in broadleaf crops. Some growers are using disc units in their permanent wheel tracks to sow the crop there, which retains more firmness in the wheel track than using tines.

Photo 4.15 a) Bare Wheel track; b) Fuzzy Wheel track; c) Sown Wheel track (Source: Western Australian Agriculture Authority).

4.4.1 Setting up the bar row spacings for the wheel tracks

(exert from Webb et al. 2004)

When setting up the bar the guess row is very important to consider. The guess row is the gap between two neighbouring seeding runs, for example one row spacing (Figure 4.8). If the guess row is not considered when setting up the bar, the gap between two neighbouring seeding runs can be too small or rows may overlap. The overall width of one seeding pass is obtained by measuring outside tine to outside tine plus one row spacing (half a row spacing at either end). It is important to measure this as it may be sold as a 60 foot seeder but may not be exact.

Tine spacing does not have to be evenly spaced across the bar. A variation in tine spacing, such as rows between the wheel tracks closer together, can provide some extra in-crop guidance. This is particularly helpful if you do not have an accurate guidance system on all machines or if the guidance system is not working. Some farmers start by:

1. setting up the tines for a centre row or central gap in the middle of the seeder bar
2. setting the tines in place around the wheel track
3. setting the tines on the edges on the bar
4. filling in the gaps.

If you are going to change the row spacing between cereal and pulse crop or summer crops you may wish to keep tines more evenly spaced. If you are planning to include an inter-row shielded sprayer in the system, ideally the tine spacing needs to be the same on both sides of the bar.

The following row spacings work well if alternating between wide and narrow row spacings using 3 m centre wheel tracks:

- 37.5 cm/75 cm
- 25 cm/50 cm
- 19 cm/76 cm

If using 2 m wheel track centres, try:

- 34 cm/101 cm
- 50 cm/101 cm

4.4.2 Wheel track maintenance

(exert from Webb et al. 2004)

Good wheel track maintenance to avoid long-term problems relies on setting up the system well by:

- choosing the most efficient direction for the in-paddock operations and water movement
- deciding on the most convenient access for loading and unloading
- taking care with areas prone to being wet
- setting up the whole system well with unripped wheel tracks where an initial deep ripping is employed.

Once the system has been designed, it is important to maintain the wheel tracks to prevent problems such as weedy or deeply rutted wheel tracks.

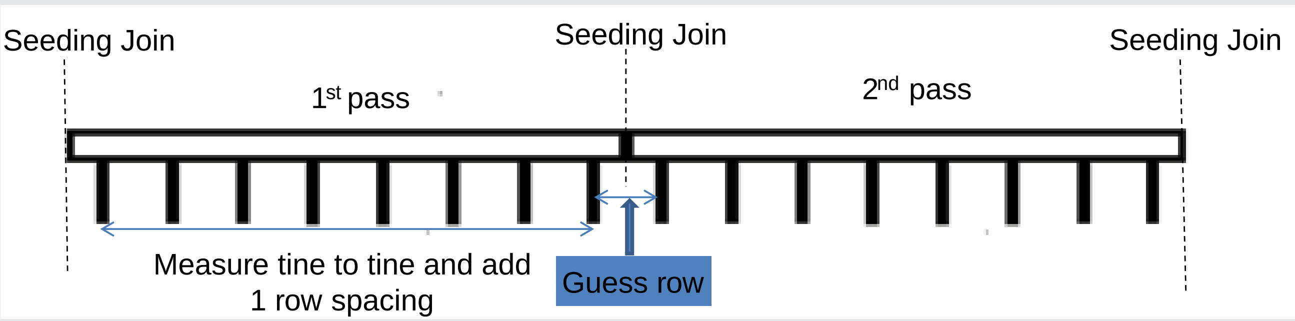


Figure 4.8 Measuring the seeder width, remember the guess row.

Making wheel tracks in wet conditions

Making wheel tracks on soil too wet and loose has sometimes caused excessive sinkage in tracks. Not cultivating or deep ripping the wheel track, cutting shallow or using disc seeding units where the wheel track is planned can help. This ensures a firmer track and less sinkage. The best approach is to avoid conditions that are too wet but, if necessary, running some tracks at slightly wider widths than others can also help to spread the sinkage.

Rutted wheel tracks

Over time wheel tracks can become rutted and rough, particularly if traversed while wet or filled with water (Photo 4.16). Ruts can be filled by a grading chain or a smudge bar mounted on the cultivator or seeder to pull dry surface soil back into the rut and firm it with a following wheel, such as from the tow behind bin. There is a custom built machine called a Grizzly Wheel Track Renovator that has been designed to drag soil back into the tracks and smooth them out (Photo 4.17). This is a separate operation but can be done outside of the busy season. Alternating wheel tracks for each operation is another option. Tyres could also be rotated to pull in soil with the tread pattern. Undersized outer duals (as explained above) may also be a useful option to minimise rutting. Some CTF growers in Western Australia are discussing filling deep ruts with gravel.

Photo 4.16 Wet wheel tracks (Source: Tim Neale, precisionagriculture.com.au).

Photo 4.17 Grizzly Wheel Track Renovator (Source: Tim Neale, precisionagriculture.com.au).

Losing depth control at seeding

If the main seeding bar wheels are in depressed wheel tracks, and the seeder has no independent depth control for each sown row, the rows near the wheel track can be sown too deeply. Independent depth control on each row using, for instance, parallelogram seeder units from Janke, Gyral and Ausplow or 'U' boot designs, can help overcome this problem (or maintenance as suggested for rutted wheel tracks).

Spray-only wheel tracks with tramline controllers

If not using a GPS guidance system too many bare wheel tracks can create confusion with the sprayer operator when it comes to choosing spraying wheel tracks. A solution to this is to set up the bar to seed wheel tracks very shallowly, compared to other rows (this digs up less wheel track and conserves some firm running), then use a tramline controller to turn off the seed only on the runs needed for spraying.

Tramline controllers can be bought from Europe or North America. These automatic controllers just need to be told how many laps of the seeder fit into one width of the sprayer. They will use electronic signals and solenoids to automatically close off the correct number of rows to fit the sprayer and spreader wheels in the paddock and match the seeder. The controller may also be able to change over the marker arms at the end of each run. The current designs are for up and back seeding. If using DGPS guidance, another option may be to seed every spraying run first with the wheel track tines up then come back and fill in with the tines down.

Controlling weeds in bare wheel tracks

If more weeds develop in bare wheel tracks than the rest of the paddock some options are:

Use a narrow bare wheel track. This means the wheels may run on the edge row causing the head in the rows of the wheel track to stay greener for longer than the rest of the crop or reduce grain quality. If the harvester fits the system, guards could be put on the knife in the wheel track zone to prevent green heads from going through the harvester.

Alternate wheel tracks for spraying so that unwheeled wheel tracks are sprayed resulting in low dust and no herbicide–blunting wheel impact on the weeds in the non-wheeled wheel tracks.

On some soil types, the use of alternate wheel tracks for spraying may also produce beneficial wheel damage to weeds in the wheel track.

Some UK farmers spray knockdown herbicide onto the tyres of the sprayer to clean up the wheel tracks.

Put extra nozzles, higher rate nozzles or drop down nozzles on the sprayer in the wheel track position. Crop deflectors could be used to minimise crop damage.

Shielded spray hoods on bare wheel tracks could be used while spraying (slowly), as a separate operation if some wheel tracks are worse than others or on the seeder (Photo 4.18).

Reduce dust when spraying. Dust from bare wheel tracks can be a problem when spraying. To reduce the dust and counter its effect on herbicide uptake, try using double nozzles as shown in Figure 4.9.

Photo 4.18 Spraying Shield and straw discs on the wheel tracks to assist with weed control in the wheel tracks (Source: Glen Riethmuller, DAFWA).

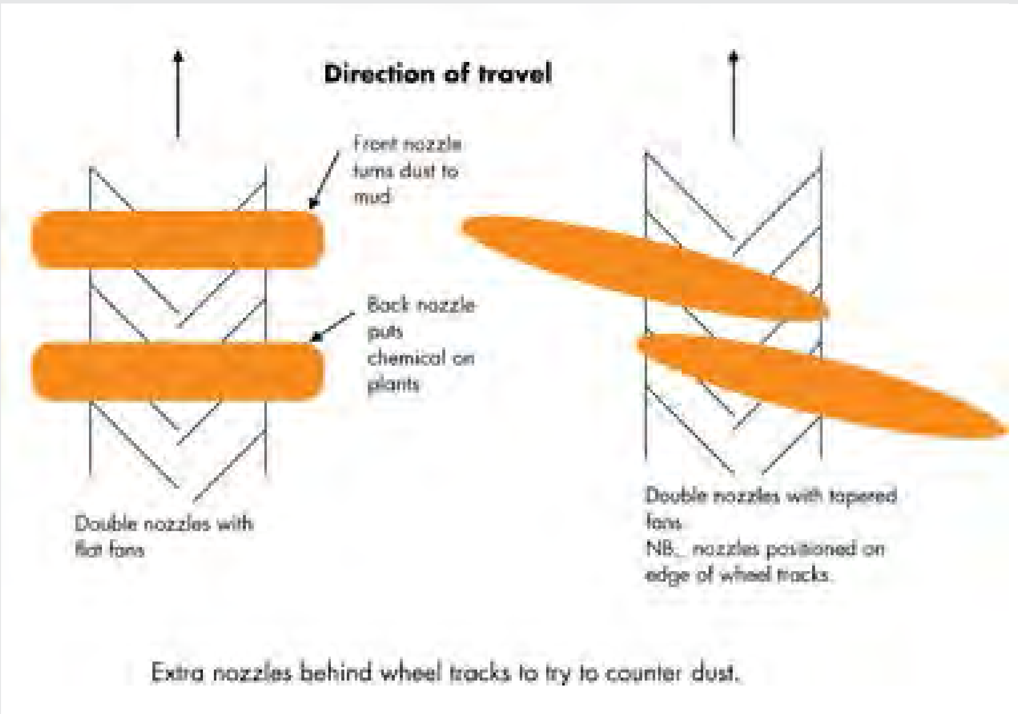


Figure 4.9 Extra spray nozzles installed behind the wheels can help overcome dust problems (Source: Webb et al 2013 originally supplied by Conservation Farmers Inc. and the Department of Natural Resources and Mines Queensland from 2003 Controlled Traffic Farming Guide. Conservation Farmers Inc, Toowoomba Queensland).

5. GUIDANCE SYSTEMS

A good guidance system will help establish evenly spaced permanent traffic lanes to minimise compaction and overlap. Controlled traffic farming systems are most efficient when DGPS autosteer systems accurate to +/- 2 cm are used. The larger the cropping area, the greater the savings from preventing overlap by using machine guidance. Increased cropping input efficiency tends to deliver three to 10 per cent savings on input costs. The larger the farm, the shorter the pay-back period. Management of underlap and driver fatigue are also important benefits of an investment in autosteer.

Ideally if adopting a CTF system, aim to purchase RTK autosteer when possible. In the meantime there are some lower cost options that can get you started.

GPS Guidance for in-crop operations is not essential if you leave a bare wheel track or central guide row. Centre guide rows can be made by widening the two middle rows or leaving a broad row (Photo 5.1). Visible tramlines are another form of post-seeding guidance for example a bare or fuzzy tramline. All post-seeding guidance relies on accurate seeder positioning with its own suitable guidance system.

Photo 5.1 A central guide row made in the centre of the bar by pushing two rows close together (Source: Western Australian Agriculture Authority).

Getting the permanent wheel tracks marked out at seeding is the most critical step when establishing a CTF system. Visual GPS guidance systems with sub-metre accuracy will not do the job as these systems do not offer accurate repeatability. A mechanical marker arm can be more accurate (Photos 5.2 & 5.3).

Photo 5.2 One marker arm on a 60 foot seeder, seeding round and round (Source: Western Australian Agriculture Authority).

Photo 5.3 Two marker arms on the seeder allow you to work up and back following the mark of the arm on the previous run (Source: Western Australian Agriculture Authority).

5.1 Marker arms

Marker arms can be as simple as a length of steel pipe supported by cables and dragging a section of anchor chain. The more advanced marker arms are fully hydraulic, double fold systems. The cost of building you own marker will vary depending on what materials you have available and the complexity of the design. The cost of a fully hydraulic arm marker arm ranges from $3500 to $6000 (2003 prices). However, this is also good payment towards a GPS system. The disadvantages of using mechanical marker arms are obstructions such as trees, and regular repairs.

5.1.1 Overcoming problems using marker arms

(exert from Webb et al. 2004)

Difficulty finding marks in stubble

The use of chains and 'mad rabbits' on marker arms is a very old method, but has advantages over a disc because of lower maintenance, a clearer mark and less dependence on the height of the arm.

Following a mark or line

This can be more accurate if a mark on the front of the bonnet is lined up with a mark on the cab screen to form a 'gun sight'. Bonnets with a central crease or line are better for this. Putting a front wheel on the mark is also reliable, but this method reduces the ability to straighten out 'wobbles'.

Difficulty finding tramlines after stock damage

There is little known about the effect of stock on tramlines. Some farmers are reporting difficulty finding the tramlines the following year from stock damage. Placing peg or selecting a landmark to mark the centre of the first run may provide guidance for future years. Contract GPS tramline marking is another option if the system used is accurate enough to return to the same place the following year.

5.2 GPS/GNSS guidance

Electronic guidance systems are based on global positioning systems (GPS) or now being called GNSS (Global Navigational Satellite Systems) that includes satellites from USA, Russia, Europe and China. These systems offer more reliability and practicality than marker arms (Photo 5.4). They range in complexity from a differential (dGPS) system that obtains corrections typically from a geostationary satellite (like Omnistar and Greenstar) a real time kinematic (RTK) system with differential correction from a local on-farm base station (Photo 5.5 and 5.6). DGPS systems have a steering accuracy of +/- 10–90 cm (sub metre) with drift from hour to hour. High quality base station systems are accurate to +/- 2 cm with little drift but they have shorter range (approximately 20 km) and most use radios, which require line of sight to transmit their correction signals. Continuously Operating Reference Station (CORS) networks are also available through many parts of Australia and can provide you RTK level accuracies without the need to purchase your own base station.

The subscription signal comes into the tractor via a 3G data plan, so this is a great option for large farms, contractors and areas influenced by hills and dense tree populations.

Photo 5.4 Case IH FM1000 screen on a tractor at the Merredin Dryland Research Institute (Source: Glen Riethmuller).

Photo 5.5 (left) Setting up a Trimble base station at GSARI Katanning (Source: Glen Riethmuller, DAFWA).

Photo 5.6 (right) John Deere base station setup with a 7 m mast and solar panels (Source: Andrew Whitlock, precisionagriculture.com.au).

Automatic steering can be applied to most current types of tractors. Automatic steering uses a steering kit fitted to each tractor and takes over from the steering wheel. The 'steer assist' types can be transferred between tractors (approximate cost $3000–$5000), although not the integrated steering kit (approximate cost $8000–$10 000), which is plumbed into the tractors hydraulics (2013 prices).

Visual guidance systems can operate up and back or round and round. Autosteer systems generally have been designed to work up and back (parallel), although a few manufacturers have developed a system to steer round and round. The cost of electronic guidance systems can range from DGPS visual guidance packages starting at $500–$40 000 plus GST for RTK GPS with autosteer (2013 prices).

Satellite reception can sometimes deteriorate or drop out. The presence of on-ground marks (such as tramlines or central marker rows) will provide some guidance when these technical difficulties occur. This is a sensible 'belt and braces' strategy. Software has been developed to predict when satellites are likely to be down. During these times you could undertake maintenance or other jobs, change shifts or fill up. Buying a GNSS receiver in addition to a GPS only receiver will allow you to access more satellites and lessen this impact.

It is recommended that when buying GPS guidance system you stay with the one brand. As each brand can use a different method for delineating A–B lines which essentially means you can end up off the wheel tracks by a significant distance as you move across the paddock.

Ideally the same A–B lines should be used for all operations. If different A–B lines are set for each operation, a wider zone can be compacted than necessary if the lines are slightly off centre each time.

Waylines are the line between two points A and B in a GPS that set the direction of travel. A complication found by CTF farmers is that not all GPS systems use the same co-ordinate systems therefore if different machines are using different GPS systems over a one kilometre distance, of a square 100 ha paddock, this can lead to an error of 450 mm in the wheatbelt of Western Australia. Some GPS systems use a spherical projection model (geographical system: latitude and longitude) where as others use a parallel projection (UTM map grid: eastings and northings).

The major manufacturers are developing software that will allow waylines set in a different co-ordinate system to be imported into their GPS however until these developments are released it is recommended to use the one brand of GPS on all machines.

Contractors using different waylines is another challenge. It is possible to export your waylines and have them on a card ready to give each contractor as they come in to commence operations. This is assuming they are using the same base station and same system. Another option is to use the A+Heading feature of the guidance system. This feature uses A as the given starting point plus the heading (compass direction) of the waylines (A–B lines) you wish to follow rather than mark a finishing point B which creates the A–B line. This will at least allow quicker start-ups for the contractor, and minor adjustments can be made in the paddock.

GPS guidance system with accuracy 10 cm can be used to set up permanent wheel tracks however be aware of drift over time or if you stop to fill up. When you come back to start the next run you may need to reset/nudge the system so you are on track. There will be some drift over time for all operations.

Guidance terminology

This is some of the terminology used to evaluate electronic guidance systems.

Accuracy—Accuracy is a statistical measurement of freedom from error or how close a measurement is to the true but unknown value. It is generally defined as an interval, confidence level or probability within which the true value is likely to occur. For example, one metre circular probability error (CEP) means that 50 per cent of the measurements are within one metre of the true position.

Cross-track error—the distance from the current wayline measured at right angles to the wayline.

Precision—Precision refers to how small a unit the instrument can measure. A centimetre level receiver is more precise than a metre level receiver, for example a poor base fix with a DGPS product can result in very precise measurements that are offset from the true position, for instance very precise but inaccurate.

Baseline—the distance between the base station and the rover/tractor.

Repeatability —Repeatability or repeatable accuracy is a statistical measurement of the accuracy with which a user can return to a previous position. The main confusion with the term repeatability is the time frame within which it is used. To reduce confusion, the term 'Absolute repeatability' is used by some manufacturers to refer to repeatability that can be used from season to season.

Wayline or A–B line—Line between two points, A and B that sets the initial direction of travel and subsequent path of travel parallel to this line.

Horizontal Dilution of Precision (HDOP)—this is a term used to describe how the satellites are positioned around the globe. If all satellites are straight across the sky it gives poor position accuracy and a high HDOP. Low HDOP is good.

6. LAYOUT PLANNING

Whole farm planning is very important when introducing new technologies such as CTF into your system, as often a change in paddock layout is required to get the most effectiveness from the new technology. CTF is traditionally done working up and back in straight lines. This is the most efficient way of working a paddock because:

- driving to a straight line is easier than a curved path
- double worked corners of round and round operations are eliminated
- most seeding and tillage equipment and especially precise inter-row or close to row operations work more easily and wear more evenly in straight line working.

The widespread uptake of autosteer guidance has led to most operations having already converted to up and back rather than round and round. However, not all paddocks maybe suited to sowing up and back because of complications with paddock shape and obstructions.

Useful tools for planning layouts include aerial photographs, farm maps, topographic and soil type maps, yield maps satellite imagery and farmer knowledge. CTF is very compatible with precision agriculture technologies such as variable rate technology and image analysis.

Some layout changes may take more than one season to put into practice but it is helpful to have a plan for the future. If in doubt about layout contact a professional consultant, as layout inadequacies may lead to logistical complications during such times as harvest or severe erosion damage in some landscapes that may often be expensive and frustrating to remedy.

To design the most efficient layout consider:

- length of run
- shape of the paddock
- access roads
- wheel track orientation and sun angle
- surface water control
- erosive wind direction
- typical crop lodging direction
- integration with tree and forage planting.

6.1 Length of run

For maximum efficiency of cropping operations, generally, the longer the run the better, as the numbers of corners and turnings are reduced. In some cases it may be practical to join paddocks (Figure 6.1).

At the same time, consider how practical long runs are and surface water control issues. Some growers are choosing to plant trees to straighten up the edges of paddocks or keep paddocks with too many obstacles as dedicated stock paddocks.

There have been cases of very long narrow paddocks being easier to harvest and can have less empty running of sprayers and spreaders when the direction is at right angles to the longest side; any additional time for extra turns when spraying and seeding is compensated by much more efficient harvesting and unloading during threatening harvest weather.

In some cases very large and long rectangular paddocks have been divided by internal roads at right angles to the longest side to be used at harvest and seeding time and maintain the efficiency of spraying operations in the direction of the longest dimension.

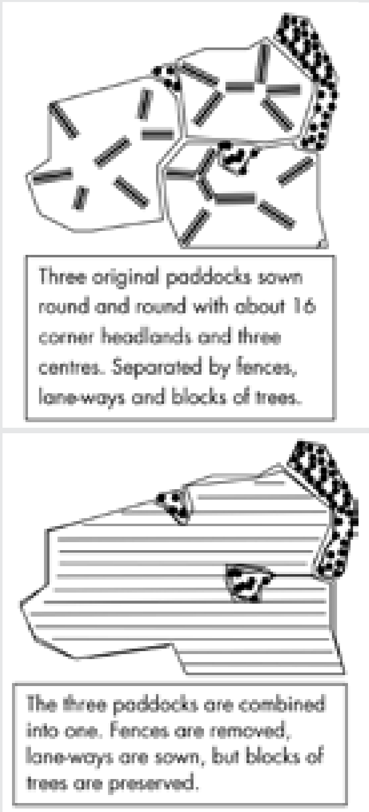


Figure 6.1 Hypothetical example of improved efficiency from longer runs Hypothetical example of improved efficiency from longer runs (Source: Western Australian Agriculture Authority).

6.2 Shape of the paddock

Hilly dissected landscapes, numerous small lakes or saltpans and irregular areas of vegetation, as well as rock outcrops and buildings often complicate the shapes of cropping paddocks, even when fences have been removed. Selective removal and (in the case of vegetation) smart replanting patterns can help simplify shapes, but the landscape may still oblige shapes that are difficult to work in cropping operations.

In very complex and broken shaped paddocks some growers have sown the majority of the area in one convenient direction, but small awkward parts are sown round and round to reduce the amount of turning on the ends of runs and reduce seeding time. However, spraying and perhaps harvesting may still be done in a common direction for the whole paddock.

6.3 Access roads

Long runs are the most efficient for loading and unloading machinery during seeding and harvesting. Think about where your access roads need to go and the more convenient headlands for unloading. Calculate how far you can travel at seeding before you need to refill and at harvesting before you need to unload. Access roads can be used to turn around on and be designed to control surface water.

6.4 Wheel track orientation

Wheel track orientation may vary depending on the characteristics of the paddock, soil type and slope. If the paddock is fairly uniform, select the longest run. Some people choose to run traffic lanes north–south to avoid driving into the sun early in the morning or late in the evening. North–south run directions can be important in Western Australia given lower sun angles in winter where you may see uneven flowering in crops like canola (especially in raised bed systems).

Some research has shown east–west orientation of rows can help crops compete better with weeds by shading them more than in north–south row orientation. This may be a justification for east–west permanent wheel track layout. However, there is also evidence of the greater exposure to solar radiation in east–west orientation causing higher leaf temperatures from more canopy heating than north–south row orientation. In drier climates and dry growing seasons this may induce crop yield and quality reduction through extra soil water use to cool the leaves by transpiration.

The other issue to consider when laying out wheel tracks is whether you go up and down slope or across slope. There are both positives and negatives for each situation, so you will need to assess each situation on an individual basis.

Working up and down allows the slope to drain uniformly and reduces the risk of rill formation from furrow overflows when the paddock is sown on the contour. The aim of up and downslope is to keep the water contained within each crop row, thus preventing concentration—similar to a tin roof. However, without careful design and some remediation, the run-off may be directed by the furrows to areas that would not normally receive the flows, causing erosion, flooding and waterlogging. In heavy rainfall episodes, run-off from wheel tracks, up and down the hill, may cause massive erosion in the tracks if the volume of water is too large, tracks too deep, slope to great or the run too long. This must be balanced against the problems of contour layouts where heavy rainfall leads to flow concentration and the formation of deep gullies in the paddock. Cross-slope layouts may also cause machinery (especially drawn implements) to 'creep' down the hill, leading to issues with staying on the CTF tracks. In these cases, implement steering is almost a necessary option.

In light rainfalls, seeding along the contour can trap moisture in the furrows. Across slope working can also distribute water evenly across the paddock. Waterlogging or erosion could occur if the water is channelled into old gully lines or low points in the paddock. In both cases erosion may occur if water collected from elsewhere enters the furrows or tracks.

6.5 Surface water control

In developing your CTF system it is important to make sure the layout of your wheel tracks are compatible with the control and safe disposal of run-off. Consulting contour maps and understanding the water movement on your property is a good background for determining wheel track layout and the appropriate control measures. Important things to consider include:

- maintaining good stubble cover
- degree of slope
- length of slope
- soil infiltration properties
- rainfall intensity
- preventing run-on from areas that shed water, such as roads or rocky outcrops
- water control and disposal options.

Soil infiltration

As a general rule, the better the soil structure, the higher the infiltration rate. After a long period of no-till seeding and no stock, soil structure between the rows can be much more permeable because the macropores and bio-pores are protected from annual disturbance. The best evidence of this happening is the lack of increased drain or dam filling, even in wet years. This seems to be occurring on many soil types, with the exception of non-wetting sands. Infiltration is expected to improve even more when wheel tracks are used as restricting compaction conserves the soil structure between tracks. Infiltration also decreases as the soil profile fills up with water. If the soil pores are already full and rain falls, run-off can occur.

Stubble cover

Maintaining good stubble cover levels is important to reduce the risk of erosion by reducing raindrop impact. Organic matter from plant roots helps to improve the soil structure by binding soil particles together and providing channels for rapid water penetration. Good stubble cover levels can be maintained by practising no-till and managing grazing; this means not overgrazing during the summer months.

Preventing run-on water

Traffic lanes should be protected from any run-on water; for example, some headlands, corners, adjacent bush or rocky outcrops can shed water into tracks and cause the beginning of rills or gullies. Traffic lanes should run over a hilltop and not stop at the top to reduce the hilltop run-off being fed down a wheel track. A track on the ridgeline is generally ok, and often the best part of the paddock to place them.

6.5.1 Options for surface water control

Where there is a likelihood of water erosion, flooding or waterlogging, conservation earthworks should be installed.

Broad base grade banks

Strategic broad grade banks located at the top of the slope and appropriate positions down-slope may assist in controlling surface water when most of the seeding is up and down slope. Broad based channels can be used on two to six per cent slopes. A common practice in eastern Australia is to drive over the banks with machinery at right angles where possible, and at no less than 45 degrees, to avoid machinery damage and erosion (Photo 6.1). The broad banks channels are four to five metres wide compared to conventional channels of one to two metres so they can be seeded all the way over or along to reduce the potential for erosion and reduce weed invasion (Figure 6.2).

Photo 6.1 Layout over broadbased banks (Source: Rob McCreath).

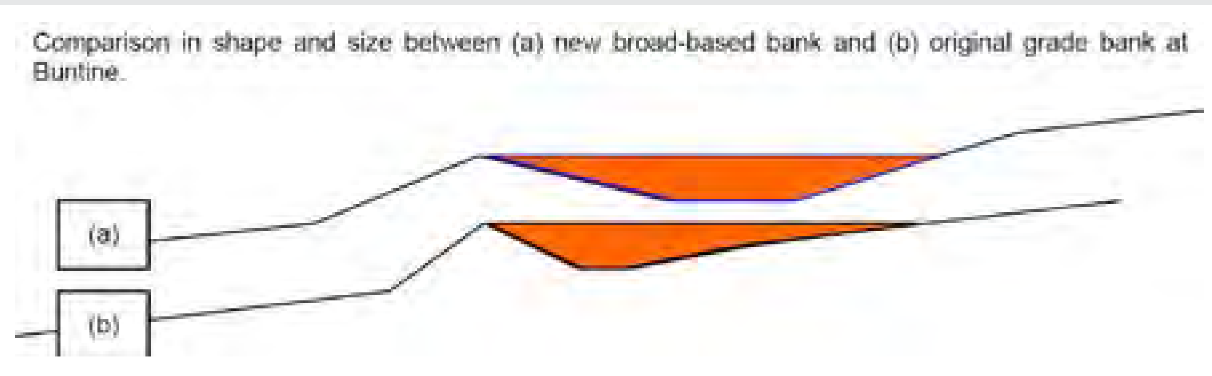


Figure 6.2 Cross section comparing the alteration of an existing bank to a broad base roll over bank (Source: Blackwell et al 2008).

Evaluation of broad based banks in Western Australia have found they do provide surface water control, however be aware of the following challenges by some farmers involved in the study:

- challenging for current large machinery to traverse slopes over 2.5 per cent
- poor seeding depth control on bank
- poor crop establishment in year one possibly due to sour soil being placed on top of the bank
- difficulty traversing the bank with sprayer even after slowing down
- impractical to harvest parallel to the direction of sowing so harvesting was done parallel to the bank.

Lower existing banks

Some growers who practice no-till and have observed run-off declining due to improvements in infiltration have tried lowering existing grade banks so they are able to be driven over by machinery. While the lower grade banks do control some run-off in some cases, they have been found to be inadequate for large rainfall events and can be a problem for machinery. Ensure you still have enough capacity in the bank, as 'half a bank is worse than no bank'. If the bank capacity is too low the bank will overflow at the lowest point that can cause concentrated rill and gully erosion that is difficult to rectify.

Access tracks catch drains

On long runs, access tracks could be made into catch drains and mounds that the seeding and spraying equipment can pass over safely during cropping operations. It is possible to work wheel tracks between existing contour banks.

Run-off from all drains and broad banks should be disposed of safely into grassed waterways, existing waterways or dams.

Experience in Western Australia of water erosion in CTF systems

Source: (Lemon 2006)

The heavy rain in early January 2006 provided a good opportunity to observe the stability of wheel tracks and raised bed drains on sloping land in Western Australia.

Interviews with several growers indicated that erosion had been minimal in parallel cropping systems running down slope. Comparisons with pasture paddocks and previous working patterns indicated that erosion could even been less in down slope working patterns.

The main problems were where water flows concentrated before finding a downhill wheel track or furrow, such as water running out of a reserve onto the paddock or a flat area within a CTF paddock where water moved across working runs prior to finding a sloping wheel track.

Other observations included:

- Erosion was worse on tracks within paddocks than on the wheel tracks.
- Cereal stubbles provided more protection than pea stubbles.
- Sown wheel tracks and furrows offered more protection than bare lines.
- Older raised beds were more stable than newly renovated beds/furrows.
- Erosion was a bit worse on wheel tracks on loamy and clay soils compared to sandy soil.

The rationale that many small furrows carrying their own water causes less erosion than a few large depressions carrying accumulated water from larger areas seems to have 'held water' in the 2006 extreme rainfall event.

6.6 Erosive wind direction

Tops of sandy hills and old dune systems can be very exposed to erosive winds. Sprayed wheel tracks in uncontrolled traffic are often observed to blow out in such exposed locations, especially when in line with the direction of the most common erosive winds. It may not be practical so sow the paddock in any other direction than the one at most risk, due to the general paddock shape. Strategies to stabilise these hill-tops, by application of topdressed clay or gravel, may be the best long term strategy to minimise the risk of damaging wind erosion.

6.7 Integration with tree and forage planting

It can be very frustrating to have previously successfully established a pattern of vegetation planting that is now incompatible with more efficient direction of cropping systems such as CTF. It has often happened when nonlinear patterns of tree plantings were compatible with previous racetrack (round and round) systems of cropping, then the farm adopts autosteer. Linear tree plantings in cropping paddocks can also lose compatibility with cropping systems when wider machinery is used.

In many cases growers have had to reluctantly remove plantings and sometimes replace them with block plantings of similar species. However, some have remained committed to the original plantings and continued to use previous methods in treed paddocks. Single trees pose no additional issues in CTF than conventional systems; and in many GPS systems there is an in-built alert system for previously marked hazards.

6.8 Using precision agriculture to design layouts

RTK guidance systems collect high accuracy elevation that can be very useful to help plan layouts to reduce the risk of waterlogging and erosion. For growers who already have RTK guidance, this is a cheap data layer as it is collected with every operation. Figure 6.3 is an example of model simulation using high accuracy elevation data to indicate where the water is ponding and the effect of changing wheel track direction to assist with drainage. In this case, orienting wheel tracks across the paddock has reduced the water ponding at the top end of the paddock. The next stage to consider is if there are any other measures that can be taken to manage the water at the lower end of the paddock.

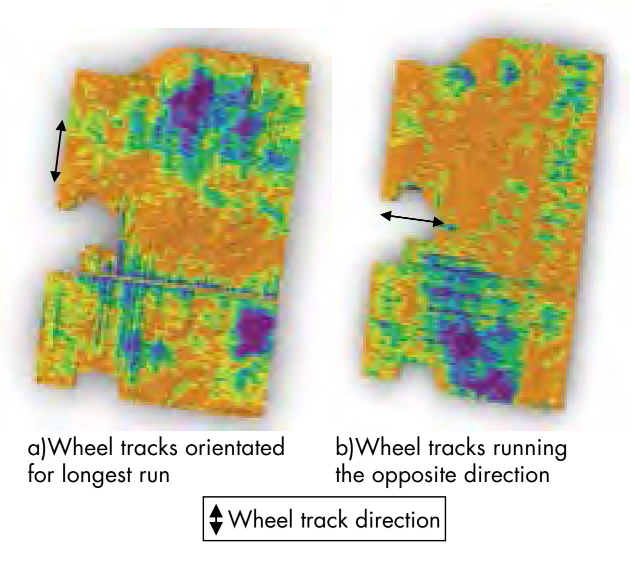


Figure 6.3 Model simulation using high accuracy elevation data to indicating change in water ponding/ waterlogging depending on wheel track orientation. Areas of dark purple indicate the deepest water through to orange that has no water ponding on the surface (Source: Tim Neale and Andrew Whitlock).

6.9 Challenges and solutions to implementing up and back working

(exert from Webb et al. 2004)

Challenge: tight turns and overlap at the end of the run for the seeding equipment.

Solution: 'rip skip': this is where every second seeding run is seeded then the seeder comes back and fills in the gaps as seen in Photo 6.2. This method can be done easily with electronic autosteer guidance.

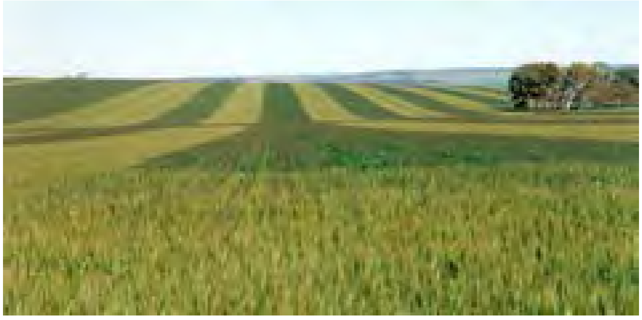


Photo 6.2 Rip skip method is visible in this photo where a different variety was put in the box to fill in the gaps. Take care not to skip too far ahead (Source: Western Australian Agriculture Authority).

Challenge: lots of switches to flick at the end of the run to lift the bar out of the ground and turn the airseeder off and back on again.

Solution A: Newer machinery may be fitted with implement control systems that can be set to do this process automatically at the end of a run.

Solution B: The 'clapper corner' was developed by Lindsay Chappel who uses the rip skipping method and leaves his bar in the ground throughout the operation, creating curved headlands on the edge of the paddock (Figure 6.4). This will be a compromise when compared to lifting the bar out of the ground on the ends and then seeding the end separately, as there will be more overlap and some parts of the headland not sown. On the other hand, the risk of errors, such as forgetting to turn the airseeder back on, is reduced. Consider seeding the ends in high weed burden situations.

Challenge: swath falls over or crop lodges. Growers working up and back have noted some problems with swathing crops down the wheel tracks as the swath tends to fall down the tracks and is too low to pick up. Another problem is lodging crops that can be picked up in one direction but not in the other.

Solution: in these cases consider aligning the layout at right angles to your prevailing wind. If this is not convenient then it may be one situation where you don't work on the wheel tracks at harvest.

Challenge: unloading at harvest.

Solution: the placement of field bins requires some planning. Work out the distance you can travel in an average crop before the harvester bin fills and put in an access road or a turn around point. Or if working with a chaser bin on the wheel tracks you need to think about what side the unloading auger is on. Harvesting alternate rows as a 'rip skip' can help.

Challenge: avoiding double sowing on the ends.

Solution: if seeding up and back there are a few options to avoid double sowing on the ends. Seed around the paddock the width of the boomspray before starting to work up and back. When turning on the ends lift your bar out when you get to the edge. The laps sown on the outside act as a guide for when to lift the bar and turn the airseeder off. Alternatively, you could seed the ends of the paddocks when you finish, or if you have a wide access road, use that as your turning point, or when using autosteer, seed a clapper corner.

Challenge: rough paddocks changing from working round and round.

Solution: seed the wheel tracks for the first few years to smooth out the paddock. Once smooth, lift the tines behind the tractor wheels. Alternatively, use a tractor with very good suspension and a comfortable seat!

6.10 Further reading on surface water control

Blackwell P, Whale P and Mildenhall L (2008) Management of surface water control for controlled traffic Farming: on slopes of less than 2.5% in the Northern Agricultural Region of WA. http://www.liebegroup.org.au/projects-2/past-projects/downhill-tramline-farming/

Keen M (1998) *Common Conservation Works Used in Western Australia*, Resource management technical report 185, Department of Agriculture Western Australia, Geraldton.

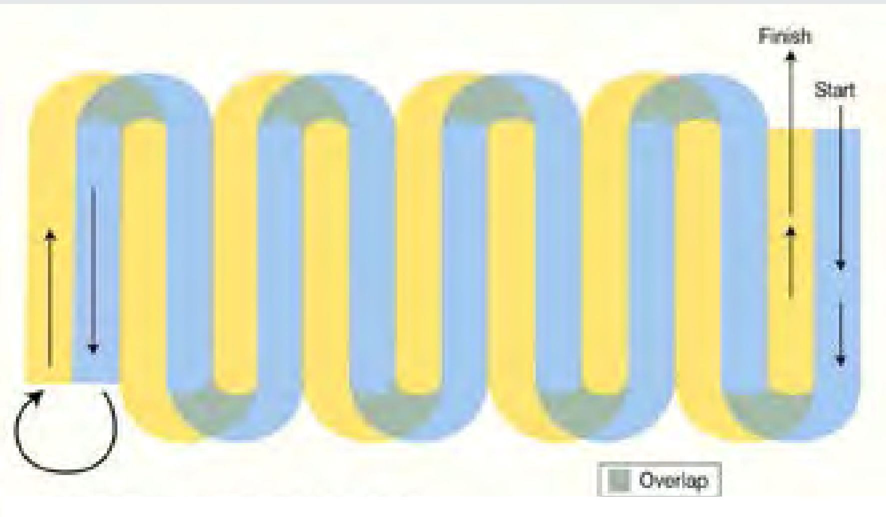


Figure 6.4
Clapper Corner (Source: Western Australian Agriculture Authority).

7. AGRONOMIC OPPORTUNITIES

Establishment of permanent wheel tracks combined with use of a sufficiently accurate guidance system can provide opportunities for in-crop agronomy and soil management without causing unwanted mechanical damage to crops or soil compaction.

Opportunities include:

- inter-row sowing which has shown to improve seeder performance, reduce potential for root disease, and also assist crops such as lentils 'climb' the wheat stubble rows to facilitate harvest
- inter-row shield spraying or mechanical weed control
- band spraying directly over the crop row, to reduce chemical costs
- relay planting (planting a new crop or pasture into an existing one before harvest)
- band application of lime, manure, fertiliser or other products
- directing chaff and weed seeds onto the wheel tracks for easier management
- a more compatible system of cropping for in-paddock large-scale trials than with machinery that has poor matching of widths and no control of cropping traffic.

7.1 Inter-row sowing

Accurate guidance systems to +/- 2 cm have made sowing on or off the previous year's crop rows achievable whether a controlled traffic farmer or not. However, being controlled traffic there is the added benefits of running on firm wheel tracks and less crop/soil damage, as well as treating all crop rows in a similar way (no wheel marks to possibly compromise the effectiveness of sowing on or between any rows).

The advantages of sowing between the crop rows compared to sowing in the same furrow each season (Photo 7.1) are better stubble handling, reduced risk of pathogens from previous crops, and reduced risk of nutrient toxicity. Caution is advised with this method in non-wetting conditions; the inter-row may have a high risk of poor establishment, especially when knife points or disks are used to sow.

Photo 7.1 Inter-row sown lupins between a wheat stubble (Source: Western Australian Agriculture Authority).

Rather than nudge the guidance system across to seed between old rows, an offset hitch on the seeder can be used to set the seeder left or right by half a row spacing and maintain good traffic control. Photos 7.2 to 7.5 are examples of offset hitches. It may be necessary to balance the pull of the bar (reduced risk of 'crabbing') by removing a tine from the side the hitch is moved towards and put it on the other side of the seeder. On some seeders other tines may also need to be moved to have a tine in front of the frame wheels to make a fresh furrow for frame guidance. The tines of larger seeders may tend to slip back into the old furrows that are the path of least resistance. An accurate guidance system or implement steer can help reduce this problem.

Photo 7.2 The late Owen Brownley's offset hitch (Source: Glen Riethmuller, DAFWA).

Photo 7.3 Mark Wandel's offset hitch (Source: Western Australian Agriculture Authority).

Photo 7.4 Offset hitch (Source: Tim Neale, precisionagriculture.com.au).

Photo 7.5 Multi-hitch for three point linkage (Source: Western Australian Agriculture Authority).

Sowing into, or immediately next to, the old rows can take advantage of the water harvesting effect of furrows and the tendency for early rains to follow preferential paths along the previous root system in the old row (Photo 7.6). This may also be an advantage for using any residual fertiliser from the previous year, although potential problems with root disease or nutrient toxicity need to be considered.

Photo 7.6 Water harvesting effect of sowing into previous year row at Hyden (Source: Western Australian Agriculture Authority).

Trials conducted at Pindar in Western Australia indicate that prefurrowing a pasture paddock dry in summer (if cover is good enough to minimise erosion risk) improves water entry and crop establishment when the crop is seeded into the furrows after early autumn rains (Photo 7.7). The main advantage may be that relatively small rains presowing can be concentrated into the prefurrows by crusting on the ridges and shedding into the furrow, reducing the risk of poor seedling establishment.

Photo 7.7 Seeding into pre-made furrows (Source: Webb et al 2004).

In non-wetting soils sowing into the previous years rows can be an advantage (Photo 7.8). Observations in trials have shown that the residual root systems from the previous crops act as pathways into the water repellent topsoil. As a result of this, the previous years rows wet up more quickly than the inter-row so in water repellent soils crops can germinate and establish more quickly and consistently (Figure 7.1).

Photo 7.8 Canola germination was much better sown into old furrows (left of photo) than between the rows (right of photo) on this non-wetting soil on the south coast of Western Australia (Source: Paul Hislop and Derk Bakker).

7.2 Inter-row shielded spraying

The even layout of a controlled traffic system is a good opportunity to use inter-row shields for spraying. Developed originally in North America as a substitute for inter-row cultivation, inter-row shields enable the use of a non-selective herbicide to be sprayed between wide crop rows to improve weed control.

Three spray circuits can be set up on the shield to run different chemicals; for example, one in the shield for between row sowing with non-selective herbicide like glyphosate, one into the row from the side of shield a selective herbicide and one on top of the row for band spraying like fungicide (Figure 7.2). This can potentially reduce the cost of herbicides by half using low cost herbicides between the rows and higher cost selective herbicides and fungicides in the crop row.

Despite showing good benefits in wide row crops in Western Australia inter-row shielded spraying has had limited uptake on broadacre farms. It is well suited to niche areas, commonly used in row cropping and smaller operations such as horticulture. It is also economic in crops that require many passes of the sprayer for fungicide and herbicides such as faba beans.

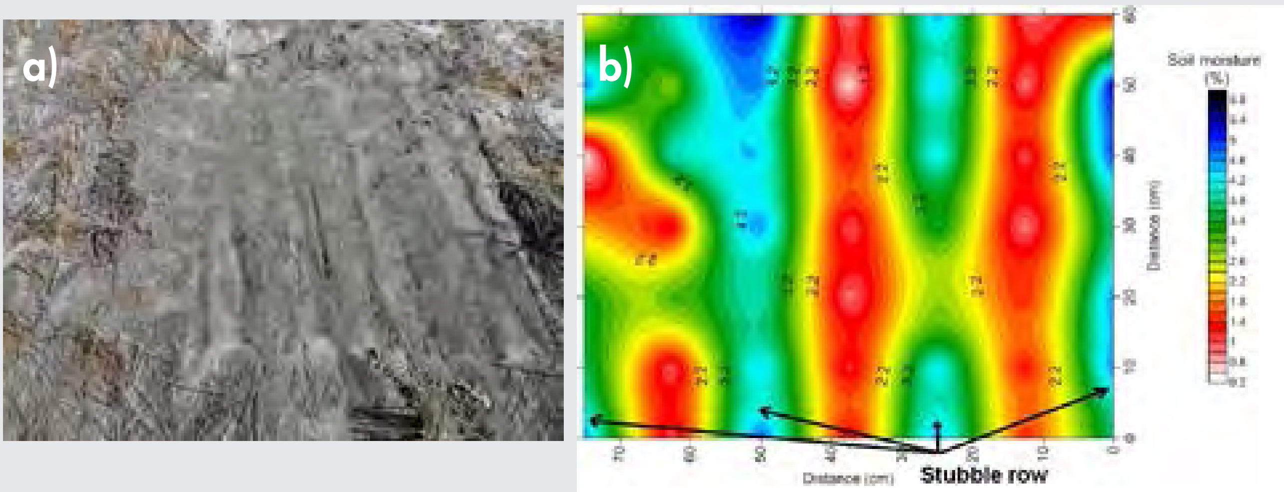


Figure 7.1 a) and b) Soil moisture pattern taken in the middle of winter in non-wetting sand near Frankland, in a paddock that was left fallow in 2012. The stubble was from 2011 (Source: Western Australian Agriculture Authority).

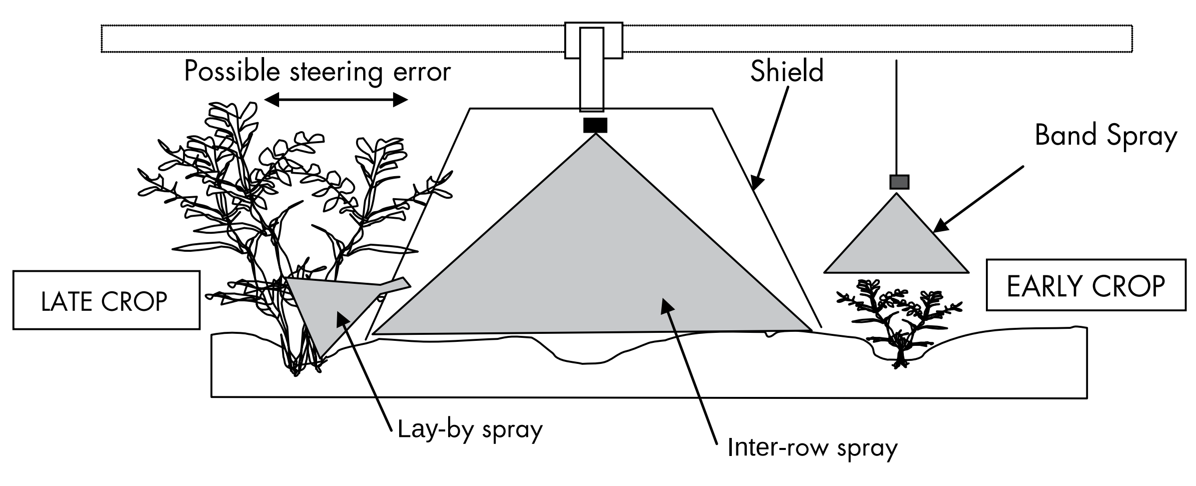


Figure 7.2 Figure 7.2 Spray circuit options in shields (Source: Western Australian Agriculture Authority).

Challenges of inter-row shield spraying found by broadacre farmers include:

1. Reduced efficiency for larger cropping programs as the tractor operates at half the normal spraying speed and the operating width is often a third of a sprayer so it is not as efficient to cover large areas. Better broadacre spray regimes and integrated weed management packages have now been developed for controlling weeds in crops like lupins for which inter-row shielded spraying showed benefits. Automatically operated tractors may overcome this limitation and allow inter-row weed control to be a more practical option in broadacre cropping.
2. Increased risk of developing herbicide gylphosate resistance if glyphosate is overused as a knockdown and in crop control or if weeds only receive a low dose (Evans et al. 2009). Weeds that receive only a half dose on the edge of the shield can potentially develop herbicide resistance. There is also a greater chance of out-crossing of glyphosate resistant plants in-between crop rows with survivors in the row, increasing the development of herbicide resistant problems. Research has shown inter-row shielded spraying in 50 cm wide row lupins can significantly reduce ryegrass population numbers and increase crop yield (Falconer et al. 2006). However, effective weed control in the row is particularly important as there was uncontrolled ryegrass in the crop rows compared to between the rows where the non-selective herbicide was sprayed. Efficacy will be greater where ryegrass populations are more susceptible to selective herbicides.

Mechanical inter-row weed control is also more convenient and efficient in a fully matched controlled traffic system. There has been a long experience of such methods in row cropping and the slow speed of such methods for large-scale operations may be better compensated by the development of automatically controlled, driverless tractors.

When setting up for inter-row shielded spraying consider the following:

- Guidance system—RTK autosteer +/- 2 cm guidance works best to reduce drift of shields.
- Seeder bar set up and row spacing-rows must be evenly spaced, but the wheel track width can be wider than the row spacing.
- Wider row spacing greater than 50 cm may be required for some crops with a more spreading canopy.
- Banding residual herbicides in crop rows can be a complementary operation.
- Shield design can vary considerably–a shield with an adjustable width provides options for varying row spacing widths.
- Mount for shield (boom, mounting arm or bracket); some shield designs allow self steering to keep good shield position.
- Nozzle mount, size and nozzle design can be very important depending on the weeds and spraying conditions and amount of retained crop residue.
- Flaps and brushes can be added to keep spray in the shield.
- A lift system to adequately lift the shields to turn at the ends or for transport.
- An anti-drip system to reduce leakages.
- A method to detect blockages in nozzles under the shield is required.

7.2.1 Shield design

Fixed shields

These are the original and most common type of shield usually mounted on a three-point linkage boom (Photo 7.9). Their position between the row is determined by the steering on the tractor therefore an accurate guidance system (+/- 2 cm RTK) is essential. The crop row must be wide enough so the shield can be far enough away not to damage the crop with steering error.

Photo 7.9 Original 'red ball' shield design (Source: Western Australian Agriculture Authority).

Self steering shields

There have been several designs made of self steering shields that have been used for inter-row shielded spraying round and round. Shields with wheels are mounted on a swivel arm on a bar. The wheels help guide the shield by either running in the furrow of unseeded rows (central wheel behind the wheel) (Photo 7.10), along the walls of the press wheel grooves when the plants are small (Photo 7.11) or along the base of the stems when the plants are bigger. These have worked with varying success, but can often accommodate curved running on the outside runs of the seeder in a paddock.

Photo 7.10 Self steering shields made from materials on farm (Source: Paul Blackwell, DAFWA).

Photo 7.11 Row crop rockets designed by Mike Collins on a 40 cm radius curve that is about the maximum angle for this set up (Source: Western Australian Agriculture Authority).

7.2.2 Nozzle selection

Selecting the right nozzles for shielded spraying to work effectively is very important. Normal boomspray nozzles are not suitable, as they have an elliptical pattern and are designed to be used with each adjacent nozzle overlapping by 50 per cent, to result in an even overall pattern.

Nozzles used for row crop spraying should have an even distribution across their width. The manufacturer normally designates them as 'even' or 'E' nozzles and they are usually supplied with the shields.

With band spraying there is difficulty in finding small enough nozzles. Trials by the Department of Agriculture and Food, Western Australia (Mike Collins) have used an 8001E nozzle at 2 bar 8 km/h, for a 12.5 cm band. This gives a water rate of 192 L/ha.

7.3 Relay planting

Relay planting overlaps the winter and summer growing season allowing a summer crop or pasture to be sown into a winter crop in spring when moisture conditions maybe more favourable for establishment (Photo 7.12). The permanent traffic lanes allow for machinery to be run on firm wheel tracks without damaging the crop. The summer crop species is planted between rows of the winter crop when it is close to maturity, for example, at leaf drop in lupins or anthesis in cereals. Soil is likely to be wetter before harvest because the winter crop shades the soil surface and would help to establish the summer crop,. However, summer crops require a minimum ground temperature at which they germinate and grow so there may be some instances where this method is not useful.

Photo 7.12 Relay planting corn into lupins at leaf drop (Source: Webb et al 2004).

Clearance of the seeder frame above the initial crop during relay planting is an important thing to consider. Some seeders may need modifications to allow them to sow with the frame set high enough to minimise crop damage, for example, knocking pods off lupins. At winter crop harvest time, the summer crop height is below the cutter bar height. This allows more time for the summer crop to access moisture before it matures. As well as increased the yield potential of the summer crop, the extra water use may aid lowering the water table in areas affected by rising water tables, such as areas low in the landscape or hillside seeps. The water must be fresh enough to support the summer crop or pastures.

7.4 Chaff on the tramlines

Some growers who have matched the harvester into the system are diverting chaff from harvesters onto the wheel tracks. This is a good alternative to burning windrows for weed seed control. The weed seeds are concentrated on the wheel track and can be target sprayed with a drop nozzle or shielded sprayer if necessary. If the chaff is thick enough it can act as a mulch preventing weed seed germination and reduce dust from summer spraying on bare tracks. Weeds and wheat have been known to germinate in the tracks after summer rain but then die out due to lack of moisture as the roots are in the mulch and can't access the compact track beneath. The extra cover may also reduce the risk of erosion down the wheel tracks.

A known benefit of chaff on the tramlines is the reduction of dust during summer weed spraying, reducing the need to use a higher volume nozzle behind the wheels of the sprayboom and lowering spray costs slightly while improving spraying efficacy.

There are no off-the-shelf chaff diversion systems available to date. Some examples of diverters engineered by farmers are shown below (Photos 7.13 to 7.15).

There is growing concern in Western Australia for poor control of herbicide resistant radish in the wheel tracks deposited with chaff. In this situation chaff carts may be a more reliable strategy for weed control.

Photo 7.13 a) Farmer designed and engineered chaff diverters; b) Chaff diverted into the wheeltrack by the chaff diverters from a three tonne crop (Source: Webb et al 2004).

Photo 7.14 a) Chaff diverter cyclone for conveying chaff and extra spreaders for straw; b) Thick chaff on the wheeltrack diverted by using this system by the late Owen Brownky (Source: Glen Riethmuller DAFWA).

Photo 7.15 Wandels chaff diverters use a belt system to drop the chaff onto one tramline (Source: Bindi Isbister, NSPNR).

7.5 On-farm trials

Fully matching CTF systems are very effective for on-farm trials at a realistic scale as all machinery operating widths are matching; thus each plot can be a seeder width and there may be no complications from soil compaction effects. This is a good way to improve agronomy by evaluating new varieties or management techniques on-farm, particularly if yield mapping is on the header (Figure 7.3).

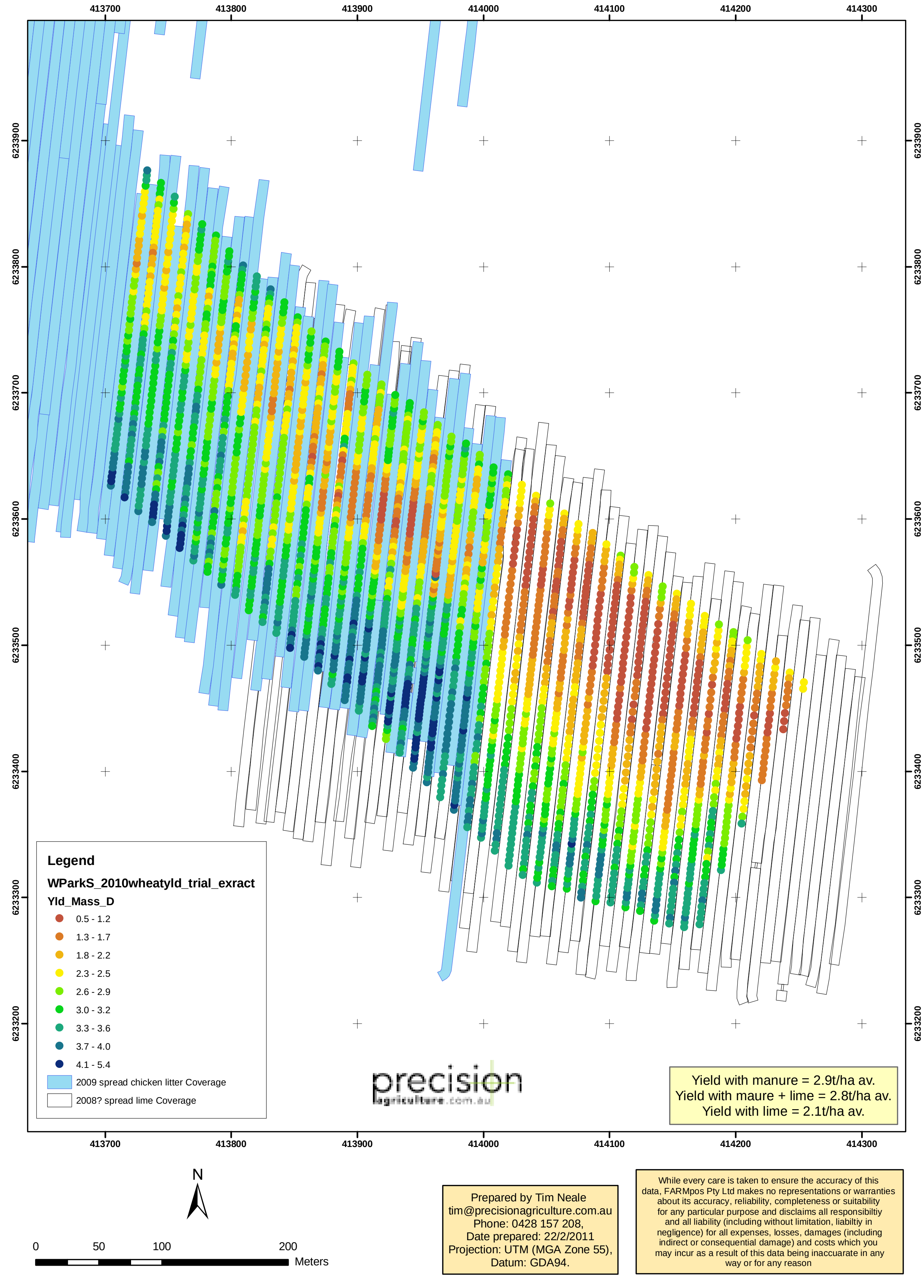
Basic principles for on-farm trial design using precision agriculture include:

- Keep it simple, test only a couple of different treatments.
- Include control strips amongst the treatments (usually the bulk paddock agronomy).
- Replicate the treatments either next to each other or in another part of the paddock
- Make treatments very different.
- Plot widths ideally need to be two to three times header width, but can be effective with the same width as the header (e.g. 9 or 12 m wide).

If you are planning to use yield mapping to record results, it is important to use the one header, harvest the trial strips in the same direction and, if possible, keep the header at a constant speed along the strips to help with even collection of yield data.

These principles have been summarised from The Paddock Guide to PA trials produced by GRDC's Agronomy Jigsaw project. For a copy of the brochure and general information on designing trials, look up the Grower Group Alliance On-Farm Trials Resource Guide 2013 at http://www.gga.org.au/page/Resources/GGA-On-farm-Trials-Resource-Guide. The following site contains helpful videos on PA trial analysis and identifying soil constraints http://www.youtube.com/user/agronomyjigsaw.

Figure 7.3 On farm trial in a CTF system using yield data to measure differences in treatments (Source: Andrew Whitlock and Tim Neale, precisionagriculture.com.au).



8. CASE STUDIES

The following case studies are from a selection of farmers throughout Western Australia that have been controlled traffic farming for five or more years. For many of them, their systems have evolved from simple marker arms to using more accurate GPS autosteer guidance systems. The most common operating width is 12 m and track width is 3 m. Some have changed their operating width from 9 or 10.8 m to 12 m and track width from 2 m to 3 m. All farms practised minimum till before adopting CTF.

8.1 John Young, Kojonup

(Revisited from the Tramline Farming Technical Manual, Webb et al. 2004)

Farm location: Kojonup

Area cropped 2003: 400 ha

Annual rainfall: 530 mm

Main soil types: gravelly sand over clay, loamy sand over clay

Enterprises: cropping wheat, canola, barley and faba beans; sheep

CTF system: 4 m seeder and 20 m sprayer

Guidance: marker arm

A controlled traffic farming system does not need to be expensive to set up. A great example of this is John Young of Kojonup, his CTF system was part of his mixed cropping and sheep enterprise. Before leasing his farm, cropping was only 400 ha of his 1100 ha farm.

The system was based on a 4 m Shearer TCD combine and a 20 m sprayer, a 1:5 matching ratio. The simple guidance system cost about $100 and consisted of a metal rod mounted under the engine of the tractor reaching the width of the combine. At each end of the rod, a trailing plastic strip was placed to run in the last row of the previous pass (Photo 8.1). As the rod is no wider than the combine, the driver can see it from the cab and there is no risk of breaking it off on trees.

Two bare wheel tracks were left on each seeding run by removing a tine from behind the Deutz DX110 tractor wheels at 1.8 m spacing (Photo 8.2). Bare tramlines provide guidance for the sprayer pulled behind a Deutz DX430 tractor. The tracks were 500 mm wide.

Challenges to the system included: occasional trouble finding the previous year's tracks after grazing the stubbles throughout summer and negotiating the many trees, rock heaps and hills in the Kojonup landscape.

To help reduce this problem John tried to keep diversions around trees during seeding in multiples of five to fit the boomspray width. John believes there was no increased erosion working up and down the slopes than when he seeded round and round. He did practice no-till and retains good stubble cover.

Benefits

John estimates his fertiliser and herbicide costs were reduced by up to 10 per cent working up and back using permanent wheel tracks. The firm tramlines provide a definite advantage for in-crop spraying. John does not need to use duals and is able to spray when many of his neighbours cannot because it is too wet. When John first started controlled traffic farming his neighbours gave him a hard time about all the missing rows in the paddock.

Photo 8.1 John's simple guidance rod to help follow the last row of the previous seeding run (Source: Western Australian Agriculture Authority).

Photo 8.2 Bare wheel tracks in the lucerne phase (Source: Western Australian Agriculture Authority).

8.2 Wes and Meg Baker, Corrigin

Location: Corrigin (33 km west)

Farm size (cropping area): 2150 ha

Main enterprise: cropping grain and hay

Growing season rainfall: 1977–2000, 336 mm; 2001–2012, 320 mm

Main soil types: light sands to grey and red clays, mainly sandy loam and gravelly loam.

CTF system: based on 11 m and 3 m track

Guidance: autosteer RTK

Wes and Meg Baker started planning a controlled traffic system in the late 1990s to reduce compaction and gain the benefits that come with it. Initially they started matching machinery widths, then matched wheel tracks and added increasingly accurate guidance systems. Wes believes 'It is a system that you can develop which will pay for itself and the benefits are measurable'.

When the Bakers first started CTF they ran sheep but these are no longer part of their system. This was an economic and lifestyle choice rather than the sheep not fitting into CTF. The wheel tracks are quite noticeable in the paddocks where the rotation has been pasture/cereal for some years now, suggesting that the machinery is compacting the soil far more than the sheep.

Not all paddocks on the farm are cropped using CTF as the Bakers also grow hay for export. The machinery required for making hay, followed by the loaders and trucks driving over the paddock to collect the bales make it too difficult for CTF.

Machinery

Wes began developing a system based on 11 m to match the header (Table 8.1). The machinery widths have remained the same; 11 m header, 11 m seeding bar, 33 m sprayer system, but modifications have been made as required when machinery has been changed over. Tines were removed from the bar to take it back to 11 m from 12 m. The second sprayer width was extended to 33 m from 30.5 m and the track width on the Hardi sprayer was extended to 3 m using axle extensions (Photo 8.3).

Photo 8.3 Sprayer with extended axels to 3 m (Source: Western Australian Agriculture Authority).

Two marker arms on the seeder were used from 2002 to 2005 (Photo 8.4). In 2006, 2-cm RTK was purchased and has been used for guidance since then (Photo 8.5).

Photo 8.4 Seeding 2004 with 2 marker arms (Source: Western Australian Agriculture Authority).

Photo 8.5 Seeding with autosteer RTK 2cm (Source: Western Australian Agriculture Authority).

Benefits of CTF

After more than 10 years under CTF, Wes has observed the soil is much softer and easier to work. He is not sure if there is any better water infiltration, as it is too hard to measure but trial results say infiltration is improved under CTF. The firm, compact wheel tracks make trafficking much easier, especially in wet conditions and in sandy soils. It means the Bakers can get in and seed or spray at critical times instead of waiting for the soil to dry out.

Wes expects that they are achieving better yields, but once again, it is too hard to measure as they don't have any uncontrolled traffic paddocks to compare to.

Table 8.1 Baker machinery setup

Operation	Machine	Width (m)	Track width (m)	Modifications
Spraying	Hardi Commander 5033 and Walker 44	33	3	Track width altered to 3 m. Second sprayer widened from 30.5 m to 33 m
	Case-IH MX255 Magnum Tractor autosteer RTK 2 cm		3	
Seeding	Bourgault 8810 with Simplicity 12000L tow behind quad cart	11	3	Removed tines to narrow the bar from 12 m to 11 m
	John Deere 9400 Tractor autosteer RTK 2-cm		Outside duals 3.6 m, Inside duals 2 m	
Harvesting	Case IH 2188 with 1040 Macdon, Case IH 2388 with 1042 Macdon. Both autosteer RTK Autofarm	11 m offset	3	
	Vennings 18 t Chaser bin (No guidance on tractor follows header tracks manually)		3	
Spreading	Norrish Spreadmore	Limesand 8 m, Crushed limestone 11 m, Urea 16.5 m	2.6	Modified spinners to spread further to reach the required width of spread.
	MX 255 Magnum Tractor with autosteer RTK 2 cm		3	

Challenges and solutions

Some modifications to paddock layout have been required to improve efficiency, for example, removal of rock heaps and grade banks removed where possible or turned into roaded catchments for dams. The direction of working has been selected for longest run rather than east–west or north–south.

Residue management is an issue, as it doesn't spread evenly to 11 m. There has also been the odd problem of stubble handling at seeding due to a higher density of residue left in the middle of the run. This tends to happen when areas of the crop are thicker and/or taller and the spreaders on the header fail to spread material properly.

Depression of wheel tracks near the headlands are an issue with the second run at the ends as the sprayer must travel at right angles to the run lines. To lessen the bump as it goes across the wheel tracks, the sprayer ground speed must be reduced and this lowers the spray pressure, resulting in a poorer spray pattern.

Another challenge is matching the final few wheel tracks. The previous seeding tractor was on duals with the outers at 3 m centres. The present seeding tractor has a wider wheel track and could possibly be matched by removing the inner duals and adjusting the outers back into a 3 m centre. But Wes wonders, 'How much more compaction are the extra wheels creating?' With the header fronts being offset, the wheels on the seeding tractor are not running outside of the where the wheels of the header runs. Wes calculated the purchase of a centre mounted header front for one of the headers would take 30 years to cover the cost using the proposed gain in returns from the benefits of CTF by reducing the area of tracking. To Wes this is not worth the investment at this stage. His current area of tracking is 20 per cent with the duals on the seeding tractor. Before starting CTF his track area was 41 per cent of the paddock.

Other precision agriculture equipment/ techniques

Wes started yield mapping in 1996. He has not done any for some time now due to one header not being set up for mapping yet. Wes is not convinced that VRT has enough benefits to make it worthwhile on their farm. Research into variable rate technology by the Corrigin Farm Improvement Group has shown variable rate, in particular nitrogen, has limited benefits in the Corrigin area. This is due to unpredictable waterlogging events that cause yields to 'flip flop' between seasons when part of the paddock may perform very well in a drier season but very poorly in wet season due to waterlogging.

The Bakers do use the practise of inter-row and in-row sowing when they need to, for example, inter-row seeding for stubble handling, and in-row seeding when chasing moisture. Wes would like to set up his sprayer with nozzles spaced at 10 inches to match the row spacing on the seeder. This would allow the inter-row to be sprayed more effectively when applying pre-emergent chemicals and possibly help make others more effective as well.

Wes believes a Weed Seeker would be a great addition to the system but it is expensive. A machine that you could own jointly with another farmer would make it economically justifiable. The wheel tracks are sown to provide competition for weeds.

The future

Ideally Wes would like to change over to a 12 m header, 12 m seeder, 36 m sprayer system to increase seeding capacity. However, this is unlikely as their time left for farming is limited and to change all machinery is too expensive. A compromise could be switching to a 1:1.5:3 ratio with an 11 m header, 33 m sprayer and changing to a 16.5 m seeder.

8.3 Case study—Paddy and Sharon Barber

Location: Gibson

Farm size (cropping area): 4700 ha

Main enterprise: cropping wheat, barley and canola

Annual rainfall: 450 mm

Main soil types: deeper white sand to sandy gravel over clay

CTF system: based on 12 m width and 3 m track

Guidance: autosteer RTK

Paddy and Sharon Barber started controlled traffic farming in 2001. Participating in the GRDC funded Tramline Tour to New South Wales in 2001 strengthened Paddy's belief that 'CTF is a simple concept with great benefits particularly in terms of reducing inputs'.

'In the beginning it was hard to justify the expense of autosteer (about $90 000) so we started with one marker arm, this was the best bang for our buck. Buying one marker arm for $2500 for a 36 ft seeder to seed round and round, leaving fuzzy for spraying and harvesting. We are now up and back with autosteer RTK guidance which maybe cheaper now. We have it in 5 machines so essentially, it is a similar cost to what it was 10 years ago and we wouldn't change it now we have it!'

Machinery

After starting round and round in 2001, Paddy changed to up and back in 2002 using visual guidance that was upgraded to autosteer in 2003 (Table 8.2). His system now in 2013 is based on 12 m, with a 3 m track compared to 10.8 m on 2 m centres in 2002. 'We are not strict about the 3 m, close enough is good enough for us and we still see the benefits.' The seeding tractor was originally run on singles so the wheel track was 3 m but it is now run on duals for more traction in wet and boggy conditions.

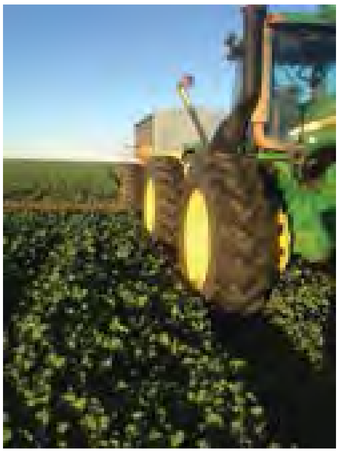


Photo 8.6 Marshall spreader and 9300 JD Tractor on 3 m wheel tracks (Source: Paddy Barber).

Table 8.2 Barber machinery setup 2013 (RTK = real time kinematic, JD = John Deere)

Operation	Machine	Width (m)	Track width (m)	Modifications
Spraying	Self propelled Nitro 4315	36	3	3 m, 4 m for some spraying and turning
	JD RTK 2 cm autosteer		3	
Seeding	JD disc seeder	12	3	
	Airseeder cart JD		3	
	JD 9420 4WD JD RTK 2 cm autosteer		3	Had taken inner dual out and run on outer but back to duals for wet conditions
Harvesting	New Holland 9090 with JD RTK 2 cm autosteer	12	3	
	Chaser Bin 30 t Trufab Grain King pulled by seeding tractor		3	
Spreading	Marshall spreader x two	24, 18, 12*	3 and 2	2nd spreader axle will be extended to 3 m
	Case 9270 autosteer JD guidance sub metre		3	
	9300JD tractor RTK 2 cm autosteer (Photo 8.6)		3	

* most spreading at 24 m but sulphate ammonia spread at 18 m and lime sand at 12 m

The first year fuzzy tramlines were sown in cereals and bare tramlines for canola and lupins. The fuzzy tramlines were easy to follow while spraying. Now that autosteer is fitted, rather than leave a wheel track, the two centre tines have been moved out of the centre to leave a 50 cm line as a back up guidance line (Photo 8.7).

Photo 8.7 Centre guide row (Source: Paddy Barber).

The tine spacings have also been adjusted so that only one row of crop is run over in the wheel track. This means the tines between the wheel track and the centre guide row are narrower than the 10 inch row spacing.

This has proved a bonus for swathing barley. Paddy has built a 'winged keel' for the back of the swather to split the barley swath into two rows onto the rows between the wheel track and the centre guideline (Photo 8.8). The narrower row spacing seems to stop the swath falling down which was a problem.

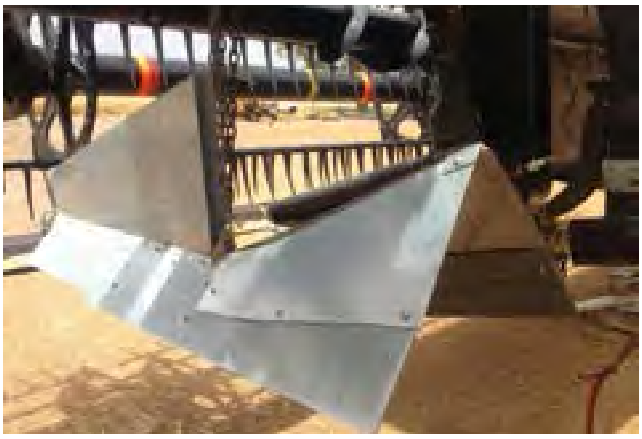


Photo 8.8 Winged keel on the swather to split the swath in two rows either side of the centre line (Source: Paddy Barber).

The chaff at harvest time is diverted into the centre guide row using a custom built shute at the back of the header in the centre. This is a modified version of diverting chaff on the wheel tracks used by other CTF farmers as a weed control method. The amount of residue left can be high (Photo 8.9). The chaff is diverted onto the guide row so it won't be disturbed during seeding, reducing weed germination, however the lines may be burnt in the future as there has been a high germination of barley in a wheat crop seeded in 2013.

Photo 8.9 Residue left on the centre guide row after harvest (Source: Paddy Barber).

Benefits of CTF

The Barbers have found by working up and back their input efficiency has increased as paddocks are easier to work and there is less over lap. The wider centre line is helpful for the drivers to get back on line after turning at the end.

Paddy is not sure if yields have increased, but thinks tramlining must be helping with compaction and softening the soil as the deep ripping he has done hasn't shown obvious differences between ripped and unripped. Paddy has not done a lot of deep ripping as the sands are patchy across the farm. Some deep ripping trials done on the farm with DAFWA, Esperance, found there was little response to deep ripping on the gravels. This reflects Paddy's observations that you can drive over the gravels and not see where you have been, but in the sands you can.

Challenges and solutions

It has been a challenge to get the chaser bin to fit the 12 m system so at this stage the chaser doesn't run on the tracks for the header to unload. The chaser does travel along the lines as much as possible in and out of the paddock.

Paddock layouts and drainage lines have been modified. Where possible, drainage lines run along the tracks. Some banks are at right angles to the run lines and are broad enough so they can be seeded over.

CTF can be a disadvantage as Paddy is keen to increase the header to 50 ft but this is very hard to match with other machinery in a CTF system.

Other precision agriculture equipment/ techniques

The last three years Paddy has done VRT fertiliser replacement from yield maps but this year they just applied a flat rate across the farm, as a precaution to running down the nutrient stores.

The future

Paddy plans to continue his controlled traffic system and move the last couple of machines out to 3 m tracks. He is considering tracked tractors in the future as an alternative to running duals at seeding because singles on 3 m are unsuitable for wet conditions.

8.4 Mick and Heather Schutz, Grass Patch

Location: Grass Patch

Cropping area: 4000 ha

Growing season rainfall: 180 mm

Main enterprise: cropping wheat, barley, canola and peas

Main soil types: clay duplex to loamy sand

CTF system: based on 12.2 m and 3 m tracks

Guidance system: autosteer RTK

Mick and Heather Schutz began controlled traffic farming in 2009 to improve input efficiencies. Three years on, input costs are less, crops look more even, plant roots look healthier and the soil has better water retention.

Machinery

The Schutz CTF system is based on 12.2 m (40 ft) and 3 m wheel tracks to include the headers (Table 8.3). The sprayer is three times the width of the seeder. All operations are guided with autosteer RTK John Deere. As new farmers to the area, the Schutz's were in a position from the beginning to set up their machinery fleet so that they match for CTF.

Various modifications have been made to get machinery on to a 3 m wheel track. Building the chaser bin with a longreach grain belt keeps chaser bin and tractor on wheel tracks while the header unloads. The seeding tractor has been changed over from a JD 8530 to JD 9460RT tracked machine eliminating the need for duals.

At this stage the wheel tracks are sown to provide some competition for weeds (Photo 8.10 and 8.11).

Photo 8.10 Schutz CTF tracks in canola (Source: Paul Blackwell).

Photo 8.11 Sown wheel tracks in wheat at Schutz farm (Source: Stephen Davies).

Table 8.3 Schutz machinery setup (JD =John Deere)

Operation	Machine	Width (m)	Track width (m)	Modifications
Spraying	Self propelled boomspray JD 4940	36.6	3	
	WeedSeeker (Owner built)	36.6	3	
Seeding	Airseeder bar Ausplow DBS	12.2	3	
	Airseeder cart JD 1910		3	
	Tractor JD 9460RT		3	
Harvesting	Header JD 9860 STS	12.2	3	Fitted powercast and owner built chaff belts
	Header JD 9770 STS	12.2	3	Fitted powercast and owner built chaff belts
	Chaser bin		3	Owner built with longreach grain belt
Spreading	Spreader (custom built)	12.2	3	New axle
	Spreading/chaser/WeedSeeker Tractor JD 8130		3	Add cotton reels to front axle

Photo 8.12 a) Water infiltration on the wheel track and b) Faster water infiltration rate off the wheel track.

Benefits of CTF

Visual inspection of the soil characteristics on the clay duplex soils suggest the soil off the wheel track is much softer than the compact wheel track. Photo 8.12a and b, taken at the same length of time after filling of the tube, demonstrate improved water infiltration rate off the wheel track.

Figures 8.1 and 8.2 show results from a paddock of Schutz's where Mick ploughed some previously clay-spread sand plain soil. The results show a reasonable trend of soil strength increasing at depth, however the soil was not wet enough for these results to be conclusive.

Challenges and solutions

Challenges to the system include the tramlines sinking on sand and educating workers where to drive in the paddock. Mick is planning to rejuvenate the sinking tramlines using a renovator to scrape soil back into the tracks.

Other precision agriculture equipment/ techniques

Mick uses a WeedSeeker boom 36.6 m on 3 m tracks that he built himself for summer spraying. Other precision agriculture technologies used on the farm include variable rate input applications. Inter-row seeding is used on most of the farm and same row seeding on nonwetting sands.

The future

Mick is looking to introduce a steerable implement hitch to help with inter-row seeding.

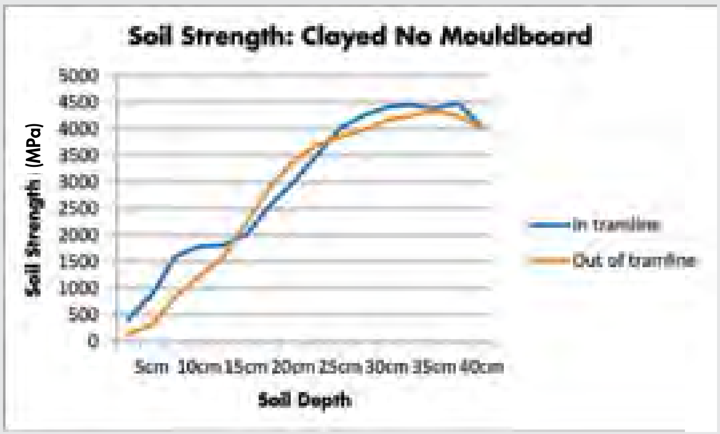


Figure 8.1 Soil strength measured by penetrometer clayed unmouldboard ploughed sandplain soil Esperance (Source: Quenten Knight, Precision Agronomics Australia).

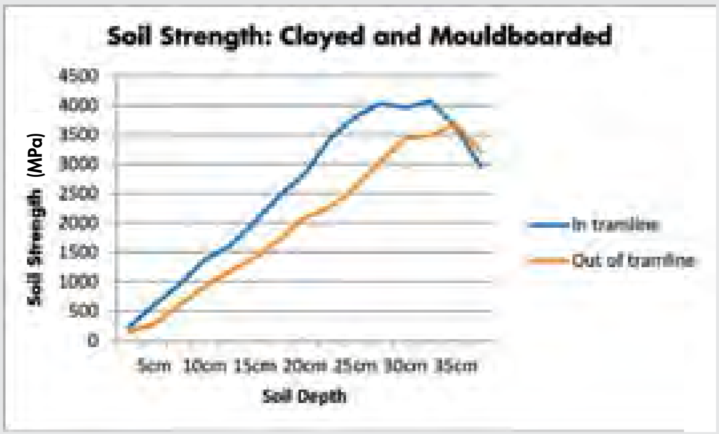


Figure 8.2 Soil strength measured by penetrometer clayed mouldboard ploughed sandplain soil Esperance (Source: Quenten Knight, Precision Agronomics Australia).

8.5 Lindsay and Karen Chappel, Perenjori

(Revisited from the Tramline Farming Technical Manual Webb et al. 2004)

Location: Perenjori

Farm size (cropping area): 6400 ha

Main enterprise: cropping, in particular, wheat

Growing season annual rainfall: 324 mm

Main soil types: york gum, salmon gum, gimlet

CTF system: based on 2:1; 18 m seeder to 36 m sprayer ratio and 2.2 m track

Guidance: autosteer GPS 10 cm

Lindsay and Karen Chappel from Perenjori have been controlled traffic farming for 12 years. They started after it became obvious to Lindsay 'it was the correct way to work our paddocks' after returning from the Tramline Farming Tour to New South Wales and Queensland in 2001.

Machinery

Since beginning CTF in 2001, their 2:1 matching seeding and spraying system on 2.2 m wheel tracks has remained the same (Table 8.4). A Beeline DGPS 10 cm autosteer guidance system is used for all machines except the header.

Some modifications were required to bring Lindsay's airseeder box track to 2.2 m (costing about $1900) and 15 minutes labour was all it took to shut down some nozzles on the boomspray to bring it to 35 m in width. Bare wheel tracks are created by lifting two tines behind the tractor wheels, making spraying very simple, 'No foam marker or bent neck!' (Photo 8.13).

Photo 8.13 Lindsay Chappel on his bare wheel tracks (Source: Webb et al 2004).

In the early years of Lindsay's CTF system when turning at the end of the run, the bar was left in the ground while sowing alternate runs to form 'curve sown' headlands. The rip skipping (sowing alternate runs) feature of the DGPS made the turns wider than if using two marker arms so the bar did not have to be taken out of the ground. Sowing was then completed by filling in the unsown runs. This is now known as the 'clapper corner'. Lindsay developed this system to avoid confusing the tractor driver by having too many switches to flick on and off at the ends of the run. Now, to provide competition for weeds, the end headlands are sown with one pass after the runs are completed.

Table 8.4 Chappel machinery setup 2013

Operation	Machine	Width (m)	Track width (m)	Modifications
Spraying	Sonic 7036	36	2.2	
	Fendt 924 with Beeline 10-cm autosteer		2.2	
Seeding	Friggstad bar and K Hart bar	18	2.2	axle modifications to fit tramline
	Bourgault bin		2.2	
	Tractor Steiger 9380 Beeline 10-cm autosteer		2.2	
Harvesting	Two Gleaner R72s no guidance	11.5	3.5	
Spreading	Norrish	18/36	2.2	
	Either seeding or spraying tractor Beeline 10-cm autosteer		2.2	

Benefits of CTF

An immediate benefit for Lindsay in implementing his CTF system was the cost saving from reduced overlap. Lindsay has reduced his overlap from 19 per cent to one per cent in paddocks. 'One paddock in previous years was always sprayed at 130 ha. Using tramlines, the paddock was only 109 ha; that is a reduction in overlap of 19 per cent. Tell that to the non-believers—a saving that big is hard to imagine'.

Layout issues

In order to have longer and more efficient runs the Chappels have had some contour banks removed. After many years of no-till the soil structure and water infiltration rate has improved so much that contour banks have not been filling with water. This has been quite an expensive exercise but Lindsay is confident the savings could be made up in one year with reduced overlap.

Lindsay is also seeding up and down slopes as he saw done on the Tramline Tour to Queensland in 2001. This is to keep any run-off evenly distributed but it has raised a few neighbours' eyebrows. Further study of this approach was undertaken in an National Landcare Program project # 043053 to examine the risks of downhill CTF. The erosion risks have not been high when run-on to the upslope end of paddocks was minimised.

Challenges

Lindsay has not been able to get the headers to match although there doesn't seem to him to be much damage done to the soil due to dry soil at harvest, so this has not been a priority.

The future

'We might have to expand our tramlines to cater for a self propelled sprayer as we seem to be doing more later sprays for radish.'

8.6 Brady and Erin Green, Nabawa

Location: Nabawa

Farm size (cropping area): 8500 ha

Main enterprise: cropping wheat, lupins and canola

Annual rainfall: 350–400 mm

Main soil types: 75 per cent yellow sand, otherwise red loam

CTF system: based on 12.2 m and 3 m tracks

Guidance: autosteer RTK

The terrible seasons of 2006 and 2007 persuaded Brady and Erin Green there must be a better way of doing things. After hearing a lot about the development CTF in the Northern Agricultural Region, Brady came into contact with Robert Ruwoldt, a successful CT farmer in Horsham, Victoria. Using CTF and no-till, Robert has been able to increase his water use efficiency to produce more grain. With his help, Brady started developing a full stubble retention and controlled traffic system in 2008.

Machinery

Since starting CTF in 2008 the Greens have gradually changed over their machinery to match 12.2 m operating width and 3 m track width (Table 8.5). This began with the purchase of a 12.2 m disc seeder and the 36 ft headers were changed over to 12.2 m. The K85 Bredal spreader was selected as it is able to spread limesand to 12.2 m. The Trufab grain king chaser bin runs on 3 m track and with an extended auger on the headers, the chaser bin is able to run on the wheel tracks while the header unloads. The sprayer is the only equipment that has not changed width since beginning CTF.

The Greens started with an 18 m tine seeder and a 12.2 m disc (Daybreak) seeder in 2008. Technical difficulties and poorer establishment with the disc unit led to having two tine bars by 2013 (Photo 8.14). A key feature of the system is a 381 mm (15 inches) tine spacing on the bar with Stilleto boots (winged boots that form two rows of crop). They allow a seeding speed of 12 km/h using smaller 350 horsepower tracked tractors. Running two rigs at a seeding rate of 28 ha/h is a better prospect for Brady than running a larger bar with a bigger horsepower tractor. The smaller tractors are more versatile and provide a better use of capital by being suitable for other operations on the farm including spraying, spreading and deep ripping while using less fuel.

Table 8.5 Green machinery setup (RTK = real time kinematic, JD = John Deere)

Operation	Machine	Width (m)	Track width (m)	Modifications
Spraying	Self propelled Miller Nitro with Trimble RTK 2 cm autosteer	36.6	3	
	Hardi 9000 on JD8360 tracked tractor with John Deere RTK 2 cm autosteer	36.6	3	
Seeding	Airseeder John Deere bar 381 mm spaced tines with Stilleto boots and a central tine	12.2		Changed from Daybreak disc seeder
	Airseeder cart JD 1910 tow behind		3	
	Seeding Tractor JD 8360 and JD8345, 350 HP tracked tractors with JD RTK 2 cm autosteer		3	
Harvesting	Two Headers JD S680 on tracks (old headers JD 9770) with JD RTK 2 cm autosteer	12.2	3	Longer auger on the header
	Chaser Bin 30 t Trufab Grain King		3	
Spreading	Spreader K85 Bredal*	12.2	3	
	Spreading Tractor JD 8345		3	
Deep ripping	Ausplow deep ripper pulled by JD 8360 Tractor	12.2	3	Moved the frame wheels to 3 m

* limesand 12.2 m, super and potash 36.6 m and urea 24.4 m

Photo 8.14 Tined seeder with 381 mm row spacing (Source: Brady Green).

Benefits of CTF

So far the most obvious benefit of the system has been improving efficiency, particularly fuel use. The lower horsepower requirement using tracked tractors running on firm tramlines has reduced fuel use. The soil condition of the loamy soils is much better then when they first started.

Challenges and solutions

Three years into a CTF system the sands were still compact between the tramlines and very acidic. On-farm trials have shown the benefits of deep ripping and extensive measurements of pH have enabled the degree of acidity to be mapped. On this basis, in 2012 and 2013 the Greens implemented an extensive program of limesand application and deep ripping between the tramlines (Photos 8.15 and 8.16).

Photo 8.15 Limesand spreading 12.2 m (Source: Brady Green).

Photo 8.16 Deep ripper with tines moved from behind the wheel tracks (Source: Brady Green).

One challenge the Greens discovered in setting up waylines is different guidance systems on the sprayer. The Nitro sprayer has Trimble guidance whereas the tractors and header use John Deere guidance. The guidance systems use different co-ordinate systems. John Deere use geographic (latitude and longitude) and Trimble use UTM (Eastings and Northings), which means they do not follow the same track and can be up to 50 cm out by the end of a large paddock. To overcome this problem the Greens set up their A–B lines for every paddock on the farm running the Nitro Sprayer and a JD Tractor one behind the other as a separate operation to seeding or harvest. It was a little time consuming but has been worth the effort as all machines now use the same waylines. The tramlines are sown to provide competition for weeds.

Other precision agriculture equipment/ techniques

Using the highly accurate guidance system the Greens inter-row sow lupins, canola and wheat where possible (if not deep ripped). The side shift on the seeding tractor guidance system is set to 10 cm This is shifted constantly in a paddock. Using 10 cm gives them two shifts per inter-row, which over time will get less but they are still straightening out the waylines. The tracked machines help keep as straight a run as possible.

The Greens have yield mapping on the their harvesters. They have mapped pH across the farm using Google Earth and target soil sampling. The maps have not been used to vary rates on the go but were used to target problem paddocks or areas.

The future

Inter-row shielding spraying may be introduced in the future on wide row lupins and canola as Brady had good success with wide row canola a few years ago. Wide rows for pulse crops are not common practice on the farm yet as the bars are not set up for wide row spacings. One limitation with shield spraying is the low hectare coverage per day due to the sprayer only being 12.2 m so its use in broadacre is restrictive.

With two new John Deere S680, headers on tracks and the completion of a two-year extensive deep ripping program this season, the Greens have achieved a fully matched CTF system, which is what they set out to. Their footprint is now 10.8 per cent. From here on there will be some fine-tuning of the system but mostly they will be 'watching with interest to see what happens.

8.7 Rohan and Carol Ford, Balla

(Revisited from the Tramline Farming Technical Manual Webb et al. 2004)

Location: Balla

Farm size (cropping area): 4000 ha

Main enterprise: cropping wheat, lupins, canola, tagasate, pasture and cows (cows and pasture are going)

Growing season annual rainfall: 250–300 mm

Main soil types: 80 per cent yellow to pale yellow sand, otherwise red loam

CTF System: based on 9 m width and 3 m track

Guidance: autosteer RTK

The need to alleviate soil compaction, improve soil health and an increasing concern that chemical farming is not sustainable was the motivation for Rohan and Carol Ford to start controlled traffic farming in 2000.

'I first saw tramlines in paddocks in Europe on a visit in 1990 and liked the idea. Later I talked to Paul Blackwell of the Ag Department and Wayne Chapman from Queensland, the gear was a suitable size to convert and we bought a JD tracked tractor that fitted the system well and converted axles to fit 3 m tramlines.'

Machinery

In 2000 Rohan seeded their 2700 ha program to tramlines using two marker arms and DGPS (John Deere) guidance system. The combination was used to improve driving accuracy because using marker arms on undulating soil was difficult. In 2002 Rohan borrowed a GPSAg system to help set up trials with Paul Blackwell, DAFWA and sowed all the crop with this system, which was a lot less frustrating than the marker arms. Rohan upgraded his seeding tractor in 2003 to a JD tracked tractor with autosteer using the John Deere RTK system. This enabled him to rip skip, sowing every second seeder run in one pass across a paddock and filling in the missed runs on the return pass.

Rohan has matched his machinery width and tracks to the harvester to reduce compaction at harvest and because 9 m was the most economical width (Table 8.6). His bar was about 10.67 m so to match his machinery widths he would have needed to widen his sprayer and buy a new 10.97 m harvester front, which would cost $20 000 alone compared to $22 000 to modify most of his equipment and purchase two marker arms.

Some modifications were required to move the wheels on the original seeder bar, airseeder box, sprayer and spreader to 3 m. The original seeding tractor a JD8870 4WD had the duals removed to run on singles (710/70R-38 radial) for the first season after which it was traded for a tracked tractor (8320T) with an adjustable track to 3 m for spraying and seeding operations.

Table 8.6 Ford machinery setup 2013 (RTK = real time kinematic, JD = John Deere)

Operation	Machine	Width (m)	Track width (m)	Modifications
Spraying	Hardi Commander S	36	3	
	JD 8100 tracked tractor with John Deere RTK 2 cm autosteer		3	
Seeding	Aus seeder S series	9	3	Frame changed to put wheels on 3 m tramline
	Airseeder cart JD 1910 tow behind		3	
	JD tracked tractor (8320T) JD RTK 2 cm autosteer		3	
Harvesting	John Deere JD9660 with JD RTK 2 cm autosteer	9.19	3	
	Chaser Bin 18 t Trufab Grain King pulled by JD8100 tractor		3	
Spreading	Roesner Multispreader	9 m* 18 m#	3	Extended axle
	JD tracked tractor (8320T) JD RTK 2 cm autosteer		3	
Deep ripping	Ausplow bar	9	3	Moved the frame wheels to 3 m

*limesand # super, potash, urea

A contract sprayer is also used with a self-propelled sprayer on 3 m tracks.

The harvester (JD 9660) is just off the wheel track on 3.4 m centres, but the chaser bin fits tracks to allow grain to be transferred from the harvester on an adjacent track.

In 2009 the 27 m Beverley hydroboom was upgraded to a 36 m Hardi Commander S boom. This required some extra work to fit to the firebreaks by doing overlap runs on the edge of the paddock and adding an extra tramline.

Other changes the Fords have made to their machinery set up include a purchasing a second hand Aus seeder DBS seeding bar in 2011 and increasing the size of the air cart in 2012.

Wheel tracks

The wheel tracks were sown in the first year because Rohan was concerned about erosion of bare tracks on his water-repellent sands. In some paddocks the Fords found the crop in the rows on the tramlines emerged first and was easy to see for post-emergent spraying. They used DGPS guidance (Greenstar) to guide them to the correct row. Rohan experimented with fuzzy tramlines but they did not work very well on the non-wetting soil, as the smooth tyre on the seeder bar did not press the seed into the sand. The airseeder cart has since been upgraded to a tow behind cart.

Rohan now uses bare wheel tracks for lupins and sown tramlines for cereals and canola. The unsown wheel tracks are 600 mm wide. A disc opener is used in place of a tine on the wheel track. For lupins the tube is blocked on the disc opener so no seed is sown in the wheel track. The row spacing is 265 mm for cereals and canola (Photo 8.17). Lupins are grown on wide rows by lifting every second tine (Photo 8.18).

Photo 8.17 Wheat on 265 mm row spacing with sown wheel tracks (Source: Paul Blackwell, DAFWA).

Photo 8.18 Wide row Lupins with bare wheel tracks (Source: Paul Blackwell, DAFWA).

Rohan has noticed the spraying wheel tracks are deeper than the less trafficked wheel tracks.

Benefits of CTF

Rohan says, 'Tramlines have given us a step in the right direction to control weeds, chemical use (resistant weeds) and a more effective use of fertiliser in our non-wetting soils'

Over the years of CTF, Rohan has observed much better soil conditions and improvements in efficiency, for example, fuel savings and a better layout of paddocks. The firm tracks also provide smoother running for spraying.

Trial results and on-farm measurements show improved yield and quality. CTF systems are very easy to do on-farm trials with as all machinery widths are matching.

Challenges and solutions

Staff education has been an annual challenge 'Educating drivers is important so they understand the reason for not driving where you are trying to grow grain.'

Fitting deep ripping in the system is still being debated with the farm consultant. In 2003, together with Dr Paul Blackwell, Department of Agriculture, Rohan experimented deep ripping in between lupins on 50 cm wide rows. The trial showed that there was no yield penalty and better wheat yields in the next year from deep ripping in between wide row lupins than deep ripping just before sowing the wheat. Ten years later the deep ripping lines are still evident. Deep ripping between wide row canola is being studied this season (Photo 8.19).

Photo 8.19 Deep ripping between wide row canola (Source: Chad Renyolds and James Hagan, DAFWA).

After six years of burning windrows, and a lot of nutrition, the Fords have purchased a chaff cart to put weeds at the end of paddocks. They have had problems with wheat seed germination in the burnt windrows and getting the windrow to burn completely on the ends leaving weed seeds there to be dragged down the runs. Increasing herbicide resistance of radish is a particular concern. Rohan believes, 'the hard wheel tracks will make towing a chaff cart easier using less fuel and strain on harvester. If you have weed seeds harvested and in the harvester I don't think it is a good idea to put them back on where you got them from'.

Other precision agriculture equipment/ techniques

Rohan uses yield mapping and has collected EM38 and gamma radiometric data across the farm. Some variable rate developments are being used on-farm to help reduce fertiliser inputs. In the future Rohan would like to have some soil moisture probes installed on the farm to improve accuracy of yield prophet estimates.

The future

Rohan believes the continuation of his CTF system will lead to, 'better soil health and minimisation of non-wetting problems'. He plans to continue with the 9.1 m system as it is a good width for deep ripping and applying soil ameliorants such as lime. In the future he could add a 60 ft disc seeder to be able to sow faster when moisture conditions are ideal, which has proven critical for good germination and crop yield in their conditions.

8.8 Nigel and Tanya Moffat, Mooynaooka and Tenindewa

(Revisited from the Tramline Farming Technical Manual Webb et al. 2004)

Location: Walkaway and Tenindawa

Farm size (cropping area): approximately 3000 ha

Main enterprise: cropping wheat, canola and lupins; some sheep (3000 ewes)

Growing season rainfall: 425 mm at Walkaway and 325 mm at Tenindawa before 2000, less now

Main soil types: undulating duplex at Walkaway and deep sand to shallow sand over rock or gravel at Tenindawa

CTF system: based on 12 m and 3 m track

Guidance: autosteer RTK

Moonyoonooka and Tenindewa farmers Nigel and Tanya Moffat accepted the challenge to control traffic in some very hilly and rocky country in 2001 using a 9 m system based on the header. They have since changed to a 12 m system to increase the size of the seeder.

The Moffats' main motivation for moving to a controlled traffic system was to reduce compaction and inputs, although in the early years they saw little evidence of a reduction in inputs.

Machinery

The Moffats started CTF in 2002 with a 3:1 width matching ratio 9 m system based on the header 30 ft. That first year (1035 ha crop) Nigel marked the spraying tramlines during summer with a borrowed autosteer RTK 2 cm system. The marks were conveniently used for spraying and spreading before seeding. At seeding two marker arms were used to fill in the gaps and bare tramlines were left. The following year the bare tracks were used for guidance. It was often tricky to see the premade marks due to stock damage or windrow burning. The Moffats have now purchased their own RTK 2 cm autosteer system and the wheel tracks are now sown to help control weeds. Shallow points are used to sow two rows in each tramline. The row spacing is 250 mm.

To set up the first CTF system some modifications were required such as extending axles with cotton reel spacers to 3 m and shortening the bar (Photo 8.20). The spraying tractor is now a JCB with axels extended to 3 m (Photo 8.21, 8.22).

Photo 8.20 Moffats original spraying tractor axle extended by cotton reels (Source: Webb et al 2004).

Photo 8.21 JCB Fastrack spraying tractor and custom built sprayer (Source: Guy Isbister, Agmech).

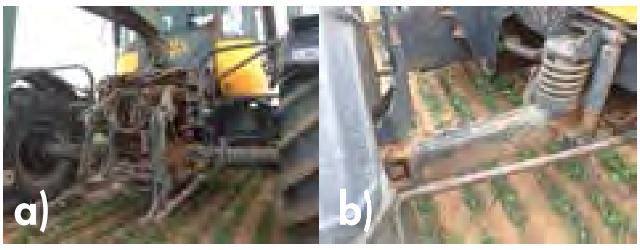


Photo 8.22 Modifications to JCB Fastrack axles a) back and b) front (Source: Guy Isbister, Agmech).

The machinery set up was converted to a 12 m/40 ft system in 2009 when a new seeding tractor was purchased. Some modifications were required to extend axles (Table 8.7). The boom sprayer and seeder are now a 2:1 ratio but the Moffats have found the edge work not a problem.

Benefits of CTF

The Moffats have observed definite fuel savings and paddocks are easier to work. In the first year working direction changed from round and round to up and back. Where possible tracks are run up and down slope. Some banks and fences have been removed to make runs more efficient. Since moving to no-till in 1995 it had become evident the contour banks weren't running water due to better soil structure and water infiltration.

Nigel notes it is, 'hard to see yield benefits due to poor seasons with low rainfall'. The property's shallow soils and a small 'bucket' for water-holding capacity mean subsoil constraints may be restricting yield benefits from CTF. Low pH has been identified at many places on the farm so they have done more liming but have not done much deep ripping yet.

Challenges and solutions

Changing over to a 12 m system, 'finance has been a challenge, but we needed to change the cropping gear anyway.' Modifications to the new machinery has been done as required. The JCB Fastrac was $100 000 and $13 000 for the wheel track modifications.

A major challenge each year is getting the drivers to understand the system and drive in the right place, even with guidance to help them.

The spreader is also not spreading limesand evenly to 12.2 m so that problem will need to be addressed in the future.

Diverting chaff on the tramlines behind the header was trialled in 2003 but has not been continued since because there have been more urgent priorities.

The future

The Moffats plan to develop the use of lime with deep ripping and generally improve soil conditions. They are looking at precision agriculture for VRT to reduce nitrogen and phosphorus costs.

Table 8.7 Moffats machinery setup 2013

Operation	Machine	Width (m)	Track width (m)	Modifications
Spraying	Own design boom	24	3	Boom length adjustments
	JCB Fastrack with TopCon X20 RTK		3	Wheel extensions
Seeding	Ausplow DBS	40ft	3	Frame changed to put wheels on 3 m tramline
	Airseeder cart JD 1910 tow behind		3	
	New Holland Tractor TJ375 ~ 375 HP on singles (duals for ripping) with TopCon X20 RTK		3	Axle lengths of tractor
Harvesting	John Deere 9650 with TopCon X20 RTK	12	3	
	Chaser bin a local model WS sheetmetal, pulled by Fastrac, use wheel tracks for guidance		3	Wheel track increased by axle modification
Spreading	Roesner 980 Multispreader on Fastrack or old JD8640 (previous seeding tractor) or JD 4250 (previous spraying tractor)	12	3	Extended axle lengths of spreader, may use better vanes on spinners to spread further
Deep ripping	Custom built deep ripper	12	3	Moved the frame wheels to 3 m

8.9 Murray and Jenny Carson and Kyle and Aimee Carson, West Binnu

Location: West Binnu

Farm size (cropping area): around 7000 ha

Main enterprise: cropping canola, wheat and lupins

Growing season rainfall: 400 mm before 2006, less now, about 330 mm

Main soil types: 80 per cent sand over gravel and deep sand, 20 per cent york gum red loam

CTF system: based on 12.45 m header, 24.9 m seeder and 37.35 m sprayer width and 3 m tracks

Guidance: autosteer GPS 10 cm

The Carson family are from West Binnu and started developing a controlled traffic farming system about ten years ago to preserve their investment in deep ripping. Deep ripping is a relatively expensive exercise to do too often and they noticed that driving all over the place soon caused a compaction problem again.

Machinery

The Carson's CTF system is based on 12.45 m to include the header (42 ft) (Table 8.8). The header is slightly wider to avoid leaving crop unharvested. Their original system has a header:seeder:sprayer matching ratio of 1:1:3. In 2010 they doubled the width of the seeder to 24.9 m (Photo 8.23). The Seed Hawk seeder operates like a sprayer as allows them to shut off and lift 10 ft sections to enable overlap seeding at the edge of the paddock and still use the original wheel tracks.

Modifications to various axles over time means almost all the machinery is now on 3 m wheel spacings apart from the seeder that has two transport stability wheels at 4 m (Photo 8.24).

Table 8.8 Carson machinery setup 2013

Operation	Machine	Width (m)	Track width (m)	Modifications
Spraying	Case Patriot SPX 4260, SPX 4420	37.5 (25 m used with WeedIt camera)	3	Added a three point linkage mouse bait spreader
	Guidance system Trimble autosteer (10 cm)		3	
Seeding	Vadastad Seed Hawk, 12" spaced tines	24.9	3	
	Seed Hawk airseeder box		3	Duals are outside the tramline
	Cat 865C seed and rip with Trimble autosteer (10 cm)		3	
Harvesting	JD 9660 STS	12.5 m "42 ft" Mid West	3	Auger on JD extended
	NH CR 970	12.7 m "42 ft" Honeybee	3	
	Chaser bin Finch 30t 9350 pulled by Case International with Trimble autosteer (10 cm)		3	Chaser bin wheel rims centre moved out and spacers on the tractor to take to 3 m
Spreading	9 t Multispreader	24.9	3	Bought with wheels at 3 m
	9350 Case International with Trimble autosteer (10 cm)		3	With modified singles, new rims.
Deep ripping	AP4 Agrowplow pulled by seeding tractor	12.45	4	Moved the frame wheels to 3 m & extended to 12.45 m

Photo 8.23 Carsons 24.9 m seeder (Source: Murray Carson).

Photo 8.24 Carsons machinery lined up showing most wheels on 3 m and some seeder wheels at 4 m (Source: Stephen Davies, DAFWA).

The airseeder box has duals for extra flotation with the insides on 3 m. The inside duals are run at higher PSI to the outer duals. The Carsons did try the 20 tonne box on singles but the weight was too much for the rims. The deep ripper was modified to 12.45 m. The auger on the original John Deere header was extended. This allows the chaser bin to run with one wheel on the wheel track while the header unloads. The augers on the newer headers were already longer so no extra modifications have been required.

The wheel track width of machines does vary slightly from 3 m so a metre zone behind each wheel track is not deep ripped so that the majority of wheels of are not running on the softer soil.

Benefits of CTF

The Carsons have seen improvements to input efficiencies. Fuel saving is a very big one when harvesting and spraying as the wheel tracks are firm and compact causing less rolling resistance.

Despite not leaving a bare tramline, the tramlines are still visible which helps the drivers find their line when turning on the ends.

Challenges and solutions

To make the system more efficient there has been some changes made to farm layout. This included taking out many fences and obstacles, such as old windmills and rock piles.

Mice can be a problem although not exclusive to CTF. A three-point linkage mouse bait spreader has been added to the sprayer and used post seeding.

Stubble management can be a challenge after a good season so the Carsons are thinking about replacing the tines with discs on the seeder. The seeder is fitted with a system to lift the bar out of the ground to clear trash blockages. In years where the stubble is too thick or not cut low enough, seeding with the current system can be frustrating as the seeder needs to be lifted frequently to clear the blockages. The Carsons have done some seeding between the rows, which reduces this problem. They do not use this method too often as they have found it works well if the soil is moist but in low moisture conditions on the non-wetting soils, seeding on or just next to the old rows leads to better seed germination and more even establishment.

The wheel tracks are seeded for weed competition.

Other precision agriculture equipment/ techniques

The Carson's use a WeedIt camera sensing weed spraying system on the SPX 4420 for summer weeds and contracting.

They have done some yield mapping but have not gone down the track of VRT yet as they have had other priorities.

The future

The Carsons will continue with CTF, aiming to make the soil healthier so it holds on to water and nutrients better, increasing their grain production.

8.10 Geoffrey and Vivienne Marshall, Hyden

(Revisited from the Tramline Farming Technical Manual Webb et al. 2004)

Location: Hyden

Farm size (cropping area): 3000 ha

Main enterprise: cropping wheat, barley, canola, faba beans and peas

Growing season rainfall: 340 mm

Main soil types: range from light gravelly sands to salmon gum gimlet (red brown clay loam)

CTF system: based on 12 m and 3 m track

Guidance: autosteer RTK

No-till farmers for twenty one years, Geoffrey and Vivienne Marshall saw controlled traffic farming as an obvious progression of their farming system. During his time involved with the development of no-till in Western Australia in the early nineties, Geoffrey observed visiting many farms around the state the effect compaction due to heavy machinery was having on crop performance; particularly from wet conditions at harvest where the detrimental effect of traffic on crop growth is visible in the paddock for many years after. Their conversion to CTF has been a progression of buying machinery based on 12 m to fit in his chosen header width.

Machinery

In the early 2000s he started developing a CTF system working with 2:1 ratio 15.2 m airseeder bar and 30.4 m sprayer on 2 m wheel tracks. In 2004 he upgraded his seeder to a 12.3 m Conserver Pak with 300 mm tine spacings and sprayer to 36.9 m on 3 m wheel track centres (Table 8.9). The change to a 3:1 machinery matching ratio means spraying is very easy as it fits evenly in the paddock.

The reduction in seeder size and running on firm tramlines have enabled Geoffrey to use a lower 260 horse powered tracked tractor than the original 320 horsepower four wheel drive tractor he had. This has led to savings on fuel and the use of a contractor for spreading as the seeding tractor is more versatile and suitable for other operations. Not using a contractor anymore was a hard decision that increased the farm work load but in the end, the contractor's machine did not fit the system. This is a big challenge for contractors who service such a wide range of clients. The tracked tractor is on narrow 400 mm tracks. Geoffrey finds the tracked machine has good power to the ground and the narrow track on a 600 mm tramline gives them a little room to move. Turning can be a little abrupt at times.

The seeder was ordered with metric row spacing which Geoffrey thinks in hindsight may not have been a wise move as the header front is in imperial. One tine was removed on the bar from behind the tracks on the tractor leaving a 600 mm tramline. A fuzzy tramline is left in wheat, barley and canola by the seed trickling out on the tramline and the following wheels of the airseeder cart pressing it in. This fuzzy row provides good extra guidance for the sprayer that, as it is truck mounted, has visual guidance.

Table 8.9 Marshall machinery setup 2013

Operation	Machine	Width (m)	Track width (m)	Modifications
Spraying	Truck mounted sprayer with visual guidance	36.9	3	Track width altered to 3 m
Seeding	Conserva pak with tow behind airseeder cart	12.3	3	Made with metric row spacings
	John Deere 8120 tracked Tractor GPS-Ag autosteer RTK 2 cm		3	Ordered with Narrow tracks 400 mm
Harvesting	Case IH 8010 with Midwest Fabrications platform with autosteer RTK	12.6 (42 ft)	3	
Spreading	Bredal	12.3, 24.6*	3	
	Same as seeding tractor		3	

*12.3 m lime, ammonium sulphate and gypsum, 24.6 m urea

The header was upgraded in 2006 to a slightly bigger capacity than his previous header with a 42 ft (12.6 m) platform Midwest Fabrication front that was the only one on the market at the time. The header has a slightly bigger capacity as the Marshalls don't use a chaser bin. The 42 ft platform has proved difficult to match with a chaser bin so the header can unload with the chaser bin on the tramlines.

Benefits of CTF

Ten years into controlled traffic farming, Geoffrey is delighted with the improvements he has seen on the farm. After so long in no-till and CTF, Geoffrey has noticed his soil health improving, 'it is softer, smells good and holds more moisture. It is very satisfying driving past paddocks with up to two kilometre runs looking along the nice straight lines at the even crop placed just next to the stubble from last year'. The Marshalls capitalise on the high accuracy guidance if seeding conditions are less than ideal, to sow as close to last year's standing stubble as possible to utilise the band of moisture that collects there.

Other benefits of the system include less inputs, for example, herbicide and fertiliser as the soils are healthier, and lower fuel use.

Challenges and solutions

Residue management maybe a potential challenge to the system if there are two to three years of good seasons creating high stubble loads. To avoid burning stubble, the Marshalls may look to use a disc machine.

The future

At this stage Geoffrey plans to stay with his 12 m system and work on some finer details such as further improvements to soil health. In the future he may add a chaser bin if there becomes a requirement to move more grain quickly. Increasing capacity is always something to think about, be it discs to increase speed at sowing or a larger header front, now 60 ft fronts are entering the market.

9. RESOURCES AND REFERENCES

9.1 Useful resources and websites

The following websites or links contain very useful information and contacts for developing a controlled traffic farming system.

Website or link	Information
Australian Controlled Traffic Farming Association (ACTFA) www.actfa.net/	Good information and contacts on CTF
Precisionagriculture.com.au www.precisionagriculture.com.au	Helpful information and contacts for advice on CTF and precision agriculture Seeding efficiency calculator Look in the training section for links to YouTube videos on CTF and setting up guidance systems
Department of Agriculture and Food, Western Australia www.agric.wa.gov.au	Search for controlled traffic or tramline farming
Grains Research and Development Corporation www.grdc.com.au http://www.grdc.com.au/GRDC-FS-ControlledTraffic	Search for controlled traffic or tramline farming GRDC over the fence Controlled Traffic farming factsheet
http://www.grassrootsag.com.au/CTF%20 brochure%20low%20res.pdf	Good farmer case studies from NSW
http://www.liebegroup.org.au/projects-2/past-projects/downhill-tramline-farming/	Management of Surface Water For Controlled Traffic Farming Technical Manual
Northern Agricultural Catchments Council www.nacc.com.au http://www.youtube.com/watch?v=qzMKJlDFeU&feature=player_embedded http://www.youtube.com/watch?v=zUlr9PKkQRM	Information on CTF CTF Youtube videos Part 1:Local farmer stories Part 2:Technical presentation
CTF Solutions www.ctfsolutions.com.au	Useful information and contacts for advice on CTF including 'how to notes'
www.controlledtrafficfarming.com	Good information on European CTF systems

The following videos provide some good explanations of CTF and issues associated with developing a CTF system:

Australian material from Precision Agriculture company website

Introduction to CTF:

http://www.youtube.com/watch?v=ncMVNwDZYsc

Explanation of CTF, more for summer croppers and up to 12m wide seeders, unseeded tramlines:

http://www.youtube.com/watch?v=Gkpz-cAGL9w&feature=player_embedded

Chaser bin modification, wheel track management, alternative guidance:

http://www.youtube.com/watch?v=_OnkyMov82Y

GRDC Casestudy CTF farmer Colin Hutchinson:

http://www.youtube.com/watch?feature=endscreen&v=aKkB6CENktk&NR=1

***United Kingdom system*—good autosteer tutorial for CTF and soil investigation demo:**

http://www.youtube.com/watch?feature=player_embedded&v=62UARwS9Y3M

***United States summer crop system*—very good technical explanation and well explained soil effects/very good advice on rut problems:**

http://www.youtube.com/watch?feature=player_detailpage&v=DCVFiMIvkik

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10. GLOSSARY

Anaerobic - living without air

Anoxic - without oxygen

Autosteer - technology that automatically steers vehicles or implements

Axle load - is the proportion of the total weight of the vehicle resting on a given axle

Banded spraying - spraying a narrow width to be on a crop row

Boomspray - another term for sprayer

Bulk density - dry weight of soil for a known volume, often in grams per centimetre cubed (g/cm^3)

Delving - bringing clay to the surface with specially designed tines

Denitrification - the reduction of nitrate (a compound) to nitrous oxide (gas) by some soil microbes when they cannot aquire enough oxygen in the soil

Dispersive soils - the soil clods collapse when the soil gets wet because the clay particles disperse into solution. In WA these soils are commonly sodic; have large amounts of exchangeable sodium on the clay.

Duplex soils - soils that have distinct layers with contrasting textures, for example sand over clay or gravel

Electrical conductivity - ability of the soil to conduct an electrical current, commonly used as a measure of salinity often expressed as milliSiemens per metre (mS/m)

Fuzzy wheel track - wheel tracks with crop planted in them by dropping seed on to the surface and rolling it in with a wheel rather than burying the seed by sowing

GNSS - Global Navigational Satellite System (new replacement term for GPS)

GPS - Global Positioning system

Grade bank - a form of earthworks for surface water control following a gradient

Header - another term for harvester

Implement steering - technology to steer an implement for example seeder instead of a tractor

Inversion ploughing - also known as mouldboard ploughing where the subsoil is mechanically inverted to the surface and the topsoil is buried

Macrofauna - soil organisms that will not pass through a 0.5mm sieve, for example termites, ants and earthworms

Macroporosity - marcopores are large pores in the soil that allow water to drain through by gravity

Mad rabbits - a device that is attached to a chain on the end of a marker arm at seeding to drag through stubble leaving a clear mark on the ground to follow the next seeding pass

Marker arms - mechanic guidance that is essentially a length of steel attached to the edge of a seeder to mark the middle of the next seeding run on the ground; designs vary

Mineralisation - conversation of organic matter into water soluble nutrients

NDVI - Normalised Difference Vegetation Index is a remote sensing technology that measures the greenness of plants to indicate crop growth or vegetation cover. It measures the light reflected from plants through a scanner. It can be captured by satellite imagery or devices mounted to aeroplanes, motorbikes, sprayers or hand held devices

Permanent traffic lane - (same as wheel track, tramline, wheel way) permanent tracks that the wheels of all heavy machinery are confined to in a CTF system

Porosity - measure of water or air filled pores in the soil, that generally decreases with depth

Racetrack - working round and round

RTK - Real Time Kinematic

Rill - shallow erosion caused by water

Rip skip - sowing alternate waylines then going back and filling in

Seeder - implement used for seeding crops, also called bar or airseeder

Spading - implement that has rotating spade attachments to coarsely mix topsoil and subsoil

Sprayer - another term for boomspray

Subsoil - below the soil surface; can be interchanged with the term subsurface

Subsoiling - European term for deep ripping

Tramline - same as wheel track

Water holding capacity - the amount of water held in the soil after drainage under gravity

WeedSeeker - patented term for sensing technology that identifies green weeds and sprays only them and not bare soil

Wheel track - (same as wheel way, tramline, permanent traffic lane) permanent tracks that the wheels of all heavy machinery are confined to in a CTF system

Wheel base - distance between two axles

11. TECHNICAL NOTES

[1] Compaction by wetting and drying.

As soils adsorb water and they drain and have water extracted from them, the forces developed between soil particles in the menisci (skins) which separate water from air can be large enough to draw soil particles together. You can see the same forces at work when you put a dry paintbrush under water then lift it out; the water films draw the bristles of the brush together. With each cycle of wetting and drying, loose decompacted soils will be drawn together more by these forces known as 'effective stress'. Extreme wetting or flooding of soils and their collapse and drainage can lead to severe compaction and hard setting. This is exacerbated by chemical instability ('gypsum responsiveness') and can be minimised by inclusion of gypsum application as well as deep ripping (Hamza and Penny 2002).

[2] Geological and Pedological causes of compaction during soil formation.

Many of the ancient soils of Western Australia have undergone extreme natural forces in their development. Previous overburden forces, even from glaciers in some places have squeezed sediments and soils together into dense hard layers in the subsoil; extreme wetting and drying events have done this too.

Additionally, there has been opportunity for natural cements made in the soil from compounds of silica, iron and manganese to solidify soil layers in the subsoil; 'coffee rock' is a common example of this in the north-eastern wheatbelt.

Many such layers may not be easily or profitably altered by current soil management techniques and caution is advised when considering curative options for the compact layers they form.

[3] Soil porosity changes by compression.

The larger soil pores (macropores) are the most easily compressed by cropping machinery, because they are usually full of air; the air is forced out of the soil when compacted. Smaller pores (mesopores) are less easily compressed, they are often full of water when the soil is moist; water cannot be compressed and is not easily squeezed out of the soil. When macropores are closed by compression they form more mesopores and allow increased water-holding. In sandy soils, which hold water poorly, this can lead to unexpected increases in crop growth and yield in dry seasons in some circumstances.

Macropores are large enough to be emptied of water by gravity; a condition usually found a day or two after heavy winter rain ('field capacity'). They play a role in transmitting air and water through the soil. Macropores include shrinkage cracks, burrows made by soil macrofauna (worms, ants and termites) and old root channels. Mesopores are small enough to retain water against the pull of gravity at field capacity, to be available to plants.

[4] Soil macroporosity, soil health and plant production.

Subsoils with sufficient macropores have little restriction to drainage and aeration. Poor aeration leads to the build-up of carbon dioxide, methane and sulphide gases, and reduces the ability of plants to take up water and nutrients. The number, activity and biodiversity of micro-organisms and earthworms are also greatest in well aerated soils and are able to decompose and cycle organic matter and nutrients more efficiently. Roots are unable to penetrate and grow through firm, tight, compacted soils, severely restricting the ability of the plant to utilise the available water and nutrients in the soil profile. A high penetration resistance not only limits plant uptake of water and nutrients, but greatly reduces fertiliser efficiency and increases the susceptibility of the plant to root diseases. Soils with good porosity will also tend to produce less greenhouse gases (carbon dioxide, methane and nitrous oxide) during wetter and warmer conditions.

Potential rooting depth is the depth of soil that plant roots can potentially exploit before reaching a barrier to root growth, and generally indicates the ability of the soil to provide a suitable rooting medium for plants. The greater the rooting depth, the greater the available water-holding capacity of the soil. During dry growing seasons deep roots can access larger water reserves to help alleviate water stress. The exploration of a large volume of soil by deep roots can also access more nutrients. Conversely, soils with restricted rooting limit plant uptake of water and nutrients, reduce fertiliser efficiency, increase leaching and can decrease crop yield. A high resistance to root penetration can also increase plant stress and the susceptibility of the plant to root diseases.

Crops with a deep, vigorous root system help raise soil organic matter levels and soil life at depth. The physical action of the roots and soil fauna, and the glues they produce, promote soil structure, porosity, water storage, soil aeration and drainage at depth. A healthy root system provides capacity for raising production and may provide significant environmental benefits. Crops are less reliant on frequent and high application rates of fertiliser and nitrogen to generate growth, and available nutrients are more likely to be intercepted, thus reducing losses by leaching into the environment.