Controlled Traffic Farming Systems for the Tasmanian Vegetable Industry

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Project Number: VG07058

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Controlled traffic farming systems for the Tasmanian vegetable industry

Horticulture Australia Project Number: VG07058 (August, 2008)

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for

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This is the final report of the above project. It covers the conduct and results of the project in detail, and also includes media and technical summaries.

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Table of Contents

List of Tables

List of Figures

Media Summary

Project VG07058 - Controlled Traffic Farming Systems for the Tasmanian vegetable industry

Controlled traffic farming (CTF) maintains the same machinery wheel tracks in cropping paddocks year after year. Soil health and crop productivity improve by eliminating compaction from the crop growth zone, and permanent compacted wheel lanes allow more efficient machinery operation. The basis of CTF is simple - plants grow better in soft soil but wheels work better on roads. The benefits of CTF include reduced energy use, improved soil health and crop yield and better timeliness of field operations.

CTF requires:

- Equipment track and working widths matched to a common base dimension.
- GPS guidance for accurate and repeatable tracking.
- Farm layout for effective management of erosion, drainage and field logistics.

Two significant technical challenges to the adoption of CTF in the Tasmanian vegetable industry were investigated:

- working and track width compatibility of equipment
- farm layouts suited to steeply undulating topography

An economic analysis was done based on vegetable industry data and CTF information from other industries. The analysis covered both fully integrated CTF and seasonal controlled traffic farming (SCTF). SCTF is a system based on common track and working widths of the equipment used up to harvest, but does not extend to integration of harvesters. Combined with GPS guidance, SCTF enables retention of compacted wheel tracks, but accepts random traffic at harvest, on account of the current difficulty of incorporating harvesters into the system. The compaction effects of harvest traffic are managed with tillage in the crop growth zone.

The Tasmanian vegetable industry grows a diversity of crops, requiring a wide range of machinery configurations. Almost no existing machinery is compatible with a common track or working width. CTF systems could be based on the current 1.6 m track width, or alternatively, 2 m or 3 m. Each option has its pros and cons, but recent industry interest in 2 m track widths for some crops suggest this will become a base, at least for the foreseeable future.

Farm layout can dictate success or failure in the adoption of CTF. Mapping of representative farms in north-west Tasmania showed effective CTF layouts are possible, despite topography and infrastructure challenges. The direction of run for many paddocks is already close to that required for CTF.

An economic analysis showed CTF could increase total farm gross margin by 50%, while a partial transition to seasonal controlled traffic farming (SCTF) could lead to a 20% increase. Crops with the greatest potential to contribute to this increase are potatoes, onions and carrots.

Future RD&E in vegetable CTF should focus on supporting industry adoption, modification and development of alternative machinery and comprehensive farm modeling and economic analysis.

Growers can take significant steps in CTF adoption for vegetables, as there are short-term advantages, even if a full collection of compatible machinery is not yet available.

Technical Summary

Project VG07058 - Controlled Traffic Farming Systems for the Tasmanian vegetable industry

Controlled traffic farming (CTF) keeps all paddock traffic in the same wheel tracks year after year. Soil health and crop productivity improve by eliminating compaction from the crop growth zone, and permanent compacted wheel lanes allow more efficient machinery operation. The basis of CTF is as simple as "plants grow better in soft soil but wheels work better on roads".

Two key issues in the successful implementation of CTF are:

- Equipment track and working widths matched to a common base dimension.
- Farm layout for effective management of erosion, drainage and field logistics.

The successful adoption of CTF in the Australian grain and cane industries has been largely based on a limited equipment suite and flat to mildly sloping topography. The Tasmanian vegetable industry faces a very different scenario, with an array of incompatible machines in use and topography ranging from gently to steeply undulating.

This project investigated these two issues – working and track width compatibility of equipment ,and farm layout design for steeply undulating topography – as key technical challenges to the adoption of CTF in the Tasmanian vegetable industry. A pilot economics analysis was also undertaken.

An audit of machinery used in the Tasmanian vegetable industry showed that almost no machinery is currently compatible with a common track or working width. However, opportunities exist for modification of some machinery to enable matching with CTF options. Some harvest machinery (e.g. single row potato harvesters) provides few options for change, and it is likely that alternative designs will be required for CTF.

Tyre width is another issue for CTF adoption. Many large machines are fitted with wide section tyres in the belief that this overcomes issues of soil compaction. A review of a selection of tyres from across the industry indicates that there are alternatives that could be used to reduce tyre width while maintaining load capacity.

Options exist for CTF systems based on the current 1.6 m track width, or alternatively, 2 m or 3 m track widths. Each option has its own pros and cons, but recent industry interest in 2 m track widths for some crops suggest this will become a base from which to work.

Layout for efficient CTF operation is a key issue that can determine the success or failure of adoption. Three representative farms from north-west Tasmania were mapped and alternative layouts designed with CTF operation in mind. It was found that the direction of run in many paddocks is already compatible with CTF layout requirements. Each farm investigated for layout had some features that were problematic for good design, but overall there were no significant issues that would prevent the implementation of a CTF layout and system. Generally, the layout of farms from a CTF perspective could be improved by the removal or relocation of some fences, re-alignment of internal access roads to ridge lines, and the construction of strategic surface drains.

An economic analysis was done for both fully integrated CTF and seasonal controlled traffic farming (SCTF). SCTF accepts random traffic at harvest, on account of the current difficulty of incorporating harvesters into the system. Compacted wheel tracks are retained with the use of GPS guidance and common track and working widths of all equipment used up to harvest. The compaction effects of harvest traffic are managed with tillage in the crop growth zone.

The economic analysis showed CTF could increase total farm gross margin by 50%, while a transition to SCTF could lead to a 20% increase. Crops with the greatest potential to contribute to this increase are potatoes, onions and carrots on account of increases in the respective gross margins. Although decreased tractor sizes help reduce machinery capital costs, these tend to be offset by changes in other areas of the equipment suite, resulting in little change in overhead costs.

The principles and benefits of CTF are well documented, but have never been adequately demonstrated in the vegetable industry because of the perception that the changes required to achieve a compatible machinery suite are too difficult to overcome. The focus of future RD&E in the vegetable industry should be on supporting adoption, modification and development of alternative machinery, and comprehensive farm modeling and economic analysis to add weight to the already known production efficiency and soil benefits.

While there are ample opportunities for research in controlled traffic, the most important contribution to the advancement of the industry that can be made at this time is to establish a commercial scale demonstration of the system at work. The changes required to machinery are often beyond the scope of any one individual in the industry, and there is little incentive for one sector of the industry to change if similar changes are not being adopted in other sectors. A project run across a number of collaborating farms is required to demonstrate what is achievable with a CTF system. Such a project would draw on grower’s existing equipment where appropriate, but would also require input of funds from industry and funding bodies to source and/or modify equipment to meet the requirements of the CTF system.

1 Introduction

Controlled traffic farming (CTF) is a system that keeps all machinery traffic associated with cropping operations in the same wheel tracks year after year. This improves soil health and crop productivity by eliminating compaction from the crop growth zone, and increases the window of opportunity for crop operations due to improved trafficability on permanent compacted wheel lanes. The basis of CTF is as simple as “plants grow better in soft soil and wheels work better on roads”.

There are three essential elements to an efficient and effective CTF system:

- all equipment must be on a common wheel track width, or multiple of it, with similarly matched working widths
- Real Time Kinematic-Digital Global Positioning System guidance (RTK-DGPS, or GPS guidance for short) is used to ensure accuracy of field operations
- farm planning must consider how changed tillage and traffic practices influence the management of erosion, drainage, irrigation, crop husbandry and field logistics

Grain and cane industry experience shows that CTF is one of the most significant farming system changes that can be made to improve profitability and sustainability. Lower operating and capital costs due to reduced fuel use and lower tractor power requirements are important, as are improved soil structure and soil-water relations.

Anecdotal evidence from simple commercial CTF operations in the fresh vegetable industry of north-west Tasmania indicates that productivity and crop quality improvements may be possible within one season.

This project has assembled information about two significant technical issues that hinder the implementation of CTF in the Tasmanian vegetable industry:

- the feasibility of changes required to equipment (particularly harvesters) to allow successful implementation of CTF
- the design of pilot CTF farm layouts to assess the feasibility of various layouts in steeply undulating topography

An economic analysis of the costs and benefits of a change to CTF in the Tasmanian vegetable industry was done using information from a range of sources, including some of the data collected as part of this project. There is very little experience with CTF in vegetables, so many of the assumptions used in the economic analysis are based on the experiences of other industries.

1.1 Current situation

Excessive wheel traffic and aggressive tillage are features of vegetable farming systems that contribute to declining soil physical and biological properties, and require high energy use. Environmentally friendly and sustainable farming systems for the vegetable industry are needed to improve profitability and sustainability. Practices such as controlled traffic farming, zero-till, rotations and the use of various cover crops and mulches are central to improving the sustainability of vegetable production. Producers are increasingly interested in more sustainable soil management, reducing fuel use and improving crop yield.

Australia leads the world in commercial adoption of CTF, where it is used across some 2 million ha of grain, cotton and cane. In these industries, CTF adoption has reduced costs, increased yields, improved timing of field operations and improved soil health and water use efficiency. Despite this success, there are few examples of CTF in the vegetable industry, and those that do exist are mostly in situations with very simple crop rotations and machinery requirements.

The Tasmanian vegetable industry is characterised by a diversity of crops (e.g. potatoes, onions, carrots, brassicas, peas, beans, pyrethrum, poppies, cereals) and consequent complexity of machinery configurations, particularly harvesters, servicing the industry.

1.2 Controlled Traffic Farming as a new system for sustainability

Extensive research over the past 40 years or more has highlighted the impacts of soil compaction on crop growth, and the use of CTF as a management tool. However, it is only in the past 10 – 15 years that significant progress has been made in industry adoption in the Australian grain industry, largely as a result of dedicated growers, supportive consultants and developments in GPS guidance technology. Adoption in the vegetable is virtually non-existent, in part due to the many challenges of adapting machinery to suit the system.

Potential benefits for the vegetable industry can be inferred from the research and practical application of CTF across a range of crops. These include:

1.2.1 Machinery benefits

- Reduction in tillage, with the possible adoption of no-till techniques
- Reduction in fuel use and tractor time
- Lower capital investment in tractor and tillage equipment inventory

1.2.2 Soil and water benefits

- Improved soil structure for crop growth and nutrient uptake
- Improved soil biology (health)
- Improved infiltration, water holding capacity and drainage, with reduced run-off and erosion

1.2.3 Crop benefits

- Higher, more uniform yield
- Improved crop quality and more even maturity

1.2.4 Farming system benefits

- Improved timeliness, leading to more double cropping opportunities and more effective and targeted crop management
- Fewer clods in root crop harvest leading to reduced harvest costs (potatoes, carrots, onions)
- Opportunity to improve tuber recovery, therefore fewer volunteer potatoes
- Opportunity for no-till sowing with benefits such as:
  - cover crop and crop residue retention
  - reduced soil erosion off crop growth areas
  - improved moisture retention
  - reduced weed pressure

  - reduced energy use and labour requirements
  - use of drip irrigation across seasons where appropriate, resulting in reduced foliar disease pressure
- Capacity to inter-row drill crops with GPS guidance
- More effective application of precision farming techniques such as yield mapping and variable application of inputs

1.2.5 Key off-farm environmental benefits

There are also a number of key off-farm environmental benefits to be obtained from the use of controlled traffic farming:

- Reduced greenhouse gas emissions due to:
  - reduced on-farm energy consumption (less tillage, lighter draft loads, more efficient use of tractor power) and in the manufacturing and transport sectors (lighter equipment, reduced fertiliser and pesticide use)
  - increased carbon capture in the soil (better soil biology and residue retention), and less loss of carbon (reductions in, or elimination of, tillage)
  - reduced nitrous oxide emissions (more efficient use of nitrogen fertilisers, less fertiliser used)
- Reduced impacts on civil infrastructure, riparian and marine environments and air quality due to reduced water and/or wind erosion
- Reduced demand on surface and ground water resources due to improved water capture and water holding capacity, and the option of drip irrigation

Although the benefits are numerous, implementation of CTF in the vegetable industry has many challenges. CTF is barely even mentioned as a farm management system for vegetables in other parts of the world. A small number of mixed vegetable/cereal growers in The Netherlands have implemented partial CTF systems, but progress towards a fully integrated system is hindered by lack of access to suitable harvest machinery, as is the case in all vegetable growing areas.

CTF requires a new way of thinking about farm planning, field logistics, drainage and erosion management, and a longer-term outlook for machinery replacement strategies. Direct monetary costs include machinery modifications, the purchase of GPS guidance technology and potential changes to farm layout, including improved drainage structures and management.

The Tasmanian vegetable industry uses a broad range of equipment, particularly for harvest, which is mostly done by contractors. There is currently no commonality of wheel track or working widths between harvest equipment used in the industry, a key issue to address in the implementation of CTF.

The topography of many vegetable farms is complex. This raises issues in relation to farm layout, operational logistics, drainage, irrigation and erosion under a farming system that requires compacted wheel tracks running up and down the slope. Erosion of compacted wheel tracks is perceived to be a significant issue under CTF. However, experience in other areas shows substantial reductions in erosion in up and down CTF paddocks during heavy rainfall events, although it must be recognised that the percentage area devoted to wheel tracks in broadacre cereal CTF systems is considerably less than would be the case in vegetables. Nevertheless, it is likely that the improved infiltration that would result from implementation of CTF would reduce run-off, and hence erosion, even in a vegetable CTF system.

The adoption of CTF in the grain industry has been a relatively simple task compared to what will be required in the vegetable industry. It is considered that if CTF can work in the Tasmanian vegetable industry, then it can work anywhere.

2 Materials and Methods

2.1 Vegetable industry harvest machinery survey

The processing vegetable industry is characterised by a diversity of machine configurations and ownership arrangements, particularly in relation to harvesters. Since a fully integrated CTF system requires machinery with common wheel track widths, matching multiples of working width, and the narrowest tyres possible, this diversity presents a challenge to the implementation of CTF.

One of the debates that inevitably arises in relation to the adoption of CTF concerns the choice of track width. Theoretically, any track width is possible. CTF is not fundamentally about the choice of track width. It is about managing soil compaction through isolation of traffic lanes from crop growth zones. The most appropriate track width to chose is the one that meets that objective in the simplest fashion. The reason the grain industry has standardized on 3 m is because grain harvesters are supplied ex-factory with a track width of 3 m, or very close to it. Since the grain harvester is the most difficult machine to modify, it makes sense to modify other equipment to suit the harvester. For similar reasons, the sugar cane industry is starting to standardise on close to 1.8 m, as the ex-factory track width of cane machinery ranges from 1.8 – 1.85 m.

The situation in the vegetable industry is not so clear cut, with a range of machine dimensions present. One of the objectives of this project was to undertake an audit of equipment used in the industry to gather accurate information on the current situation, and then explore options for change that may provide a logical pathway to the adoption of CTF.

Details on machinery that is widely used and owned individually or by numerous contractors (e.g. tractors, tillage equipment, grain harvesters) were obtained from current supplier's catalogues. This allowed review of a greater number of machines than would have been possible through a field based survey. Details on machinery that is owned by a limited number of contractors, and for which there are a limited number in use, were measured and information related to tyre sizes, track widths etc. recorded.

2.2 Mapping and farm layouts

An effective controlled traffic farming system requires the farm to be planned to account for efficient field operations, drainage, irrigation and direction of travel. Ideally, where drainage and erosion issues can be influenced by, or impacted by, topographic features beyond the boundaries of the farm, it is best to layout adjacent farms to capitalise on drainage paths and water capture opportunities. This is not always possible, particularly when adjacent farms might have different views of the future direction of their respective enterprises.

Tasmanian vegetable farms have a number of features that are significantly different from the expansive and relatively flat properties of the dryland cereal industry in the mainland Australian states. Vegetable farms tend to be small, with less than 100 ha common. Paddocks also tend to be small, so headland areas used for turning at the end of a row can easily account for 5% of the paddock area.

Current irrigation technologies have an influence on paddock size. Travelling and linear move irrigators tend to have a maximum hose length of around 300 m, which dictates the length of run that is possible in the paddock. The uptake of centre pivot irrigators in the vegetable industry in recent years has seen the removal of many fences, but the paddock layout is not necessarily ideally suited to CTF.

The topography of Tasmanian vegetable farms can range from slightly to steeply undulating, and have complex shape profiles that define numerous surface drainage pathways. Farms are often impacted by, or impact upon, other properties that are up or downslope in the landscape.

For all of these reasons, the design of CTF layouts on Tasmanian vegetable farms presents some challenges that are not present in the broadacre grain growing regions where CTF is becoming more widely adopted. To address some of the issues of CTF layout for vegetable farms, this project undertook to design layouts for three representative vegetable farms in north-west Tasmania.

The farms chosen represent a diversity of situations, from relatively flat and simple in terms of existing fixed infrastructure, to steeply undulating with small paddocks. Ground-based GPS mapping was used to obtain survey data of fixed infrastructure (roads, fences, buildings, windbreaks etc.) and topographic data. This was done by driving most of the paddocks after harvest, although some had to be done by walking due to crops still being in the ground.

The CTF design layout was approached in two different ways for each farm. Firstly, a layout was designed that fitted into the existing paddock and infrastructure constraints. Secondly, since all the mapping data are digital, the farm was “cleared” of any infrastructure or features that could be moved (fences, poorly sited roads, outlier trees etc.) and the CTF layout re-designed without those constraints. The purpose of this exercise was to determine the level of improvement in layout that could be obtained by removing or re-locating obstacles that interfered with an efficient layout.

Each of the farms was visited during the course of the project by the consultant selected to design the layout maps. This gave him the opportunity to view the farms first hand and ground truth the data provided by the GPS mapping and the satellite photographs.

On completion of the mapping and layout exercise, workshops were held with the owners of the properties and a number of other growers who are interested in CTF. Each co-operating grower was provided with a copy of the maps showing their existing layout and proposed alternatives that should be considered if they were implementing CTF.

2.3 Economics

Although data from CTF experiences in vegetables are very limited, a number of assumptions regarding the benefits of CTF can be made with a reasonable degree of confidence based on the experiences of other industries and a wide range of research from around the world. An economics analysis was undertaken based on these assumptions and additional information regarding cost estimates of machinery changes required to implement CTF in vegetables. Information from grain industry examples was used to project savings in fuel use, time used for field operations and crop yields (McPhee et. al., 1995b; Bowman, 2008; Scott, 2008).

The economic analysis assessed the potential advantages of Seasonal Controlled Traffic Farming (SCTF) and Controlled Traffic Farming (CTF), compared to a Conventional (C) system. The comparison was made using a basic set of assumptions and a model farm rotation.

2.3.1 General assumptions

Some general assumptions underlying the analysis are summarised in Table 1.

Table 1. Assumptions used in economic analysis

SCTF	CTF
Yield	
5% average increase	15% average increase
Quality & uniformity	
5% possible improvement	10% possible improvement
Machinery power requirement	
No large tractors required	No large tractors required
30% reduction in primary tillage power	60% reduction primary tillage power
No change in sowing or spraying tractors	No change in sowing or spraying tractors
Equipment	
20% reduction in use of rotary tillage equipment	50% reduction in use of rotary tillage equipment
50% reduction in use of deep rippers	90% reduction in use of deep rippers
50% reduction in use of rotary hoes	100% reduction in use of rotary hoes
50% reduction in tillage time for peas and beans	100% reduction in tillage time for peas and beans
20% reduction in tillage time for carrots, onions, pyrethrum & poppies	50% reduction in tillage time for carrots, onions, pyrethrum & poppies
No change to harvesting equipment	Potato, onion & carrot harvesting to use chaser bins
GPS guidance system required for non-harvesting equipment	GPS guidance system required for all equipment
Irrigation	
No change in application method	No change in application method
10% reduction in water use	25% reduction in water use

A model farm was analysed using crops, contract conditions and cost structures that relate to the farming conditions of north-west Tasmania. The model assumes an intensive program involving crops typical of the area – vegetables, pharmaceuticals and industrial ingredients. Vegetable crops include crops for processing (freezing) (e.g. potatoes, peas, beans, broccoli) and the local/export fresh markets (e.g. carrots, onions). The rotation spans a total of 12 years, including 7 years of intensive cropping and 5 years of pyrethrum, a perennial crop used by farmers to replace the traditional pasture phase. The cropping phase includes two years in which two crops are grown in the one year. Pyrethrum is not ready for its first harvest until around 16 months after establishment, hence a zero yield in Y1. Details and yield projections are summarised in Table 2.

Table 2. Crop rotation and yield

Year	Crop	Area	Gross Yield		
			Conventional	**SCTF**	**CTF**
			(C)	**(C+5%)**	**(C+15%)**
		(ha)	(t/ha)	(t/ha)	(t/ha)
1	Peas/	10	6.0	6.3	6.9
	Broccoli		13.0	13.7	14.9
2	Potatoes	10	55.0	57.8	63.2
3	Poppies	10	1.9	2.0	2.2
4	Carrots	10	70.0	73.5	80.5
5	Onions	10	65.0	68.3	74.8
6	Peas/	10	6.0	6.3	6.9
	Beans		12.0	12.6	13.8
7	Potatoes	10	56.5	59.3	65.0
8	Pyrethrum Y1	10	0.0	0.0	0.0
9	Pyrethrum Y2		4.8	5.0	5.5
10	Pyrethrum Y3		3.8	4.0	4.4
11	Pyrethrum Y4		3.5	3.7	4.0
12	Pyrethrum Y5		3.3	3.4	3.7

2.3.2 Basic machinery

Basic items of machinery are listed in Table 3. This is not an exhaustive list of plant and equipment required to run a property of the size assumed in this model. However, the items listed represent the key differences between the systems under study. These key differences include:

- No heavy tractors for the SCTF or CTF systems
- Reduction of heavy implements for SCTF e.g. mouldboard plough, deep ripper and rotary hoe
- Elimination of mouldboard plough and rotary hoe for CTF
- Allowance for GPS guidance systems in SCTF and CTF systems

The total costs of basic items identified here are similar for all systems. SCTF machinery costs an estimated 1.7% more than Conventional whereas CTF equipment is 1.3% cheaper than Conventional.

Table 3. Basic machinery inventory

	C		SCTF		CTF	
Equipment	(No.)	(Total $)	(No.)	(Total $)	(No.)	(Total $)
Heavy tractor for primary tillage	1	120,000	0		0	
Medium tractors for medium tillage	1	90,000	2	200,000	2	200,000
Light tractor for sowing/spraying	1	40,000	1	50,000	1	50,000
Mouldboard plough	1	25,000	1	15,000	0	
Deep ripper	1	7,000	1	5,000	1	3,000
Rotary hoe	1	12,000	1	8,000	0	
Rotary tiller	1	25,000	1	25,000	1	25,000
Boom sprayer	1	7,000	1	7,000	1	7,000
Fertiliser spreader	1	800	1	800	1	800
GPS guidance	0	0	1	30,000	1	30,000
Irrigation equipment		500,000		500,000		500,000
Total		**$826,800**		**$840,800**		**$815,800**
Change				1.7%		-1.3%

2.3.3 Machinery operating costs

The analysis has estimated the operating costs of conventional tractor and plant operating for heavy, medium and light work at $44, $28 and $16 per hour respectively. This is calculated on the basis of:

- Diesel consumption of 25, 15 and 8 l/h respectively
- Oil consumption of 2.5% of diesel use
- Repairs and maintenance equivalent to 2% of the purchase price per year (including implements), assuming 500 h/y for heavy and medium work and 250 h/y for light work.

Costs for SCTF and CTF systems are correspondingly less (Table 4). Note that the cost of light work for SCTF and CTF systems have increased compared to Conventional due to the inclusion of GPS guidance equipment.

Table 4. Operating costs

	C		SCTF		CTF	
	(l/h)	($/h)	(l/h)	($/h)	(l/h)	($/h)
Heavy	25	44.00	18		10	
Medium	15	28.00	13	29.00	11	25.00
Light	8	16.00	8	17.00	8	17.00

2.3.4 Gross margin analysis

The basis of comparison between Conventional, SCTF and CTF is by a detailed analysis of gross margins. These relate to known (or estimated in the case of beans, broccoli and carrots) prices and costs associated with 2008-09 crop contracts.

2.3.4.1 Gross margins

A gross margin is defined as the gross income from an enterprise less the variable costs incurred in producing it. Variable costs are those costs directly attributable to an enterprise and which vary in proportion to the size of an enterprise – e.g. if the area of crop doubles, then the variable costs associated with growing it, such as seed, chemicals and fertilisers, will roughly double.

A gross margin is not profit because it does not include fixed or overhead costs such as depreciation, interest payments, rates and permanent labour, which have to be met regardless of enterprise size. Gross margins are generally quoted per unit of the most limiting resource, for example, land, labour, capital or irrigation water. In this case, the margins are calculated on a per hectare basis.

The calculation of a gross margin is the essential first step in farm budgeting and planning. It enables a direct comparison of the relative profitability of enterprises that compete for similar resources, and consequently provides a starting point for determining the overall enterprise mix on the farm. It should be noted that where different enterprises require different resources, such as machinery, labour and capital, additional calculations should be undertaken to determine if the change to the enterprise mix is worthwhile. The GST is ignored in the analysis presented here.

2.3.4.2 Contractor costs

Contractor costs have been included in the gross margins where appropriate - e.g. sowing most crops, fertiliser cartage and harvesting and cartage of all crops. No change has been assumed between the Conventional, SCTF and CTF systems. This assumption would not apply if relatively new items of conventional machinery were modified for SCTF or CTF use. However, when conventional items have reached the end of their economic life and are upgraded to new machinery, the extra capital costs to comply with either SCTF or CTF requirements are not expected to be significant.

2.3.5 Farm overheads

Direct labour costs have been included in the gross margins. These are based on Level 3 casual rates according to the Tasmanian Farming and Fruit Growing Award and take account of wage increases effective from August 2008. Labour rates used in this report include 9% superannuation and 4.5% workers compensation.

As for other overheads, it has been assumed that there will be no change in general overhead costs - e.g. rates, communications, accounting etc. Some changes in machinery insurance costs would be expected but these are likely to be minor and have been ignored in this analysis.

Machinery ownership costs (i.e. interest and depreciation) have not been included in this assessment. As the overall values of the machinery inventories are similar, the ownership costs are unlikely to change significantly. A more in depth analysis may identify certain items of machinery that are used for more or less hours per year – e.g. tractors. Whilst it could be argued that this would normally affect the length of time held and/or the resale value, both of which affect ownership costs, it could equally be argued that machinery changeovers would still occur on a regular basis to take advantage of new technologies.

3 Results

3.1 Vegetable industry harvest machinery survey

3.1.1 Machinery Configurations

One of the major challenges facing implementation of a fully integrated CTF system in the processing vegetable industry is the diversity of machine dimensions and ownership arrangements. Given that the basis of a fully integrated CTF system is machinery with common wheel track widths, common or multiples of working width, and the narrowest tyres possible, the following table gives some indication of the challenge in the industry.

Table 5. Track and tyre widths currently used in the Tasmanian vegetable industry

Equipment	Track width (mm)	Tyre section width (mm)	Working width (mm)
Tractors	1625, 1730, 1830	350 – 600	
Single row potato, carrot, onion harvesters	2000 – 2500	300 – 600	810
Tricycle carrot, potato, onion harvesters	1100 – 2600	600 – 750	750 – 1600
Pea, bean harvesters	2200 – 2600	400 – 750	2950 – 3330
Cereal, pyrethrum, poppy harvesters	3000 – 4000	700 – 800	4550 – 8000

The most common tractor track widths used in Tasmania for in-crop work are 1.625 m and 1.73 m (dictated by potato row spaces of 32″ and 34″), although tractors used for primary tillage may have wider track widths. Most vegetable crops are grown in rows or beds based on one of those track widths. Some operators are moving to 2 m track widths for the purpose of increasing the cropped area, but CTF is not generally a consideration in these decisions.

About 11 crops are regularly grown within the vegetable industry. Only seven of those are vegetables, the remainder being crops grown for both agronomic rotational and economic benefits. The additional crops include pyrethrum, poppies, pastures and cereals. The integration of row crops (most of the vegetable crops) and broadacre crops (those that are more like cereals) makes the adoption of CTF more of a challenge than if only vegetables or cereals were grown. Across the 11 crops most commonly grown in Tasmania, some 17 different types of harvest machinery are used, with as many as 25 different configurations in relation to tyre and track width. Table 2 outlines some of the major pieces of harvest equipment used and the key dimensions of track width, tyre section width and working width.

Table 6. Harvest machines used in the vegetable industry and their characteristics

Harvester type	Type	Track width (mm)	Tyre section width (mm)	Effective working width (mm)
Potato	Grimme (1 row)	2000 – 2500	300 – 500	810
	Grimme (2 row)	2000 – 2500	300 – 500	1625
Onion	Top-Air (1 bed)	2220	240	1625
	Whulmaus 1733P	2600	500	1625
	Hilder	2580	550	1625
	Top-Air (2 bed)	3280	240	3250
Carrot	ASA-lift	2150	250	300
	Simone	2600	750	750
	AMC	2480	400	1620
Pea	FMC 979AT	2530	700	3330
Bean	Pixall 120	2210	590	2950
	FMC BH7100	2100	750	3050
Pyrethrum windrower	Macdon	3050	540	4550
Poppy	Holmes	2300	710	5500
	Radford	3000	775	5500 – 8200
Cereal / pyrethrum	various	3000	750	6000 – 9000 (cereals) 4550 (pyrethrum)

3.1.2 Options for change

Changing the track width of machines may be as simple as extending the axles, but many factors have to be considered when contemplating such modifications. The design of some machines makes them particularly difficult to change. An easy change on difficult machines is the best place to start when looking CTF modification options. This may be done by reversal of wheel rims if the rims are asymmetrical, or the addition of small spacers, provided these do not significantly increase loads on axles and bearings, or create difficulties with steering mechanisms.

As agricultural machines have increased in size, there has been more widespread use of wide section tyres to reduce ground pressure and provide a more comfortable operator environment. Unfortunately, wide section tyres on heavy machines make little difference to the degree of soil compaction below the tillage zone, and they are generally incompatible with CTF vegetable production because of the land area they impact. In addition to changes in track width, movement to a CTF system would logically look to narrower tyres to reduce the area devoted to wheel tracks. Often this may mean larger diameter tyres to provide adequate load carrying capacity, so the availability of adequate space to accommodate a taller tyre is an important consideration in reviewing the suitability of various machines for modification.

In addition to issues of track width, an integrated CTF system requires the working widths of machinery to be some multiple of the bed width in order to maintain operational efficiencies. For some machines, such as sprayers and some seeders, this is a relatively simple change to make. The change is not quite so simple for many harvesting machines used in the industry.

Apart from the mechanical ease or complexity of change, logistical considerations also factor in decisions about changing track widths. For example, even if every machine could change to suit a common track width, operators would be reluctant to change if the resultant machine widths imposed additional limitations on public road transport. In Tasmania, the maximum road transport limit is 5 m. Vehicles over 3.5 m can only travel in daylight hours. Vehicles from 3.5 - 4.5 m require a front pilot vehicle, and vehicles 4.5 - 5 m require front and rear pilot vehicles. Vehicles under 3.5 m require various combinations of warning signs, lights etc. For these reasons, it would be desirable to keep most agricultural machines under 3.5 m total width. This suggests a maximum track width of 3 m and a maximum tyre width of 500 mm.

3.1.3 Tractors

A catalogue-based survey was conducted of a range of tractor brands that are popular within the Tasmanian vegetable industry. Data on adjustability of track widths were collated for a total of 88 tractors in the 40 –180 kW range. An assessment was made of the number of tractors that could easily be adjusted to 2.0 m and 2.2 m track widths, without exceeding the manufacturer's standard recommendations. The reasons for selecting these particular track widths were:

- there is current interest in the vegetable industry in moving to a 2 m track width for operational reasons, aside from any interest in CTF
- a 2.2 m track width would minimise the alterations required to running gear on bean harvesters, and preliminary investigation suggested it may be a reasonable track width for some root crop harvesters
- a preliminary review of tractor data indicated that 2.2 m would be about the maximum track width that could be easily attained within manufacturer's warranty conditions and without after-market modifications
- an increasing number of implements are being manufactured in 1 m increments, making a 2 m track width suitable for 2, 4 or 6 m equipment

The survey showed that 44 (50%) were capable of being adjusted to 2.0 m track centres, and 6 (7%) to 2.2 m, whilst staying within the manufacturer's standard recommendations. If very simple additional measures are considered, such as spacer plates not exceeding 50 mm, the number increased to 54 (61%) for 2.0 m centres, and 19 (22%) for 2.2 m centres. In the power range of interest in the vegetable industry, very few tractors are available that can achieve a track width greater than 2.2 m within standard configurations and manufacturer's warranty.

Modifications to achieve track widths of 3 m have become reasonably common place amongst CTF operators in the cereal industry. Such changes have been warranty backed by some tractor manufacturers and generally cost from $6,000 - $12,000, although have been known to be as much as $25,000 for some types of tractor. The cost is very dependent on the degree of change required in the transmission and the front-wheel assist drive train. Track widths over 2.2 m will be difficult to achieve in the vegetable industry without moving into the realm of specialist retro-fit modifications.

The specific requirements for any given tractor to have its track width extended beyond the manufacturer's standard recommendations, even by small amounts, would be a matter for more detailed investigation on a case by case basis, and discussion with the supplier/manufacturer. In addition, although there is cereal industry experience in converting to 3 m track widths, this has all been with tractors over 120 kW in size.

There are limitations with the strength of components in smaller tractors, although there are recent examples of 70 – 80 kW tractors in Europe being extended to 3 m track widths. The longevity of those changes remains untested.

3.1.4 Tillage equipment

It should be possible, under a fully integrated CTF system, to eliminate most tillage operations used in vegetable production. With compaction managed by CTF, and soil condition becoming more suitable for approaches such as no-till, it is hoped that tillage would no longer be required, although there may still be some situations that require tillage. With this in mind, a catalogue-based survey of key tillage implements was conducted to determine what changes might be necessary to allow tillage implements to fit a CTF system. The implements of most interest are deep rippers, power harrows and reversible ploughs, as these represent a significant amount of the tillage effort that is expended in the vegetable industry at present.

The need for deep rippers would essentially disappear with the implementation of a fully integrated CTF system. However, in interim stages, in which it might be possible to retain key wheel tracks, but not possible to totally avoid traffic on the crop beds, there would still be a need for such implements. The other use for such implements might be remedial tillage of the interface between tracks and the crop bed, even in a fully established CTF system. The most common implement of this type used in the Tasmanian vegetable industry is the Agroplow, which is available in working widths from 1.5 m – 8.9 m. Most vegetable growers use implements with a working width around 3 – 4 m. These are relatively easy to adjust to fit a CTF system. Retention of compacted wheel tracks in set locations can be achieved by removing or re-positioning the tynes that track immediately behind the tractor tyres. This may require adjustment of the locations of other tynes, but this is easily done. The bigger issue will be ensuring that the total working width is an appropriate multiple of the track width, while also maintaining a reasonable level of field efficiency. Depending on the specifics of a given situation, this may require an extension of the frame of the implement.

Although there are some variations between manufacturers, power harrows are generally available from 1.2 – 2.1 m widths in 0.3 m increments, 2.5 – 5.0 m widths in 0.5 m increments and 6 – 8 m in 1 m increments. Power harrows are not an ideal implement for use in a CTF system, but relatively minor adjustments can be made to allow them to fit the system. Once again, the retention of key compacted wheel tracks can be achieved by removing the tynes from the rotating elements that track in line with the tractor tyres. A similar modification can be made to rotary hoes.

Reversible ploughs are basically unsuited for use in a CTF system because they shift soil sideways during operation, and so are incompatible with the objective of retaining defined separation between wheel tracks and crop growth zones. For that reason, there are no practical modifications that are relevant to the objective of incorporating their use in a CTF system.

3.1.5 Planting equipment

3.1.5.1 Potato planters

The most common potato planters are 2-row, with some trend to 4-row machines. Adjustments in row spacing are available to the extent of about 100 mm, which caters for the current common row spacings – 760, 810 and 860 mm. A CTF system may provide opportunities for alternative planting configurations for potatoes, including on beds with narrower row spacing than is currently used. While the potato planter is not a major barrier to the adoption of CTF, it is unlikely there would be significant scope for modification of existing machines. If a CTF system was based on 2 m track centres, existing 2-row potato planters could be used, with a changed in-row spacing to maintain plant population density. It is more likely that new designs would provide the opportunity for alternative row widths to suit a CTF system, such as three rows to a bed.

3.1.5.2 Precision seeders

Precision seeders are used for sowing crops like carrots, onions, poppies and beans. They come in a range of different configurations, but generally all have some degree of adjustability, of row spacing through sideways re-positioning of the units on the tool bar. The specific configuration of unit spacing would be dependent on the row spacing required for the crop in question, and the track width adopted for a CTF system. It is unlikely that an existing precision seeder would just happen to be suitable for CTF use without any modification. However, the possible variations are numerous, and the changes required relatively simple, so these machines are not likely to present a significant barrier to CTF adoption. Another consideration surrounding row width is the possibility of arranging row width to allow inter-seeding of the next crop.

A more significant limitation related to precision seeders is likely to be the matching of zero-till soil engaging technology with metering systems suited to the wide range of vegetable seed sizes. Currently it is relatively easy to purchase zero-till precision seeders for large seeded crops (beans, peas, corn etc.). The seeders with metering systems suited to small seeded crops (carrots, onions etc.) generally do not have zero-till capability. This problem can be overcome to some extent by coating small seeds to make them more amenable to handling through metering systems that handle large seeds.

3.1.6 Potato harvesters

The most common potato harvester in Tasmania is of the offset single row bunker design. Offset single row harvesters usually have adjustable track widths, but this does not generally assist with matching track widths for CTF purposes. The tyre arrangement on such harvesters is offset to account for the offset load of the product bunker. While some harvesters have capacity to change track width, it is not just track width that is relevant, but also wheel location across the machine, to maintain stability due to offset loads while still tracking directly behind the tractor tyres. For this reason, the tyres on this type of harvest are very difficult to align with the tractor track width and still maintain stability.

Some twin row harvesters are in use. Depending on the outloading conveyor arrangement, such harvesters may also exhibit significant offset loads, so they tend to have similar wheel and axle arrangements as the single row machines. A number of European and US manufactured potato harvesters have intake widths that would be suitable for some of the likely choices of track width in a CTF system. The selection is limited, and any of those machines would still require modification to fit into CTF.

3.1.7 Onion harvesting machinery

Onion harvest uses a number of different machines, depending on the approach taken. Lifters, toppers and harvesters may all be used. Lifters are relatively simple machines, but have little scope for modification. A change in bed width would most likely require a new lifter built to suit the bed dimensions. Toppers may be used as part of a windrow turning process, or they may be incorporated as part of a harvester. Either way, the impacts of changes in bed width will be much the same for toppers as they are for harvesters.

Onion harvesters come in a range of shapes and sizes, with an equivalent diversity in tyre arrangements. A number of single row potato harvesters are used with onion pick-up fronts. These have tyre and axle arrangements as described previously for potato harvesters.

The other major harvester type is manufactured by Top-Air. These harvesters are centre pull machines with a multi-tyred arrangement under the rear of the machine. The single bed harvester has 4 tyres while the twin bed unit has 6 tyres. Both machines have capacity for track width adjustment through extension of the sub-frame and re-positioning of wheel brackets. However, from a CTF perspective, the most important change required would be a conversion to just two tyres to carry the same load as the existing 4 or 6. Another change required would be the addition of a weight frame and weights to balance the offset load that occurs on account of the discharge conveyor. Changes such as those suggested are possible without compromising the operation of the harvester. Alternative harvester designs are available that would be able to fit a CTF system based on 2.0 m or 2.2 m beds, although some re-arrangement of wheels might be required (Fig 1).

Fig 1. Different tyre configurations for current Top Air twin bed (left), single bed (centre) and alternative style single bed (right) onion harvesters

3.1.8 Carrot harvesters

Two types of carrot harvester were included in the audit of machines. The three point linkage ASA-lift is a light machine with limited adjustability options for track width. A similar machine has been modified for use in a CTF fresh market leek and carrot growing operation in Tasmania. Even so, the result is not ideal, as there is insufficient side shift available on the picking head to allow a whole bed to be picked without moving off the adjacent wheel tracks.

The Simone is a tricycle style harvester, a design feature that is, unfortunately, becoming more common in the larger root crop harvesters (Fig 2). There are no track width adjustment options for this type of harvester, and with the tricycle design, it is basically unsuited for use in CTF operations. Apart from single row TPL machines, there are no carrot harvesters that lend themselves to relatively easy incorporation into a CTF system. However, on the basis of information currently available, it appears that there may be harvesters of European design that may lend themselves to modification to suit a CTF system, although the mechanical change required is likely to be significant. At this stage, none of this style of machine is present in Tasmania.

Fig 2. Front and rear views of tri-cycle carrot harvester showing wheel arrangements that are incompatible with CTF.

3.1.9 Pea viner

The most widely used pea viner in the Tasmanian industry is the FMC 979AT-3.3B with a current track width of 2.53 m. These machines cost over $650,000 and are owned by the processing companies. There is no capacity for the track width of the pea viner to be reduced as there is inadequate room between the tyres and the sub-frame to allow sidewall clearance at a narrower track width. Because pea viners have a considerable amount of fore-aft and side-to-side adjustability as part of their leveling system, there is little opportunity to cope with taller tyres. A narrower track width has implications for machine stability when working on slopes. Reversal of the wheel rims could extend the track width to a maximum of 2.97 m.

The current pea viner working width is 3.33 m. This is a very convenient width, as it allows road travel without the need for escorts, which would be required for widths greater than 3.5 m. Any track width chosen for a vegetable industry CTF system, apart from 3 m, is likely to require a different working width for the pea viner to maintain operational efficiencies. On the basis of enquiry made to pea viner manufacturers, it appears alternative width fronts are not available. Modification of a pea viner front is a complex task that is unlikely to be undertaken by the processing companies without very convincing evidence that the change is warranted. Provided the track and bed width chosen is somewhat compatible with the operating width of the pea viner, it would be possible to fit it into a CTF system. One of the major drawbacks is the requirement of the viner to operate across the fall of the crop, which may not coincide with the direction of a CTF layout. However, there may be other changes that can be made to the pea harvester operation to overcome this issue. Although the pea viner would not be too difficult to fit in to a 3 m CTF system, it would be a difficult machine to incorporate into any other track width. The other issue of importance is the crop itself, and the need to harvest the crop in relation to its direction of fall.

Fig 3. Pea harvester (above) and view showing tyre clearance and construction of axles (right) that limits options for modification for CTF

3.1.10 Bean harvester

Neither bean harvester measured (Pixall 120 and FMC BH7100) has any capacity for easy track width change through rim reversal. There is little capacity to reduce the track width due to clearance limitations. It would be possible to gain small increases in track width through the use of spacers, but this would be unlikely to add more than about 100 mm to existing track widths without moving into the realm of major changes. There is no room to fit taller tyres to either bean harvester because of space limitations imposed by the cab.

The working width of the Pixall 120 bean harvester is 2.95 m, which, once again, is a convenient width for road transport reasons. With modification a major task, the alternative of purchasing a different width picking front would be the most attractive option, but it appears that such an alternative is not available.

The FMC bean harvester is an even more difficult proposition. Unlike the Pixall harvester, the picking front, feed mechanism and cleaning system are all the same width. A change to the picking front width would require either a complete re-build of the harvester to maintain full width conveying and cleaning systems, or major alterations after the picking front to re-distribute the picked product to allow efficient cleaning. Neither appear to be practical options. Along with the pea viner, the bean harvester is a difficult machine to incorporate into a CTF system that is based on anything other than a 3 m track width.

3.1.11 Pyrethrum windrowers

Pyrethrum is a good crop to consider for a CTF system, as it is in the ground for about 4 seasons with spraying and harvesting the only field operations after initial ground preparation and sowing. The dominant windrower used for pyrethrum is the Macdon, although there are also reversible tractor units. The Macdon has a track width of 3.05 m and a cutting front width of 4.55 m. Conversion of this to a wider track width, if necessary to match a 2 m / 4 m CTF system, and matching the cutting front, would be no more challenging than changes that have already been made to cereal harvesters in other industries. The tractor-based units can achieve the normal range of track widths available for tractors, namely around 2 m.

3.1.12 Grain harvesters

Cereals are often grown in the vegetable industry as a rotational break crop and to provide organic material for soil benefits. At current prices, cereals are also a quite attractive economic proposition. Consequently, grain harvesters are an important part of the equipment mix that needs to be considered in a CTF context. Grain harvesters are also used for pyrethrum harvest.

Rather than review a whole range of grain harvesters for the machinery audit, a few harvesters that are representative of the machines used in Tasmania were selected, and advice obtained from those experienced in the modification of grain harvesters for CTF adoption. Since grain harvesters are supplied ex-factory on 3 m track centres (or close to it), an assessment was made of the modifications required to achieve track widths of 4 m or 4.4 m, since these would straddle two beds of 2 m or 2.2 m systems, respectively. These track widths were chosen for the reasons outlined earlier in relation to the tractor survey.

Modifications to achieve track widths of 4 m have been done on a variety of grain harvesters in the dryland cereal industry. The process is relatively simple, and involves removal of the final drives, insertion of a main beam extension, replacement of the final drives and replacement of the drive axle with a new extended axle. The cost is generally somewhere in the order of $10,000.

The modification is not without its issues. There is a risk of voiding the warranty, and there has been some indication that harvester manufacturers will not warrant machines extended beyond 3 m track width, even though a number of harvesters are sold with options that allow track width extension to 4 m. It is always the responsibility of the owner to seek advice from the manufacturer on this issue.

A track width extension to 4 m will have implications for road transport and the requirement for escorts, depending on the final overall width. It is unlikely that the total width would be less than 4.5 m. Extension to a 4.4 m track width is unlikely to be a viable option, as the overall width would be in excess of 5 m, and therefore would have special escort requirements.

Fig 4. Grain harvester axle extension (3.2 m - 4 m) to allow straddle of 2 m raised beds

In addition to the track width modifications, it is also necessary to ensure that the cutting front is modified to allow matching of working widths. Standard width fronts of 6 m or 9 m are readily available, so could be ordered with the harvester, or bought as a replacement front. For other widths, (e.g. 8 m to match a 4 m track width), the cost of modification of an existing front is approx. $10,000, plus freight. Companies with expertise in these modifications are mostly based in Queensland. An alternative would be to purchase a standard 6 m or 9 m front, with an indicative second hand cost of $10,000 - $15,000.

If a chaser bin is to be used for grain haul out, it would normally be necessary to extend the outloading auger to allow the chaser bin to remain the correct distance from the harvester and within the CTF wheel tracks. In most cases, such modifications could be made for $1,000 or less, although some manufacturer supplied kits cost up to $1,500. Chaser bins are not normally used in the Tasmanian cereal industry, and it is unlikely that adoption of CTF would necessarily alter that situation.

Fig 5. Grain harvester auger extension to allow adequate reach to the chaser bin when on 3 m CTF tracks

Auger extensions present some potential problems. Some kits that can be purchased may restrict grain flow, and there are anecdotal accounts of gearbox failure due to the resultant increased loading. Most grain harvesters are now designed with horizontal outloading augers, but early model harvesters with inclined augers may present an electrocution hazard if extended more than 1 m.

Many large harvesting machines, including grain harvesters, are fitted with wide section tyres for the dual purposes of lower ground pressure and operator comfort. Under a controlled traffic system for vegetables, wide section tyres result in a large area of land being devoted to wheel tracks. For example, 700 mm wide tyres on a 3 m track width results in 23% of the area being under wheel tracks. Consequently, benefits can be gained by using tyres with a narrower section width, but they must still be able to carry the required load. There are a limited number of manufacturers supplying tyres of less than 500 mm section width with the load capacity required for a fully laden grain harvester. The conversion to narrower high strength tyres requires heavy duty rims, and costs, with second hand rims, approx. $6,000 per machine.

3.1.13 Poppy harvesters

There are two dominant types of poppy harvester used in the Tasmanian industry. One has the cutting front mounted on a reversible tractor with a trailed collection bin. The track width of these should be able to be matched to whatever is possible for the particular tractor, which will generally be around 2 m. Current models are at 2.3 m with 710 mm section width tyres. Narrower tyres would provide more options for track width. The other type of harvester has been developed and built by a local contractor and is based on similar dimensions to most grain harvesters, namely 3 m track width with 700 – 800 wide tyres, and a variety of cutting front widths. These machines could be modified to a 4 m track width, but such a change would introduce the need for additional escorts for road travel.

3.2 Tyre selection

As agricultural machinery has become larger and heavier, the response of manufacturers has been to fit larger section tyres with the objective of reducing soil damage. The disadvantage of wider tyres is that, not only do they continue to damage soil structure, they also increase the area of wheel tracks in the paddock. Another key aspect of using wider tyres at lower pressure is to act as a suspension system for the machine. The cushioning of the tyre protects the machine frame from excessive stress and provides a more comfortable ride for the operator.

CTF aims to minimise the width of wheel tracks, within the bounds of still being able to operate the machine. Harvesters usually have the widest tyres of any machine used on the farm, with section widths of 600 – 800 mm becoming common. However, if tyre selection is considered from a CTF perspective, with a narrow footprint being a key objective, then it is necessary to look for alternatives To take an example, Table 3 outlines some possible alternative tyres for one harvester used in the Tasmanian vegetable industry. The tyre specifications given in the first line of the table are the current standard tyre. The alternative tyres in the table provide a narrower footprint with a similar load capacity and similar diameter. These suggestions should not be taken as recommendations – they are given merely to indicate that in any given situation, there may be alternatives that are worth investigating in an effort to reduce tyre width for CTF operations. Each individual machine would need to be reviewed in the context of its specific characteristics.

Table 7. Existing tyre and two possible alternatives with reduced section width.

Tyre	Design width (mm)	Design dia. (mm)	Load capacity (kg)	Pressure (kPa)
750/65R26 (existing)	754	1610	5,000	220
23.1-26	587	1605	5,300	320
23.1-26 IND 12 PR	587	1580	4,750	190

3.3 Conclusion – machinery audit

Three main machinery issues need to be addressed for the Tasmanian vegetable industry to make progress in the adoption controlled traffic farming – track width, working width and tyre section width. The current situation with a diversity of machine styles, tyre arrangements, working widths and tyre sizes is incompatible with a CTF system. While there is scope for modification of some machines, a number of key machines in the industry (e.g. potato and carrot harvesters) are incompatible with CTF. The only option at present is to move to different designs of harvesters that would provide some scope for modification to suit CTF. This is unlikely to happen immediately, as there is a reluctance on the part of many in the industry to invest in different machinery when they are still uncertain of the benefits to be obtained. In addition, while the main expenditure on harvest equipment is made by contractors, the major benefits of CTF accrue to growers. Considerable thought and planning needs to be invested in how such changes, that have significant industry-wide potential, can be implemented while sharing the costs and benefits. CTF has not been a consideration in past machinery selections. However, as growers become more aware of the benefits, it is likely that changes to more adaptable machinery will occur when it is time to upgrade equipment.

3.4 Mapping and farm layouts

3.4.1 Alternative layouts

Three farms were chosen for the mapping and layout part of this project. Aerial photo maps of the farms were provided by Agricultural Resource Management Pty. Ltd. (ARM) from images supplied by the Tasmanian Department of Primary Industries and Water (DPIW). The layout exercise indicated that the direction of run of many paddocks is already consistent with good CTF layout principles. In some cases, relatively simple changes to farm layout could be implemented which would improve the farm design not just for CTF, but also for conventional farming operations. Some areas on some farms would be difficult to drain effectively even with the best layout options available. Layout maps and explanatory notes are included for two of the farms as examples. In all cases, north is to the top of the page.

Fig 6. Existing layout showing access roads (black) and direction of operations (yellow) in each paddock.

Figure 6 shows an aerial photo map of one of the farms chosen for this part of the project. The yellow arrows indicate the current travel directions of operations, largely dictated by the direction of slope. Figure 7 shows the preferred direction of run for a CTF layout assuming the layout is constrained by existing infrastructure such as fences, roads and irrigation systems. The blue dotted lines are suggested drains and H denotes irrigation hydrants. Several pivot irrigators are used on this farm. A number of paddocks are already farmed in directions that would be suitable for a CTF system established within existing constraints of roads and irrigators. Surface drains would be required to better manage run-off from areas in which the direction of travel is not totally consistent with slope and natural drainage.

Fig 7. Suggested layout within the constraints of existing infrastructure showing access roads (black), direction of operations (yellow) and drains (blue).

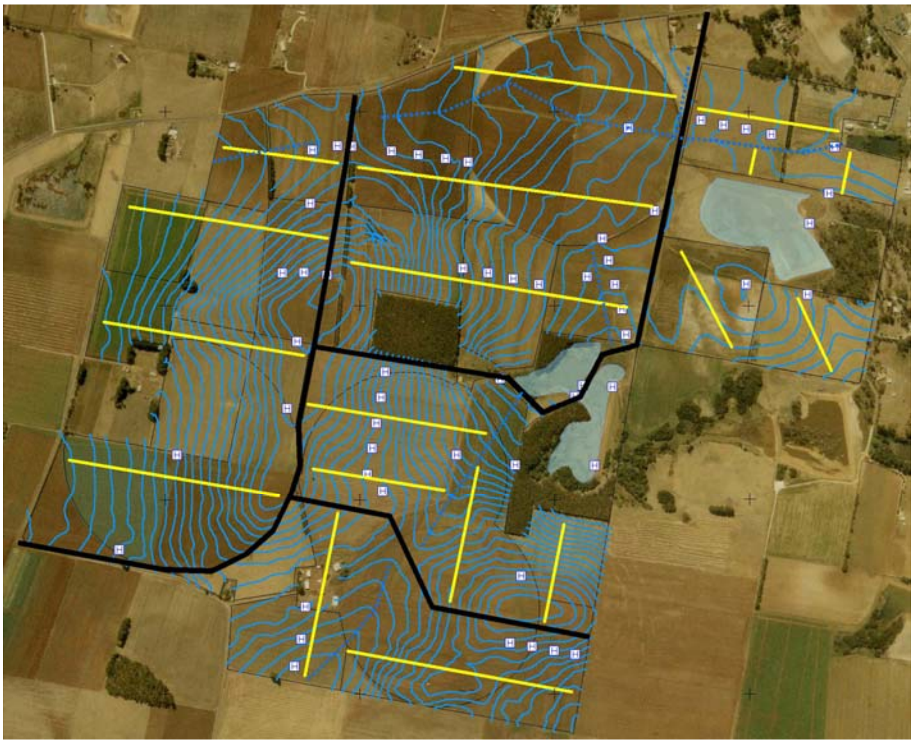

Fig 8. Direction of run layout unconstrained by existing infrastructure.

Figure 8 shows a suggested layout for the same farm assuming there are no constraints of existing infrastructure, such as fences, roads and irrigation systems. While some key areas maintain the same direction of run as is currently in place, and were also suggested in Fig 7 for a constrained CTF layout, other parts of the farm require a major re-orientation for optimum implementation of CTF. This could have significant implications for irrigation infrastructure. Some roads have been re-aligned to make better use of higher parts of the landscape. This is generally preferred as the roads then have minimal effect on drainage.

Although it would be possible to operate this farm in the layout shown in Figure 7, it would function more effectively from a drainage and vehicle movement perspective if it were laid out as shown in Figure 8. While this farm is not engaged in an immediate process of moving to CTF, the alternative layout highlights the importance of considering layout design before making significant changes or investments in infrastructure such as irrigation.

Fig 9. Existing layout showing access road (black) and direction of operations (yellow) in each paddock.

Figure 9 shows an aerial photo map of another of the farms chosen for mapping and layout indicating the current directions of operations in each paddock. Figure 10 shows the preferred directions of run for a CTF layout assuming the layout is constrained by existing infrastructure such as fences, roads and travelling irrigators. Once again, a number of paddocks retain the current direction of run in the new layout, although there are a couple of key changes in the central paddocks on the western side of the farm. The eastern-most paddock that could be farmed in either direction from the perspective of CTF, but would preferentially be farmed in the long direction for efficiency purposes.

Fig 10. Suggested layout within the constraints of existing infrastructure showing access roads (black) and direction of operations (yellow).

Fig 11. Farm layout unconstrained by existing infrastructure.

Figure 11 shows a suggested layout for the same farm assuming there are no constraints of existing infrastructure, such as fences, roads and irrigation systems. While a number of paddocks maintain the same direction of run as previously, significant changes are suggested for the layout of access roads and the paddocks toward the south-west of the farm. Access roads have been re-routed to ridge lines to minimise drainage impacts.

Re-orientation of the south-western paddocks could cause some issues from the perspective of headlands, as the suggested layout would require sacrifice of some currently cropped area to provide turning areas and run-out rows when planting crops. Likewise, the eastern-most paddock is now worked in a direction which is not parallel to either fence, which would also result in a number of run-out rows. On a relatively small farm engaged in the production of high value crops, loss of productive area to headlands and turning areas is an important consideration.

Once again, this farm is not engaged in an immediate process of moving to CTF, but the alternative layout highlights some key issues that should be considered before making future investment decisions.

3.4.2 Summary of mapping outcomes

The Tasmanian vegetable industry has a well established practice of working up and down slope. This has been largely driven by machinery tracking issues and operator safety, both of which are compromised when working cross-slope in steeply undulating country. As a result, Tasmanian vegetable farms tend to be worked in directions that are largely consistent with good CTF layout principles. Location of access roads and irrigation infrastructure is often not consistent with good CTF layout, which is not surprising since CTF has never been a consideration in farm layout up until now. Nevertheless, of the farms mapped, relatively simple changes to road layout, without necessarily changing irrigation infrastructure, would enhance the performance and operation of a CTF system. The key learning from this part of the project has been to reinforce the importance of mapping and layout design as a starting point in whole-of-farm implementation of CTF. It is a cheap investment on which to base future decisions, many of which potentially require substantial investment.

3.4.3 Mapping workshops

After the mapping layouts were completed, workshops were held with growers and industry representatives to discuss the results and the importance of considering farm layout as part of a transition to CTF. A number of issues that impact on layout were highlighted in the workshops, as listed below:

- Paddock shape and size
- Side slope
- Length of run for harvest haul out, irrigation and operational efficiency
- Irrigation technology
- Physical barriers – tress, fences, roads, drains
- Isolated paddock features – e.g. rocky outcrops
- Ability to stay on the compacted tracks
- Erosion
- Water logging
- Access for daily operations
- Crop type

3.5 Conclusion – mapping and layout

A good layout is an essential foundation on which to base a CTF system. While the farms mapped as part of this project showed a few potential failure situations, due to the difficulty of always ensuring that traffic is across the contour, most farms would be suited to the establishment of a CTF system. The issue of most concern, and which only on-ground experience will resolve adequately, is the risk of erosion in the wheel tracks of an up and down slope CTF system. The reality is that the existing farming system already faces this issue, and with improved infiltration in the crop zones, it is envisaged that the situation will only improve with CTF.

3.6 Economic analysis

3.6.1 Individual Crops

Table 5 shows the gross margin that is potentially achieved for each crop under the three systems. They are ranked from lowest to highest on the basis of the $/ha return for the CTF system. In pure dollar terms, potatoes are the most responsive to CTF, closely followed by onions and carrots. Income from these crops has increased significantly from a combination of projected yield and quality bonuses. The least responsive crop in dollar and percentage terms is pyrethrum.

Table 8. Crop return comparisons under different farming systems

	C	**SCTF**	**CTF**	**Change**					
				SCTF v C	CTF v SCTF	CTF v C	SCTF v C	CTF v SCTF	CTF v C
	($/ha)			($/ha)			%		
Pyrethrum	1,500	1,700	2,100	200	400	600	13	24	40
Peas	1,400	2,000	2,400	600	400	1,000	43	20	71
Broccoli	2,300	2,900	3,800	600	900	1,500	26	31	65
Poppies	2,800	3,200	3,900	400	700	1,100	14	22	39
Beans	2,700	3,400	4,100	700	700	1,400	26	21	52
Onions	2,600	3,500	5,100	900	1,600	2,500	35	46	96
Carrots	2,800	3,700	5,200	900	1,500	2,400	32	41	86
Potatoes	8,300	9,500	11,400	1,200	1,900	3,100	14	20	37

Note: The gross margin for pyrethrum represents an average over its 5-year life.

Figure 6 shows the actual gross margin under the Conventional system (blue) plus the potential increase by converting firstly to SCTF (red) then fully to CTF (green). In all cases, there are substantial benefits associated with progressing beyond SCTF and adopting the full CTF system.

Fig. 12. Comparison of gross margins between crops under alternative farming systems

3.6.2 Business Benefit

From an overall business perspective, farm gross margin can potentially increase from \$340,000 per annum (Conventional) to \$414,000 (SCTF) and to \$518,000 (CTF). Increasing income is overwhelmingly responsible for the increases (Table 7). Gross margin, as a percentage of income, can potentially increase from 40% (Conventional) to 46% (SCTF) and to 52% (CTF).

Variable cost components associated with increased yield, such as "contract harvest and cartage" and "other" (which includes yield and income related levies) rise with controlled traffic. However, these are more than offset by reductions in other costs related to irrigation, machinery operation and labour.

3.6.3 Industry Benefit

If the assumptions used in this analysis can be achieved, there are likely to be substantial industry benefits associated with the adoption of CTF, including:

- Reduced use of resources such as water and energy
- Reduced reliance on expensive heavy machinery
- More sustainable use of the soil resources
- Higher yields and better quality thereby reducing pressure on land and improving efficiencies
- Greater opportunity for contractors to maintain costs by increasing the speed of harvest and by spreading ownership and operating costs over more tonnes
- More profitable farm businesses without increasing overall costs
- Greater capacity of the industry to withstand external pressures, such as overseas competition

3.7 Conclusion – economics

Although this analysis has relied on a range of assumptions drawn from other industries, it is clear that there is considerable economic potential to be gained from CTF, both at the individual farm level and across the industry. The establishment of some pilot projects to implement CTF on commercial farms is an essential step to gaining more robust information on which to base a more rigorous economic analysis.

Table 9. Comparison of annual economic performance of three different farming systems

				Change					
	C	**SCTF**	**CTF**	SCTF v C	CTF v SCTF	CTF v C	SCTF v C	CTF v SCTF	CTF v C
Gross Income	**$843,000**	**$893,700**	**$996,600**	**$50,700**	**$102,900**	**$153,600**	**6.0%**	**11.5%**	**18.2%**
Variable costs									
Seed/plants	57,700	57,700	57,700						
Lime	3,500	3,500	3,500						
Fertiliser	143,900	143,900	143,900						
Sprays	54,100	54,100	54,100						
Irrigation									
HEC	32,000	28,800	24,000	-3,200	-4,800	-8,000	-10%	-17%	-25%
Repairs	10,700	9,600	8,000	-1,100	-1,600	-2,700	-10%	-17%	-25%
Contract work	36,700	36,700	36,700						
Contract harvest/cartage	88,900	93,300	101,900	4,400	8,600	13,000	5%	9%	15%
Tractor/plant									
Fuel & oil	22,000	11,400	9,000	-10,600	-2,400	-13,000	-48%	-21%	-59%
Repairs	7,300	3,800	3,000	-3,500	-800	-4,300	-48%	-21%	-59%
Casual labour	33,300	23,800	22,900	-9,500	-900	-10,400	-29%	-4%	-31%
Other	12,000	13,200	13,700	300	500	800	2%	4%	6%
Total variable costs	**$503,000**	**$479,800**	**$478,400**	**$-23,200**	**$-1,400**	**$-24,600**	**-4.6%**	**-0.3%**	**-4.9%**
Total gross margin	**$340,000**	**$413,900**	**$518,200**	**$73,900**	**$104,300**	**$178,200**	**21.7%**	**25.2%**	**52.4%**
GM as % of income	**40%**	**46%**	**52%**						

4 Discussion

4.1 Suitable track widths for CTF

Defining the most appropriate track width for a CTF system is often a challenge. Although the grain industry has settled on 3 m, based on the ex-factory dimension of harvesters, there were many years when other options were pursued based on other factors. The diversity of equipment in the vegetable industry does not immediately suggest an obvious choice. Any move to a fully integrated controlled traffic system in the vegetable industry will require major changes for many pieces of equipment.

However, when the integration of equipment is considered, it becomes clear there are three choices that maximise the ease of change:

- 1.6 m / 3.2 m – a mixed system based on the current standard track width
- 2 m / 4 m – a mixed system based on 2 m, or
- 3 m

In the mixed system, vegetable equipment would be based on the smaller dimension, and cereal or similar equipment would be based on the larger dimension.

Another factor to consider in track width selection is the agronomic requirements of crops, and whether or not certain crops might perform better under different spatial arrangements. The current track width of 1.625 m has evolved on no real basis other than mechanical change. The track widths discussed here are also considered in the context of ease of mechanical change, not crop requirements. There is no doubt that a wider track width and the improved soil conditions arising due to CTF will provide agronomic benefits for crops, even if there are alternative spatial arrangements that might be deemed to be superior.

4.1.1 1.6 m / 3.2 m mixed track width option

The option of mixing track widths on a 1:2 ratio has certain attractions for an industry that grows a mix of row crop vegetables and broadacre cereals, or crops grown in a similar style. The larger dimension (3.2 m), being twice the smaller dimension is ideally suited to cereal harvest equipment. Although pea and bean harvesters don't currently match with any other equipment, a dimension around 3 m would be as easy as any to achieve. The smaller dimension (1.6 m) is generally fairly easy to achieve for some equipment, but would still require significant change in the style of some harvesters – e.g. potato, onion and carrot harvesters. The biggest disadvantages of the narrower track width are the percentage of land area devoted to wheel tracks, and hence reduced cropping area, and the risk of machine instability on narrow track widths. With the advent of larger machines, there is a trend to wider, not narrower, track widths for stability and productivity reasons, so a system based around 1.6 m is unlikely to viewed favourably.

4.1.2 2 m / 4 m mixed track width option

Tractors capable of 2 m track width are reasonably easy to obtain and there are no warranty liability issues with manufacturers. Current styles of potato, onion and carrot harvester do not suit 2 m, but there are machines on the market (although rarely used in Tasmania) that will either fit a 2 m track width, or could be modified relatively simply to match. In addition, there are some machines used in the current 1.625 m system that could fit a 2 m system with minor modification.

Grain harvesters, which are also used for pyrethrum harvest, can be modified to a 4 m track width relatively easily, enabling them to straddle two 2 m beds, although such a change would present additional road transport issues. Pyrethrum windrowers would have to be changed from the current 3 m track width. The cutting width would also need minor change.

Pea and bean harvesters don't fit a 2 m system. While it might be mechanically and structurally possible to extend their track widths to 4 m, it would be a major modification. The cutting fronts will not cope with that option, and there doesn't appear to be any simple way of dealing with this issue.

A significant downside of the 2 m / 4 m option is that some machines, particularly grain harvesters, would exceed the 4.5 m overall width limit at which it is possible to travel on public roads with only a front pilot vehicle. The suggestion of a 4 m track width for larger machines is not viewed favourably in the industry.

4.1.3 3 m track width option

There are very few tractors available ex-factory capable of a 3 m track width, and they are very much in the large power range (generally 120 – 200 kW). Some tractors can be modified after-market to a 3 m track width, but experience with this change in smaller tractors (less than 100 kW) is limited to a few isolated European examples. The reliability of such a change is unknown. Conversions to 3 m track widths in the Australian grain industry have been confined to tractors greater than 120 kW.

Current styles of potato, onion and carrot harvester do not suit 3 m, but there are a limited number of machines on the market (although not currently used in Tasmania) that will either fit a 3 m track width, or could be modified relatively simply to match. One of the downsides of this approach is that machines capable of handling a 3 m track width will inevitably be much larger than those required for a 2 m system. This increases weight, length, power requirements and cost, as the 3 m system would require a completely new suite of equipment for these crops. However, under a fully integrated controlled traffic system, the draft and rolling resistance requirements of such machines will be less than many currently used options on account of the friable nature of the crop bed and the compacted wheel tracks.

Harvest logisitics are also an issue to consider when looking at track width options. Using potatoes as an example, a current single row harvester in an "average" paddock (approx. 300 m length of row) will recover about 1.7 t of crop in a single pass. Depending on the row configuration used, and yield improvements as a result of CTF, this could become 7 t in a single pass when harvesting a 3 m bed. This change has significant implications for the selection of the number and capacity of chaser bins, which in turn influences additional tractor purchases.

Grain harvesters, which are also used for pyrethrum harvest, are currently supplied ex-factory at 3 m track width, as are some pyrethrum windrowers. The cutting width of the windrowers would need changing to either 3 m or 6 m. The smaller of these changes would impact operational efficiency, while the larger would change the volume of the windrow with consequent issues for effective crop drying.

It should be possible to modify pea and bean harvesters to a 3 m track width, and the picking fronts would be very close to the desired width for both efficiency and matching the track width system.

An advantage of the 3 m option is that most machines would be just less than 3.5 m overall width, the legal limit before front escort vehicles are required for road travel. However, a 3.5 m vehicle would still present transport safety issues on narrow country roads. Table 4 summarises the relative ease associated with the changes that need to be made for either a 2m / 4 m or a 3 m system to work.

All of the options have a range of advantages and disadvantages. While mechanically the 1.6 m / 3.2 m option is probably the easiest, the high percentage of land area devoted to wheel tracks (25 – 30%) is a major drawback.

The 2 m / 4 m CTF system offers many advantages. Despite the fact that current pea and bean harvester designs don't fit this system, the ease of converting tractors and root crop harvesters to 2 m suggests that this is a more likely option for the industry at the current stage of CTF development. In addition, there is already interest in the industry in changing tractors to 2 m for operational reasons. Such a change will flow on to other machinery, such as tillage, planting and spraying equipment. The percentage of land area devoted to wheel tracks is 25 – 30%. Such a choice is unlikely to see crops dependent on larger harvesters (peas, beans, cereal, pyrethrum, poppies) included in the CTF system due to the difficulties in converting those machines to a 4 m track width.

The 3 m system offers the greatest combination of advantages in terms of minimising wheel track area (about 15%), improved stability and full integration of the vegetable and broadacre crops. Pea and bean harvesters, difficult machines to fit into any system, are more likely to fit the 3 m system than any other option. A major drawback of this option is the lack of root vegetable harvest machinery capable of operating in this system. This is particularly the case for top-pull carrot harvesters. Although there are few options available, it is possible to find onion and potato harvesters that could be modified to a 3 m track width and a 2.5 m bed width. Probably of more importance is an off-farm issue – safe travel on narrow country roads. There are many movements of large harvest machines during the summer harvest season, but a 3 m system adopted for CTF purposes would result in a significant increase in the movement of wide vehicles, and a significant increase in the requirement for escort vehicles. Farm to farm tractor movement occurs at all times of the year with much greater frequency and many more machines than is the case for the summer harvest period.

Regardless of the option chosen, the adoption of CTF in the Tasmanian vegetable industry will only progress with the acceptance that some machines are not going to change in the near future, but with the hope that there might be options for change at some time in the longer term.

Table 10. Relative ease of changes to machinery to achieve different track and working width options for CTF.

	1.6 m / 3.2 m system		2 m / 4 m system		3 m system	
Machine	**Track width**	**Working width**	**Track width**	**Working width**	**Track width**	**Working width**
Tractors	Easy	Not relevant	Easy	Not relevant	Possible for larger sizes	Not relevant
Carrot harvesters	Possible	Possible	Possible	Possible	Difficult	Difficult
Onion lifters	Available	Available	Possible	Possible	Possible	Possible
Onion harvesters	Available	Available	Available	Possible	Possible	Possible
Potato planters	Possible	May be possible	Possible	Possible	Possible	Possible
Potato harvesters	May be possible	Available	Possible	Available	Possible	Available
Pea harvesters	May be possible	Possible	Very difficult	Very difficult	May be possible	Possible
Bean harvesters	May be possible	Possible	Very difficult	Very difficult	May be possible	Possible
Grain harvesters	Available	Available	Possible	Available	Available	Available
Pyrethrum windrowers	Possible	Possible	Possible	Possible	Available	Available
Poppy harvesters	Possible	Possible	Possible	Possible	Available	Possible

Notes on table: available – options are readily available, although not widely used at present; possible – mechanically achievable through modification or new design although not currently used; difficult – no options currently available and modification judged to be difficult

4.2 Farm layouts for CTF

The success and efficiency of CTF operations can be greatly influenced by farm layout. One fortunate aspect of the Tasmanian vegetable industry is that field operations generally take place up and down slope, which is consistent with good CTF practice from dryland cereal areas, notwithstanding that the slopes in Tasmania are considerably steeper. This direction of travel minimizes issues with surface drainage, although there is still some potential for erosion issues in the wheel tracks. Even so, because of the complexities of the landscape, many farms will have small areas that are at risk of erosion or drainage failure because the direction of travel is along, rather than across, the contour in that area. There is insufficient experience in the Tasmanian environment to judge whether or not wheel track erosion will be an important issue.

One of the biggest changes that will be required to improve the efficiency and operational logistics of CTF is the removal of fences to create bigger paddocks. Turning areas and headlands are important aspects of CTF layout, and the influence of run-out rows can be significant, particularly in irregularly shaped paddocks. With good agricultural land commanding high prices, dedication of productive areas to headlands and turning areas needs to be minimized within the context of providing a layout suitable for the adoption of CTF. Larger paddocks will reduce the area of land devoted to headlands and turning areas.

The other aspect that is likely to take some change is the re-alignment of access roads to make the best use of high points in the landscape, which helps minimize the impact of roads on surface drainage.

Existing irrigation infrastructure has the potential to complicate CTF layout. With most CTF experience being in dryland environments, the incorporation of irrigation technology will require some planning. The Tasmanian vegetable industry makes extensive use of centre pivot irrigators, which inevitably leave wheel tracks that will cut across the direction of travel for CTF operations. There may be a need for some track maintenance operations to ensure adequate drainage from irrigator wheel tracks. Lateral move irrigators may be a better choice, but only if the layout is done first. Retro-fitting layout to a lateral move irrigation system does not necessarily result in an ideal CTF layout.

It is predictable that most CTF layouts will need to be designed with some existing infrastructure constraints in mind, particularly irrigation systems. However, it is impossible to over emphasis the importance of doing mapping and layout design before new investments are made in roads, drains and irrigation system upgrades. The cost of layout design is insignificant compared to the benefits of being able to base new investment (e.g. irrigation) and changes to existing structures (e.g. fences and roads) on a well-designed layout.

4.3 Economics

Given the limited experience with CTF in the vegetable industry, it was necessary to conduct a preliminary economic analysis using a range of assumptions based on information from other industries. In all cases, the assumptions used are within the realms of possibility under a CTF system. The major economic impact is in the area of potential yield increases, with added benefits of reduced operating costs. The greatest potential for cost reductions lie in the areas of machinery operation and irrigation.

Of the crops included in the model farm rotation, potatoes are the most responsive to CTF in pure dollar terms, closely followed by onions and carrots. Potential income from these crops increased significantly due to a combination of projected yield improvements and quality bonuses. The least responsive crop in dollar and percentage terms seems to be pyrethrum.

Total farm gross margin has the potential to increase by around 20% with adoption of a SCTF system, and by over 50% if a full CTF system was implemented. Assuming little to no change in overhead costs, this should translate to increased farm profitability.

Controlled trafficking has the potential to substantially improve the sustainability of the soil and water resource and reduce energy consumption. At an industry level, the benefits of controlled trafficking should improve overall efficiency and sustainability of the industry and increase its capacity to withstand external pressure.

Additional economic modeling is required, but there is a need to establish functional, commercial-scale pilot projects to demonstrate SCTF and CTF systems in the vegetable industry so that performance data can be gathered.

4.4 Factors to consider for a transition to CTF in vegetables

4.4.1 Seasonal Controlled Traffic Farming - SCTF

It is clear there are many challenges to overcome to implement a fully integrated CTF system in the vegetable industry, particularly in relation to the compatibility of machinery. However, the use of GPS guidance, and simple modifications to some machinery, makes it possible to implement a seasonal controlled traffic farming (SCTF) system as a step along the way.

In SCTF, the aim is to ensure that all traffic except harvest traffic returns to the same wheel tracks throughout the season. With GPS guidance, tractors can return to the same wheel track locations, even if the whole paddock has been compacted by harvest traffic. In that way, the wheel tracks can be kept while the soil between can be cultivated and used for growing crops.

Depending on the implements used, such an arrangement can be put in place at the time of primary tillage after harvest. For example, if primary tillage is done with a deep ripper or chisel plough, the tynes that follow the tractor wheels can be removed. This reduces the amount of energy required for primary tillage and maintains the compacted state of the wheel tracks. Other implements (e.g. rotary harrows) can be similarly modified by removing the tynes that match with the tractor wheel tracks.

With relatively simple modifications it should be possible to ensure that all tillage and in-season wheel traffic remains in the same wheel tracks up until the point of harvest.

Such a system would make little difference to the way in which crops such as onions or carrots are grown, but potatoes would require some changes to row arrangements. In current practice, soil from the tractor wheel track is used to help form the potato mounds. Under SCTF (and CTF) systems, it is likely that the wheel track would be too compacted to provide friable soil for used in the formation of the mound.

Similarly, crops such as peas, poppies, pyrethrum and cereals, which are normally grown without exclusion of wheel tracks, may require some re-arrangement of row configuration. Several seasons of SCTF would result in compacted wheel tracks that may not make a good seed bed for any of the crops mentioned.

SCTF has been used by a number of growers in Europe for some years, with what they believe to be benefits for their production system, and this is on soils that are not known for their capacity to self-repair. One advantage of the red ferrosol soils of the north-west coast of Tasmania is that they are very resilient when it comes to structural repair. In this context, SCTF may have a role to play as a transitional phase.

4.4.2 A 2 m / 3 m system

Another possible pathway forwards for CTF in Tasmania is the use of a hybrid system, based on 2 m for vegetable crops and 3 m for broadacre crops, with the 3 m track width straddling the 2 m track width. Careful selection of crop rotation and working widths for machinery can minimise the apparent incompatibility of these two systems when used together.

Calculation of the percentage of land area devoted to compacted traffic lanes is always of interest in relation to CTF, and is a good measure of how well the system has been integrated. The area of wheel track is minimised when wheel tracks and working widths are fully integrated, and the narrowest section width tyres possible are used.

As an example of what can be achieved, a fully integrated 3 m cereal CTF system would generally have a wheel track area of about 11 %. This compares to a minimum tillage production system with wheel tracks over 70 % of the paddock – and that is not accounting for the soil that is trafficked more than once. In reality, the total wheel track area is usually 100 - 200 % of the paddock area – i.e. most of the paddock has been trafficked more than once.

The total wheel track area in vegetable production tends to be close to 300% of the paddock area, with 100% of the paddock receiving at least one wheeling in a season.

Table 11 outlines % wheel track areas for a range of production systems.

Table 11. Wheel track areas for alternative systems of CTF

System	% wheel track area
Minimum tillage cereal	70
Matched 3 m CTF cereals	11
Conventional vegetables	100
Matched 1.6 m / 3.2 m CTF vegetables	29
Matched 2 m / 4 m CTF vegetables	32
Matched 3 m CTF vegetables	25
Matched 2 m / 3 m hybrid CTF vegetables	46

The table indicates that a 2 m / 3 m system may be an alternative transitional system for the Tasmanian vegetable industry. Even though the percentage of tracked area is still relatively high, it is a significant improvement on normal vegetable industry practice. Another advantage is that a significant portion of the 3 m traffic would occur when soil conditions are dryer, such as pyrethrum or poppy harvest. While this does not totally avoid soil damage, it would at least be minimised under such conditions.

One possible option as a pathway forwards would be to base as many crops as possible around a 2 m track width, which would suit all the root crops, and accept that other wider tracked machines will not fit the system for the time being. This would tend towards a seasonal controlled traffic system, but would provide the opportunity to maintain an integrated controlled traffic system over a number of seasons using a rotation of crops that fit 2 m.

4.4.3 Conversion costs

The level of investment required by a grower to convert to either SCTF or CTF is very dependent on the individual circumstances. GPS guidance is required, regardless of the system adopted. Guidance system costs range from \$20,000 - \$50,0000, plus \$5,000 - \$10,000 for steering controls on each tractor.

The changes required for SCTF are relatively minor if the working width of current machinery happens to be compatible with the SCTF track width. If not, changes would be best made when in the process of equipment upgrade, since some tillage machines are not suitable for modification. In these circumstances, the costs of conversion are the marginal cost of making an alternative purchasing decision to enable integration, rather than just replacing existing equipment like for like. For most farms, this cost is likely to be less than \$20,000.

Conversion to full CTF is another matter completely. 3 m is the most likely track width option to accommodate the diversity of machinery in the vegetable industry, but even this is not guaranteed for all machinery. Estimates of cost given here are based on the assumption of a 3 m system.

The major costs for a fully integrated 3m CTF system are going to fall on contractors, since it mostly harvest equipment that is the limiting factor. Once again, GPS guidance and steering will be required, with the same costs as outlined above for SCTF. The cost for changes to harvest equipment range from about \$30,000 to \$200,000 per machine, depending on whether the conversion can be made through modification, or has to be done through replacement with alternative types of machines. The costs for growers would once again be the marginal purchase costs of new equipment to match the desired working width, plus approximately \$10,000 per tractor to convert to a 3 m track width.

4.4.4 Minimising the conversion costs

The Tasmanian vegetable industry is heavily dependent on contractors for harvest, and increasingly so for other aspects of production, such as primary tillage, planting and spraying. This feature of the industry will tend to make the adoption of CTF easier for growers, if contractors are prepared to make the change. However, this will require some mechanism for contractors to gain from the adoption of CTF, as most of the production and environmental benefits accrue to the grower. The contractor can really only aim to gain first mover advantage by early adoption of the system. Conversion of harvest systems to CTF is most likely going to remain in the realm of contractors or large owner-operators, as this is going to require a change in the type of machinery used. This will reduce the cost of conversion to the individual grower who doesn't own a harvester.

Some growers operate collective arrangements in which equipment and resources are shared across enterprises. These situations obviously have the capacity to reduce the cost of conversion to the individual grower.

The diversity of crops in the Tasmanian industry presents additional costs to the process of conversion to CTF. It would be possible to reduce both the complexity and the cost of conversion by reducing the number of crops grown, but this comes at the cost of reducing options for the grower. Despite the complexity of the industry, the range of crops on offer is attractive to many growers, as it provides them with many opportunities to adjust cropping programs to maximise profit as the returns on different crops fluctuate with market conditions.

Progress towards a fully integrated CTF system in the vegetable industry will take some time, but options such as SCTF can enable a start to be made. Only through experience with the system and recognition of the benefits to be gained will the industry find solutions to the mechanical challenges that exist. Conversion to CTF by growers, with the accompanying substantial benefits, would over time be likely to increase the propensity for contractors and manufacturers to make the necessary alterations to machinery to capture market share.

4.5 Pathways forwards for CTF in the vegetable industry

4.5.1 Initial steps for industry adoption

Implementation of SCTF would be a valuable starting point for the vegetable industry. While this system ignores the impact of harvest traffic, because of the current difficulties of including harvest machinery in the system, the retention of compacted wheel tracks is still a useful step forwards. The retained wheel tracks will provide benefits for traction and reduced energy use, and the amount of soil damage in the crop growth zone will at least be limited to harvest traffic, rather than during the whole production cycle.

The easiest steps forwards for the industry to take are:

- investment in GPS guidance, which provides operational benefits apart from the application of CTF, and,
- a general move towards a common wheel track width and modular implement widths.

The Tasmanian vegetable industry is actively contemplating a broader move to 2 m wheel track widths. While this will not enable a fully integrated CTF system in conjunction with broadacre crops that use 3 m track width machinery, it offers a number of other productivity advantages. The next step is for growers and contractors to either modify, or purchase new at the time of equipment upgrade, tillage, planting and spraying equipment in multiples of 2 m. In conjunction with guidance, this will enable an easy transition to SCTF, which is a foundation from which fully integrated CTF can be pursued in future.

4.5.2 Future projects

There are a number of key project areas that need to be explored in relation to SCTF and CTF in the vegetable industry. These include:

- establishment of SCTF and CTF through modification and in-field demonstration of compatible machinery systems
- agronomic work focused on alternative spatial arrangements for some key crops (e.g. potatoes) grown under CTF
- more refined economic and environmental analyses

The change to CTF is going to require some significant capital investment on the part of many players in the industry, but there is little incentive to do that until the benefits have been demonstrated in the local environment. For this reason, investment in the modification of equipment, and demonstration of its use and the benefits to be obtained, are the most pressing needs for future CTF development in the vegetable industry. Projects with these objectives have the potential to provide a significant return on investment of R&D funds.

4.5.3 Estimated benefits of SCTF and CTF projects

4.5.3.1 Economic benefits

The estimates outlined below for both SCTF and CTF projects are very preliminary, but indicate that the potential to be gained from such projects is far from marginal. The economic benefit to the industry for both SCTF and CTF is premised on the analysis done as part of this project. The project costs and adoption rates have been estimated based on knowledge of the equipment required and the structure of the Tasmanian vegetable industry.

Table 12. Assumptions and projected benefits of investment in SCTF projects

Project cost ($)	**Adoption timeframe (y)**	**adoption in timeframe (%)**	**NPV industry benefit over timeframe ($m)**	**IRR (%)**
400,000	5	30	13.2	430
400,000	10	30	13.6	140
800,000	5	30	10.3	170
800,000	10	30	13.3	90

Table 13. Assumptions and projected benefits of investment in CTF projects

Project cost ($)	**Adoption timeframe (y)**	**adoption in timeframe (%)**	**NPV industry benefit over timeframe ($m)**	**IRR (%)**
2,500,000	5	10	9.0	85
2,500,000	10	10	7.4	40
2,500,000	10	20	18.4	65

Notes on Tables 12 and 13:
- The estimation of IRR is highly dependent on the rate of adoption and the level of adoption achieved within the time frame.
- SCTF is a relatively easy change to adopt, so it is possible that relatively high rates of adoption could be achieved in a short time, once the benefits are demonstrated.
- A CTF project is disadvantaged by the high cost of specialist equipment purchases. However, the adoption level and rate could be significantly higher than indicated in the above estimates on account of two factors:

- a preceding SCTF project would establish a significant foundation to full CTF conversion resulting in existing awareness and acceptance of the benefits, so uptake would be more rapid
- a move to full CTF will require some major players to be brought into the fold, (particularly contractors), and once they are converted, the impact on the level of adoption would be dramatic.

4.5.3.2 Environmental benefits

CTF offers numerous environmental benefits, but analysis of these in the vegetable industry context is at a very preliminary state of development. Recently published figures for the grain industry suggest reductions of 90% in soil and nutrient loss, 60% in fuel use (and consequent CO_2 emissions) and 90% in nitrous oxide emissions (Bowman, 2008). These figures relate purely to input factors, and do not account for carbon sequestration benefits. A preliminary carbon accounting analysis for the cereal industry showed a 30% reduction in greenhouse gas impacts when moving from stubble mulch operations to zero-till CTF (Tullberg, 2008). There is no reason why CTF projects in the vegetable industry will not deliver similar, if not greater, benefits after a period of industry adoption.

5 Technology transfer

5.1 Workshops

Technology transfer activities directly linked to this project consisted of some workshops and media articles. The workshops were held over two days (June 17 – 18, 2008) and focused on the issue of farm mapping and layout design for CTF on vegetable farms. Attendees at the workshop included the owners of the farms that were used as representative of the north-west coast of Tasmania, and others invited on account of their interest in CTF. The workshop was conducted by Tim Neale (CTF Solutions), who was engaged to prepare alternative layouts for the selected farms.

The workshops explained the importance of mapping and layout in relation to CTF systems, and visited the farms that had been selected for layout design. A total of 17 growers and industry representatives attended the workshops. Following the two days of workshops, a cut down version of the workshop was conducted at a Soil Health Essentials day, which was attended by 90 people. Although these workshops didn't explore the issues to the same depth as the earlier ones, they provided excellent exposure for a range of topics around CTF, including mapping and layout design, for a large audience.

5.2 Media

Articles have been prepared for:
Dec 2007 – Tas Regions
April 2008 – Advocate newspaper
June 2008 – Tasmanian Farmers and Graziers magazine, Primary Focus

The information arising from this project was displayed in posters at the Tasmanian Farmers and Graziers Association conference, Launceston, July 17, 2008 and at the 6th Australian Controlled Traffic Farming Association annual conference, Dubbo, 12-14 August, 2008.

Copies of media articles and posters are included in Appendix A.

5.3 Field days

Aside from the technology transfer activities directly associated with this project, there have been a number of other activities related to the development and promotion of CTF in the Tasmanian vegetable industry. These were not specifically related to this project, but provided the opportunity for information transfer about this project, its findings and CTF issues in general. These included:

12 March, 2008 – industry representative meeting to discuss a coherent move to wider track widths, specifically 2 m.

22 and 28 April, 17 May, 2008 – field days, "Echobank", Gawler, Tasmania, farm of John McKenna, cooperator for NLP funded CTF project. Demonstration and discussion of onion crop grown under CTF.

June 19, 2008 – Cradle Coast NRM Soil Health Essentials day, Forthside Research Station.

6 Recommendations

6.1 Situation summary

The benefits of controlled traffic farming (CTF) have been established through research over the last 40 years, and more recently through commercial adoption, particularly in the Australian grain and cane industries. The increased rate of uptake of CTF has been greatly aided by the improvements in, and reducing cost of, GPS guidance technology. Current estimates put adoption in the grain industry at around 15% and about 10% in the cane industry.

The grain and cane industries both use a quite limited range of machinery, so the mechanical changes required to achieve compatible track and working widths are generally limited in both extent and number. The changes to farming practices, and in some cases, farm layout, are probably more significant than the machinery changes.

The situation in the vegetable industry is quite different, being complicated because many vegetable growers also grow crops that are more broadacre in nature. In Tasmania, important non-vegetable crops include poppies, pyrethrum and cereals. All of these crops are well suited to a 3 m track width system. In addition, vegetable crops such as peas and beans are more akin to broadacre crops in their harvest than they are to other vegetables, such as carrots, potatoes and onions. Vegetable harvest machinery has very little in common when it comes to working widths and track widths, and this is one of the key issues facing the adoption of CTF in vegetable production.

6.2 Initial steps for adoption

Implementation of SCTF would be a valuable starting point for the vegetable industry. Although SCTF ignores the impact of harvest traffic, the retention of compacted wheel tracks is still a useful step forwards. SCTF is a relatively easy step for the industry to make, as all it requires is the use of GPS guidance and adoption of a common wheel track width and modular implement widths. This will enable an easy transition to SCTF, which is a foundation from which fully integrated CTF can be pursued in future.

The costs to growers for conversion to either SCTF or CTF can be reduced by collaborating with neighbours or using contractors, strategies which are already being used in the Tasmanian vegetable industry.

6.3 Future project recommendations

There are many research and development opportunities for CTF in vegetables. The changed soil conditions that will arise as a result may well alter soil water relations, with impacts on irrigation and drainage. Crop production systems and timeliness will change, with impacts for management of fertilisers and other crop inputs.

However, key project areas that need attention to make significant progress in the implementation of CTF in the vegetable industry include:

- establishment of SCTF and CTF through modification and in-field demonstration of compatible machinery systems
- agronomic work focused on alternative spatial arrangements for some key crops (e.g. potatoes) grown under CTF
- more refined economic and environmental analyses

- initial trial conversion to CTF in the most suitable crop types, where the capital cost of equipment conversion is lowest to demonstrate the benefits on a commercial crop rotation.

The most important of these, in terms of enhancing the rate of adoption, is to implement and demonstrate the potential of CTF in the field. Conversion to CTF will require significant investment on the part of many players in the industry, but there is little incentive to do that until the benefits have been demonstrated in the local environment.

For this reason, investment in the modification of equipment, and demonstration of its use and the benefits to be obtained, are the most pressing needs for future CTF development in the vegetable industry. Preliminary cost benefit analyses (as outlined in Section 4) show that projects with these objectives have the potential to provide a significant return on investment of R&D funds, both in economic and environmental terms.

6.4 Recommendation

There is a clear need for investment of R&D funds to support the establishment and demonstration of Seasonal Controlled Traffic Farming in the first instance, and subsequently, a fully integrated pilot Controlled Traffic Farming system in the vegetable industry. Such projects will only be successful with substantial cooperation from growers and other industry stakeholders, and will require funding over at least 5 years to establish and demonstrate the preliminary benefits of the system. Subsequent to the establishment of the system, there will be opportunity for significant on-going research to fully capture the benefits of controlled traffic farming in the vegetable industry.

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9 Appendix A

9.1 Media articles

TIAR VEGIE

Small steps forwards for controlled traffic in vegetables

Controlled traffic farming (CTF) is a crop production system that keeps all tractor, implement and harvester wheel traffic in the same tracks year after year. Implementing means soil compaction is eliminated from the crop growth zone, and machinery operates much more efficiently on compacted wheel tracks.

Why go to the effort of implementing a CTF system? Very simply – plants grow better in friable soil but wheels work better on roads. Friable soil has increased water-holding capacity, allows excess water to drain away quickly and improved aeration.

The concept of CTF is very simple but the practicalities are more difficult, especially in the vegetable industry, which relies on a wide variety of equipment, particularly harvesters, none of which were ever designed with common wheel track widths in mind. There is virtually no adoption of CTF in the vegetable industry worldwide due to the issues surrounding machinery compatibility.

Nevertheless, small steps towards the use of CTF are being made in the Tasmanian vegetable industry, with two projects this year.

A project funded by Horticulture Australia Ltd and hosted by Tasmanian Farmers and Graziers Association (TFGA) will investigate some of the technical barriers to the adoption of CTF. Data is being gathered on the characteristics of a wide range of machinery used in the vegetable industry to identify where the opportunities lie for modification to allow more compatible operations. Some pilot farm layouts will be done for a limited number of farms to determine the practicalities of implementing CTF in various slope, paddock size and irrigation configurations.

A second project, hosted by Cradle Coast NRM and funded by the National Landcare program, is investigating the use of CTF on a local vegetable farm. A part of that project is looking at no-till sowing of vegetable crops. No-till and CTF have become a very successful mix in the dryland grain industry in other parts of Australia.

It is still early days with both of these projects. An onion crop has been sown into a paddock that was prepared under a simple CTF system, but it will be some time before there is much to see of the benefits of CTF.

While in Queensland recently, John McPhee (TIAR) had the opportunity to visit some vegetable, pineapple and cane growers to observe their progress towards CTF systems. Unfortunately for the Tasmanian industry, there weren't any earth-shattering solutions to the challenges we face in implementing CTF.

Grain growers have been the most successful in implementing CTF due to the limited number of machines they use, and the similarity of the different crops they grow. Mixed cropping enterprises, such as vegetables and increasingly sugar cane, which is now rotated with other crops, inevitably come up against the challenge of modifying machinery to suit the system – and often the ideal piece of equipment doesn't exist. But that is not stopping those who see the potential from having a go.

Growers interested in CTF, or either of the current projects, should contact John McPhee (TIAR – 03 6421 7674), Peter Aird (Serve-Ag – 03 6498 6800) or Jason McNeill (DPIW – 03 6421 7695). John, Peter and Jason are all actively involved in the current CTF projects.

Tas Regions, December 2007

CTF trial underway

■ DPIW REPORT

INTEREST is rapidly growing in the idea of controlled traffic farming (CTF) systems for the vegetable industry. CTF aims to keep all wheel traffic in permanent lanes within the paddock from year to year.

In its most developed form, CTF requires all equipment track and working widths to be matched to maximise the benefits of friable soil in the cropping zone and compacted soil in the wheel tracks.

CTF is increasingly being adopted in the grain and cane industries interstate.

However, the vegetable industry is finding CTF a harder nut to crack.

The diversity of the vegetable industry makes achieving equipment commonality for CTF a major challenge.

Two projects are underway to help meet this challenge.

The first is funded by Horticulture Australia and has been contracted to the Tasmanian Institute of Agricultural Research by TFGA.

This project is looking at the machinery constraints to CTF adoption and investigating issues surrounding efficient farm layout for CTF operation.

The second project, funded by the National Landcare Program, is being conducted by DPIW on behalf of Cradle Coast NRM. This project has been working with Gawler farmer John McKenna to establish, grow and harvest a crop of onions under a CTF system.

A recent field day highlighted this project and attracted an interested group of people to observe progress and engage in discussion.

The CTF onion crop was harvested a couple weeks ago using a direct loading Top-Air harvester.

The harvest operation had to rely on a box trailer and wooden bins to carry the crop from the paddock, because at this time there is no access to a chaser bin, which would fit the requirements of the CTF system.

Nevertheless, the crop was harvested and the CTF system was held largely intact.

The differences in soil condition between the conventionally managed areas and the CTF areas are stark.

The isolation of wheel tracks has resulted in a friable soil tilth, which requires minimal tillage to bring to a seed bed condition.

In addition, the tractor power required for remedial tillage is much reduced compared to conventional tillage practices.

■ Growers or industry representatives interested in these projects can contact Jason McNeill (DPIW — 0408 550 226), John McPhee (TIAR — 0407 845 612) or Peter Aird (Serve-Ag — 0408 143 295).

Trial harvest of an onion crop grown under a CTF system on the McKenna property at Gawler.

Advocate, 1 May, 2008

Coming to Grips With Controlled Traffic Farming in the Vegetable Industry

Controlled traffic farming (CTF) keeps all paddock traffic in the same wheel tracks year after year. The benefits of CTF are numerous and include reduced energy use, improved soil health and crop yield and more timely management of field operations. The basis of CTF is as simple as "plants grow better in soft soil but wheels work better on roads".

CTF requires:

- Equipment track and working widths matched to a common dimension
- GPS guidance for accurate field operations
- Farm layout for effective management of erosion, drainage and field logistics

A Horticulture Australia Ltd (HAL) project called for by the TFGA Vegetable Council is investigating two significant technical challenges to the adoption of CTF in the Tasmanian vegetable industry:

- the working and track width compatibility of equipment
- farm layouts that account for steeply undulating topography

The Tasmanian vegetable industry grows a diversity of crops, requiring a wide range of machinery configurations. The survey has shown that almost no machinery is configured to a common track or working width. However, options exist for CTF systems based on the current 1.6m track width, or alternatively, 2m or 3m track widths. Each option has its own pros and cons, but recent industry interest in 2m track widths for some crops suggest this will become a driver for change. In some cases, the changes required are relatively simple. Other machines present considerable challenges to achieve a common track width.

Investigating alternative farm layouts is a key first step in the adoption of CTF, as the layout can dictate success or failure in the adoption process. A number of representative farms in north-west Tasmania have been mapped. Alternative farm layouts are currently being prepared to determine if existing infrastructure and topography present significant challenges to the implementation of efficient CTF layouts.

Despite the fact that there are many incompatibilities between machinery used in different crops, the increasing use of GPS

Continued Page 12

From Page 10

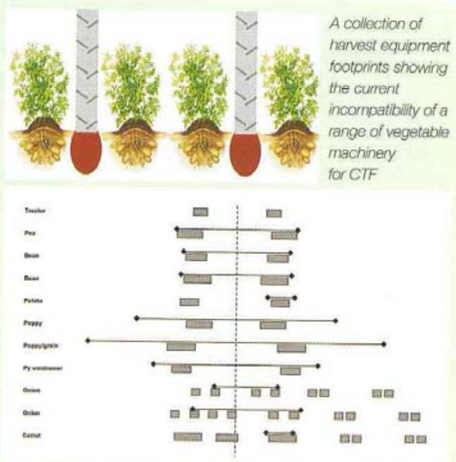
guidance in the industry opens opportunities for growers to make a start in converting to a CTF system. Returning to wheel tracks in a set location each season offers some advantage, even if all the machinery required for a fully integrated system is not currently available.

The results of the current project will be presented in the coming months and at the TFGA Conference in Launceston on 17-18 July 2008.

John McPhee – Vegetable Centre, TIAR

CTF gear for maize in NZ

Some of the more difficult machinery for vegetable CTF



A collection of harvest equipment footprints showing the current incompatibility of a range of vegetable machinery for CTF

Photos and diagrams courtesy of Genevieve Turville, EO, Vegetables and Agriculture

CTF - Mapping and Layout

CTF Layouts for Vegetable Farms

Effective farm layout is important for the success of controlled traffic farming (CTF). Layout needs to address direction and efficiency of field operations, access roads, erosion, drainage and irrigation. Tasmanian vegetable farms vary from slightly to steeply undulating, and often have complex shape and drainage profiles. Layouts designed for a selection of vegetable farms indicate that effective layouts are possible for undulating vegetable farms. Key design principles include placing access roads on ridge lines, with operational travel directions being down slope from there. Current paddock layout should not be a constraint to good CTF layout design.

The map (left) shows travel directions for field operations in the existing farm layout. The areas either side of the central access road are irrigated with a lateral move irrigator.

The map (right) shows travel directions for CTF field operations within the existing road and irrigation constraints. The dashed blue lines are drainage lines for surface flow.

The map (left) shows travel direction for CTF field operations without existing infrastructure constraints. The access road is re-located, and travel directions re-oriented to manage drainage and erosion. This could still be irrigated with the linear move irrigator provided drainage is provided for the irrigator wheel tracks.

Poster displayed at Tasmanian Farmers and Graziers Conference, Launceston, July 17, 2008 and Australian Controlled Traffic Farming Association Conference, Dubbo, August 12-14, 2008.