Final Report

Wide span faming: economics and logistics feasibility study

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Public summary

Controlled Traffic Farming (CTF) has proven to be very beneficial in the grain industries, where adoption, particularly in Australia, is increasing and provides improved yield, economic, resource use and environmental benefits. There has also been some adoption in other industries like cane, cotton and some sectors of horticulture that rely predominantly on hand harvest. Unfortunately, machinery, particularly harvest machinery, used in many annual mixed horticultural cropping operations is not compatible for CTF, so the industry is unable to attain the benefits achieved in other cropping industries. This project investigated the economic feasibility of adopting Wide Span (WS) technology for controlled traffic in annual horticulture. Economically viable application of WS technology would allow effective adoption of CTF in annual horticulture and subsequently provide a wide range of economic, productivity and environmental benefits.

The PhD student on this project took an approach that models the economic consequences of WS adoption at both the farm and whole of industry levels, with the Tasmanian vegetable industry as the case study. Components of the study have included: compiling machinery inventories and costs representative of current production operations; modelling existing cropping rotations; determining seasonal machinery demand across a number of crops; considering how operational practices might change with the adoption of WS technology, and the consequent impacts on machinery inventory and use; economic modelling of how farm returns might change based on crop gross margins; application of the farm-based modelling at an industry-wide scale; and the impact on contractor margins. An underlying assumption of the modelling work is that the WS machinery would be owned by contractors, rather than individual growers. This is a reasonable assumption given a growing trend for the use of contractors for a range of operations on many vegetable farms.

Results of the study indicate a high probability of improved returns for growers compared to current random traffic farming systems. Similarly, returns for the entire industry were likely to improve, although the extent of these improvements would be heavily influenced by the capital cost of the WS system, which at this stage is unknown. Machine capital cost also had a very significant impact on the profitability of contractors. Other studies have concluded that WS technology should both improve work rates of any given operation and reduce the number of field operations required, and it is likely that these changes will more than offset the potential higher capital costs of the equipment.

Drawing on other studies about greenhouse gas (GHG) emissions and other environmental factors associated with vegetable production, an assessment was done of the potential environmental benefits of WS technology. This showed there are likely to be substantial reductions in environmental impact through the use of the WS, and the monetary value of the resulting societal benefits would more than adequately cover the cost of transition to new technology if viewed from a whole of system perspective. Although there are still many practical and economic unknowns surrounding the application of WS technology in the vegetable industry, this study provides further insight into the potential of WS adoption in annual horticulture.

Keywords

Controlled traffic farming; wide span; gantry; vegetables; Tasmania; economic feasibility; modelling.

Introduction

The objective of this project was to undertake an economics and logistics feasibility study of adopting Wide Span (WS) technology in annual horticulture. The use of WS technology (sometimes referred to as gantries) would enable the widespread adoption of Controlled Traffic Farming (CTF) in highly mechanised annual horticulture, such as vegetable production. There is a large body of evidence outlining the economic, productivity and environmental benefits of CTF in crop production, but it is difficult to realise these benefits in annual mixed cropping horticulture because of the incompatibility of current machinery designs. The availability of economically viable WS technology would transform annual horticultural production systems from the current tractor-based system to one based on WS tractors, allowing the effective application of CTF systems and bringing with it the wide range of production, economic and environmental benefits that are known to occur under CTF.

Soil degradation is one of the most serious resource sustainability issues in annual horticulture. This is brought about by the endless cycle of compaction caused by traffic (particularly harvesters) and remedial tillage, which is only partially effective at removing the effects of traffic compaction. Controlled Traffic Farming (CTF) isolates load bearing wheel traffic to permanent compacted wheel tracks, leaving the rest of the soil free of compaction to provide the best possible soil environment for growing crops. Integration and matching of machinery dimensions to allow all load bearing wheels to travel in the same tracks are essential for implementing a controlled traffic system. This is a challenging goal in annual horticulture due to the diverse designs of harvesting machinery used across a wide range of crops, each of which has its own design and function demands.

The benefits of CTF are many and include: 50-80% reduction in tillage energy requirements; improved timeliness; improved capability for zero-till and double, relay and inter-cropping; improved soil structure, leading to improved infiltration, soil water storage and internal drainage; improved soil biology; reduced erosion; improved yield (Dickson and Ritchie, 1996a, b; Dumas et al., 1975; McPhee et al., 2015; McPhee et al., 1995; Neale and Tullberg, 1996; Perdok and Lamers, 1985; Rodgers et al., 2018; Tullberg, 1994; Vermeulen and Mosquera, 2009). Previous HAL funded projects 'Development and demonstration of CTF techniques for production of potatoes and other vegetables' (MT09040) and 'On-farm demonstration of CTF for vegetables' (VG10080) showed significant improvements in soil physical conditions and reductions in tillage requirements in controlled traffic field trials (McPhee et al., 2015).

Other industries (grain, cane, cotton) continue to make progress in the adoption of CTF with resultant significant improvements in whole farm productivity and sustainability (Tullberg et al., 2007; Yule et al., 2000). Many years of research have shown improved yields and lower costs, while commercial experience in the grain industry points to 2-4 fold productivity improvements in some circumstances. In the grain industry, ex-factory modifications to conventional and readily available equipment have met the dimensional integration needs of CTF. The annual horticulture sector, particularly mechanised vegetable production, faces significant challenges in implementing a fully integrated CTF system because of the lack of dimensional integration between machinery, particularly harvesters, and the difficulty of achieving integration through effective modification of large, expensive, conventionally designed capital items. This barrier could be overcome with the use of common track gauge Wide Span tractors (in the range of 6-10 m wide), which provide a tool carrier for all equipment used in the production system, and hence avoid the challenges of trying to modify and integrate machines of differing operating widths and tyre/axle configurations. Such a transformational change in technology is potentially applicable to all annual horticultural crops, although its application is most immediately relevant in mixed cropping situations, which are common in the vegetable, potato, sweet potato and onion industries.

The first known public exhibition of the WS concept was in 1858 (a steam-driven gantry that travelled on wooden rails) and it has since seen development for research purposes in the 1970s-90s (Chamen et al., 1994a; Chamen et al., 1994b; Chamen et al., 1992; Hilton, 1986; Holt and Tillett, 1989; Hood et al., 1987; Monroe and Burt, 1989; Taylor, 1994; Tillett and Audsley, 1987; Tillett and Holt, 1987; Tillett et al., 1988) and attempts at commercialisation in the 1980s-90s. Most recently (2013), a prototype WS was built by ASA-Lift (Danish manufacturer) in conjunction with a vegetable farmer in Denmark (Pedersen, 2011; Pedersen et al., 2013). This particular machine was designed for light cultivation and onion harvest, but development stalled due to lack of funds and a ready market for the technology. While it is possible to integrate WS and conventional tractor systems, the true potential of the WS will only be realised with transformational system change based on the WS (Pedersen et al., 2016). Since the ASA-Lift prototype, developments in Canada have led to a medium sized autonomous tool carrier which, while not specifically designed for gantry-style operation, could easily be adapted to function as a WS. The current target for its application is seeding and spraying in the grain sector. WS developments are continuing in Europe with the launch of the Nexat, which won a gold medal innovation award at AgriTechnica 2022 (NEXAT | Be part of a new agricultural revolution). Unlike previous attempts at commercialising the WS, the developers of the Nexat have taken the approach of developing an integrated system that provides not just the tool-carrying platform but also tillage, seeding, spraying and harvest equipment. The absence of this integration has been a major shortcoming of previous efforts to commercialise WS technologies. While these efforts are targeted towards the grain industry, the same principles would apply to the development of WS technology for the vegetable industry, albeit with a wider range of seeding and harvesting options required to service all crops in a rotation.

Economic studies of CTF are not common, although those that have been done provide evidence of superior economic performance on farms using CTF. The limitation regarding WS technology is that it is not readily available in the market, so any economic analysis needs to draw on what is known about the performance of tractor-based farming systems, both random traffic and CTF, extrapolated to the conditions where the area devoted to wheel tracks is reduced by a factor of 2-3. HAL project VG13081 'Prioritise vegetable crop commodities for mechanisation' identified the Wide Span as a transformative technology worthy of investigation for annual horticulture. Another major limitation of economic modelling of WS systems is, because they are not commercially available in the market, factors such as capital cost have to be estimated based on imperfect knowledge.

The project 'Wide span faming: economic and logistics feasibility study' undertook economic modelling to assess the impact of WS adoption at the farm and industry levels to test the economic feasibility of WS adoption. Logistics investigations assessed the demand for WS platforms based on known harvest schedules and machine demand under current production and mechanisation systems. The impact of the project relates to a number of aspects of farm productivity, resource use and management priorities within the vegetable industry strategic investment plan, namely: adoption of technologies; mechanisation, automation and robotics; climate; and water and soil.

As one of the projects in the National PhD Leadership Program, the focus of the project 'Wide span faming: economic and logistics feasibility study' was long-term transformational change in the horticulture sector. As such, near term outcomes are unlikely. One outcome of the project would be to provide information to help improved strategic decision making about further investment in the development and adoption of WS systems for annual horticulture. The focus of this project was the national vegetable industry, although once developed and proven viable, the technology could be applied to any annual horticultural crop, and, with changes in physical design, the concepts could also be applied to perennial horticultural crops, albeit with some growth height limitations.

Methodology

The approach of this project was to model the economic impact of WS adoption at both the farm and whole of industry levels, with the Tasmanian vegetable industry as the case study. Components of the study included:

compiling machinery inventories and capital and operating costs representative of current production operations: interviews and discussions were held with a number of growers and contractors in the Tasmanian vegetable industry in an effort to quantify common machinery inventories used for specific crops as well as across crops. Work rates and costs of operation were gained through these same sources. Capital costs of machinery were sourced from major equipment suppliers in the vegetable production region of Tasmania.

modelling existing cropping rotations: there is no such thing as a standard rotation, but certain crops tend to dominate the area of production. Grower input was sought to design a 'standard' rotation based on eight crops with each crop occupying a percentage of the cropped land. During modelling simulations, the percentage area of each crop could be varied within upper and lower bounds such that the relative ranking of each crop remained much the same.

determining seasonal machinery demand across a number of crops: data were sourced on duration of specific field operations (e.g. cultivation, seeding, harvest) and delivery rates of product to factories and pack houses at harvest time to estimate the seasonal demand for machinery such as cultivators, seeders and harvesters.

considering how operational practices might change with the adoption of WS technology, and the consequent impacts on machinery inventory and use: as the WS is not a commercially available technology, some level of assumption and estimation is required to apply what is known about how CTF influences farm operations to make judgements about how practices might change with the application of WS technology in the annual horticulture sector. For example, there is reasonably good information reported in the literature about how CTF reduces the need for tillage in various circumstances, including in vegetable production. Based on this knowledge, some assumptions can be made about how operational practices and machinery inventories might change with the use of a WS.

economic modelling of how farm returns might change based on crop gross margins: A key assumption was made about the ownership model that would likely exist around the WS technology. The Tasmanian vegetable industry is very heavily serviced by contractors, particularly in relation to harvest, and increasingly for other operations like spraying, seeding and tillage. The high capital cost of vegetable harvesters makes contracting a logical model, and in some cases harvest machinery is owned by the same companies that process and pack the vegetable products – e.g. pea, bean, carrot and onion harvesters are almost exclusively owned by the companies who contract the growing of the crops. For these reasons, it was assumed the WS technology would be owned and operated by contractors rather than individual growers. In reality, and in the essence of time, it is possible that some large-scale growers might own WS equipment, but for the purposes of this study, it was assumed the ownership would rest with contractors.

Using the Tasmanian vegetable industry as a case study for the project, publicly available crop gross margin calculators were used for farm-level analysis. A model was structured in MS Excel with a Vose ModelRisk® add-in. The advantage of ModelRisk® is that it allows a large number of variables to be altered within user-defined ranges to produce a range of outputs based on 10,000 simulations of the model for each modelling run. The graphical outputs from these simulations include declining probability curves that make it possible to identify the probability of any particular result. Also included are sensitivity plots that rank various inputs on the basis of their influence on the output. These are particularly useful as they help to identify whether an input that has particularly uncertain knowledge about it actually has any significant impact on the end result. Sometimes the absence of accurate input data can be disconcerting but it turns out that the uncertain factor could vary significantly without making much impact on the end result.

application of the farm-based modelling at an industry-wide scale: using readily available information about the size of the Tasmanian vegetable industry (crops, areas, yields, tonnages, prices etc.), the farm based analysis was scaled up to assess the potential impact at the whole of industry level. The impact on contractor returns was also modelled.

environmental economics: drawing on other studies into GHG emissions and soil erosion, an effort was made to estimate the economic benefits of environmental improvements that could potentially arise due to the adoption of WS technology. By combining research into GHG emissions in vegetable production and changes in GHG emissions as a result of CTF, it has been possible to make some estimates of the GHG emissions benefit of using WS technology. A similar approach was used in relation to soil erosion. Economic costs were then applied to the predicted GHG emissions based on a carbon credit price of $75/t, and soil erosion costed at $624/ha/mm/y, a figure derived from a Tasmanian-based soil erosion calculator which includes valuing the loss of nutrients and carbon in soil lost due to erosion.

Photos/images/other audio-visual material

As this was largely a desk-based modelling project, there are no images to include. The completed thesis contains all the illustrative material required.

Results and discussion

The PhD candidate's thesis was submitted for examination on 21 March 2024. A version of the thesis as submitted is included with this report. However, it is noted that the examination process commonly leads to a revision of the thesis prior to graduation being conferred. Whilst it is unlikely this would lead to major changes in results and conclusions, it is noted that the thesis as provided is not a final version.

Conclusions of the study indicate the following:

- *Farm scale economic modelling:* results from modelling indicate that the WS CTF system ha a high probability of delivering economic benefits to farmers. Based on a cost-benefit ratio analysis, it was concluded that farmers could potentially increase profits by more than 20% in both the short-term (one year) and long-term (10 years) by using the WS CTF system. The analysis was premised on the assumption that the WS system would be owned and operated by contractors in order to more effectively amortise the capital and changeover costs from the current tractor-based random traffic farming system. Net present value (NPV) and sensitivity analysis revealed that crop yields are significant factors influencing profitability. This is not surprising, but it does underscore the importance of improved crop yields as a target outcome of the adoption of WS CTF. Extensive research and commercial experience around the world in a wide range of crops indicates that, in the absence of soil compaction, yield improvements ranging from minimal to 100% or more are possible. Yield is only one of the factors that improves with the adoption of CTF, others being reduced energy use and tillage inputs and improved timeliness, all of which can lead to improvements in economic returns for the grower, and some of which are difficult to model.
- *Whole of industry modelling:* modelling suggests that the use of a WS CTF system could increase the total value of the vegetable and allied crops (such as poppies, pyrethrum etc.) industry by as much as double its current value (expressed in Net Present Value terms). It was concluded that most of this value would arise from improved crop yields due to improved soil conditions and a reduction in capital cost of equipment on the basis that the WS provides a common platform for many operations. This would be particularly applicable to harvesters which would not require dedicated self-propelled machines but rather could draw on the essential components to be mounted on a WS frame. At this stage of conceptual development it was assumed that this would be possible, although there are several design and equipment access hurdles to overcome before such a system would see commercial adoption.
- *Contractor returns:* the adoption of CTF, either conventional-tractor based or premised on WS technology, faces a particular challenge based on the structure of the vegetable industry. The industry, particularly in Tasmania, relies heavily on the use of contractors to perform many field operations. This is particularly true of harvest of almost all crops, and for seeding of many crops. The use of contractors is also expanding for other operations such as spraying and tillage, largely driven by the increased capital and ownership costs of machinery that might only be used for a limited period of time in the year. Therefore, contractors play a particularly important role in the introduction of new technologies, which means they also carry the cost of technology replacement and changeover. Adopting a new technology is not a difficult decision to make when there is a clear benefit to the contractor. In the case of WS CTF, the benefits (in terms of soil sustainability and yield improvement) flow predominantly to the grower and the broader industry/society complex – yet it is the contractor who bears the cost of technology upgrade. In this project, economic modelling was done to determine the impact of WS adoption on contractor economic returns. Unsurprisingly, the economic viability of contractors was heavily influenced by the capital costs of the WS technology, and the extent that work rates could be improved, both of which are currently unknown. However, by modelling contractor and grower returns, it was determined that there will likely be situation where faster work rates (contractor and grower benefit) and improved crop yields (grower benefit) allow a slight increase in contractor charges (contractor benefit, grower loss) to improve contractor returns and the benefit to the industry overall.
- *Environmental impacts:*
  - Greenhouse gases – emissions of all GHGs in vegetable production (soil emissions of CO_2, N_2O, CH_4 and fuel

emissions of CO_2) were modelled to be approximately 50% lower under WS CTF compared to random traffic production systems. According to the modelling, the reductions in emissions for the WS CTF system were attributed to lower soil CO_2 emissions and reduced fuel consumption emissions, primarily a function of fewer tillage operations and lower draft. Although under current government policy there is no carbon cost incurred by individual growers or the industry as a whole, costs were estimated based on the current Australian carbon credit price of $75/t. This indicated an annual industry cost for RTF production of $5.6 million compared to $2.9 million for WS CTF.

- Soil erosion – soil erosion losses can be quite variable. Based on other data sources, it was estimated that soil erosion losses under RTF production systems could range from 7.3-86 t/ha/y, while WS CTF losses would likely be 1-7.4 t/ha/y. Using median values and likely ranges, and a cost of $624/ha/mm/y of soil lost, ModelRisk® modelling estimated industry-wide annual costs of $53.9 million for RTF systems compared to $4.8 million for WS CTF – a reduction of more than 90%.

Overall, it is concluded that a transition to WS CTF would be beneficial for growers and the industry, although the process of transition would need to take careful account of the impact on contractors who predominantly carry the cost of technology change. One of the most significant limitations of this research is that accurate costs of WS technology are not yet available. Despite a history dating back to 1858, WS is a nascent technology that is only now starting to attract attention in broadacre grain production in Europe on the back of novel developments in recent years. It will be some time before options suited to annual horticulture start to appear.

While the economic results generated in this research leave some room to question the value of such a transformational change in technology, at least at the individual grower and contractor level, there are enough positives to indicate that WS technology should be seriously considered when further progress has been made in its development. This is particularly from the environmental sustainability perspective, in which the WS is unmatched by other technologies currently available.

Outputs

Table 1. Output summary

Output	Description	Detail
Published PhD thesis	As a project in the National PhD Leadership Program, with a goal of long-term change in the industry, the primary output of this project will be the published PhD thesis. Published peer-reviewed papers may also be published subsequent to completion.	The PhD thesis has been submitted for examination and will become publicly available after examination , corrections and acceptance.

Outcomes

Table 2. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
The primary outcome of this project is to provide new knowledge and insights into the potential economic benefits of WS-based CTF systems for annual horticulture and hence help inform decisions on future research and adoption activities.	This project aligns with the Advanced Production Systems strategy in that the purpose of WS CTF is to protect soil and improve productivity of crop production. The work is applicable to the System Design: Practice and Management investment theme. It also applicable to Innovation and Disruption in the context that the adoption of WS CTF would be a hugely transformative and disruptive change in the industry, even if it is not aligned with the biological foci of the Innovation and Disruption investment them.	The PhD thesis provides insights into the value or otherwise of pursuing transformational change in the annual horticulture sector, which is relevant to the Advanced Production Systems fund.	As the PhD thesis is yet to be examined and accepted, evidence of the impact of the project will be some time in the future. Further, as the project focused on modelling a conceptual change to farming systems, developments in the WS technology would be required before evidence of impact would occur.

Monitoring and evaluation

The M&E process for this project was embodied in the normal and regular meetings that took place between the PhD candidate and the supervisory team, so no formal M&E questions were posed in the context of KEQs. These meetings were conducted mostly at fortnightly intervals along with annual reviews that determined the candidate's capacity to continue with the PhD.

Two factors relevant to candidate performance became apparent throughout the duration of this PhD project. Firstly, the disruptions of COVID, while not as great as they would have been if this had been a field-based project, were nonetheless present and included the candidate succumbing to COVID more than once, requiring times of rehabilitation and disruption.

The other factor was the candidate's limited background knowledge of agricultural production systems. The candidate came with a background in business and accounting, which was clearly useful from the economic modelling perspective, but their limited knowledge about vegetable production proved to be a challenge in developing an understanding of how the conceptual WS CTF systems would operate as compared to current farming system practices.

Recommendations

As a project in the National PhD Leadership Program, the focus of this study was long-term transformational change in the annual horticulture sector. With the long-term nature of this work in mind, the focus of the project was desk-based economic feasibility modelling, so consequently there will be no immediate practical applications of the findings from the project. However, as this project was in progress, the latest prototype WS (Nexat) was released in Europe - NEXAT | Be part of a new agricultural revolution. Although very much designed for, and targeted at, the grains industry, the proof of concept of the technology over a wide range of operating conditions is encouraging for the future application of similar technologies in the annual horticulture industry.

Future RD&E could reasonably investigate the benefits of long-term lack of traffic compaction for vegetable crop production. Much work in the area of compaction effects on vegetable production has been done, but little has focused on the benefits of the long-term absence of traffic and minimisation of tillage, which has been shown in other industries to accumulate with significant benefits for productivity and sustainability. Such research would provide more robust information for the prediction of the future viability of WS adoption than is possible with modelling that had to make a range of assumptions about important factors that influence the economic outcome.

While modelling indicated consistent economic benefits from the adoption of WS CTF, some may consider them to be insufficient to warrant such a transformational change in technology from RTF to WS CTF. Nevertheless, this work showed that WS technology should be seriously considered in the future when its development is further progressed. As environmental accounting matures, it is expected that the sustainability advantages of WS CTF will become much more important and attractive to industry, and for this reason alone, developments in WS technology should be closely monitored for future application in annual horticulture.

Refereed scientific publications

No referred publications produced.

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Intellectual property

No project IP or commercialisation to report