Final Report

# Study to review automation opportunities within the avocado production system


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## Project:

Study to review automation opportunities within the avocado production system (AV22002)

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## Public summary

The Australian avocado industry is projected to grow in both value and volume of production over the next 5 years, but growers are facing challenges to maintain profitability as supply grows faster than demand. Efficiency gains through optimal use of labour and other inputs are desired to drive industry productivity and profitability.

Automation technologies are now commercially available to avocado growers and there is widespread acceptance in the industry that technology will in future be critical to address labour supply and cost challenges, but the view from growers is of skepticism that the currently available technologies are appropriate to deliver sufficient benefits to justify adoption. An online survey open to all Australian avocado growers identified harvesting as the main priority area for automation, with pest and disease management, orchard establishment and canopy management also identified as important areas by many growers. Detailed interviews were undertaken with 12 growers to explore the areas identified in the online survey in more detail.

While harvesting is the most labour-intensive activity, the growers did not believe that it can currently be automated to any great extent. All growers expressed a desire for automation and process efficiency as a means of better utilising their workforce to improve fruit yield and quality rather than as a means of significantly reducing their workforce. Growers noted that there are financial and business-related risks when adopting technology, but some also pointed out that they take personal risks when adopting new technology, in particular the emotional toll that failures, and particularly repeated failures, takes on them. Several growers also noted that wasted time spent implementing technology that ultimately fails was also a consideration when assessing whether to try new technology.

Examination of picker activity when undertaking ground and platform picking operation identified two major areas where significant variability in labour-use efficiency occurred. Using a digital technology to track individual pickers completing different component tasks in a picking cycle starting and ending with emptying fruit into a bulk bin, it was evident that significant variability existed between pickers. Opportunities to reduce variability and increase average picker efficiency include technologies to assist in selection of efficient pickers and/or training of pickers to improve efficiency, and technologies to monitor picker performance. Management of bin running, the placement and transport of bulk bins for fruit receival from pickers, varied between farms and was second area where significant time losses occurred if bins were located at longer distances from pickers and/or were not available for periods when full bins were transported to the packhouse. Process efficiency improvements as well as technological solutions may be implemented to address this area. Assessment of spraying and pruning operations identified the potential for technology to increase the time use efficiency by reducing the number of refilling steps for spraying and reducing the orchard floor clearing activity in pruning. A series of recommended steps were developed based on the insights gained from the grower survey and interviews and the time and motion study of harvesting and pruning operations.

## Keywords

Avocado, automation, agtech, harvesting, labour, time and motion, efficiency

# Introduction

This project was undertaken to review automation opportunities within the avocado production system. It was initiated by the Australian avocado industry and funded by Hort Innovation. The project reviewed current grower management practices to identify areas of greatest opportunity for efficiency and productivity improvements, and reviewed technologies applicable to those areas of opportunity.

**Project Challenge:**
The avocado industry has benefitted from favourable market conditions over the past decade, characterised by strong domestic demand and increasing production. This large increase in production volume has driven value increases, but there is evidence that unit price is decreasing as supply is growing faster than demand. While the Australian avocado industry is projected to grow in both value and volume of production over the next 5 years, growers will face challenges to maintain profitability as supply grows faster than demand. Efficiency gains through optimal use of labour and other inputs are desired to drive industry productivity and profitability.

The industry is spread across seven production regions located in Western Australia, Queensland, New South Wales and the Tristate border region of South Australia, Victoria and New South Wales. The industry occupies a production area of over 19,000 ha and has an annual value in excess of $500m. Being spread across broad geographic regions and made up of varying sized enterprises, each production business has varying labour use and requirements depending on the size of the farm, complexity of production (i.e. critical timings of crop emergence, pest management, weed pressure, harvests efficiency), access to labour and regional issues. A comprehensive approach is therefore required to identify potential solutions across different business size and location segments to support growers in progressing changes to improve productivity and labour use efficiency.

**Project Scope:**
The project examines areas and options within the production system (in-field through to harvest) to reduce labour costs through improved productivity. It aimed to identify areas where there is high labour dependency and high costs which may provide opportunities for improved processes or for technology to implemented. It involves a review of current grower management practices for potential improvements, including identifying the complexity of the process that needs to be overcome. Coupled with this a review of technologies already available, or likely to emerge in the future, was completed to identify automation option that may address identified areas where improved labour use efficiency is likely to have the greatest impact.

Most avocado production processes require labour inputs, and while some growers have data on specific task labour requirement, there is little detailed understanding of time spent by staff in the many elements of activity that make up each process. Picking, for example, may involve time taken to mobilising the workforce to the orchard, distributing harvesting equipment and organising picking teams, filling picking bags, moving between trees/rows, moving to bulk fruit bins, taking scheduled breaks and unscheduled breaks, time loss awaiting arrival of replacement bins, and so on. Time spent on each of these elements varies between workers and also with picking strategy (selective v strip picking), ground v platform picking, crop fruit load, orchard density, and so on. Time and motion studies were undertaken to assess the breakdown of processes into component elements and identify the elements of processes where efficiency gains are most likely to be made. Data on the component elements of activity within the high labour dependency processes are needed If the avocado industry is to effectively incorporate emerging agtech into the production system to improve labour use efficiency. Nuanced data is required to target processes in different industry segments, with appropriate automation requirements potentially varying with production system and size, and regional location. Short term and long term strategies are required given currently available technology may not match areas of highest identified need.

**Project Objectives:**

- Identify processes, gaps or limitations within the production system, that could provide a cost or resource (labour) saving through automation or process improvement.
- Identify and describe the processes that could be automated in enabling this technology/opportunity for the avocado industries.

# Methodology

The project consisted of three research and information assimilation activities. Firstly, information was gathered from avocado industry participants on production system activities that were considered to be the most labour intensive as well as grower perceptions about production practices where resource (labour) saving through automation or process improvement could be implemented. This activity involved an online survey of grower nationally, and in-depth semi-structured interviews with avocado growers in different production regions and with varying production scales. The second activity undertaken was a series of time and motion studies undertaken to gather in-depth information on the time staff spend doing component tasks involved in completing specific production practices such as harvesting fruit. The time and motion studies focused on production practices identified as most labour intensive in the grower survey and interview activity. The third activity was a global scan of available technologies that were considered applicable to labour intensive production practice areas identified in activities 1 and 2. Analysis of information from the first three activities was undertaken to develop a set of recommendations to support growers to implement automation and process efficiency changes in their production systems.

## 1. Grower survey and interviews

The avocado industry in Australia is complex, with production distributed across a wide geographic and climatic range and containing producers of varying production scales and management of crop production. To gain sufficient insight into the industry to target aspects of production where automation is most likely to have an impact, a grower survey and grower interviews were conducted. An exploratory mixed methods (quantitative and qualitative data) study design was used incorporating an online survey and in-depth semi-structured interviews with growers. Ethics approval to conduct the study was obtained from the CQUniversity Human Research Ethic Committee (Application Reference Number: 0000024310).

a) In consultation with industry representatives, a set of survey questions was developed to explore all likely labour-intensive processes (orchard soil preparation, planting, slashing, pruning, pest/disease management, nutrition, irrigation, fruit load estimation, fruit development and quality management, harvesting). The survey was hosted on an online survey platform Qualrics and contained a series of qualitative and quantitative questions. The survey questions are attached as Appendix 1. An invitation to complete the survey was sent via Avocado Australia (AA) to all AA members throughout Australia, and the survey remained open for 6 weeks. A range of demographic data was collected including farm location; area under production; tree age; fruit variety; annual production and staffing levels. This demographic data enabled a more granular analysis of production process constraints based on farm attributes. Participants were able to select which production system processes which they believed could most benefit from automation as a labour-saving strategy, and were then asked a series of questions to refine the specific farming actions that they believed could be automated. Open-ended qualitative questions were used to better understand why growers felt particular processes were major constraints, and to also gather data on technology currently or previously used to reduce labour costs and/or improve process efficiency. The last section of the survey invited growers to nominate if they wished to participate in a one-on-one interview, as the next phase of engagement.
b) In-depth semi-structured interviews were conducted with twelve avocado growers. Three participating growers were selected based on their affirmative survey response to being interviewed. The remaining nine growers were selected to ensure as broad a range of grower / enterprise attributes as possible, based on locality, size of enterprise and representation of the avocado industry within a given production area. Interview participants represented all seven of Australia's key avocado growing areas (North, Central and S.E. Queensland, Northern and Central New South Wales, the Tristate area, and Western Australia). Each grower was asked ten open-ended questions regarding their perceptions of automation based on personal experiences and any aspirations or concerns they may hold regarding the adoption of new technologies or practices. The interview questions are attached as Appendix 2. The interviews, conducted in person, via phone or via videoconferencing, were recorded and transcribed verbatim for analysis.

The quantitative data from the online survey was statistically analysed using SPSS v 26, and descriptive statistics, correlations and regression analyses were produced. The qualitative data from the online survey and semi-structured interviews was analysed using thematic analysis.

## 2. Time and motion studies

The high labour cost areas of crop production identified in component 1 were studied in detail to identify potential efficiency gains. Standard industry practices were documented and divided into work elements for time and motion studies. The Digital Assistant technology, developed by project collaborator Harvest Ant was used to automate data capture in time and motion studies. Up to 10 staff at a time were individually tracked while performing the targeted work processes with time, location (movement) and speed automatically recorded. Use of the technology allowed a larger volume of data collection than video or observational data capture. Automated time and motion data was supplemented with observational studies to aid in interpretation of the recorded data.

The project assessed 4 production processes identified as high labour cost areas in component 1 of the project: ground picking, cherry picking, pruning and spraying. Locations and types of production systems (scale of production, planting density, production system management targeted for data collection were determined based on prioritization assessment in component 1.

For the harvesting data collection, the picking task was defined as a series of repeats of the same cycle, with each cycle consisting of several component tasks commencing and finishing with the picker leaving the bulk fruit collection bin. Tasks were moving to the tree, picking fruit from the tree, moving between trees, moving to the bulk bin and time spend unloading fruit into the bin.  At each site and sampling date a combination of coarse data and fine data was collected. Course data consisted of total cycle length which was recorded by individual pickers who were each equipped with a Digital Assistant and would record the start of a new cycle/end of a current cycle by holding the Digital Assistant next to a Reader at the bin prior to returning to the trees to pick more fruit. Fine data consisted of time spent by a picker at each of the component tasks and was recorded by a team member using a Digital Assistant to record when each task commenced.

Results of the time and motion studies were presented to the project steering committee to ensure industry engagement and to test broader applicability and validity of the conclusions drawn from the studies.

## 3. Global scan of available and emerging technologies

A list of commercially available (and late-stage commercialisation) technologies that are potentially applicable to ‘high cost’ areas identified in components 1 and 2 was compiled. The technical evaluation of technology included assessment of applicability (evidence of strengths and weaknesses of the technologies) and farming system integration compatibility (how well does the technology fit with other elements of the production system). Information was gathered from technology manufacturers as well as, where possible, current users of the technologies in other industries and researchers who have assessed the technologies. A ‘potential future technologies’ list was generated through a review of the literature and covered technologies that are not yet commercially available or likely to soon be available but could be game changers if the technology ideas translate into viable commercial products.

Case studies of technology being used in avocados and other tree crop industries were compiled. These included available evidence of product complexity, compatibility within production systems, trialability, flexibility for modifications to suit specific farm needs, technical support requirements, and return on investment calculations where sufficient data are available.

# Results and Discussion

## 1. Grower survey and interviews

Forty-eight commercial avocado growers responded to the online survey, of which 34 completed all questions. Respondents represented all six key avocado growing regions in Australia, with farms ranging from 2 to 750ha (Table 1).

**Table 1.** Participants of the online survey, according to region, farm size and staff numbers.

| | Farm size | | | | Average # off-season staff | | | Average # on-season staff | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | <20ha | 20-50ha | >50ha | Total | <20ha | 20-50ha | >50ha | <20ha | 20-50ha | >50ha |
| North Qld | 3 | 0 | 2 | 5 | 4 | - | 3.5 | 14 | - | 23 |
| Central Qld | 0 | 2 | 3 | 5 | - | 2 | 27.5 | - | 17 | 62 |
| South East Qld | 2 | 0 | 1 | 3 | 2.5 | - | 6 | 2.5 | - | 28 |
| Northern NSW | 0 | 4 | 0 | 4 | - | 2 | - | - | 5.8 | - |
| Central NSW | 0 | 0 | 2 | 2 | - | - | 6 | - | - | 11.5 |
| Tristate | 2 | 5 | 0 | 7 | 1 | 4.5 | - | 3 | 16.5 | - |
| WA | 4 | 3 | 1 | 8 | 1.8 | 2 | 14 | 4.5 | 8.3 | 45 |
| **Total** | **11** | **14** | **9** | **34** | | | | | | |

Survey participants were asked how many staff they employed on an average day in the non-harvesting season (off-season) and the harvesting season (on-season). Given the range of farm sizes, staffing was categorised according to farm size. It is clear from the data that smaller farms tend to employ more staff per hectare in the off season than the medium and larger farms. During the harvest season, this trend is reversed with larger farms employing significantly more staff per hectare than the medium and smaller farms.

Participants were asked to select two areas of the avocado production farming system that they believed had the highest labour dependency in which cost savings could be made through automation.  Eighty five percent of participants stated that the harvesting process was the most labour intensive and could most benefit from automation (Table 2).  Approximately one third of the participants (29.4%) selected pest and disease management, 21% selected orchard establishment and 15% selected canopy management. Western Australia was the only growing region to identify irrigation as a priority area. Pest and disease management was identified as a priority by a higher percentage of growers in Queensland production regions than in the production regions in other states.

**Table 2**: Automation Priority Areas Selected by Survey Participants

| | Orchard establishment | | Orchard floor management | | Canopy Management | | Pest & disease management | | Nutrition | | Irrigation | | Harvesting | | Other | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N Qld | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 3 | 60.0% | 1 | 20.0% | 0 | 0.0% | 5 | 100.0% | 1 | 20.0% |
| C Qld | 1 | 20.0% | 0 | 0.0% | 2 | 40.0% | 2 | 40.0% | 0 | 0.0% | 0 | 0.0% | 5 | 100.0% | 0 | 0.0% |
| SE Qld | 2 | 66.7% | 0 | 0.0% | 0 | 0.0% | 2 | 66.7% | 1 | 33.3% | 0 | 0.0% | 2 | 66.7% | 0 | 0.0% |
| N NSW | 1 | 25.0% | 0 | 0.0% | 1 | 25.0% | 1 | 25.0% | 0 | 0.0% | 0 | 0.0% | 1 | 25.0% | 0 | 0.0% |
| C NSW | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 4 | 200.0% | 0 | 0.0% |
| Tristate | 2 | 28.6% | 1 | 14.3% | 1 | 14.3% | 1 | 14.3% | 0 | 0.0% | 0 | 0.0% | 6 | 85.7% | 0 | 0.0% |
| WA | 1 | 12.5% | 0 | 0.0% | 1 | 12.5% | 1 | 12.5% | 2 | 25.0% | 3 | 37.5% | 7 | 87.5% | 1 | 12.5% |
| **Total** | **7** | **20.6%** | **1** | **2.9%** | **5** | **14.7%** | **10** | **29.4%** | **4** | **11.8%** | **3** | **8.8%** | **29** | **85.3%** | **2** | **5.9%** |

Areas of harvesting that were identified by survey participants as having potential for automation were: 1. Hand-picking from hydraulic picking platforms (cherry pickers) (identified by 76% of participants), 2. Hand-picking from the orchard floor (34%), 3. Carrying fruit from picking bags/picking crates to bulk bins (28%), 4. Educating labourers regarding which fruit to pick (selective harvesting) (28%), 5. Organising labourers (pickers) (14%), 6. Transporting fruit from the orchard to the pack shed/storage shed (14%) and 7. Fruit ripening testing (dry matter testing) (7%).

Aspects of pest and disease management that were identified by growers as targets for automation were: 1. Foliage cover spray for insect/disease control (60%), 2. Spot spraying for insect/disease control (40%), 3. Surveying orchards for diseased or pest outbreaks (20%), 4. Trunk injections for Phytophthora (root rot) control (30%), 5. Scouting orchard for insect pests (10%) and 6. Establishing drainage for Phytophthora (root rot) control (10%).

Orchard establishment tasks identified in the survey were: 1. Planting the trees (43%), 2. Soil mounding (29%), 3. Installing irrigation (29%), 4. Applying fertilizer (29%), and 5. Marking rows (14%). The canopy management tasks that were identified were: 1. Clearing branches post pruning (80%), 2. Tree shaping and hedging (60%), 3. Selective limb removal (60%), 4. Tree height control (40%), 5. Chemical control (40%), and 6. Mulching branches (40%).

Some survey participants responded to the open-ended survey questions to specify any technologies they had used to address labour costs in each of the respective priority areas and outline the benefits and drawbacks of those technologies (Table 3).

**Table 3**: Grower Comments Regarding Adopted Technologies

| Technologies Tested | Benefits | Drawbacks |
|---|---|---|
| GPS Guided Tractor | Less Breakages | High lease cost |
| Automatic planter | Fast; reduced labour; precise tree spacing | Cost and scheduling of contractors |
| Large mechanical pruning saw | Reduced labour cost | Less fruit set in interior of trees |
| Tracmap farm management system | Increased reliability | High subscription costs |
| Soil probes and computer controlled irrigation | Reduced labour, remote control, precision of irrigation application, water savings | Poor internet connectivity, high cost |
| Labour training videos | Reduced labour costs | Cost to develop videos, extras computers required |
| Cherry pickers | Reduced labour costs | Equipment cost, lack of competent operators |

Harvesting was clearly the highest labour dependency activity that the time and motion studies needed to focus on, with both ground and platform harvesting operations requiring study. Survey results informed the interview phase where perceptions were examined in order to inform the on-farm data collection and the project recommendations.

**Interview Results**

All twelve interviewed growers expressed optimism regarding the future of Australia's avocado industry. Despite this optimism, growers discussed varied experiences with automation and efficiency improvements and overall their attitude to technology adoption could be summarised as a 'healthy cynicism' reflecting a belief that automation will be part of the industry's future but that appropriate technologies are yet to become available. Following analysis of grower's verbatim responses, their perceptions of automation and efficiency improvements within avocado production can be summarised into three broad themes:

- **Automation is not a 'one size fits all' solution**

Growers do not believe automation is a suitable solution in all situations or contexts. The Australian avocado industry is complex and spans many, varied geographical areas and involves producers of varying production scales and crop management practices. This complexity and variety was reflected in growers' perceptions of automation and efficiency improvements. Several growers discussed technology not being fit for their specific production systems. They noted that their priorities and challenges were not the same as growers in other regions, and automation does not always offer a solution to their problems. Challenges such as pest and disease pressure as well as climatic factors such as rainfall, temperature and humidity were raised by several growers as issues that varied between regions. For example, Western Australian growers do not experience the pest and disease pressures experienced by North Queensland growers and therefore, automated spraying may not be seen as a priority area for automation in Western Australia.

The 'smaller' scaled growers generally believe that the size of their farming system does not warrant automation and that it would only be useful at a larger scale. Scale is also considered an important factor in justifying investment in automation. Small-scale growers noted that they would need to utilise it more extensively than is practical to achieve a return on investment. The capital expense of automation also presented a significant barrier to small-scaled growers. They noted that their inability to afford automation, coupled with the perceived ability of larger growers to do so, made it challenging to remain competitive.

Several small-scale growers also cited the lack of resources, smaller staffing numbers and less access to external funding as challenges that may not be shared by larger-scale or corporate growers. Respondents also pointed out that small-scale growers make up a substantial portion of all growers and therefore, the challenges they encounter individually also present significant barriers to the adoption of automation across the broader Australian industry.

- **Automation will be important moving forward**

Most interviewees expressed optimism in the Australian avocado industry, citing the current expansion of export markets into Indonesia and China and the reputation of Australian avocados as a consistently high-quality product.  Growers acknowledged that automation and adoption of new efficiency improvements must be part of their ongoing management practices if they are to capitalise on these markets and remain competitive on the international market. Several growers pointed out the current price of avocados, noting that the industry is currently tight and that growers are operating under extremely tight margins as distinct to previous years, of which many growers reflected on how times had changed. Participants demonstrated a strong desire for improvement to remain profitable as a result, with many expressing openness to change as a means to achieve this. Despite growers' general perception that technology is not yet fit for purpose, several emphasised the role that automation could play in the improvement of their businesses, strengthening a sense of openness to automation among respondents.

A large proportion of growers also identified improvements to their work-life balance as a major driver of their openness to technology, citing the personal flexibility and freedom that automation had the potential to deliver. Many placed significant importance on the personal benefits of automation because as small-scale, family growers, they noted that they make personal sacrifices for their farms, including a lot of after-hours time spent on farm related tasks. Several growers noted the advantages that automation has for their workers, with staff safety in particular identified as a major advantage of automation. Staff safety in some cases determined what growers adopted, with some respondents detailing investments made to keep staff safe.

Both small and large-scale growers were acutely aware of initiatives being implemented in overseas countries and expressed the need for continued support in trialing of new technologies. Growers were adamant that these trials needed to be conducted in real-world, commercial farming conditions, in collaboration with growers.

- **Automation is a risk**

A large proportion of respondents identified technical risks as a major barrier to adoption, and a major risk of investing in automation. These technical risks included equipment failures and unreliability as well as inaccurate data. These risks resulted in a lack of confidence and trust in autonomous systems, impacting the success of technology adoption on farm. Technology breakdowns were a particular concern for growers, who value their ability to maintain and repair their older, less technical equipment themselves rather than relying on someone with the particular set of skills needed to service and maintain equipment. Not being able to maintain the equipment themselves, or by those they trust and enjoy working with such as their preferred local mechanics and providers, contributed to a lack of control that growers felt when considering the risks of investing in technology. Relying on technical providers also influenced this perception, as many growers expressed dislike and distrust of technology companies to provide the support needed of highly complicated and advanced equipment.

Growers noted that they highly value the knowledge and opinions of other growers who are using technology over other sources of information. In addition to peer networks, growers commented that field days where they could connect with other growers and see the technology in action were valuable. The majority of growers noted that while they accept information as reliable from other growers as well as trusted sources such as their agronomists, there is a lack of trust in technology salesman and agtech companies. This mistrust together with perceived risks of implementing new technology and the lack of fit for purpose formed the basis of growers perceptions of cynicism towards automation. Most growers were noted that they had had negative experiences with technology, and that this has impacted their willingness to try again.

Participants noted that there are significant risks when adopting technology. Growers expressed strong dissatisfaction with technology providers and their 'snake-oil salesman' approach to marketing their products. The main risks are both financial and business related, but some also pointed out that they take personal risks when adopting new technology, in particular the emotional toll that failures, particularly repeated failures, takes on them. Several growers also noted that wasted time spent implementing technology that ultimately fails was also a consideration of the risks taken to try new technology.  This holds special significance for small scale family growers who often make personal sacrifices and dedicate significant amounts of time to their business, especially out of hours. Growers thus value their time, as it directly impacts their and their families quality of life, with many participants highlighting the personal benefits that automation can provide over financial and return on investment considerations.

## 2. Time and motion studies

**Ground harvesting operations**

Time and motion data for ground picking was collected from 7 commercial avocado orchards on 13 different days. A total of 69 pickers were engaged in the study and more than 3000 distinct picking cycles were monitored. Each picking cycle covered the time when a picker left commenced picking fruit on a tree, moved between trees, walked to the bulk collection bin, unloaded fruit into the bin and walked back to a tree. Each picker would typically complete multiple picking cycles each shift.  Ground picking time and motion studies were conducted in Western Australia, Central Queensland, North Queensland and Northern NSW (Table 4).

**Table 4.** Summary of ground picking time and motion study data. Times are expressed as minute.seconds.

| | Western Australia | Central Queensland | North Queensland | New South Wales | Total |
|---|---|---|---|---|---|
| **No. of sites** | 2 | 2 | 2 | 1 | **7** |
| **No. of cycles** | 67 | 1132 | 1090 | 882 | **3171** |
| **No. of days** | 3 | | 4 | 3 | **10** |
| **No. of pickers** | 7 | 27 | 20 | 15 | **69** |
| | | | | | **Average** |
| **Cycles/hour** | 20.11 | 10.50 | 11.80 | 14.99 | **14.35** |
| **Kg/hour** | 290.99 | 151.97 | 170.68 | 216.89 | **207.63** |
| **Cycle length** | 3.27 | 6.01 | 4.56 | 4.06 | **4.37** |
| **Picking** | 2.45 | 3.48 | | 2.28 | **3** |
| **Moving between trees** | 0.27 | 1.01 | | 0.52 | **0.47** |
| **Walking to bin** | 0.09 | 0.15 | | 0.08 | **0.11** |
| **Time at bin** | 0.09 | 0.14 | | 0.11 | **0.11** |
| **Walking back to tree** | 0.15 | 0.16 | | 0.5 | **0.27** |
| **% of cycle spent picking** | 79.25 | 78.11 | | 59.45 | **72.27** |

The average length of the picking cycle across all sites and days was 4 minutes and 37 seconds, and varied from over 6 minutes for the two Central Queensland sites to three minutes and 27 seconds at the two Western Australian sites. Pickers spent more time per cycle moving between trees and picking fruit at the CQ sites than the WA sites but a similar percentage of the picking cycle was spent performing the fruit picking task. In contrast, at the NSW site the pickers spend 20% less time during the cycle picking fruit., with proportional increase in time spent on moving between trees.

Site information was collected for each of the seven sites used for ground picking time and motion studies (Table 5).

**Table 5.** Site information for ground picking time and motion studies

| | Region | Western Australia | | Central Queensland | | North Queensland | | NSW |
|---|---|---|---|---|---|---|---|---|
| | **Site** | **WA1** | **WA2** | **CQ1** | **CQ2** | **NQ1** | **NQ2** | **NSW1** |
| **Site** | **Size** | Small | Large | Large | Large | Large | Large | Large |
| | **Topography** | Sloped | Flat | Sloped | Sloped | Sloped | Flat | Highly sloped |
| | **Tree age** | Young | Mid-age | Young | Mid-age | Young | Mid-age | Mid-age/young |
| | **Tree density** | Normal | Normal | Normal | Normal | Normal | Normal | Normal |
| | **Fruit load** | Heavy | Heavy | Heavy | Heavy | Heavy | Light | Heavy |
| | **Alternate bearing** | On-year | On-year | On-year | On-year | On-year | On-year | On-year |
| **Harvest** | **Bin runner** | Intermittent transfer<br>Dedicated bin runner | Continuous transfer<br>Dual picker/bin runner | Continuous transfer<br>Dedicated bin runner | Continuous transfer<br>Dedicated bin runner | Continuous transfer<br>Dual picker/bin runner | Intermittent transfer<br>Dual picker/bin runner | Continuous transfer<br>Dual picker/bin runner |
| | **Picking format** | Via interrow | Via tree row | Via tree row | Via tree row | Via tree row | Via tree row | Via tree row |
| **Pickers** | **Experience** | Inexperienced | Inexperienced | Inexperienced | Inexperienced | Inexperienced | Inexperienced | Inexperienced |
| | **Sex** | Male/female | Male/female | Male/female | Male/female | Male/female | Male | Male/female |
| | **Nature of employment** | Directly by grower | Via contractor | Via contractor | Via contractor | Directly by grower | Directly by grower | Directly by grower |
| **Shift** | **Pickers** | 10 | 6 | 10 | 12 | 12 | 5 | 10 |
| | **Hours/day** | 7.5 | 7.5 | 7 | 7.5 | 7 | 7 | 7.5 |

Disaggregated data for each of the individual pickers monitored in the project provide information on variability in picking efficiency between growers as well as variability in picking performance of each picker over the duration of the monitoring period (table 6). Comparisons between pickers on a single date reflect variability in picker efficiency as all pickers are harvesting in the same section of orchard at the same time. Caution is needed for comparisons between sites and dates as site factors (crop load, site conditions, etc) as well as weather conditions may vary.

**Table 6**. Cycle length (mean and standard error) for individual pickers at each site and sampling date in each region. Times are presented as minutes.seconds in the table.

| | | **Region** | **Western Australia** | | | **Central Queensland** | | | **North Queensland** | | | **New South Wales** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Site** | **WA1** | | **WA2** | **CQ1** | | **CQ2** | **NQ1** | | **NQ2** | **NSW1** | | |
| | | **Day** | **1** | **2** | **1** | **1** | **2** | **1** | **1** | **2** | **1** | **1** | **2** | **3** |
| | **Site average** | **Average cycle time** | 2.37 | 3.15 | 4.17 | 6.04 | 6.16 | 6.1 | 5.06 | 4.42 | 6.25 | 4.27 | 4.09 | 3.54 |
| | | **Average SE** | 0.22 | 0.36 | 0.27 | 0.14 | 0.42 | 0.33 | 0.10 | 0.15 | 0.37 | 0.20 | 0.20 | 0.20 |
| **Picker** | **1** | Average | 2.2 | 3.15 | 3.28 | 4.49 | 4.48 | 2.39 | 5.47 | 4.05 | 7.55 | 5.17 | 4.38 | 5.57 |
| | | SE | 0.18 | 0.36 | 0.14 | 0.14 | 0.14 | 0.22 | 0.12 | 0.11 | 0.53 | 0.17 | 0.23 | 0.38 |
| | **2** | Average | 1.37 | | 3.38 | 4.48 | 5.05 | 6.06 | 4.47 | 4.25 | 5.02 | 3.44 | 3.26 | 3.28 |
| | | SE | 0.11 | | 0.19 | 0.09 | 0.25 | 0.21 | 0.1 | 0.12 | 0.28 | 0.1 | 0.16 | 0.14 |
| | **3** | Average | 3.56 | | 5.46 | 9.44 | 5.15 | 7.12 | 5.02 | 4.18 | 7.22 | 4.28 | 4.22 | 3.39 |
| | | SE | 0.37 | | 0.49 | 0.19 | 0.15 | 0.35 | 0.1 | 0.23 | 0.51 | 0.52 | 0.21 | 0.21 |
| | **4** | Average | | | | 5.5 | 5.18 | 9.24 | 5.04 | 5.09 | 6.54 | 3.49 | | 3.1 |
| | | SE | | | | 0.14 | 0.36 | 1.13 | 0.1 | 0.15 | 0.31 | 0.14 | | 0.13 |
| | **5** | Average | | | | 6.11 | 11.34 | 6.34 | 4.42 | 4.45 | 4.54 | 3.11 | | 3.15 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SE | | 0.11 | 0.21 | 0.24 | 0.09 | 0.12 | 0.24 | 0.09 | | 0.13 |
| | **6** | Average | | 4.5 | 6.49 | 6.07 | 5.37 | 4.09 | | 6.43 | | |
| | | SE | | 0.18 | 0.6 | 0.26 | 0.1 | 0.15 | | 0.32 | | |
| | **7** | Average | | 6.14 | 6.44 | 5.25 | 4.45 | 6.34 | | 3.59 | | |
| | | SE | | 0.15 | 1.48 | 0.2 | 0.08 | 0.17 | | 0.09 | | |
| | **8** | Average | | | 4.4 | 7.19 | | 4.09 | | | | |
| | | SE | | | 0.18 | 0.38 | | 0.13 | | | | |
| | **9** | Average | | | | 6.03 | | | | | | |
| | | SE | | | | 0.17 | | | | | | |
| | **10** | Average | | | | 5.32 | | | | | | |
| | | SE | | | | 0.27 | | | | | | |
| | **11** | Average | | | | 5.27 | | | | | | |
| | | SE | | | | 0.24 | | | | | | |

Significant variability in both the mean length of the picking cycle and variability (expressed as standard error) is evident between individual pickers. While weight of fruit per joey bag picked was not able to be measured, and may vary between picking cycles and between pickers, the use of mean values calculated over multiple picking cycles does provide a reliable measure of variability as well as a repeatable measure of the picking pattern of each picker. Note that the 2 sets of data for site WA1 show lower mean cycle times than for other sites as this was the only site where fruit was picked into buckets rather than joey bags. Mean picking cycle time varied between 2 minutes and 39 seconds for picker 2 at CQ2 to 11 minutes and 24 seconds for picker 5 at the second sampling date at CQ1. With up to a fourfold variation in picking efficiency between pickers, this aspect was examined in more detail to determine if process efficiency or automation options may be applicable to deliver cost and efficiency gains. The second major difference between individual pickers was in the variability in picking cycle length, with data for some pickers showing much larger standard error values indicative of larger differences in time taken to complete each picking cycle over the duration of the recording period.

An example of variation in picker efficiency can be seen in Figure 1. Picking cycles varied between pickers at the same site on the same day from the fastest picker with a picking cycle of three minutes forty seconds to the slowest picker at seven minutes and two seconds.

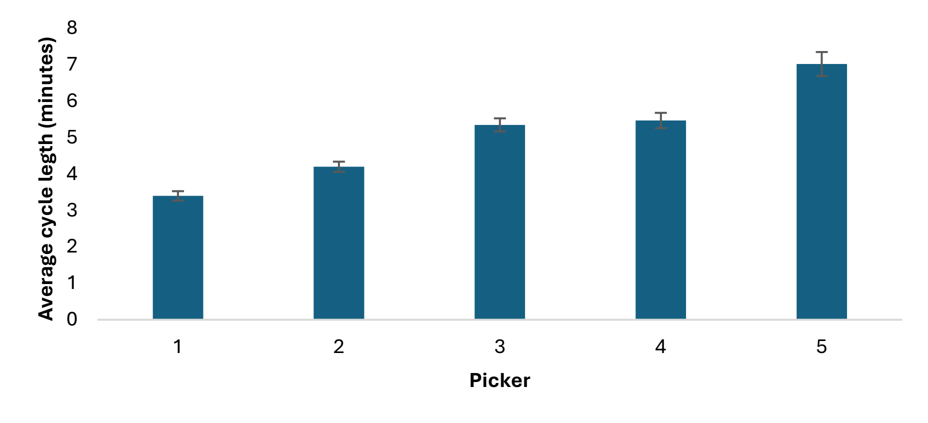


**Figure 1.** Mean cycle length (bars show standard error) for individual pickers monitored at the same site and on same day.

To assess the significance of the variability in picker efficiency, the projected weight of fruit harvested per hour was calculated using a low, medium and high bag weight (based on fruit weights in joey bags measured at bin transfer point in a previous study) of 12.89, 14.47 and 15.71kg/bag and the number of bags picked based on the measured mean cycle times of four pickers. Assuming a return price to grower of $3/kg of fruit, the calculated return per hour varies from $266.83 for the slowest picker and lightest bag weight to $518.86 for the fastest picker and heaviest bag weight (Figure 2).

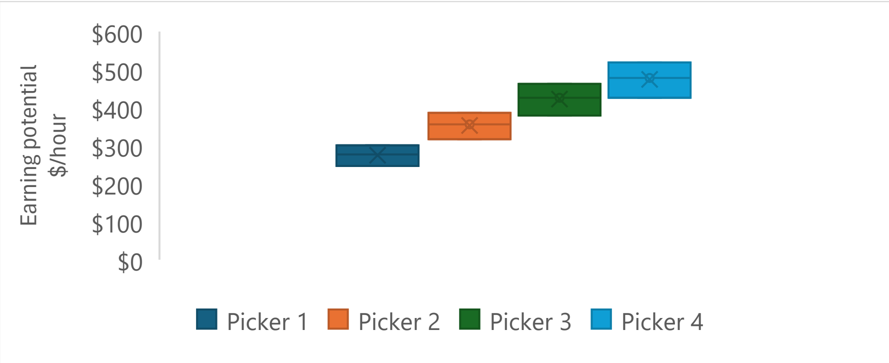


**Figure 2.** Calculated earning potential based on 3 bag weight scenarios, measured cycle times of 4 pickers on the same day at one site and a return to grower of $3/kg of fruit.

Comparing the returns from the 4 pickers for a median bag weight of 14.47kg of fruit, there is a $200/hr or 72% increase in return for the fastest picker ($477.91/hr) compared to the slowest picker ($277.09/hr). Where pickers are paid per hour rather than by piece rates, the impact of this differential on returns per unit of labour cost is significant.

Picker productivity was also noted to change over the day due to fatigue (figure 3).

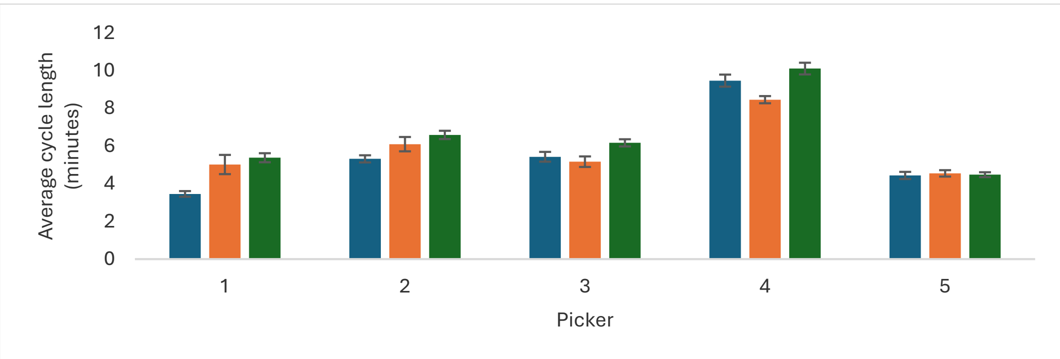


**Figure 3**. Mean cycle length (bars show standard error) for individual pickers monitored at the same site and on same day over three work shifts (first 2 hour shift in blue, second shift in orange, third in green).

The mean picking cycle length increased by 55% and 23% for pickers 1 and 2 over successive shift, with picker

3 also displaying a longer picking cycle by shift 3. Picker 4 had a much longer picking cycle than the other pickers in each shift while picker 5 maintained a shorter than average picking cycle across all three shifts. Site and weather conditions will influence fatigue development. Declines of 50% in picking efficiency between first and last shifts over a day would represent approximately $100/hr lower productivity for a picker in the last shift compared to the first pick. Identifying and managing fatigue is therefore an area that should be considered where fatigue risk is high.

As expected, the proportion of time spent on different components of the picking cycle also varied between picking cycles for each picker. However, analysis of individual picker data does highlight the impact of the bin run system on the efficiency of pickers. In the example shown in Figure 4, individual picking cycles from 3 pickers at 3 sites were observed to vary and differences in bin run efficiency are evident in the percentage of the picking cycle spent on the 5 component tasks displayed for each cycle.

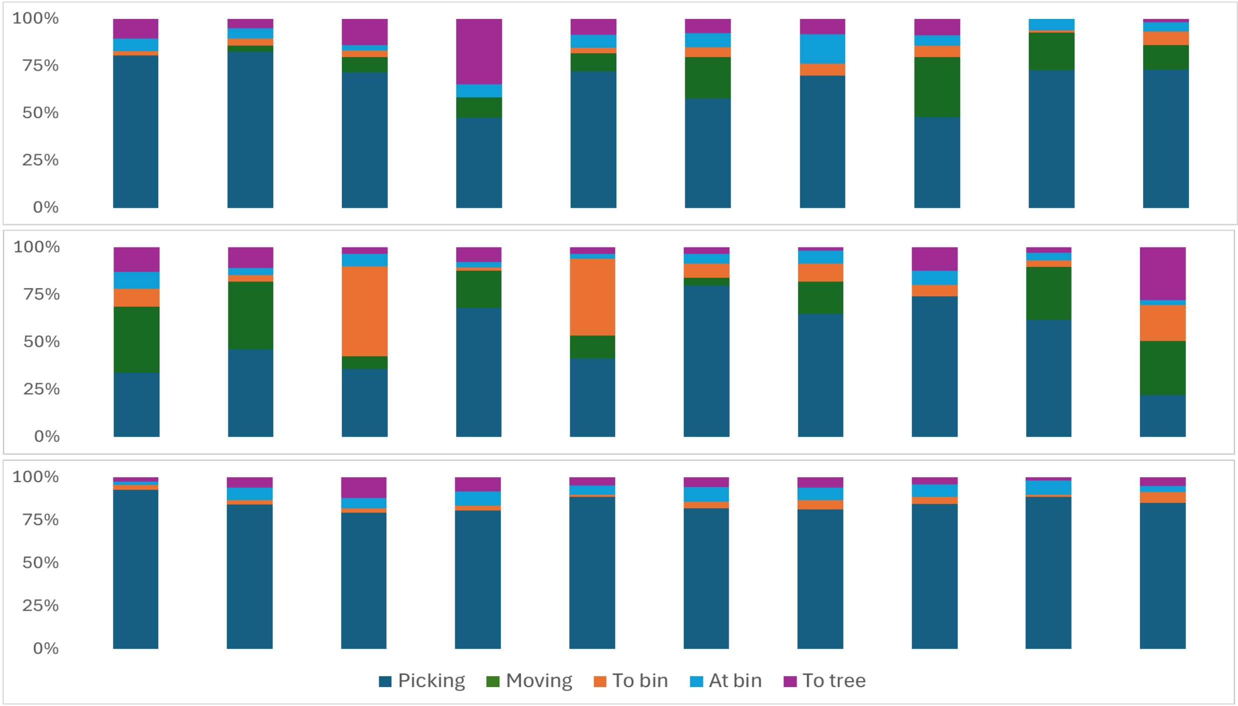


**Figure 4.** Individual picking cycles for 3 pickers at 3 sites (CQ1 top, CQ2 middle, NSW1 bottom) with varying bin run efficiencies.

The picker at site 2 (middle set of picking cycles) has 2 picking cycles with extended time to bin, representing time waiting for a new bin to arrive before unloading of the fruit could occur.

When mean and standard error calculations are made for the pickers at the three sites from which the Figure 4 data are drawn, the differences in mean time spend moving to bin and at bin, as well as the variability, are significantly higher at the site where the bin run system was less efficient (Figure 5).

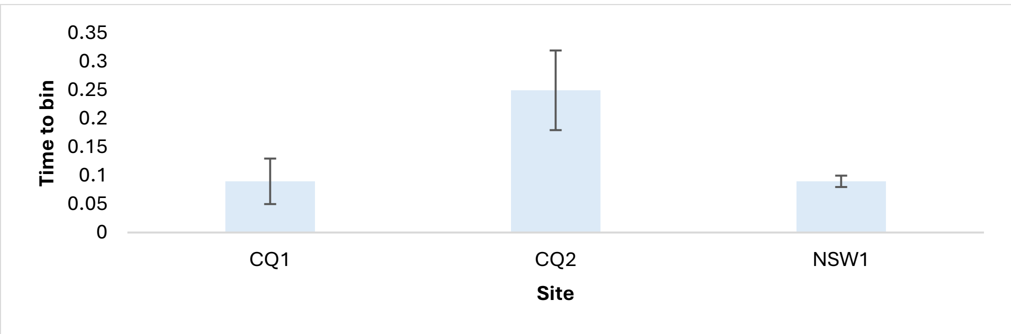


**Figure 5.** Average time (minutes.seconds) spent moving to bin before unloading fruit. Bar indicated standard errors.

The difference in time per picker spent waiting for bins between efficient bin run sites (CQ1, NSW1) and the less efficient site (CQ2) was 15 seconds, which equates to $24/hr per picker.

## Platform picking harvesting operations

Time and motion data for cherry picker harvesting was collected from 7 commercial avocado orchards on 9 different days. A total of 30 pickers were engaged in the study and 368 distinct picking cycles were monitored. Each picking cycle covered the time when a picker left commenced picking fruit on a tree, moved the cherry picker between trees, drove to the bulk collection bin, unloaded fruit into the bin and moved to a tree to commence the next picking cycle. Each picker would typically complete multiple picking cycles each shift. Cherry picker harvesting time and motion studies were conducted in Western Australia, Central Queensland, North Queensland and Northern NSW (table 7).

**Table 7.** Summary of platform picker harvesting time and motion study data.

| | Western Australia | Central Queensland | North Queensland | New South Wales | Total |
|---|---|---|---|---|---|
| **No. of sites** | 2 | 2 | 2 | 1 | **7** |
| **No. of cycles** | 6 | 66 | 22 | 274 | **368** |
| **No. of days** | 2 | 3 | 2 | 2 | **9** |
| **No. of pickers** | 3 | 12 | 1 | 14 | **30** |
| | | | | | **Average** |
| **Cycles/hour** | 2.75 | 2.46 | 4.16 | 4.59 | **3.49** |
| **kg/hour** | 148.54 | 132.73 | 224.89 | 247.86 | **188.51** |
| **Cycle length** | 21.43 | 29.38 | 16.08 | 13.2 | **20.02** |
| **Picking** | 15.47 | 14.22 | 7.51 | 8.58 | **11.45** |
| **Moving between trees** | 8.06 | 5.51 | 4.41 | 1.19 | **4.79** |
| **Driving to bin** | 0.59 | 0.43 | 0.26 | 0.34 | **0.41** |
| **Time at bin** | 1.26 | 1.06 | 0.48 | 0.22 | **0.76** |
| **Driving back to tree** | 1.12 | 1.55 | 0.57 | 1.37 | **1.15** |
| **% of cycle spent picking** | 60.84 | 56.20 | 52.60 | 75.66 | **61.33** |

Site information was collected for each of the seven sites used for platform picking time and motion studies (Table 8).

**Table 8.** Site information for platform picking time and motion studies

| | **Region** | **Western Australia** | | **Central Queensland** | | **North Queensland** | | **NSW** |
|---|---|---|---|---|---|---|---|---|
| | **Site** | **WA1** | **WA2** | **CQ1** | **CQ2** | **NQ1** | **NQ2** | **NSW1** |
| **Site** | **Size** | Small | Large | Large | Large | Large | Large | Large |
| | **Topography** | Sloped | Flat | Sloped | Sloped | Sloped | Flat | Highly sloped |
| | **Tree age** | Young | Mid-age | Young | Mid-age | Young | Mid-age | Mid-age/young |
| | **Tree density** | Normal | Normal | Normal | Normal | Normal | Normal | Normal |
| | **Fruit load** | Heavy | Heavy | Heavy | Heavy | Heavy | Light | Heavy |
| | **Alternate bearing** | On-year | On-year | On-year | On-year | On-year | On-year | On-year |
| **Harvest** | **Bin runner** | Intermittent transfer<br>Dedicated bin runner | Continuous transfer<br>Dual picker/bin runner | Intermittent transfer<br>Dual picker/bin runner | Continuous transfer<br>Dedicated bin runner | Continuous transfer<br>Dual picker/bin runner | Intermittent transfer<br>Dual picker/bin runner | Continuous transfer<br>Dual picker/bin runner |
| **Pickers** | **Experience** | Inexperienced | Inexperienced | Experienced | Inexperienced | Experienced | Inexperienced | Inexperienced |
| | **Sex** | Male/female | Male | Male/female | Male/female | Male | Male | Male |
| | **Nature of employment** | Directly by grower | Via contractor | Directly by grower | Via contractor | Directly by grower | Directly by grower | Directly by grower |
| **Shift** | **Pickers** | 10 | 4 | 2 | 12 | 12 | 4 | 10 |
| | **Hours/day** | 7.5 | 7.5 | 7 | 7.5 | 7 | 7 | 7.5 |

Disaggregated data for each of the individual pickers provide information on variability in picking efficiency between sites/growers as well as variability in picking performance of each picker over the duration of the monitoring period (table 9). Comparisons between pickers on a single date reflect variability in picker efficiency as all pickers are harvesting in the same section of orchard at the same time. Significant variability in both the mean length of the picking cycle and variability (expressed as standard error) is evident between individual pickers.

**Table 9.** Cycle length (mean and standard error) for individual pickers at each site and sampling date in each region. Times are presented as minutes.seconds in the table.

| | | **Region** | **Western Australia** | | **Central Queensland** | | | **North Queensland** | | **New South Wales** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Site** | **WA1** | **WA2** | **CQ1** | | **CQ2** | **NQ1** | **NQ2** | **NSW1** | |
| | | **Day** | **1** | **1** | **1** | **2** | **1** | **1** | **1** | **1** | **2** |
| **Site average** | | Average cycle time | 21.31 | 22.07 | 23.56 | 19.53 | 34.45 | 14.46 | 13.58 | 14.59 | 15.05 |
| | | Average SE | 6.19 | 9.11 | 15.24 | 6.41 | 16.25 | 4.44 | 2.1 | 7.16 | 3.35 |
| **Picker** | **1** | Average | 21.31 | 22.07 | 23.56 | 20.49 | 27.35 | 14.46 | 11.48 | 15.15 | 14.21 |
| | | SE | 3.1 | 2.49 | 2.49 | 4.16 | 7.15 | 1.56 | 0.42 | 0.28 | 1.22 |
| | **2** | Average | | | | 20.09 | 20.55 | | 16.08 | 11.41 | 16.37 |
| | | SE | | | | 1.16 | 3.38 | | 0.39 | 0.33 | 1.53 |
| | **3** | Average | | | | 18.42 | 50.4 | | | 12.45 | 26.05 |
| | | SE | | | | 3.57 | 6.41 | | | 0.56 | 3.29 |
| | **4** | Average | | | | | 44.03 | | | 9.26 | 12.27 |
| | | SE | | | | | 12.29 | | | 0.23 | 1.04 |
| | **5** | Average | | | | | 34.09 | | | 10.44 | 9.09 |
| | | SE | | | | | 6.48 | | | 0.52 | 0.28 |
| | **6** | Average | | | | | 37.35 | | | 27.54 | 11.49 |
| | | SE | | | | | 5.11 | | | 4.31 | 0.41 |
| | **7** | Average | | | | | 32.19 | | | 16.22 | |
| | | SE | | | | | 8.15 | | | 1.44 | |
| | **8** | Average | | | | | 30.42 | | | 9.5 | |
| | | SE | | | | | 7.04 | | | 0.47 | |

Mean picking cycle time varied between 9 minutes and 47 seconds for picker 8 at the first sampling date at NSW1 to 44 minutes and 3 seconds for picker 4 at CQ2. As with ground picking, differences between picker efficiencies represent approximately a $200/hr range. Differences between picking cycle durations for individual pickers was also evident where bin run efficiency varied.

Mean and standard error values for the platform pickers at the same three sites where bin run efficiency was noted to vary for ground picking revealed a similar trend. Mean time to bin and variability between picking cycles were significantly higher at the site where the bin run system was less efficient (Figure 6).

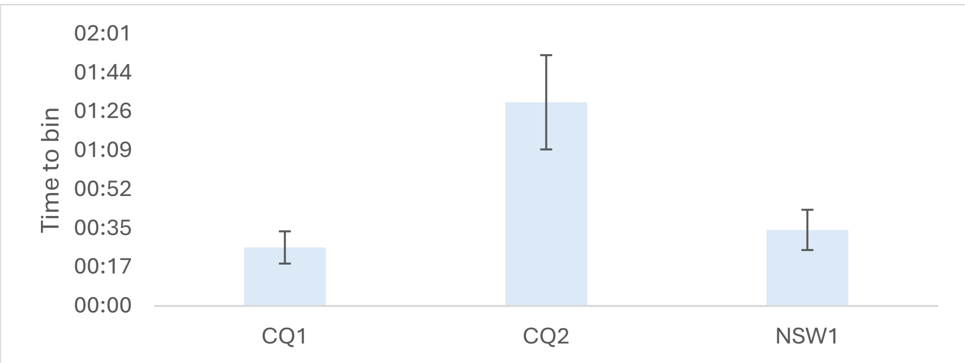


**Figure 6.** Average time (minutes.seconds) spent moving to bin before unloading fruit. Bar indicated standard errors.

A 49 second difference in mean time to bin corresponds to a loss of $8.64/hr for each picker at CQ2 when compared to pickers at the other 2 sites with more effective bin running processes.

**Spraying operations**

Assessment of spraying operations was undertaken on three separate days at one site with 4 different spray operators. Seventeen individual spray cycles (from commencing tank fill through to return to filling station) were monitored with the cycle comprising driving from filling station to trees where spray was to be applied, spraying of trees, driving back to the filling station and refilling the tank. As expected given the nature of spraying operations, there was less variability between sprayers than was observed in variability between pickers. The average spray cycle was 55 minutes (Table 10).

**Table 10.** Summary of spay operation time and motion study data.

| | | | |
|---|---|---|---|
| | **Average** | **Average cycle length** | 55.1 |
| | | **Average SE** | 2.46 |
| **Sprayer** | **1** | **Average** | 56.32 |
| | | **SE** | 4.29 |
| | **2** | **Average** | 51.5 |
| | | **SE** | 2.5 |
| | **3** | **Average** | 59.08 |
| | | **SE** | 0 |
| | **4** | **Average** | 1.00.09 |
| | | **SE** | 13.05 |

Sixty two percent of the time in the spraying cycle was spent applying spray to trees with twenty one percent spent moving between the tank refill station and the trees and seventeen percent filling the tank (Figure 7).

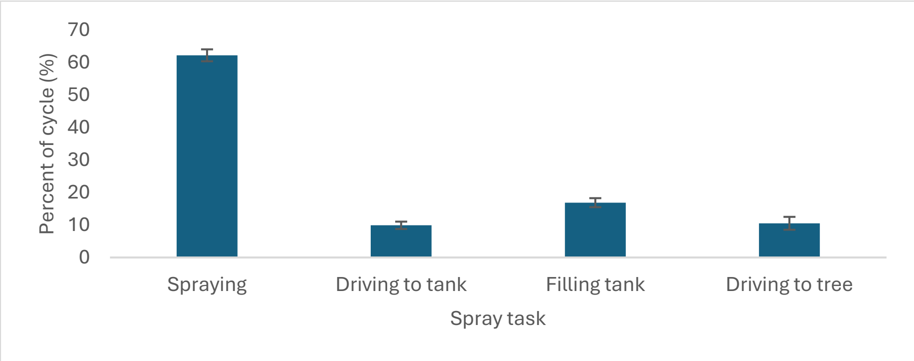


**Figure 7.** Percentage of the spray cycle completing component tasks

Variations in spray cycle task times would be expected with different sprayer types and orchard layouts. The data from this time and motion study is indicative of a typical spray operation in a larger avocado orchard. Increasing spray operation efficiency (the percentage time in each cycle spent applying spray) would reduce the time required to spray orchard block.

**Pruning operations**

Time and motion data was collected at one site in CQ during pruning of mature trees. Over a 7 hour 10 minute and 43 second monitoring period, the staff spent an average of 3 hours 34 minutes and 48 seconds on breaks or moving to and from pruning sites, and in the remaining 3 hours 35 minutes and 55 seconds 40.5% of the time was spent pruning and 59.5% was spent raking and moving pruned materials into the rows.

## 3. Global scan of available and emerging technologies

The review of literature, industry papers and available industry data on technology products with potential to address the labour challenge faced by avocado growers focused on autonomous harvesting and harvest aid technologies, harvest process efficiency technologies, pest and disease management technologies and orchard and tree management technologies. Commercially available (and late-stage commercialisation) technologies that were considered potentially applicable to these areas were identified.

As the range of technologies available is constantly changing due to new product launches, company mergers and acquisitions and company failures, a list of all technologies reviewed has not been presented. Online sites maintaining up to date listings of AgTech products and suppliers are available and include Agtech finder (https://agtechfinder.com/product-directory) and NSW Government Farms of the Future (https://www.dpi.nsw.gov.au/dpi/climate/farms-of-the-future).

The project team undertook a technical evaluation of technology applicability (evidence of strengths and weaknesses of the technologies) and farming system integration compatibility (how well does the technology fit with other elements of the production system) of AgTech identified through the global scan. A report summarizing applicable technology areas and listing products and providers assessed as most applicable to address the labour use efficiency areas was prepared (Appendix 3). As each grower's labour cost and efficiency situation is unique and varies with farm size, production complexity, and regional issues, specific technology recommendations have not been made. The review output was combined with the findings from the grower survey and interviews and the time and motion study data to develop recommendations for strategies to improve labour use efficiency through increased automation in the avocado industry.

## Outputs

### Table 11. Output summary

| Output | Description | Detail |
|---|---|---|
| Avocado automation AgTech review and case studies report | Review of commercially available AgTech products applicable to avocado industry labour use efficiency improvements | Report is attached to the project final report |
| Grower Engagement | • Avocados Australia R&D Forum (Brisbane)<br>• Avocados Australia - Central Qld Export Regional Forum (Bundaberg)<br>• Avocados Australia - South Qld Regional Forum (Crows Nest)<br>• Grower meeting (The Avocado Collective) Ringbark, WA<br>• Avocados Australia - Tamborine / Northern Rivers Avocado Field Day (Mountain Top)<br>• Avocados Australia - Central Qld Regional Forum (Childers) | • Call for growers to participate in grower survey and meeting key AA personnel (50 attendees)<br>• Call for growers to participate in grower survey / interview process (50 attendees)<br>• Discussions with growers in 'round robin ' session (60 participants)<br>• Discussions with growers and demonstration of Harvest Ant technology (8 attendees)<br>• Discussions with growers and demonstration of Harvest Ant technology (70 attendees)<br>• Discussions with growers and demonstration of Harvest Ant technology (110 attendees) |
| Grower -based publications | • 10th and 23rd August 2023 – Avocado Australia Grower Notices<br>• Autumn 2024 Edition of Avocados Australia 'Talking Avocados' magazine | • Direct invitation to all Avocado Australia members to participate in survey / interview<br>• Feature article outlining purpose of project and summarising grower survey results |

## Outcomes

**Table 12. Outcome summary**

| Outcome | Alignment to fund outcome, strategy and KPI | Description | Evidence |
|---|---|---|---|
| Avocado growers are provided with knowledge and potential opportunities for improved labour efficiency through adoption or adaptation of processes or technologies. | This aligns with the Avocado industry Strategic Investment Plan 2022-2027:<br>Outcome 2: The Australian avocado industry has improved profitability, efficiency and sustainability through globally competitive production systems, orchard management, varieties, innovative research and development (R&D) and sustainable best management practices (BMPs).<br>Strategy 3. Reduce costs of production through identification and adaptation of technologies<br>KPI. Technologies and approaches to improve cost efficiencies are identified and shared with growers | The project has identified areas where technologies and process efficiencies have potential to reduce costs and increase labour use efficiency, and developed recommendations for industry. | Feedback from growers was gathered at grower engagement events. |

## Monitoring and evaluation

**Table 13. Key Evaluation Questions**

| Key Evaluation Question | Project performance | Continuous improvement opportunities |
|---|---|---|
| 1. To what extent has the project achieved its expected outcomes? | The project achieved the expected outcome of identifying constraints and opportunities for automation. | Timeframe for data collection and analysis was longer than anticipated due to technical issues, resulting in less time to present findings to growers. |
| 2. How relevant was the project to the needs of intended beneficiaries? | The grower interviews identified a high level of skepticism towards agtech, so the approach to promoting technologies to the intended beneficiaries needed to be changed to fit grower perspectives. | Need for a carefully implemented strategy to increase grower awareness of and experience with automation technologies to promote diffusion of new technologies and processes. |
| 3. How well have intended beneficiaries been engaged in the project? | Engagement with growers at field days organized by the industry communications program and through avocadoes Australia communication channels was not as effective as anticipated. | The technology used for time and motion study data collection was not as effective as anticipated, resulting in delays in receiving data for analysis. Most effective engagement for dissemination of project findings would have been at the end or after the project timeframe. |
| 4. To what extent were engagement processes appropriate to the target audience/s of the project? | Feedback from growers at field days was positive, indicating that the engagement was appropriate. | The project team was not able to get a formal presentation time at the field days, so were restricted to brief summary presentations in addition to discussions with growers at events. |
| 5. What efforts did the project make to improve efficiency? | Maintaining open communication channels with avocadoes Australia and industry communications program teams | Project findings will be presented to growers in the CQ region after project completion, and information made available for delivery to growers in other regions. |

## Recommendations

The intended outcome of the project was to provide the avocado industry with knowledge of potential opportunities for improved labour efficiency through adoption or adaptation of processes or technologies. Recommendations are therefore directed at strategies for industry, and Hort Innovation, to consider for implementation to capture the identified opportunities.

### Technology and process efficiency opportunities

- Fully autonomous harvesting technology is not at a commercially viable level but is emerging rapidly and viewed by industry as likely to be implemented in industry in the future. The technology is currently being targeted at larger fruit industry sectors (eg apple), with broader applicability likely to emerge from systems optimized for those sectors. Working with commercial suppliers to adapt the technology to operate in (potentially modified) avocado orchards is likely to deliver viable technology backed up by established supplier business models and service provision. We recommend that the avocado industry and Hort Innovation regularly review the status of fully autonomous harvesting systems with the view to initiating trials of commercial products when evidence of uptake and effectiveness in other fruit industries is established.
- Improvements in efficiency and proficiency of pickers is the area most likely to increase labour use efficiency. Given growers have expressed a strong desire not to replace staff but to achieve better outcomes with their teams, implementation of technology and process efficiency improvements for pickers will have a lower barrier to adoption than other technology areas given the skepticism growers expressed about AgTech. The capacity to monitor performance of individual pickers creates opportunities for selection of high performers as well as ‘gamification’ in picking where recording of performance drives increased productivity as each individual strives to perform better than others. Recommended technologies for improvements in efficiency and proficiency of pickers include:
    - Picker data collection technologies such as Harvest Ant
    - VR and augmented reality tools for enhancing training of pickers

  As these technologies are not at full commercial viability, research and development to establish viable products for the avocado industry is recommended.
- Efficiency of bin running systems is another area where gains in labour use efficiency can be made. The large differences noted between sites in this project suggest that growers may be able to implement improvements without new technology adoption. At sites where lack of mobile signal coverage inhibits communication between picking crews/supervisors and packhouses, technology such as Zetifi may improve bin run efficiency. Autonomous collaborative robots such as Burro that can move fruit from field to packhouse have potential to transform the bin run systems in avocado orchards by eliminating the need for dedicated or dual role staff managing the movement of bins. This technology is at a commercially viable stage with increasing adoption across multiple industry sectors. Evaluation and demonstration trials with interested avocado growers are warranted to adapt the technology for the industry and gather performance and return on investment data to support adoption of the technology.
- Data capture and analysis tools that can be used to inform decision making with labour allocation and bin run optimization would complement adoption of autonomous collaborative robots in bin run systems. Technology such as Green Atlas, which is at a commercially viable stage with increasing adoption across multiple industry sectors, allows mapping of fruit numbers across the orchard prior to harvest. Other ground based and aerial sensing platforms may deliver the same information. It is recommended that in combination with autonomous collaborative robot trials, evaluation and demonstration trials with interested avocado growers be undertaken to gather performance and return on investment data to support adoption of the technology.
- Crop protectant application systems including fully autonomous and variable rate application technologies should be evaluated in avocado to establish effectiveness and viability. The GUSS sprayer is being used commercially in tree crop situations and may have application in larger avocado businesses. The Smart Apply system is applicable to large and small orchard systems as it can be fitted to existing sprayers and will lead to reduced chemical application so improved labour use efficiency in spraying operations. Evaluation and demonstration trials of these technologies are warranted if there is sufficient industry interest in automation opportunities outside of the major labour use area of harvesting.

- Technologies that may support efficiency gains in pest and disease management and in orchard floor and tree management were identified in the AgTech review. Labour savings associated with these technologies are likely to be small in comparison to harvesting and spraying gains, but assessment of technologies could be included in evaluation trials where growers express strong interest.

## Technology adoption strategies

- The technology adoption process includes stages of awareness, interest, evaluation, trialing, activation and adoption. Based on the grower survey and interviews, it is evident that the majority of growers in the avocado industry are aware of AgTech and many are interested (widespread recognition that technology will be increasingly used by the industry). Evaluation and trialing of technologies are also common, but appears to be the stages where AgTech is failing to gain traction. Growers are largely skeptical of emerging technologies and the suppliers that they deal with when evaluating or trialing products. Development of a support program that will assist growers in navigating the evaluation and trialing stages is recommended. The program must be grower driven as evaluation and trialing of products by other groups such as research providers contributes to the awareness and interest stages rather than grower evaluation and trialing.
- The nature of risks taken by growers in progressing through the technology adoption process needs to be understood in more detail. Perceptions of benefits are balanced against perceived risks when making decisions on trialing, activation and adoption of technology into the production system. Emphasis in programs promoting uptake of AgTech tends to focus on financial risks, but based on interview responses in this project it is clear that emotional and social risks should also be considered. Research to better understand the perceptions of growers is recommended in parallel to the evaluation and trialing support program to inform the strategies that will best meet the needs of growers. This will be particularly relevant for development of nuanced approaches to suit growers at the different scales of production.

## Intellectual property

No project IP or commercialisation to report.

## Acknowledgements

We would like to thank the industry representatives, industry/regional development officers and other industry key stakeholders who provided valuable insights during the course of this project. We would especially like to extend our thanks to the following individuals within who assisted this research:

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## Appendices

Appendix 1: Grower Survey questions

Appendix 2: Grower Interview Quenstions

Appendix 3: AgTech Review

APPENDIX 1

Australia's avocado industry is predicted to grow rapidly over the next five years and growers may find it challenging to maintain profitability if supply exceeds demand. Central Queensland University, in conjunction with Avocados Australia, is undertaking a project to identify areas of avocado production where we can make the greatest cost savings through automation. We would appreciate your assistance with identifying the areas of your avocado production system you believe could be made more cost effective through automation. Your participation in this survey is voluntary and you are free to withdraw at any time without explanation or penalty.

If you have any questions, please contact the research team:

p.h.brown@cqu.edu.au or d.lelagadec@cqu.edu.au or the CQU Research Ethics Committee: ethics@cqu.edu.au.

Participation in the survey is regarded as acknowledgement that you are over 17 years old and consent for CQUniversity to use the information you provide. This survey is anonymous, and you cannot be identified by your survey responses.

Additional information regarding this study can be accessed **here**.

Demographic questions: We'd like to know a little about the location of your avocado farm(s)

Please provide the postcode(s) of the area(s) in which your avocado farms are located (list more than one if applicable).

Approximately how many hectares of avocados do you farm in each of Australia's main avocado growing regions?

Northern Queensland

Central Queensland

South East Queensland

Northern NSW

Central NSW

Tristate area (South Australian Victoria, South West NSW, Tasmania)

Western Australia

What is the age range of the **majority** of your avocado trees (select 1 only).

- 1 -5 years
- 6 - 15 years
- 16 - 30 years
- More than 30 years

Which are the main commercial varieties on your farm(s) (you may select more than 1).

- Hass
- Shepard
- Wurtz
- Sharwil
- Other

Approximate staffing levels. On an average day, how many people work on your farm(s) during:

☐

Off season Harvest

☐

season

This is where you get to select two areas of production on which you think we should focus our research. You will be allowed two selections.

Which area of the avocado production system do you believe has the **highest** labour dependency in which cost savings may be made through automation? Select your **first** option.

○ Establishing the orchard (orchard planning, soil preparation, tree planting) ○ Orchard floor management

○ Canopy management

○ Pest and disease management ○ Orchard nutrition

○ Irrigation Harvesting

○

○ Other

☐

You have selected ‘Establishing the orchard’. Can you tell us, more specifically, which area of ‘Establishing the orchard’ you think we could automate? You may select more than one.

☐ Planning the orchard layout ☐ Land clearing

☐ Soil tillage

☐ Marking the rows ☐ Establishing drains ☐ Soil mounding

☐ Establishing ground cover between tree rows ☐ Installing irrigation

☐ Preparing the planting holes ☐ Applying fertiliser

☐ Planting the trees ☐ Staking the trees ☐ Applying mulching

☐ Applying polythene trunk protector sleeves

☐ What technologies (e.g. GPS guided tractors), if any, have you used to reduce labour costs in establishing the orchard?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

Would you like to add anything?

You have selected 'Orchard floor management'. Can you tell us, more specifically, which area of 'Orchard floor management' you think we could automate? You may select more than one.

☐ Chemical weed control

☐ Mechanical weed control (mowing) ☐ Soil erosion

☐ Orchard drainage

☐ Establishing ground cover between tree rows ☐ Applying mulching

☐ What technologies (e.g. GPS guided tractors), if any, have you used to reduce labour costs in orchard floor management?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

Would you like to add anything else about 'orchard floor managing'?

☐

You have selected 'canopy management'. Can you tell us, more specifically, which area of 'canopy management' you think we could automate? You may select more than one.

☐ Tip pruning of young trees

☐ Tree shaping and hedgerow pruning ☐ Selective limb removal

☐ Tree height control

☐ Chemical canopy size control (growth regulators) ☐ Tree thinning (tree removal)

☐ Removal of dead wood in the trees

☐ Clearing away the branches after pruning ☐ Mulching the branches after pruning

☐ What technologies (e.g. GPS guided tractors), if any, have you used to reduce labour costs in canopy management?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

☐

Would you like to add anything else about 'canopy size control'?

You have selected 'Pest and disease management'. Can you tell us, more specifically, which area of 'Pest and disease management' you think we could automate? You may select more than one.

☐ Scouting orchard for insect pests

☐ Surveying orchards for diseased or pest outbreaks ☐ Spot spraying for insect/disease control

☐ Foliage cover spray for insect/disease control

☐ Trunk injections for Phytophthora (root rot) control Establishing drainage for Phytophthora (root rot) control

☐

☐ What technologies (e.g. GPS guided tractors), if any, have you used to reduce labour costs in pest and disease management?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

☐ Would you like to add anything else about 'Pest and disease management'?

Perhaps tell us about the major pest/disease in your orchards.

You have selected 'Orchard nutrition (fertilisers)'. Can you tell us, more specifically, which area of 'Orchard nutrition (fertilisers)' you think we could automate? You may select more than one.

☐ Collecting soil samples for analysis ☐ Sampling for leaf analysis

☐ Applying foliage fertilisers ☐ Fertigation

☐ Spread soil fertilisers

☐ Applying mulching/green mulch

☐ What technologies (e.g. GPS guided tractor), if any, have you used to reduce labour costs in orchard nutrition?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

☐ Would you like to add anything else about 'Orchard nutrition (fertilisers)'?

You have selected 'Irrigation'. Can you tell us, more specifically, which area of 'Irrigation' you think we could automate? You may select more than one.

☐ Monitoring soil moisture content ☐ Scheduling irrigation

☐ Applying irrigation (turning taps on and off)

☐ What technologies (e.g. neutron probes for soil moisture monitoring), if any, have you used to reduce labour costs in irrigation?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

☐

Would you like to add anything else about 'Irrigation'?

You have selected ‘Harvesting’. Can you tell us, more specifically, which area of ‘Harvesting’ you think we could automate? You may select more than one.

☐ Fruit ripening testing (dry matter testing) ☐ Organising labourers (pickers)

☐ Transporting labourers to the orchards and between orchards

☐ Educating labourers regarding which fruit to pick (selective harvesting) ☐ Hand-picking from the orchard floor

☐ Hand-picking from hydraulic picking platforms (cherry pickers) ☐ Carrying fruit from picking bags/picking crates to bulk bins

☐ Transporting fruit from the orchard to the pack shed/storage shed

☐ What technologies (e.g. GPS guided tractors), if any, have you used to reduce labour costs in harvesting?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

☐

Would you like to add anything else about 'Harvesting'?

Block 3

Which area of the avocado production system do you believe has the **highest** labour dependency in which cost savings may be made through automation? Selection your **second** option.

○ Establishing the orchard (orchard planning, soil preparation, tree planting) Orchard floor management

○

Canopy management

Pest and disease management Orchard nutrition

Irrigation Harvesting

Other

You have selected ‘Establishing the orchard’. Can you tell us, more specifically, which area of ‘Establishing the orchard’ you think we could automate? You may select more than one.

Planning the orchard layout Land clearing

Soil tillage

Marking the rows Establishing drains Soil mounding

Establishing ground cover between tree rows Installing irrigation

Preparing the planting holes Applying fertiliser

Planting the trees Staking the trees Applying mulching

Applying polythene trunk protector sleeves

What technologies (e.g. GPS guided tractors), if any, have you used to reduce labour costs in establishing the orchard?

What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

☐ Would you like to add anything?

You have selected 'Orchard floor management'. Can you tell us, more specifically, which area of 'Orchard floor management' you think we could automate? You may select more than one.

☐ Chemical weed control

☐ Mechanical weed control (mowing) ☐ Soil erosion

☐ Orchard drainage

☐ Establishing ground cover between tree rows ☐ Applying mulching

☐ What technologies (e.g. GPS guided tractors), if any, have you used to reduce labour costs in orchard floor management?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

☐ Would you like to add anything else about 'orchard floor managing'?

You have selected ‘canopy management’. Can you tell us, more specifically, which area of ‘canopy management’ you think we could automate? You may select more than one.

☐ Tip pruning of young trees

☐ Tree shaping and hedgerow pruning ☐ Selective limb removal

☐ Tree height control

☐ Chemical canopy size control (growth regulators) ☐ Tree thinning (tree removal)

☐ Removal of dead wood in the trees

☐ Clearing away the branches after pruning ☐ Mulching the branches after pruning

☐ What technologies (e.g. GPS guided tractors), if any, have you used to reduce labour costs in canopy size control?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

☐ Would you like to add anything else about ‘canopy size control’?

You have selected ‘Pest and disease management’. Can you tell us, more specifically, which area of ‘Pest and disease management’ you think we could automate? You may select more than one.

☐ Scouting orchard for insect pests

☐ Surveying orchards for diseased or pest outbreaks ☐ Spot spraying for insect/disease control

☐ Foliage cover spray for insect/disease control

☐ Trunk injections for Phytophthora (root rot) control

☐ Establishing drainage for Phytophthora (root rot) control

☐ What technologies (e.g. GPS guided tractors), if any, have you used to reduce labour costs in pest and disease management?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

☐ Would you like to add anything else about 'Pest and disease management'?

Perhaps tell us about the major pest/disease in your orchards.

You have selected 'Orchard nutrition (fertilisers)'. Can you tell us, more specifically, which area of 'Orchard nutrition (fertilisers)' you think we could automate? You may select more than one.

☐ Collecting soil samples for analysis ☐ Sampling for leaf analysis

☐ Applying foliage fertilisers ☐ Fertigation

☐ Spread soil fertilisers

☐ Applying mulching/green mulch

☐ What technologies (e.g. GPS guided tractor), if any, have you used to reduce labour costs in orchard nutrition?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

☐

Would you like to add anything else about 'Orchard nutrition (fertilisers)'?

You have selected 'Irrigation'. Can you tell us, more specifically, which area of 'Irrigation' you think we could automate? You may select more than one.

☐ Monitoring soil moisture content ☐ Scheduling irrigation

☐ Applying irrigation (turning taps on and off)

☐ What technologies (e.g. neutron probes for soil moisture monitoring), if any, have you used to reduce labour costs in irrigation?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

☐ Would you like to add anything else about 'Irrigation'?

☐

You have selected 'Harvesting'. Can you tell us, more specifically, which area of 'Harvesting' you think we could automate? You may select more than one.

☐ Fruit ripening testing (dry matter testing) ☐ Organising labourers (pickers)

☐ Transporting labourers to the orchards and between orchards

☐ Educating labourers regarding which fruit to pick (selective harvesting) ☐ Hand-picking from the orchard floor

☐ Hand-picking from hydraulic picking platforms (cherry pickers) ☐ Carrying fruit from picking bags/picking crates to bulk bins

☐ Transporting fruit from the orchard to the pack shed/storage shed

☐ What technologies (e.g. GPS guided tractors), if any, have you used to reduce labour costs in harvesting?

☐ What were the benefits of these technologies (e.g. reduced labour costs)?

☐ What were the drawbacks of these technologies (e.g. cost of purchasing/hiring the equipment)?

☐ Would you like to add anything else about 'Harvesting'?

Thank you for participating in this survey. As the second part of this study, we would like to speak personally with a cross-section of avocado growers who undertook this survey, to gain more insight into their responses. We plan to conduct interviews either face-to-face, via the Internet (Zoom) or by phone. If you are interested in speaking with us, please click on this link to leave your contact information. Please be assured that your contact details cannot be linked back to the survey that you have just completed. Thank you very much for your time and we look forward to speaking with you further.

Powered by Qualtrics

APPENDIX 2

## **Grower Interviews - Introduction 1 (If grower participated in grower survey)**

*Thank you very much for being part of our project and agreeing to share your insights and experience as a grower. I know that you are flat out at the moment so really appreciate your time.*

*Thanks very much also for participating in our grower survey. You would have read the summary of the project at the beginning of that survey, but to reiterate, I work for CQUniversity's agricultural research team based in Bundaberg and we have been engaged by Hort Innovation (with support from Avocados Australia) to undertake a study aimed at reviewing automation opportunities within the avocado production system. For the purposes of this study, we are only looking at the on-farm areas of avocado production – not the packing, processing or marketing areas. I'm well aware that there are many opportunities for automation in these areas but they are outside the scope of this study.*

*I've sent you a few Powerpoint slides that show the results of our grower survey, indicating the production areas that growers believe offer the greatest opportunities for automation.*

*I also sent you the list of questions that I would like to run through with you to gain a better understanding of your perceptions as a grower, of automation and efficiency improvements within avocado production. These questions do not have hard and fast or right and wrong answers but are there to guide our discussion.*

*I'd also like to check that you are OK with me recording our discussion. The reason I do this is because I want to ensure that I accurately capture what you say in your words. I do not want to paraphrase or misinterpret what growers tell me – it is important in this process that it is your words and not my version of them that end up in any reporting. All quotes will be anonymous and you won't be be identified in any documents or reports that come out of this study.*

*Before we begin, do you have any questions or concerns regarding the process?*

## ***Grower Interviews – Introduction 2 (If grower did not participate in grower survey)***

*Thank you very much for being part of our project and agreeing to share your insights and experience as a grower. I know that you are flat out at the moment so really appreciate your time.*

*I'm not sure if you are aware but we have conducted a survey of all Avocado Australia members. You may or may not have seen the emails that came out regarding that survey?*

*If not, as a background to this project, I work for CQUniversity's agricultural research team based in Bundaberg and we have been engaged by Hort Innovation (with support from Avocados Australia) to undertake a study aimed at reviewing automation opportunities within the avocado production system. For the purposes of this study, we are only looking at the on-farm areas of avocado production – not the packing, processing or marketing areas. I'm well aware that there are many opportunities for automation in these areas but they are outside the scope of this study.*

*I've sent you a few Powerpoint slides that show the results of our grower survey, indicating the production areas that growers believe offer the greatest opportunities for automation.*

*I also sent you the list of questions that I would like to run through with you to gain a better understanding of your perceptions as a grower, of automation and efficiency improvements within avocado production. These questions do not have hard and fast or right and wrong answers but are there to guide our discussion.*

*I'd also like to check that you are OK with me recording our discussion. The reason I do this is because I want to ensure that I accurately capture what you say in your words. I do not want to paraphrase or misinterpret what growers tell me – it is important in this process that it is your words and not my version of them that end up in any reporting. All quotes will be anonymous and you won't be be identified in any documents or reports that come out of this study.*

*Before we begin, do you have any questions or concerns regarding the process?*

## Interview Questions

1. (a) If grower completed the grower suvey..

   From your perspective, why are the areas you selected most suitable for automation/efficiency improvements? Can you please share any experiences that influenced your selections?

   (b) If grower did not participate in the grower survey…

   Having reviewed the production areas identified in the grower survey, from your experience, which areas do you believe are most suitable for automation / efficiency improvements? Can you please share any experiences that influenced your selections?

2. How do you envisage automation/efficiency reducing labour or production costs or increasing profitability in these areas? (Prompts: e.g. increase yield, reduce costs, save labour, or improve product quality, or something else?)

3. I'd like to hear about any existing or new technologies or processes that you believe are worth exploring further. Why do you find them promising?

4. There are always concerns and reservations about introducing new technologies and processes into existing operations. From your perspective, what are some of the risks and challenges regarding automation or new technology adoption in the avocado industry? (Prompt - these risks and challenges may be on-farm or industry wide)

5. What are some collaboration or partnership opportunities you think would assist with automation or new technology adoption within the avocado industry?

6. Do you collect data on your avocado farming operations? If so, how do you currently use this data and are you interested in technologies that provide real-time data and analytics for better decision-making?

7. What kind of infrastructure and resources do you have on your farm that can support automation or efficiency gains (e.g., irrigation systems, power supply) and are you open to investing in infrastructure improvements if needed?

8. Are you and your farmworkers prepared for the training and learning curve associated with the new technologies or efficiencies you are considering? (Prompt: Is there any support or training you think you would need for you to be prepared?)

9. Do you have any additional insights or experiences you would like to share regarding automation or increased efficiencies in your avocado growing operations?

10. Are there other avocado farmers in your network who have successfully implemented automation technologies or efficiency products that we should talk to?

APPENDIX 3

# AgTech Review

A desktop research activity consisting of a review of literature, industry papers and available industry data on technology products with potential to address the labour challenge faced by avocado growers was undertaken. The AgTech review focussed on commercially available (and late-stage commercialisation) technologies that were considered potentially applicable to the 'high cost' areas identified by growers through the industry survey and interviews. Technologies applicable to harvesting, pest and disease management, irrigation management and orchard floor management represented the majority of commercially available products captured in the review.

Comprehensive listings of products and suppliers can be found on several online sites. Two online resources that best identify AgTech products and services in the Australian market are:

- Agtech finder (https://agtechfinder.com/product-directory )
- NSW Government Farms of the Future (https://www.dpi.nsw.gov.au/dpi/climate/farms-of-the-future )

The project team undertook a technical evaluation of technology applicability (evidence of strengths and weaknesses of the technologies) and farming system integration compatibility (how well does the technology fit with other elements of the production system) of AgTech identified through the industry survey and interview processes and scanning of online listings. Information was also gathered from technology manufacturers as well as, where possible, current users of the technologies in other industries and researchers who have assessed the technologies.

Selected technologies are presented in the following section as examples within technology application fields. Given the increasing number and range of technologies and technology providers emerging, and changes in the sector due to mergers, acquisitions and business failures, it is prudent to base an analysis of potential improvements in labour use efficiency through technology adoption on the technology application fields rather than on specific technologies. In addition, each grower's labour cost and efficiency situation is unique and varies with farm size, production complexity, and regional issues. Given this variability, a one-size-fits-all set of technology recommendations is unlikely to lead to significant adoption of solutions or substantial improvements in farm viability. This review of technologies is therefore intended to highlight specific examples of products that help illuminate the possible strategies for increased automation in the avocado industry.

# Harvest related technologies

Harvesting represents the largest in-field labour activity in avocado orchards and in other hand-harvested tree crops. For this reason, development of fully autonomous robotic harvesting systems has been a focus of government and industry funded research programs and has lead to development of a large range of robotic harvesting products including several that are at commercial prototype stage. The systems are yet to find significant commercial adoption and evidence suggests that further refinement of the technologies, business models for product supply, and service support capacity will need to occur before widespread adoption occurs. Other technologies designed to address specific tasks within the harvesting operations are better positioned for adoption at the current time. These include technologies that may augment tasks being undertaken by picking crews, such as use of autonomous vehicles to transport picked fruit from field to packhouse, and technologies that may assist in management of the labour resource on farms. Examples of technologies that are most likely to be applicable to the avocado industry are listed below.

## Robotic harvesting

Autonomous harvesting using robotic systems are not yet fully commercial and available to avocado growers. A 2022 review (Zhou et al, 2022) assessed 47 prototype and commercial robotic harvesting systems for fruit crops, including 12 that were designed for tree crops. They concluded that very few of them have been proven reliable for commercial operation and in most cases they do not meet the requirements of low damage, high harvest rate and fast speed at the same time. The technology is however rapidly developing and likely to be available commercially, as early generation models, to the avocado industry in the next 10 years.

***Technologies developed and/or tested in Australia***

**Ripe Robotics** (https://www.riperobotics.com/)

The robotics system is not yet fully commercial but has had several seasons of testing under commercial conditions in apple orchards. Five major iterations of harvesting robot prototypes have occurred to produce the current design, Eve, which is designed to pick apples, plums, peaches, and nectarines and is capable of analyzing fruit for size, colour, and quality.

**Agricultural Robotics** (https://agriculturalrobotics.com.au/mango-auto-harvester/ )

An autonomous mango harvester developed by CQUniversity and under commercialisation by Agricultural Robotics. The system has a modular bank of 4 picking arms delivering picked fruit to a modified existing industry harvest aid base for washing and transfer to fruit bin. As mango tree architecture is more similar to avocado than the apple and stone fruit trellised systems on which most other harvesters are based, this platform may be more applicable to the industry.

***Technologies available commercially in other countries***

**FFRobotics** (https://www.ffrobotics.com/ )

The Israeli company FFRobotics markets a fully automated mechanical picker for fresh fruit including citrus, apples, pears, peaches and cherries. The robotic platform has 10 picking arms and adjusts to fit row spacings. The design may not be suitable for larger tree canopies such as avocado without appropriate canopy management programs being adopted.

**advanced.farm** (https://advanced.farm/technology/apple-harvester/ )

The US company developed commercial strawberry harvesting robotic system and have used the technology from that robotics platform to develop an apple harvester. The current configuration has an autodrive system and is designed to operate in trellised orchards with 2.7-3.7m row spacing.

**Tevel** (https://www.tevel-tech.com/ )

Fruit harvesting system developed in Israel utilising flying autonomous robots tethered to a fruit receival platform. Manoeuvrability of the flying robot pickers may make the system more applicable to avocado than flexible arm picking systems as they can better navigate within the canopy.

***Technologies under development in other countries***

**NARO** (https://www.naro.go.jp/english/topics/laboratory/fruit/138191.html )

Prototype harvesting robot developed by the Japanese National Agriculture and Food Research Organization (NARO), in collaboration with Ritsumeikan University and an auto parts manufacturer DENSO Corp., for apples and pears. The system has been developed for V-shaped trellis systems so is not suitable for avocado in its current form.

**Abundant Robots** (https://waxinvest.com/projects/abundant-robots/ )

US based robotics company that developed an apple picking robot. The original business folded in 2021 but was acquired by an investment firm. Given the level pf investment, the technology appears likely to be commercially available in the near future.

## Automation aids for harvesting

***Technologies developed and/or tested in Australia***

**Burro** (https://burro.ai/ )

Autonomous transport platforms able to move along predetermined paths to replace the need for a tractor and driver to complete tasks such as moving picked fruit from field to packhouse. The technology is fully commercial and has been adopted on farms in the US. This technology has potential as a component of more efficient bin running systems in avocado orchards. The vehicles have been trialled in Australia and Burro have an Australia agent (Agri Automation, https://agriautomation.com.au/burro/ ).

**Naio Technologies** (https://www.naio-technologies.com/en/oz/ )

Naio Technologies has a range of products that are focussed on weed control but the Oz robot can operate as an autonomous transport platform similar to Burro.

***Technologies under development***

**Harvest Ant** (https://harvestant.com/ )

The Harvest Ant digital assistant has been designed to digitise the picking activities in horticultural crops. The company also has prototype technology for ergonomic picking bags and picking bucket systems that combine with the digital assistant technology to collect real time data on weight of fruit being picked and location where the picker is working.

**Farm VR** (https://farmvr.com/ )

Farm VR are an Australian company who produce virtual and augmented reality tools for education purposes in agriculture. Virtual reality experiences and environments that enhance training of pickers to improve productivity may be of value to the avocado industry.

## Process efficiency technologies

There are multiple ways in which decision making for labour use efficiency within harvesting may be impacted by technologies. The two technologies below are highlighted as examples and were selected as they have been trialled by avocado growers in Australia.

**Zetifi** (https://zetifi.com/ )

Connectivity solutions using smart antennas and Wi-Fi coverage extension products. In situations where mobile signal coverage is poor, connectivity products such as those developed by Zetifi can support communication between picking crews, supervisors and packhouse staff to coordinate key activities such as bin movement between orchard and packhouse.

**Green Atlas** (https://greenatlas.com/ )

The Green Atlas Cartographer is a combination of hardware and software that allows flower, fruit, weed, pest counts and tree structure to be mapped. Fruit load mapping prior to harvest may assist in optimising labour allocation for picking and management of bin running to ensure picker time is used effectively. The technology has been used in avocado and Australian service providers operate in Central Queensland, Tristate and Western Australian avocado production regions.

# Pest and Disease Management Technologies

Technologies developed to address pest and disease issues in crops have predominantly focussed on crop productivity and input use efficiency gains but labour savings may be possible through use of some of the technologies. Crop protectant application technologies can deliver chemical usage rate savings and environmental benefits with lower labour inputs where autonomous deliver platforms and/or more precise application of product to trees are involved. Remote sensing and pest/pathogen detection technology targeting early detection of pests and diseases as well as improved spatial distribution data can inform more efficient spray application programs which may reduce the time required for crop protectant applications.

### Crop Protectant Application Technologies

**GUSS Autonomous Sprayers** (https://gussag.com/ )

GUSS is a self-driving ground spray vehicle being used commercially in tree crops in the US and Australia. The system is designed to reduce labour requirements for spray operations as well as providing safety benefits by reducing risk of exposure to chemicals for farm workers.

**Smart Apply** (https://smartapply.com/ )

The Smart Apply technology uses LiDAR (light detection and ranging) to detect the presence of individual trees and automatically adjusts spray volume based on size and foliage density. The system is compatible with most air-blast spray units. The system stops spraying between trees and row changes, adjusting without human intervention. A reduction in the amount of chemical applied in the crop reduces the number of spray runs required and therefore reduces labour required for spray operations.

## Pest and Disease Detection

**BioScout** (https://www.bioscout.com.au/ )

Automated disease monitoring technology, delivering real-time detection and reporting of fungal spore numbers in crops. Detection of spore levels combined with weather data from the weather station included in the system can generate warning of disease risk for crops. The system can currently detect a range of diseases including Alternaria. Real time reports are accessible via a web based dashboard.

**iScout** (https://metos.global/en/iscout/ )

The METOS iSCOUT is an automated pest monitoring system incorporating a camera system and sticky plate, and is able to monitor a wide range of pest species that are attracted to specific pheromone or feeding lures. Daily insect counts are web and mobile apps. Fruit flies and banana spotting bugs can be monitored with the system.

**Rapid Aim** (https://rapidaim.io/what-we-do/ )

Automated pest insect monitoring technology, delivering real-time detection and reporting of pest numbers in crops. A mobile app displays pest data including pest population trends over time. The system currently can detect Queensland Fruit Fly as well as three other pest species not relevant to avocado producers, but may be expanded to include pests of avocadoes.

### Remote Sensing of Crop Health

**Aerobotics** (https://www.aerobotics.com/farm )

Aerobotics technology uses multispectral and thermal imagery, taken from an aerial drone, to deliver a range of tree crop data. Tree health scores are reported based on the NDRE index calculated from crop images and may reflect pest or disease status of trees as well as other stresses such as nutritional deficiencies. The technology offers irrigation insights and tree counts (missing trees within blocks).

# Orchard and Tree Management Technologies

Technology products may reduce labour requirements associated with avocado crop management tasks outside of the major in-field activities of harvesting and pest/disease control. Two specific areas highlighted below address time spent on orchard floor maintenance and on irrigation management, with both technologies having been demonstrated in tree crop systems in Australia.

## Orchard Floor Management

**Swarm Farm Robotics** (https://www.swarmfarm.com/ )

Swarm Farm is an Australian company producing autonomous farm vehicles that are being used commercially for field operations such as spraying, slashing and land preparation. Most applications have been in broad acre farming situations, but the technology has been demonstrated in tree crops where it may have applicability for reducing labour costs in mowing/slashing operations between rows.

## Irrigation Management

**SWAN Systems** (https://www.swansystems.com/industries/horticulture/ )

SWAN integrates a range of data sources and crop models to determine crop water needs. A dashboard displays the data including projected future irrigation needs, facilitating data driven decision making. Automation of irrigation systems using the integrated data may reduce labour costs associated with irrigation operations. The system is designed to be hardware agnostic so can operate with most irrigation systems that avocado growers are using.