Impact assessment of the investment:

Implementing precision agriculture solutions in Australian avocado production systems (AV18002)

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Hort Innovation

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Executive summary

What the report is about

Ag Econ conducted independent analysis determine the economic, social, and environmental impact resulting from delivery of the avocado project *Implementing precision agriculture solutions in Australian avocado production systems (AV18002)*. The project was funded by Hort Innovation over the period April 2019 to April 2022 using the avocado research and development levy and contributions from the Australian Government. The project was delivered by the University of New England (UNE)

The analysis applied a five step analytical process to understand the impact pathway and collect supporting data.

Review documents	Engage stakeholders	Map logical framework	Cost-benefit analysis	Discuss implications
Contracts Milestones Final reports	Hort Innovation Researchers Growers Supply chain	Activities Outputs Outcomes Impacts	RD&E costs Adoption curve Adoption benefits NPV, BCR, IRR, MIRR	So what?

Research background

AV18002 continued the work of previous levy investment ST15016 to improve spatial mapping technology of the Australian avocado industry, capturing all plantings above 1 ha, and also to refine and validate two remote sensing-based yield forecasting methodologies (CropCount and Time Series), which were trialled with commercial growers in key growing regions. A minimum viable product (MVP) mobile application was developed to provide grower access to CropCount, with a commercialisation plan developed (and taken into the follow on project AV21006).

Key findings

The nominal investment cost of $1.42 million was adjusted for inflation (ABS, 2024) and discounted (using a 5% real discount rate) to a 2023-24 present value (PV) of costs equal to $1.95 million.

The analysis conducted a detailed evaluation of the AV18002 impact pathway through a logical framework. From this process, economic, environmental and social impacts were identified as having the potential to be realised from both improved industry spatial data (supporting improved industry risk management and issues analysis), and improved accuracy of farm level yield estimates (supporting efficiencies in harvest inputs such as labour).

A review of available data and discussions with stakeholders identified sufficient data to model the farm level benefits of improved yield estimate accuracy.

This generated total PV benefits of $13.58 million, with a benefit cost ratio (BCR) of 6.97:1.

Given the relationship between AV18002 with preceding (ST15012) concurrent (AS19001) and follow on RD&E (AS23000) the analysis took a program approach that estimated the total benefits from the program, and apportioned these to individual investments based on their cost share. As a result, while the ratio of benefit to costs remains constant across the individual projects and the program as a whole (BCR of 6.97:1), the total benefits of $13.58 reflect only 26% of total program benefits ($52.27 million).

The analysis incorporated conservative assumptions, particularly for the commercialisation and adoption of the yield mapping tools. Reflecting the underlying uncertainty for many variables, sensitivity testing showed a wide potential impact range of between 0.25:1 and 33.16:1. The sensitivity testing also showed that 99% of the model simulations had a BCR greater than 1:1 (i.e. a positive impact), giving a high level of confidence that the AV18002 investment will generate a positive impact off the farm level benefits alone.

Despite the clear impact pathway for industry level benefits of improved spatial data (disaster response and strategic planning and engagement), there was insufficient data identified to confidently quantify the benefits. Improved data relating to these benefits, as outlined in this analysis, would support an estimate of benefit and likely further increase the RD&E impact quantified in this analysis.

The key findings of the AV18002 impact assessment are summarized in Figure 1 below.

Keywords

Impact assessment; cost-benefit analysis; avocado; remote sensing; spatial mapping; yield; forecasting; tree crop map

Figure 1. Summary of impact assessment findings

AV18002 Precision agricultural solutions

RD&E activities

Total RD&E costs:

- $1.42 million (nominal value)
- 80% R&D levy and Government matching, and 20% UNE and Circul8 in-kind.

Research activities:

- In coordination with a national tree crop program (ST19001), build on the outputs of ST15016 to improve the accuracy of industry spatial mapping of avocado orchards, with annual updates.
- Improve farm level yield mapping methods including the *CropCount method* and *Time Series method*.
- Develop a minimum viable product (MPV) CropCount app and commercialisation plan.

Extension activities:

- The ATCM was made accessible via the AARSC ATCM Dashboard and the AAL website.
- ATCM promoted through the industry and market data capture projects (AV16006 and AV20000).
- Promote project outputs through print and online media, and online presentations and webinars.

Outcomes

Outcomes:

- Improved resources and knowledge regarding the geographical distribution of avocado orchards (>1ha) in Australia.
- Improved resources and knowledge for predicting avocado yield. With accuracy increased from 74% (existing manual counts) to 82-84%, and reliable estimates achieved up to four months prior to harvest.
- Commercialisation of yield estimate tools was ongoing through the follow on project AV21006.
- Uncertainty remains over the timeframe for commercialisation and likely industry adoption.

Impacts

Industry economic impacts:

- Improved field and farm level management regarding logistical planning of operations (harvest scheduling, number of pickers and bins required, etc.) and post-harvest decisions such as the storage, handling, packing and forward selling.

Socio-economic impacts:

- Increased capacity to respond to and manage industry level issues such as biosecurity or natural disaster, minimising the economic and social (psychological) costs.
- Improved analysis of industry issues, supporting improved strategic planning and broader resource allocation.

Total attributable benefits and impact:

- Present value (PV @ 5% discount) RD&E costs of $1.95 million.
- PV estimated benefits of $13.58 million between 2027 and 2052.
- Net PV (NPV) of $11.63 million.
- Benefit cost Ratio (BCR) of 6.97:1 with a 90% confidence of a BCR between 2.36:1 and 19.39:1.

Introduction

Evaluating the impacts of levy investments is important to demonstrate the economic, social and environmental benefits realised through investment to levy payers, Government and other industry stakeholders. Understanding impact is also an important step to inform the ongoing investment agenda.

Reflecting its commitment to continuous improvement in the delivery of levy funded research, development and extension (RD&E), Hort Innovation required a series of impact assessments to be carried out annually on a representative sample of investments of its RD&E portfolio. Commencing with MT18011 in 2017-18, the impact assessment program consisted of an annual impact assessment of up to 15 randomly selected Hort Innovation RD&E investments (projects) each year. In line with this ongoing program, Ag Econ was commissioned to deliver the *Horticulture Impact Assessment Program 2020-21 to 2022-23* (MT21015).

Implementing precision agriculture solutions in Australian avocado production systems (AV18002) was randomly selected in the 2021-22 sample. This report presents the analysis and findings of the project impact assessment.

The report structure starts with the general method of analysis used, followed by the RD&E background and an outline of the impact pathway in a logical framework, then describes the approach used to quantify the identified costs and benefits including any data gaps and limitations to the analysis, presents the results including from the sensitivity analysis, and finally discusses any implications for stakeholders.

General method

The impact assessment built on the impact assessment guidelines of the CRRDC (CRRDC, 2018) and included both qualitative and quantitative analysis. The general method that informed the impact assessment approach is as follows:

1. Review project documentation including project plan, milestone reports, outputs and final report.
2. Discuss the project delivery, adoption and benefits with the Hort Innovation project manager, project researcher/consultant, growers and other relevant stakeholders (see *Stakeholder consultation*).
3. Through a logical framework, qualitatively map the project's impact pathway, including activities, outputs, and outcomes to identify the principal economic, environmental, and social impacts realised through the project
4. Collect available data to quantify the impact pathway and estimate the attributable impacts using cost-benefit analysis (over a maximum 30 years with a 5% discount rate), and then sensitivity test the results to changes in key parameters.
5. Discuss the implications for stakeholders.

Contracts Milestones Final reports	Hort Innovation Researchers Growers Supply chain	Activities Outputs Outcomes Impacts	RD&E costs Adoption curve Adoption benefits NPV, BCR, IRR, MIRR	So what?

The analysis identified and quantified (where possible) the direct and spillover impacts arising from the RD&E. The results did not incorporate the distributional effect of changes to economic equilibrium (supply and demand relationships) which was beyond the scope of the MT21015 impact assessment program. A more detailed discussion of the method can be found in the *MT21015 2022-23 Summary Report* on Hort Innovation project page Horticulture Impact Assessment Program 2020/21 to 2022/23 (MT21015).

Project background

Industry bodies, growers, and agronomists from three of Australia's tree crop industries identified the need for new technology to address national and farm priorities.

At the national level, an accurate record including location and tree crop type of all commercial orchards was requested. At the farm and orchard level, priorities included the accurate mapping and forecasting of yield and fruit quality (size and maturity), as well as improved technologies for measuring tree heath, the incidence of specific diseases such as phytophthora, and canopy structure for improving light interception by targeted limb removal. In response to these requests a number of academic, government and commercial entities were engaged with demonstrated expertise in technologies such as remote sensing, robotics, machine vision analytics, land class mapping and the development of industry specific geographical information systems (GIS).

From 2015 to 2018 the Rural R&D for Profit Project *Multi-scale monitoring tools for managing Australian tree crops* (ST15012) sought identify a range of commercially available and emerging crop mapping and monitoring technologies to deliver on these priorities.

From this program of work, the initial Australian Tree Crop Map (ATCM) was developed and published in 2017 by the University of New England's Applied Agricultural Remote Sensing Centre (AARSC). The ATCM mapped the extent (area and location) of all commercial avocado orchards over 2 ha. This map was established using existing industry data (e.g. member mailing addresses), ACLUMP mapping products, remote sensing analytics, ground based surveys and citizen science through the ATCM: Survey and the Industry Engagement Web App (IEWA). The delivery of the initial map identified 13,136 ha (total) of commercial avocado orchards in Australia. While this output was extremely well received by industry, it did not have a mechanism to capture future plantings and did not include orchards under 2ha in size.

ST15012 also identified the potential of remote sensing for measuring variability in tree health as well as for yield forecasting and yield mapping using the 18 tree calibration method. Globally, the use of satellite based remote sensing technologies for the forecasting of avocado fruit yield had been limited. However, the results reported for Australian conditions were extremely encouraging, with predictions of average crop yield far exceeding the accuracies achieved by the currently adopted commercial methods.

Building on ST15012, project AV18002 sought to:

- Establish the capacity to maintain and refine the national production area map of commercial avocado orchards.
- Further develop and validate the technologies, to predict yield parameters and tree health, under Queensland (Qld) growing conditions.
- Develop a minimal viable product (MVP) mobile application that will provide avocado growers with up-to-date information of yield, fruit size and phytophthora severity (Cyber Geigy rating).
- Integrate the national orchard map of crop area with the self- calibration of satellite imagery with on-ground measures of yield parameters, and an understanding of the influence seasonal weather conditions, to develop a more accurate yield forecasting system at the orchard, farm and national level.

AV18002 aligned with the Avocado Strategic Investment Plan (SIP) 2022-2026 through:

- Outcome 2: Industry supply, productivity and sustainability. Strategy 3. Reduce costs of production through identification and adaptation of technologies.
- Outcome 4: Business insights. Strategy 4. Use production forecasts to inform long-term and/or in-season market planning and supply strategies in domestic and international markets.

Project details

AV18002 was funded from 2019 to 2022 (Table 1).

Table 1. Project details

Project code	AV18002
Title	Implementing precision agriculture solutions in Australian avocado production systems
Research organization(s)	University of New England's Applied Agricultural Remote Sensing Centre
Project leader	Andrew Robson (UNE AARSC)
Funding period	April 2019 to April 2022
Objective	Providing the Australian avocado industry with greater access to new technologies and innovations that offer direct benefits to on farm production as well as industry wide data collation and management.

Logical framework

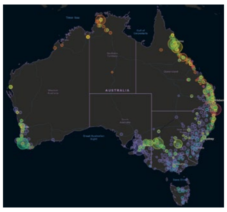
The impact pathway linking the project's activities and outputs, and their assessed outcomes and impacts have been laid out in a logical framework (Table 2).

Table 2. Project logical framework detail

RD&E activities

- **Updated industry spatial map**.
  - In coordination with a national tree crop program (ST19001), AV18002 built on the original Australian Tree Crop Map (ATCM) from ST15012 to:
    - Map all Australian commercial avocado orchards >1ha (refined from the previous >2ha), drawing on industry and publicly available data, validation with field work.
    - Include a mechanism to capture future plantings.
  - Undertook industry surveys and engagement to refine ATCM modelling including: ATCM Survey, Avocado Survey, Industry Engagement Web App.
- **Yield forecasting**
  - Built on the findings of ST15002 to further validate the relationship of canopy reflectance, measured by remote sensing technologies, to yield parameters and tree health.
  - Refined and validate two remote sensing-based yield forecasting methodologies:
    - **'CropCount'** (from ST15016) methodology validated in commercial orchards near Bundaberg and Mareeba in 2019/20 and 2020/21. A minimum viable product (MVP) mobile application was developed to provide grower access to CropCount. The project team participated in the GATE2020 program and developed a video promoting the MVP.
    - **'Time series'** comparing historic yield data with for 7 farms with available historical records across Western Australia (WA) (3), Qld (3), and South Australia (SA) (1).
  - Participate in the GATE program (run by New South Wales DPI and supported by Horticulture Innovation) to identify pathways that support the final development and commercialisation of the App.

RD&E outputs



- **Annual updates to the avocado industry spatial map**
  - The updated national map of avocado orchards was published within the ATCM as a publicly accessible feature service.
  - The ATCM was made accessible via the AARSC ATCM Dashboard and the AAL website.
    - Australian Tree Crop Dashboard, incorporating all other participating tree crops from ST19001, and including separate maps/applications for:
      - ATCM: Severe Weather App. Update with weather overlay every 10 minutes.
      - Bushfire Rapid Response Map
      - ATCM survey, for engaging with industry to validate and update the ATCM. Through the project, 136 submissions were made resulting in 484ha of new avocado orchard, 54ha of orchard removed (misclassified), and 856ha confirmed.
    - Avocados Australia Map, incorporating an 'avocado only' map application, including a cut-out avocado survey contributing the ATCM survey.
- **Refined and validated yield forecasting methodologies**
  - 'Crop Count' method, with MVP mobile application.
  - 'Time Series' method.
- **Extension.**
  - Promotion of the ATCM and surveys through the industry and market data capture projects (AV16006 and AV20000).
  - The project has been promoted through print and online media, and online presentations and webinars, with COVID-19 impacting the ability to conduct face-to-face workshops.
- **Research capacity.**
  - 1x PhDs supported through the project.

Outcomes

- **Industry spatial maps.** Improved resources and knowledge regarding the geographical distribution of avocado orchards (>1ha) in Australia. The technology has the potential to compliment existing orchard planting data was collected through OrchardInfo (as part of AV16006 and ongoing project AV20000). However, OrchardInfo also captures tree age, and variety, alongside avocado volume data (Infocado), and general market trends (e.g. pricing). Building on the work of ST15012, AV18002 and AS19001, AS23000 will improve the ATCM to provide additional industry information such as variety, planting date, management, and productivity, potentially removing the need for manual OrchardInfo and Infocado data collection in the future.
- In addition to AS23000, the spatial mapping work has also supported ongoing research:
  - AS20003 (finished Sep 2023), delivering a national map of protected cropping systems.
  - AV21006 (due to be completed May 2024). Providing ongoing updates to the avocado national spatial map, as well as ongoing development of yield forecasting tools (below).
- **Yield forecasting tools** Improved resources and knowledge regarding avocado yield prediction.
  - **CropCount** provided more accurate block-level yield prediction at time of harvest by improving grower tree sampling and fruit count by accounting for annual variations in crop performance from severe weather events, pest and disease, and irregular bearing. CropCount achieved average yield estimate accuracy of 84% compared to up to 74% from to existing manual counts. CropCount yield estimate accuracy was lower for younger trees with small canopies. App may be most relevant to mid-to-large-scale growers with an export focus where the impacts of inaccurate yield forecasting are more significant. Further refinement of the CropCount method and MVP including expanded testing across a broader range of Australian growing regions was being undertaken through AV21006, as well as ongoing discussions for commercialisation, with no commercial partner yet identified.
  - **Time Series** provided more yield prediction up to four months prior to harvest by comparing historical satellite imagery with historical yield data to understand the relationship between tree growth profiles and yield. The Time Series method required historic records, but required no field work, and used freely available imagery. Time Series method achieved yield accuracy averaging 82%, compared to 77% accuracy from grower visual estimation, but the Time Series had more difficulty accounting for annual variations such irregular bearing. This method received interest across Australia's growing regions (Qld, WA, SA). Further refinement of the Time Series method was being undertaken through AV21006 as well as further steps for product development and commercialisation.
  - Through AV21006 the yield forecasting tools were trialled by Costa Group (UNE 2022); however, stakeholders noted that this had not translated significant industry interest in a future commercial product. In contrast, international interest had resulted in commercial agreements being developed for yield forecasting of avocados in New Zealand (NZ Avocado) and South Africa and Africa (Westfalia).
  - Stakeholders also noted increased competition in yield prediction from existing commercial providers (LandIQ) and new entrants replicating CropCount (Aerobotics).

Impacts

Potential impacts identified for the outputs delivered through AV18002 (in conjunction with the broader program of work including ST15012, AS19001, AS23000) include:

- National avocado mapping (ATCM)
  - [Socio-economic] Increased capacity to respond to and manage industry level issues such as biosecurity or natural disaster. Benefits of improved disaster management would include rapid and efficient resource allocation (disaster management costs), minimising the extent of industry production losses, and avoided health and wellbeing costs to farm staff including psychological stress and strains on business and community relationships related to biosecurity and natural disaster events (CSIRO 2020 and CSIRO 2021). To date no disasters had occurred requiring industry response.
  - [Socio-economic-environmental] Improved industry analysis including environmental, social, and economic analysis of industry issues, supporting improved strategic planning for RD&E needs (for example through AAL and Hort Innovation) and broader resource allocation (for example state and national departments). As an example, the AV18002 Final Report noted that the spatial mapping was used by AAL as part of engaging with the Qld Government with regards to the repair of the Paradise Dam. Stakeholders also noted that the ATCM was being used by ABARES and ABS to compliment their own organisational data collection and analysis.
- Yield forecasting
  - [Economic & environmental] Improved block level tree management regarding yield related water and nutritional requirements, maximising yield while avoiding the overapplication of inputs with potential environmental impacts.
  - [Economic] Improved field and farm level management regarding logistical planning of operations (harvest scheduling, number of pickers and bins required, etc.) and post-harvest decisions such as the storage, handling, packing and forward selling.
- General benefits from spatial mapping and yield forecasting.
  - [Socio-economic] Support/increase avocado industry spillovers including employment and economic stimulant to local communities (The CIE 2023).

Project costs

The project was funded by Hort Innovation, using the avocado research and development levies and contributions from the Australian Government, with additional funding from research partner UNE and Circul8.

Nominal investment

The project funding period was 2019 to 2022 (Table 3). Hort Innovation overhead costs were added to the direct project cost to capture the full value nominal of the RD&E investment.

Table 3. Project nominal investment

Year end 30 June	Hort Innovation (AV levy and Gov't matching) ($)	Hort Innovation overheads[1] ($)	Other funding ($)[2]	Total nominal cost ($)
2019	200,000	42,589	57,551	300,141
2020	233,855	43,314	67,293	344,463
2021	232,266	37,728	66,836	336,830
2022	301,469	48,904	86,750	437,123
Total	**967,590**	**172,536**	**278,431**	**1,418,557**

1. The overhead and administrative costs were calculated from the Financial Operating Statement of the Avocado Fund Annual Reports, averaging 18% for the AV18002 funding period (2017-2023).
2. In kind funds from UNE and Circul8 for salaries equipment and MVP hosting were provided in the contract as a lump sum, so have been apportioned yearly based on Hort Innovation cash costs.

Present Value of investment

The nominal total investment cost of $1.42 million identified in Table 3 was adjusted for inflation (ABS, 2024) into a real investment of $1.65 million (2023-24 equivalent values). This was then further adjusted to reflect the time value of money using a real discount rate of 5% (CRRDC 2018), generating a present value (PV) of costs equal to $1.95 million (2023-24 PV).

Project impacts

The impact pathways identified in Table 2 were evaluated against available data to determine if their impact could be quantified with a suitable level of confidence.

Data availability to quantify the impact pathways

While consultation with industry stakeholders highlighted uncertainties relating to the commercialisation and adoption of yield mapping tools in Australia, stakeholders also recognised the ultimate benefits of yield forecasting once a commercial product becomes available. Sufficient data was obtained from the project reporting and other resources to quantify the potential benefits with regards to improved input efficiencies. Other impacts were unable to be quantified due to a lack of data, which is explained in more detail below.

Impacts valued and valuation framework

In line with the above, a model was developed to estimate the improved resource efficiency resulting from more accurate farm yield estimates:

- [Economic] Improved field and farm level management regarding logistical planning of operations (harvest scheduling, number of pickers and bins required, etc.).

The model includes an estimated timeline for commercial availability of the yield forecasting tools and subsequent adoption, as well as an uncertainty factor to account for some of the uncertainties expressed by stakeholders for commercialisation and adoption including the potential for competing products. In the counterfactual (without adoption scenario), growers continue to use manual-visual counting with a low level of yield forecasting, which stakeholders noted could result in potential over or under allocation of harvest resources such as labour. In contrast, with adoption of the outputs from AV18002, growers can achieve a higher level of yield forecasting accuracy potentially reducing the over or under allocation of harvest resources.

Impacts unable to be valued

Due to a lack of data, the following impacts were unable to be quantified:

- [Socio-economic] Increased capacity to respond to and manage industry level issues such as biosecurity or natural disaster. There was a clear impact pathway for the use of improved industry data, most notably for improved response and management to natural disasters or biosecurity events. Risk can be quantified through a combination of likelihood (e.g. annual chance of occurrence) and consequences (e.g. likely dollar damage), with improved risk management seeking to decrease the consequences through improved preparedness and response. However, data for quantifying this reduction in risk was not identified. Case study examples of improved risk management from the use of the spatial mapping tool would serve to inform a general estimate of benefit; however, the industry has been fortunate to not have incurred any such events to date. Reduced disaster risk also relates to avoided health and wellbeing costs associated with disaster events. These health and wellbeing effects, such as avoided or reduced psychological stress that can affect growers and their communities, may be more profound than the direct economic impact (CSIRO, 2020 and CSIRO 2022). The CSIRO research also noted that health and wellbeing affects are harder to quantify than economic impacts, which is consistent with the lack of data identified through this analysis.
- [Socio-economic-environmental] Improved industry analysis including environmental, social, and economic analysis of industry issues. Industry strategic analysis to inform planning and stakeholder engagement is a broad impact area that also lends itself to case study analysis. During the project the avocado, macadamia and mango industries used the spatial mapping of plantings in the Burnett region of Qld (from AV18002 and ST19001) to inform engagement with the Qld government regarding the need to repair the Paradise Dam, thereby contributing to the justification for repairs and ensuring the ongoing water security and productivity of the regions tree crop production. However, attributing a benefit to the spatial mapping or the avocado industry more specifically would be particularly difficult given the large number of stakeholders affected by the Paradise Dam including horticulture (avocados, macadamias, mangos, citrus, bananas, pineapples), other agriculture (livestock, sugarcane, and other cropping), industrial, and urban use.

- [Economic] Improved field and farm level management regarding post-harvest decisions such as the storage, handling, packing and forward selling. While stakeholders noted this as a potential benefit from improved yield estimates, there was not data available to quantify relative to existing practice.
- [Socio-economic] Support/increase avocado industry spillovers including employment and economic stimulant to local communities. The CIE (2023) highlighted the flow-on (spillover) effects of the avocado industry as a source of employment and economic stimulant to regional communities. By supporting increased industry productivity, AV18002 supports a corresponding increase in spillovers to local avocado communities. While this analysis quantified the direct impacts for industry productivity (labour savings), the flow-on effects require additional analysis using economic models that capture regional and national linkages, which are beyond the scope of the R&D impact assessment program (CRRDC 2018).

Data and assumptions

The required data relating to the impact pathway was collected from the project documents and other relevant resources (Table 4). Where available, actual data was applied to the relevant years, with estimates applied for any data gaps and projections into the future based on analytical techniques (for example correlations and trend analysis), or stakeholder estimates, or both. A data range was incorporated to reflect underlying risk and uncertainty. This was particularly relevant where estimates were needed due to data gaps, and where projections were made into the future. These ranges were then analysed through sensitivity testing (see *Results*).

Table 4. Summary of data and assumptions for impact valuation

Variable	Value	Source & comment
	General data and assumptions	
Discount rate	5% (± 50%)	CRRDC Guidelines (2018)
Industry production	Reaching 185,000 tonnes by 2039 (± 28%)	Based on industry production projections (AAL, 2023). See *Appendix A. Data and projections.*
Commercially available	2027 (± 2 years)	Estimate in discussion with stakeholders. Commercialisation discussions commenced as part of AV21006, with no commercial partner identified to date.
Adoption speed	Maximum adoption in 7 years (± 2 years)	Estimate in discussion with stakeholders. See *Appendix A. Data and projections*.
Maximum adoption and market share	25% (± 100%)	Estimate in discussion with stakeholders, who indicated there had been low interest in general so far among Australian avocado producers to date, and an increase in the likelihood of competing products, leaving some uncertainty over adoption in Australia. If adoption were to occur, stakeholders noted it would be more likely among a smaller number of larger growers (who account for the majority of production).
Adoption cost ($/t)	$4.8 (± 25%)	Estimate in discussion with stakeholders who noted a potential commercialisation cost of $200/block (tested at a range of $150-$250). An average block size of 4.5 ha was taken from AV18002 reporting, with average yield of 9.2 t/ha from Avocado Benchmarking (Hall, 2016).
Baseline labour and contracting costs ($/t)	$1200	Avocado Benchmarking (Hall, 2016).
Labour efficiency benefit (% of labour costs)	9% (-33% +179%)	Estimate from AV18002 reporting with current practice (manual inspection) yield estimate accuracy average of 76% (ranging from 74-77%), compared to yield prediction tool accuracy of 83% (82-99%).
Attribution to AV18002	26% (-25%)	Attribution based on cost share of total RD&E including (ST15012, AV18002, and AV21006) as recommended by the CRRDC Guidelines (2018). See *Appendix A. Data and projections*.
RD&E counterfactual	100% (± -25%)	The extent to which the investment would be undertaken without Hort Innovation investment. Given the relatively small size of the Australian avocado industry in an international context, it was considered unlikely that a product would be made specifically suited to Australian production conditions without levy investment through Hort Innovation.

Results

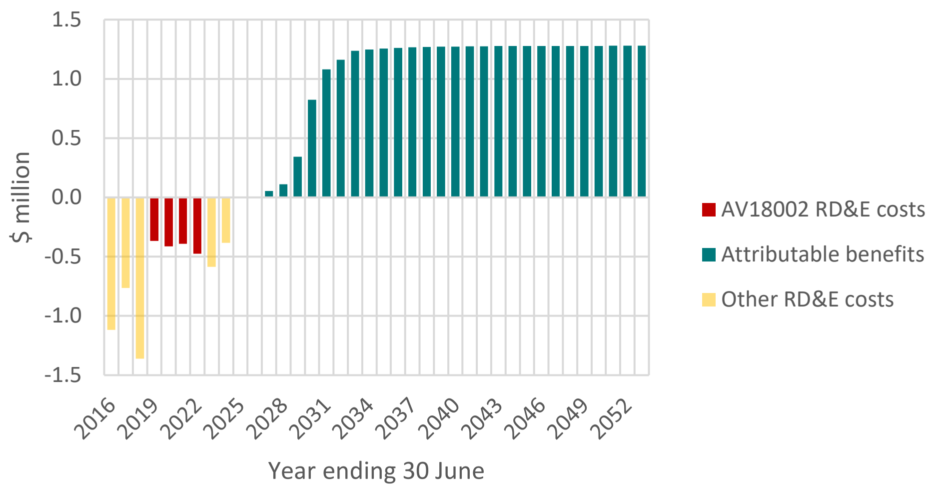
The analysis identified total PV costs (PVC) of $1.95 million (2023-24 PV) between 2018-19 and 2021-22, and estimated PV benefits (PVB) of $13.58 million (2023-24 PV) accruing between 2026-27 and 2052-53 (Table 5). When combined, these costs and benefits generate a net present value (NV) of $11.63 million, an estimated benefit-cost ratio (BCR) of 6.97 to 1, an internal rate of return (IRR) of 18% and a modified internal rate of return (MIRR) of 11%.

Table 5. Impact metrics for the total investment in project AV18002

Impact metric	Years after last year of investment						
	0	5	10	15	20	25	30
PVC ($m)	1.95	1.95	1.95	1.95	1.95	1.95	1.95
PVB ($m)	0	0.14	3.37	6.88	9.67	11.86	13.58
NPV ($m)	-1.95	-1.81	1.42	4.94	7.72	9.91	11.63
BCR	0	0.07	1.73	3.53	4.97	6.09	6.97
IRR	Negative	Negative	11%	16%	17%	18%	18%
MIRR	Negative	Negative	8%	11%	11%	11%	11%

Figure 2 shows the annual undiscounted attributable benefit and cost cash flows for AV18002.

Figure 2. Annual cash flow of undiscounted total benefits and total investment costs

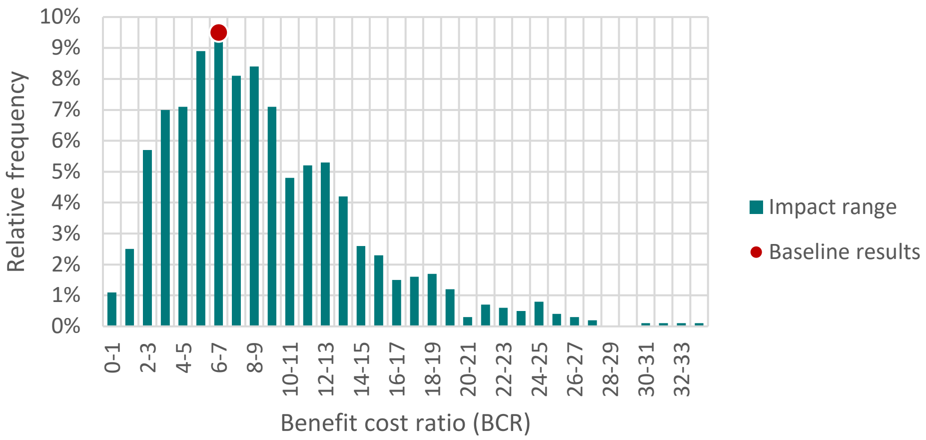


Sensitivity analysis

Given the risk and uncertainty associated with a number of underlying modelling variables, the potential model variation was estimated and drivers of variation identified. The sensitivity testing used @Risk stochastic modelling to incorporate the combined effect of changing all variables across their full ranges over 1000 simulations. This process showed:

Impact variation (Figure 3). Compared to the baseline BCR or 6.97:1, the 1000 simulation showed a potential BCR range of between 0.25:1 and 33.16:1, with 90% of results falling between 2.36:1 and 19.39:1 (i.e. excluding the low probability tails), 99% of results having a BCR greater than 1:1 (i.e. a positive impact), and with a simulation average of 9.01:1 (above the baseline results). Considering the conservative assumptions particularly around commercialisation and adoption, these results give a high level of confidence that the investment will generate a positive impact.

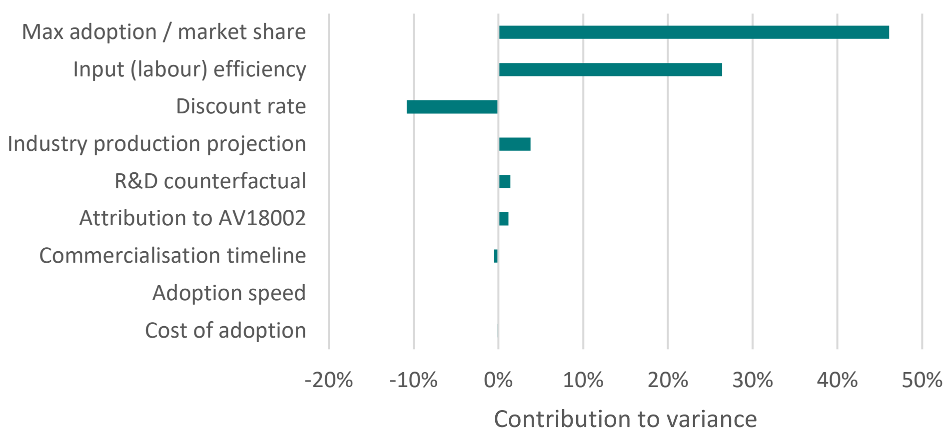
Figure 3. Impact variation over 1000 simulations



Contribution to variance (Figure 4). Contribution to variance is a measure of how much a variable contributes to the total variance of an output. Contribution to variance also shows whether a variable is positively or negatively correlated with impact. A negative contribution to variance, with bar extending to the left, indicates that this input has a negative effect on BCR: increasing this input will decrease the impact.

- **The maximum adoption or market share** had the largest contribution to variance (46%) reflecting the uncertainty over this figure and the subsequent wide value range applied, and showed a positive correlation to impact (with higher adoption/market share resulting in higher impact). A minimum industry adoption of 4% is required to generate a positive RD&E impact (although this may not be a sufficient adoption rate to support commercial profitability).
- **The labour input efficiency** benefit had the second highest contribution to variance (26%, with positive correlation) reflecting the potentially high level of accuracy of the yield forecasting tools relative to existing manual fruit counting. At the baseline cost of $200/block, labour input efficiencies of just 2% would be required for a positive impact, compared to the baseline 9% improvement in yield estimate accuracy achieved with yield mapping compared to the existing manual/visual method.
- **The discount rate** showed had the third largest contribution to variance (11%), but with a negative correlation to impact. The breakeven discount rate is reflected in the IRR (18%), or the MIRR (11%) if we assume that generated cashflows are reinvested at the risk-free discount rate.
- **The estimated adoption cost** of the yield mapping tools of $200/block was shown to be insignificant compared to potential cost savings from input (notably labour) efficiencies, with less than 1% contribution to variance. With a baseline labour saving of 9%, the breakeven adoption cost would be approximately $4000/block.

Figure 4. Contribution to variance



Implications and learnings

The logical framework of AV18002, supported by discussions with stakeholders, identified a broad range of potential social, environmental and economic benefits from the adoption of the two key project outputs: a spatial mapping tool, and two yield mapping tools.

The analysis modelled the farm level benefits of improved resource allocation as a result of more accurate yield forecasting. Over the 30 year analysis period, this generated a total industry benefit of $13.58 million (2023-24 PV) compared to AV18002 RD&E costs of $1.95 million (2023-24 PV) generating an industry impact (BCR) of 6.97:1.

Given the relationship between AV18002 with preceding (ST15012) concurrent (AS19001) and follow on RD&E (AS23000) the analysis took a program approach that estimated the total benefits from the program, and apportioned these to individual investments based on their cost share. As a result, while the ratio of benefit to costs remains constant across the individual projects and the program as a whole (BCR of 6.97:1), the total benefits of $13.58 reflect only 26% of total program benefits ($52.27 million).

The analysis incorporated conservative assumptions, particularly for the commercialisation and adoption of the yield mapping tools. Reflecting the underlying uncertainty for many variables, sensitivity testing showed a wide potential impact range of between 0.25:1 and 33.16:1, with the primary driver of modelling variance coming from the ultimate rate of adoption and market shares for the yield mapping tools. The estimated adoption cost of the yield mapping tools of $200/block was shown to be insignificant compared to potential cost savings from input (notably labour) efficiencies, with less than 1% contribution to variance. With a baseline labour saving of 9%, the breakeven adoption cost would be approximately $4000/tonne, highlighting the potential for farm level benefits if even moderate improvements in cost efficiencies can be achieved. The sensitivity testing also showed that 99% of the model simulations had a BCR greater than 1:1 (i.e. a positive impact), giving a high level of confidence that the AV18002 investment will generate a positive impact off the farm level benefits alone.

The logical framework also highlighted the potential benefits of improved industry spatial mapping, including improved disaster response and improved industry analysis; however, due to a lack of data to estimate an attributable benefit these were unable to be quantified. Improved data relating to these benefits, as outlined in this analysis, would support an estimate of benefit and likely further increase the RD&E impact quantified in this analysis.

Stakeholder consultation

Where possible, Ag Econ sought to engage multiple stakeholders across key areas of the logical framework and impact pathway to augment existing information and data sources, and reduce any uncertainty or bias from individual stakeholders. All stakeholders were engaged through telephone or online meetings, with follow up emails as necessary. Consultation followed a semi-structured approach in line with broad topics relating to the impact pathway and associated data requirements. Table 6 outlines the stakeholders consulted as part of this impact assessment and the topics on which they were consulted.

Table 6. Stakeholder consultation by theme

Stakeholder details		Consultation topics						
Stakeholder and organisation	**Stakeholder type**	**Related research**	**Research inputs**	**Research outputs**	**Research immediate outcomes**	**Follow on research**	**Stakeholder adoption**	**Impact areas and data**
Kathryn Young, Hort Innovation, Head of Sustainability R&D	RD&E process owner / manager	✓	✓	✓	✓	✓		✓
Eduardo Barbosa, Hort Innovation, R&D Manager	RD&E process owner / manager	✓	✓	✓	✓	✓		✓
Andrew Robson, AARSC, Director	RD&E practitioner	✓	✓	✓	✓	✓	✓	✓
Matthew Fealy, Blue Sky Produce, Manager	RD&E stakeholder				✓		✓	✓

Glossary of economic terms

Benefit-cost ratio (BCR)	The ratio of the present value of investment benefits to the present value of investment costs.
Cost-benefit analysis (CBA)	A conceptual framework for the economic evaluation of projects and programs in the public sector. It differs from a financial appraisal or evaluation in that it considers all gains (benefits) and losses (costs), regardless of to whom they accrue.
Direct Effects	Impacts generated for the funding industry as a result of adoption of the RD&E outputs and recommendations, typically farm level outcomes relating to productivity and risk.
Discounting and Present Values	The process of relating the costs and benefits of an investment to a base year to reflect the time value of money or opportunity cost of RD&E investment. The analysis applies a real discount rate of 5% in line with CRRDC Guidelines (CRRDC 2018) with results sensitivity tested at discount rates of 2.5% and 7.5%.
Economic Equilibrium	Due to a market's underlying supply and demand curves, changes in supply will have an impact on price and vice-versa. The Economic Equilibrium is the point at which market supply and price are balanced. Estimating the magnitude of market response to changes in supply or demand is a complex and demanding task that is considered beyond the scope of most CRRDC Impact Assessments (CRRDC 2018).
Gross Margin (GM)	The difference between revenue and cost of goods sold, applied on a per hectare basis and excluding fixed or overhead costs such as labour and interest payments.
Internal rate of return (IRR)	The discount rate at which an investment has a net present value of zero, i.e. where present value of benefits = present value of costs.
Modified internal rate of return (MIRR)	The internal rate of return of an investment that is modified so that the cash inflows generated from an investment are re-invested at the rate of the cost of capital (in this case the discount rate).
Net present value (NPV)	The discounted value of the benefits of an investment less the discounted value of the costs, i.e. present value of benefits - present value of costs.
Nominal and real values	Nominal values reflect the actual values in a given year (e.g. contracted RD&E expenses). These are converted to real (inflation adjusted) values to make them comparable across time.
Spillover Effects	Impacts generated for stakeholders who did not fund the RD&E, including other agricultural industries, consumers, communities, and the environment.

Abbreviations

AARSC Applied Agricultural Remote Sensing Centre

ATCM Australian Tree Crop Map

CRRDC Council of Rural Research and Development Corporations

CSIRO The Commonwealth Scientific and Industrial Research Organisation

RD&E Research, Development and Extension

SIP Strategic Investment Plan

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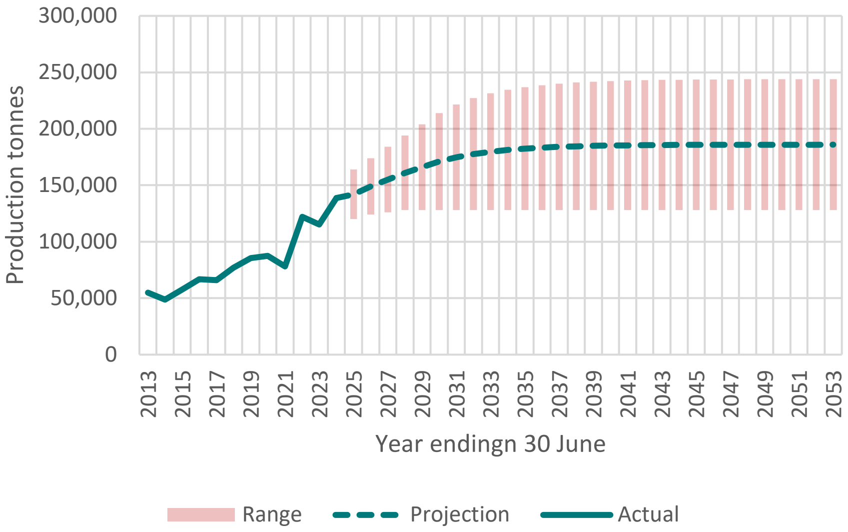
Appendix A. Data and projections

Industry production

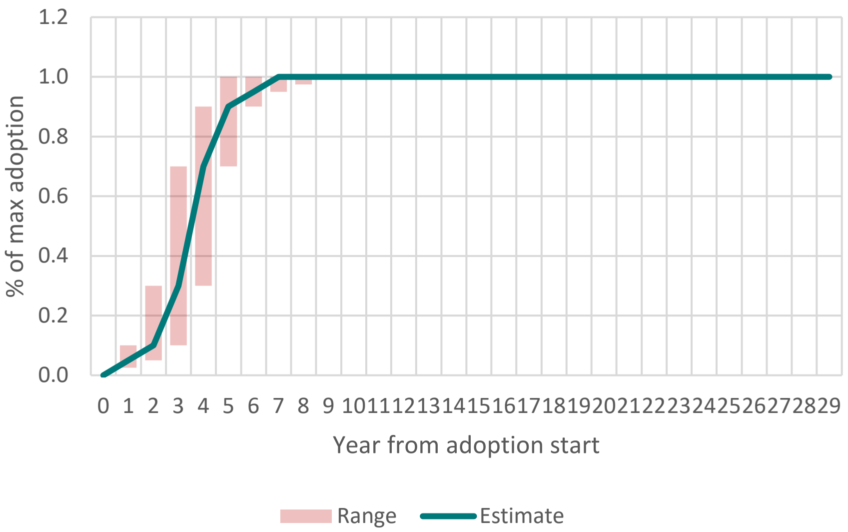
Figure 5 shows projected industry avocado production (tonnes) was taken from Facts at a Glance 2022/23 for the Australian avocado industry (AAL 2023), peaking in 2036 with a potential range of between 128,000 tonnes per year (with no new plantings above current levels, to 237,000 tonnes per year (from continued new plantings above current levels).

Figure 5 Projected industry avocado production (tonnes)



Yield mapping tool adoption speed

Figure 6 shows the estimated adoption speed of the farm yield mapping tool, informed from discussions with stakeholders, with peak adoption reached in 5-9 years.



RD&E program costs

Three investments were identified as part of the broader RD&E program delivering yield and spatial mapping tools for the avocado industry. The PVC share of AV18002 was used to attribute a share of the total program benefits to the project (Table 7 and Figure 7).

Table 7. Total program cost by investment stage

Investment stage	Total PVC ($m)	% Total PVC	Years	Annual average PVC
ST15012	4.55	61%	3	1.52
AV18002	1.95	26%	4	0.49
AV21006	1.00	13%	2	0.50
Total program	7.50	100%		

Figure 7. Undiscounted program costs by investment stage

Ends.