Impact assessment of the investment:

Innovative rootstocks for the Australian macadamia industry (MC16000)

*By George Revell, **Ag Econ***
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Hort Innovation

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Level 7
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Telephone: (02) 8295 2300

www.horticulture.com.au

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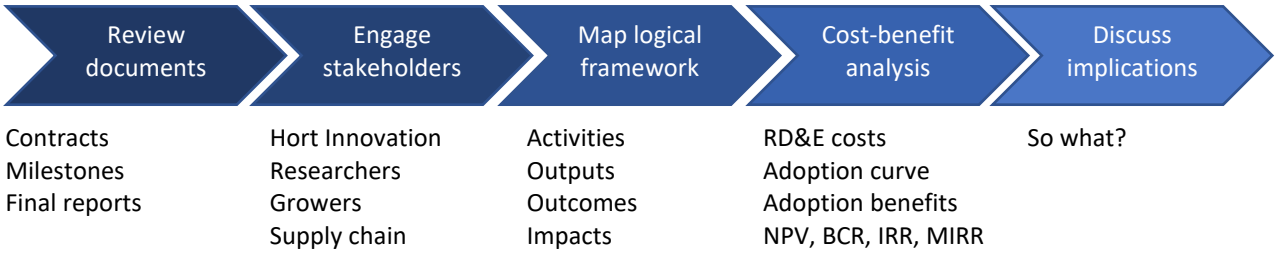
Executive summary

What the report is about

Ag Econ conducted independent analysis determine the economic, social, and environmental impact resulting from delivery of the vegetable project *Innovative rootstocks for the Australian macadamia industry (MC16000)*. The project was funded by Hort Innovation over the period February 2017 to December 2022 using the macadamia research and development levy and contributions from the Australian Government. The project was delivered by the Department of Agriculture and Fisheries, Queensland (QDAF).

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



Research background

Recognizing the need for macadamia rootstock research, in 2007 QDAF planted an extensive field experiment on a commercial orchard near Bundaberg consisting of 2,044 trees on 204 different rootstocks. This large field-trial resource formed the cornerstone of MC16000, which aimed to go beyond endorsing current industry practice and efficiently investigate a vast array of genetic material to pinpoint a small group of genotypes that offer best prospects of productivity improvement.

Key findings

The nominal investment cost of $0.46 million was adjusted for inflation (ABS, 2024) and discounted (using a 5% real discount rate) to a 2022-23 present value (PV) of costs equal to $0.70 million.

Through a logical framework, a review of the available data to quantify the impact pathway, and discussions with 10 stakeholders, the analysis identified a clear pathway to impact for MC16000. Drawing on the trial site established by QDAF in 2007, MC16000 refined trial research practices and identified “best bet” rootstocks (notably ‘A268’, ‘Own Venture’ and ‘A4’) with improved performance (particularly yield) relative to the two established industry rootstocks “Beaumont” and “H2”. The project established a new high replication trail of the most promising rootstocks to enable verification of the MC16000 findings, while at the same time recommending that growers and nurseries commence their own small scale propagation and trials of the new varieties.

The analysis estimated the industry benefits with regards to improved productivity (yield) and profitability) and profitability resulting from the new rootstocks. Given the uncertainties over the future trial outcomes (estimated to be evaluated in 2029 to 2034), the analysis applied conservative assumptions for yield benefit and adoption. Even with these conservative assumptions, the research demonstrated large benefits relative to the RD&E costs.

The model identified expected benefits of $6.12 million (2023-24 present value (PV) using a 5% discount rate) accruing between 2027 and 2053. When compared to the total funding from all sources of $0.70 million (2023-24 PV) between 2017 and 2023, the results showed a positive RD&E impact with a net present value (NPV) of $5.42 million, an estimated benefit-cost ratio (BCR) of 8.78 to 1, an internal rate of return of 13% and a modified internal rate of return of 12%.

Sensitivity analysis tested the results for uncertainty around the underlying variables, which was particularly important given the future projections conducted in the analysis. As expected, this sensitivity testing showed a potentially wide range in the results reflecting with a BCR ranging from less than 0.06:1 and 28.45:1 across 1000 simulations of the model, with 90% of results falling between 2.07:1 and 18.30:1. The variation was driven primarily by the relative yield variation of the new rootstocks relative to established varieties, and to a lesser extent, the rate of diffusion and adoption of the varieties.

Despite the underlying uncertainties in the modelling projections, the analysis gave a high level of confidence that the investment will generate a positive impact.

The key findings of the MC16000 impact assessment are summarized in Figure 1 below.

Keywords

Impact assessment; cost-benefit analysis; macadamia; rootstock

Figure 1. Summary of impact assessment findings

MC16000 Innovative rootstocks

Queensland Government | Department of Agriculture and Fisheries

Hort Innovation

Total RD&E costs:

- $0.46 million (nominal value)
- 65% R&D levy and Government matching, and 35% QDAF in-kind.

Research activities:

- From 2017 to 2022, evaluate the performance of 204 potential new rootstock varieties in a 10 year old 2000 tree commercial orchard trial near Bundaberg.
- Verify new and more efficient methods of yield assessment, developed by QDAF in 2012.
- Establish a second, higher-replication trial of the 14 most promising rootstocks (across 651 trees) in November 2021.

Extension activities:

- An article in AMS New Bulletin (Winter 2021) encouraging growers/nursery people to test and plant the identified higher performing rootstocks.
- Trial site visitors included commercial and research horticulturists, growers, consultants, managers and investors.
- 1 x Scientific paper.

Outcomes:

- High performing rootstocks (notably 'A268', 'Own Venture' and 'A4') averaged 23% higher nut in shell yield compared to industry standard 'H2' and 'Beaumont'.
- Growers and nurseries recommended to commence small scale commercial trials of the new rootstocks.
- Obvious impacts on tree size and vigour (e.g. dwarfing) were lacking beyond a few rootstocks that produced small and unhealthy trees.
- A new and more efficient research technique for assessing yield was validated for industry, reducing labour and cost for future trials.

Industry adoption:

- Adoption is expected to be modest until the higher replication trial results are known (estimated 2029 to 2034). Given the uncertainty, a final adoption of 25% to 90% of new plantings was estimated.

Industry economic impacts:

- Increased productivity (yield) and profitability for macadamia growers.

Socio-economic impacts:

- Increased flow-on employment and economic stimulant to supply chains and local communities.

Total attributable benefits and impact:

- Present value (PV @ 5% discount) RD&E costs of $0.70 million.
- PV estimated benefits of $6.12 million between 2027 and 2053.
- Net PV (NPV) of $5.42 million.
- Benefit cost Ratio (BCR) of 8.78:1 with a 90% confidence of a BCR between 2.07:1 and 18.30:1

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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).

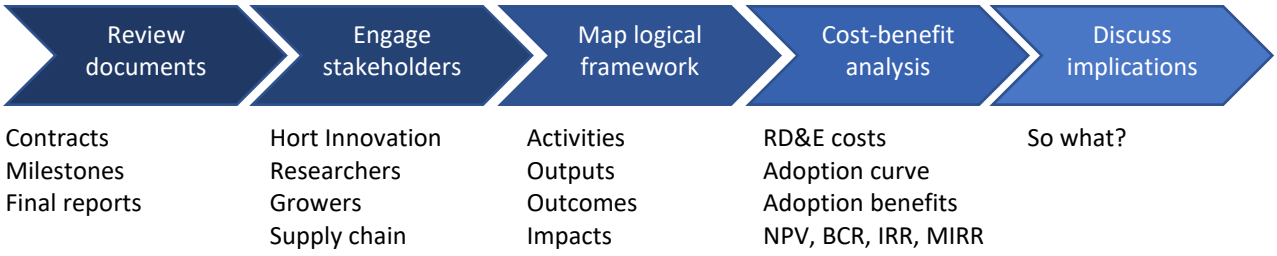
Innovative rootstocks for the Australian macadamia industry (MC16000) was randomly selected in the 2022-23 sample. This report presents the analysis and findings of the project impact assessment.

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.



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

The six-year project was delivered during a time of significant industry expansion. In 2016, the industry consisted of about 650 growers and 17,000 ha planted to macadamias, while in 2021 this had increased to about 800 growers and 32,500 ha, of which approximately 25,000 ha were bearing (Hort Innovation 2024). In 2022, the industry was continuing to expand rapidly, with substantial new plantings underway in new and existing regions (AMS, 2022). At the same time, strong international growth in macadamia production—particularly in African countries, as well as China, Vietnam and South America—meant that Australia's historical dominance of global production was slipping (ABC, 2021).

Ongoing growth in areas planted to macadamias around the world and the focus on maintaining Australia's reputation as a supplier of premium nuts highlighted the importance of a strategic and industrywide approach to increasing production and profitability.

Rootstocks were identified as one potential area of productivity gain, which was included as one of the priority research areas contributing to the 2017-2021 Macadamia Strategic Investment Plan (SIP), Outcome 2 *Improved production systems covering plant breeding, intensive orchards and novel technologies*. Within Outcome 2, dwarfing rootstock was a particular area of interest for the macadamia industry. While rootstocks are recognized as an extremely cost-effective means of improving orchard productivity both with regards to yield and yield efficiency of inputs (Rom & Carlson 1987; Castle & Warrington 1995), little research had been done on rootstocks in macadamias (Trochoulias 1992). Efforts to demonstrate rootstock effects on macadamia yield (Neal et al., 2016) had not seen the industry progress beyond rootstocks like 'H2' and 'Beaumont', selections chosen by commercial nurserymen for their seedling vigour and ease of vegetative propagation characteristics.

In 2007, the Department of Agriculture and Fisheries, Queensland (QDAF) planted an extensive field experiment on a commercial orchard near Bundaberg to support the collection of rootstock performance data. The trial consisted of 2,044 trees (3.5 m x 7 m spacing) on 204 different rootstocks, representing 141 named varieties collected from 8 different pollination environments. 'HAES741' was used as the standard scion across the whole trial because of its commercial importance. The trial site was treated as a normal commercial orchard and received a very high standard of management throughout the life of this project. New and more efficient methods of yield assessment were developed so that this large field trial could be measured prior to every commercial harvest starting from the first season (2012).

This large field-trial resource formed the cornerstone of MC16000, which aimed to go beyond endorsing current industry practice and efficiently investigate a vast array of genetic material to pinpoint a small group of genotypes that offer best prospects of productivity improvement.

MC16000 aligned with the Macadamia SIP 2022-2026 through:

- Outcome 2: Industry supply, productivity and sustainability.

Project details

MC16000 was funded from 2017 to 2022 (Table 1).

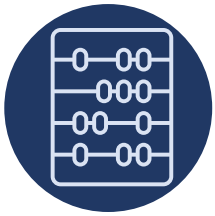
Table 1. Project details

Project code	MC16000
Title	Innovative rootstocks for the Australian macadamia industry (MC16000)
Research organization(s)	Department of Agriculture and Fisheries, Queensland (QDAF)
Project leader	Malcolm W. Smith (QDAF)
Funding period	February 2017 to December 2022
Objective	Investigate a vast array of genetic material to pinpoint a small group of genotypes that offer best prospects of productivity improvement

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	 	• The 10 year old large scale commercial orchard in Bundaberg formed the cornerstone of the project and shaped the methodology employed. • The trial design allowed the role of the pollen parent in rootstock performance to be investigated. • Yield assessment were made prior to every commercial harvest from 2017 to 2022 (building on the 5 years of data already collected). • New and more efficient methods of yield assessment, developed by QDAF in 2012, were verified for accuracy. • After three seasons (2017-2019) results were reviewed (from a horticultural perspective, prior to statistical data analysis) which suggested that an additional field trial was required to properly test a much smaller subset of treatments (but with great replication). The necessary germplasm was collected for 14 rootstocks, propagated in the Bundaberg Research Station nursery, grafted during 2020 (across 651 trees representing 44 different rootstock treatments) and planted in commercial blocks near Bundaberg in November 2021.
RD&E outputs	 	**Research outputs** • A new rootstock trial of 14 promising rootstocks planted in November 2021. • A smaller subset of rootstocks recommended as being ready for small scale commercial adoption and trials (notably 'A268', 'Own Venture' and 'A4'). • A new and more efficient yield assessment methodology supported by 10 years of data. **Extension outputs** • An article was prepared for the AMS New Bulletin (Winter 2021) encouraging growers/nursery people to test and plant 'A268', 'Own Venture' and 'A4' in 10-20% of new plantings for comparison with the traditional rootstocks 'H2' and 'Beaumont'. Individuals and small groups were taken to the trial site so that they could appreciate the material being used to generate the data, and the scale of the experiment. Visitors included commercial and research horticulturists, growers, consultants, managers and investors.

Outcomes

End of project outcomes

- **New research and industry knowledge** on rootstocks and productivity relating to:
  - **The role rootstocks on yield, canopy, growth rate, nut drop pattern**.
    - High performing rootstocks (notably 'A268', 'Own Venture' and 'A4') averaged 23% higher nut in shell yield compared to industry standard 'H2' and 'Beaumont'. The research recommended that growers include the new rootstocks in a conservative strategy of 10% to 20% of new commercial plantings, while maintaining existing commercial rootstocks 'H2' and 'Beaumont'. While 'H2' and 'Beaumont' were mid-range in their performance amongst the 141 named varieties in the trial, the research noted they still represent a good choice until the superior performance of the new rootstock options can be confirmed in large block plantings (planted in November 2021). Large scale propagation of the new rootstocks will be dependent on nurseries accessing source material. It was proposed in the December 2022 Final Report that the project team collect seed from 2-5 of the best performing treatments in the experiment, by returning to the original source tree, and then distribute this seed in bulk to interested commercial nurseries. This had not occurred as of July 2024 due to time/resource constraints.
    - The poor performance of many rootstock treatments, with the implication that growers must insist on known rootstock germplasm when establishing new plantings.
  - **The influence of rootstock on wind-blows**, which could be used to inform future research on the relationship between rootstocks, wind, and long-term tree health.
  - **The potential for a dwarfing rootstock.** While there was good evidence that rootstocks influenced yield, obvious impacts on tree size and vigour were lacking beyond a few rootstocks that produced small and unhealthy trees. As such, there were no clear opportunities to reduce tree size using rootstocks (dwarfing rootstock), despite the large amount of genetic material screened in the experiment.
- **Validated research techniques.** A new and more efficient research technique validated for assessing yield (first developed in 2012 prior to the project).

Longer term outcomes

- Verification of the "best bet" rootstocks in new trials (planted November 2021) with greater replication, which will refine the recommendations developed from the original trial. If the results of MC16000 are validated, this would give confidence for nurseries and growers to increase their propagation and planting of the new rootstocks at commercial scale.
- Promising rootstocks have the potential to be incorporated into broader regional variety trials (currently MC17006) that have typically relied on 'H2' and 'Beaumont'.
- An improved understanding of the role of the pollen parent in rootstock performance will help in developing better commercial rootstocks for non-apomictic tree crops that do not develop proper root systems via vegetative propagation.

The improved rootstock knowledge and resources have the potential to generate the following impacts:

- [Economic] Farm productivity gains (improved yield with unchanged or lower costs) resulting from improved rootstock selection improving enterprise profitability.
- [Socio-economic] Increased macadamia industry spillovers including employment and economic stimulant to local communities (The CIE 2023).
- [Social] Supporting the long term supply of affordable domestic macadamia nuts to Australian consumers, resulting in increased consumption (Kantar 2022) and an increase in associated health and wellbeing benefits (AMS 2024; Hort Innovation 2020).

Project costs

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

Nominal investment

The project funding period was 2017 to 2023, with no funds spent in 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 (MC levy and Gov't matching) ($)	Hort Innovation overheads[1] ($)	Other funding[2] ($)	Total nominal cost ($)
2017	31,143	6,288	20,111	57,542
2018	47,464	9,584	30,650	87,698
2019	50,461	10,301	32,585	93,347
2020	46,883	8,938	30,275	86,096
2021	45,480	7,414	29,369	82,263
2022	0	0	0	0
2023	31,803	5,176	20,537	57,517
Total	**253,234**	**47,701**	**163,527**	**464,463**

1. The overhead and administrative costs were calculated from the Financial Operating Statement of the Macadamia Fund Annual Reports, averaging 19% for the MC16000 funding period (2017-2023).
2. In kind funds from QDAF for salaries 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 $0.46 million identified in Table 3 was adjusted for inflation (ABS, 2024) into a real investment of $0.56 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 $0.70 million (2023-24 PV). The results were sensitivity tested changes in the discount rate between 2.5% and 7.5%.

Project impacts

The impact pathway 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

The logical framework demonstrated a clear impact pathway for the identification and recommendation of higher performing rootstocks, and subsequent industry adoption and impact. While the initial adoption is likely to be limited in line with MC16000 recommendations for a low-risk adoption approach, a higher rate of adoption and impact is likely to be achieved once the results of the follow-on higher replication trials (established in MC16000) become available, and if these results further demonstrate a high yield advantage of the new varieties. The impact pathway was also supported by detailed yield performance data provided through the project, and the availability of additional robust industry data sources (notably Macadamia benchmarking MC18002 and MC22000) and stakeholder consultation.

Impacts valued and valuation framework

In line with the above, a model was developed to estimate:

- [Economic] Farm productivity gains (improved yield with unchanged or lower costs) resulting from improved rootstock selection improving enterprise profitability.

Without investment scenario. Without the new varieties industry will continue to use the existing H2 and Beaumont rootstocks. These rootstocks have an average yield of 3.08 t/ha (NIS) (QDAF 2023).

With investment scenario. Results and recommendations to trial the new rootstocks ('A268', 'Own Venture' and 'A4') were provided through MC16000 from 2023. Small scale farm trials are likely to have taken place, limited by the availability of the new rootstock varieties, and also the risk presented before larger scale (increased replication) trials are complete. Results from the larger scale trials are estimated to be 2029 to 2034 once trees reach maturity. While the MC16000 trials showed the new rootstocks to yield +23% compared to existing rootstocks, uncertainty remains regarding the extent to which these results will be validated by larger scale trials, so a baseline gain of 11% was applied (50% or the MC16000 results, difference due to rounding). Once the results of the large scale trials start to become available, growers and agronomists will have increased certainty as to the relative performance of the new rootstocks, resulting in a step up in propagation and planting from 2033. The level and speed of adoption, as a proportion of newly planted trees, was estimated using the CSIRO ADOPT methodology. Newly planted trees were estimated based on projections of 1) industry expansion (new development), and 2) replanting of older orchards as they become unproductive. As such, the new rootstocks were assumed to simply replace the existing rootstock selections, without incurring any "adoption cost". The value of any increase in yield from the new rootstocks was based on a projection of the NIS $/kg price, less yield related costs (nutrition, irrigation, sorting, freight, levies). Finally the proportion of the total benefits attributed to MC16000 was estimated based on the investment cost of MC16000 relative to the whole program of investment (2007 to 2034).

Impacts unable to be valued

The following impacts were unable to be valued:

- [Socio-economic] The contribution of the macadamia industry as a source of employment and economic stimulant to regional communities has been highlighted in previous Hort Innovation research (The CIE 2023). Increased macadamia farm yield, revenue, and profitability would generate flow on benefits to the regional communities in which the industry operates. While this analysis quantified the direct impacts for macadamia industry value, 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).
- [Social] Supporting the long term supply of affordable domestic macadamia nuts to Australian consumers, resulting in increased consumption (Kantar 2022) and an increase in associated health and wellbeing benefits (AMS 2024; Hort Innovation 2020). While increased production has the potential to put downward pressure of prices and thereby encourage increased domestic consumption, as an increasingly export focussed industry (72% exported in 2023, Hort Innovation 2023) the macadamia price is primarily driven by global supply and demand. As such, while it is possible for health and wellbeing benefits associated with increased macadamia production, the size of this benefit is potentially minor, and furthermore requires equilibrium modelling to capture the supply-price-demand effect, which is typically 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)
Annual industry macadamia new plantings	Average 902 hectares per year	See *Appendix A. Macadamia industry projections*.
Adoption of new varieties	Maximum 25% to 90% of new industry plantings using new varieties starting 2022.	See *Appendix B. Diffusion and adoption using the ADOPT framework*.
Baseline yield	Mature tree yield of 3.08 t/ha NIS	See *Appendix A. Macadamia industry projections*.
New rootstock yield benefit	11% (± 100%)	While the MC16000 trials showed the new rootstocks to yield +23% compared to existing rootstocks, uncertainty remains regarding the extent to which these results will be validated by larger scale trials, so a more conservative relative yield performance of 0% to 23% was applied (average 11%) using a triangular probability distribution with a baseline yield gain of 11% (50% or the MC16000 results, difference due to rounding), and a 5% chance of less than 3.6% yield gain, or more than 19% yield gain).
Macadamia NIS price	Reaching $4.5/kg NIS by 2028 (± 21%)	See Appendix A. Macadamia industry projections.
Macadamia yield related costs)	$1.03/kg NIS	Nutrition, irrigation, sorting, freight, and levies estimated on a per kg NIS basis from benchmarking data (QDAF 2023) and stakeholder consultation.
Impact attributable to MC16000	49%	The modelling framework calculated the total benefit resulting from the new rootstock varieties. However, MC16000 only makes up part of the broader rootstock RD&E program (to-date and future). As such, the attributable benefits considered the cost share of MC16000 relative to all other investments in the program. See *Appendix C. Total program cost.*
Counterfactual attribution	75% (± 33%)	A low-moderate likelihood that the MC16000 research would have been undertaken even without Hort Innovation funding. While QDAF planted the trees in 2007 with the intention of conducting some kind of rootstock research, this was always with the intention of gaining external funding.

Results

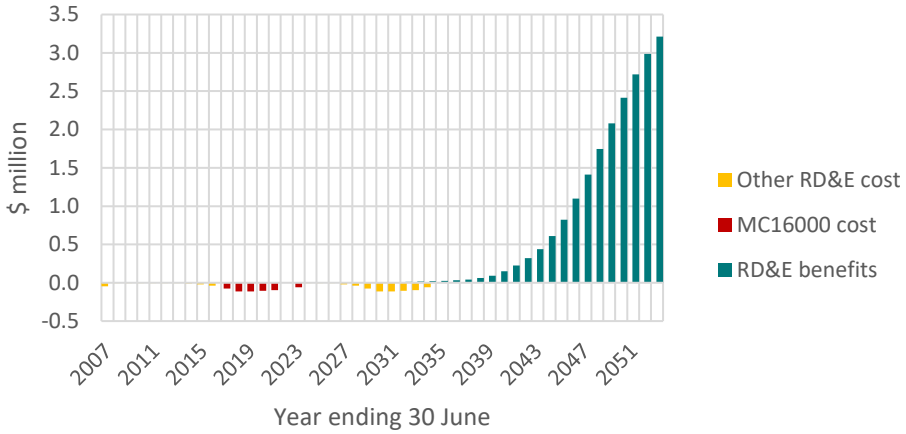
The analysis identified PV costs (PVC) of $0.70 million (2023-24 PV) between 2016-17 and 2022-23, and estimated PV benefits (PVB) of $6.12 million (2023-24 PV) accruing between 2027 and 2053 (Table 5). When combined, these costs and benefits generate a net present value (NV) of $5.42 million, an estimated benefit-cost ratio (BCR) of 8.78 to 1, an internal rate of return (IRR) of 13% and a modified internal rate of return (MIRR) of 12%.

Table 5. Impact metrics for the total investment in project MC16000

Impact metric	Years after last year of investment						
	0	5	10	15	20	25	30
PVC ($m)	0.70	0.70	0.70	0.70	0.70	0.70	0.70
PVB ($m)	0.00	0.00	0.03	0.13	0.65	2.55	6.12
NPV ($m)	-0.70	-0.70	-0.66	-0.56	-0.05	1.86	5.42
BCR	0.00	0.00	0.05	0.19	0.93	3.66	8.78
IRR	Negative	Negative	Negative	Negative	5%	11%	13%
MIRR	Negative	Negative	Negative	Negative	5%	9%	12%

Figure 2 shows the annual undiscounted costs and attributable benefits for the total investment of MC16000, and includes other contributing RD&E costs for comparison.

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

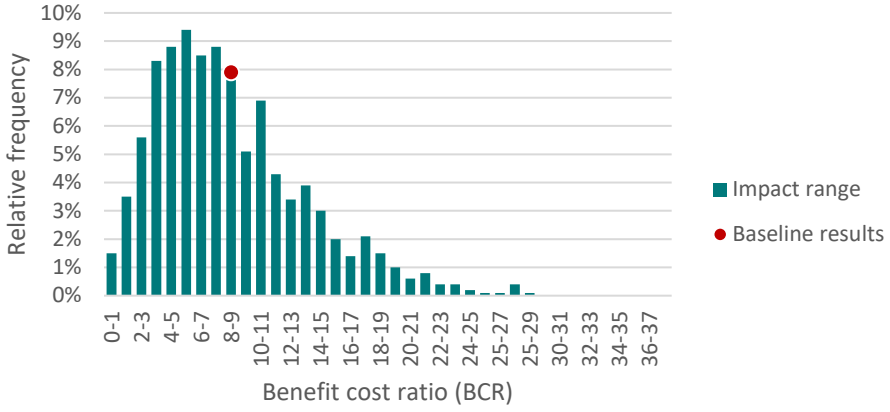


Sensitivity analysis

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:

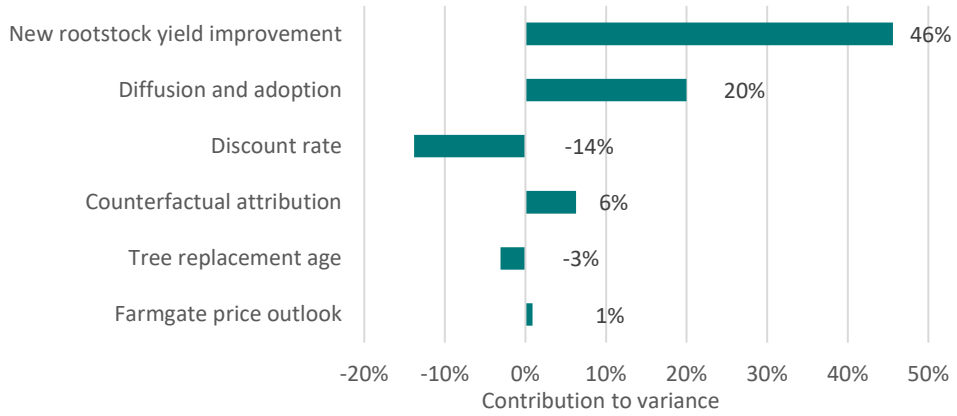
- **Impact variation (Figure 3)**. Compared to the baseline BCR of 8.78:1, the 1000 simulation showed a potential BCR range of between 0.06:1 and 28.45:1, with 90% of results falling between 2.07:1 and 18.30:1 (i.e. excluding the low probability tails), and a simulation average of 8.47:1 (below the baseline results). Of the 1000 simulations, 99% had a BCR greater than 1:1 (benefits greater than RD&E costs), giving a high level of confidence that the investment will generate a positive impact.

Figure 3. Impact variation in results 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 performance of the new rootstocks relative to the existing varieties showed the largest contribution to variation of 46%. A minimum yield benefit of 1.3% was required to achieve a positive impact (breakeven yield benefit). The diffusion and adoption of the new varieties across the nurseries and orchards showed the second highest contribution to variation of 20%. Keeping all else equal, a minimum industry adoption of 14% (below the tested range of 25% to 90%) was required to achieve a positive impact. Both of these variables had a positive correlation with investment impact. The discount rate had the third highest contribution to variance (accounting for 14% of variation), but with a negative correlation with investment impact. The breakeven discount rate is reflected in the IRR (13%), or the MIRR (12%) if we assume that generated cashflows are reinvested at the risk-free discount rate.

Figure 4. Contribution to variance



Implications and learnings

The analysis identified a clear pathway to impact for MC16000. Drawing on the trial site established by QDAF in 2007, MC16000 refined trial research practices and identified "best bet" rootstocks (notably 'A268', 'Own Venture' and 'A4') with improved performance (particularly yield) relative to the two established industry rootstocks "Beaumont" and "H2". The project established a new high replication trail of the most promising rootstocks to enable verification of the MC16000 findings, while at the same time recommending that growers and nurseries commence their own small scale propagation and trials of the new varieties. The research also looked at the potential for dwarfing rootstocks, which is a key area of interest for the industry, but found no dwarfing characteristics in the 204 trialled varieties.

A model was developed to evaluate the impact of the "best bet" rootstocks with regards to improved productivity and profitability. The analysis considered the full program cost, including previous QDAF investments (19% of total), the MC16000 investment (49% of total), and the need for future investment to complete the high replication trials (32% of total investment). When considering the benefits, the model included six key variables, which were all tested for sensitivity.

The lack of other research into rootstocks, combined with the promising results from the MC16000 trial and the small number of established rootstocks in the macadamia industry, supports the potential for a high uptake of the new rootstocks if they can be further validated for their yield, vigour, and disease susceptibility attributes.

Given the uncertainties over the future trial results, the analysis applied conservative assumptions for yield benefit and adoption. Even with these conservative assumptions, the research demonstrated large benefits relative to the RD&E costs, with a baseline BCR of 8.78:1.

In addition, sensitivity testing was undertaken to understand the potential variation in the results given changes in the underlying variables. This identified a potential impact range of between 0.06:1 and 28.45:1, with 90% of results falling between 2.07:1 and 18.30:1 giving a high level of confidence that the investment will generate a positive impact. The variation was driven primarily by the relative yield variation of the new rootstocks relative to established varieties, and to a lesser extent, the rate of diffusion and adoption of the varieties.

When the results of "best bet" high replication trial become available, the additional data will provide an improved

understanding of the relative performance of the new rootstocks, giving growers and nurseries increased confidence in their adoption decisions, and also providing a more accurate estimate of industry impact.

It is also important to highlight the long timeframe for the benefits to be realised. As the follow on trials were only planted in 2021, trial completion is not likely to be completed until 2034. Adoption is estimated to start in 2025 based on the preliminary findings of MC16000 but is not likely to increase substantially before the completion of the follow on trials in 2034. As a result, adoption is not expected to peak until 2043, and with macadamia trees taking 19 years to reach maximum production, the full benefit of the new rootstocks wont be realised until 2066. Notwithstanding the high level of uncertainty when looking this far into the future, the long timeline highlights potential deficiencies in the traditional 30 year window when considering the impact of breeding programs for tree crops. This issue is particularly relevant to fruit and tree crop levy industries and therefore distorts the impact assessments of these industries relative to other horticulture (vegetable, turf, and nursery) and other agriculture (livestock and broadacre cropping).

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**
Ben Callaghan, Hort Innovation R&D Manager	RD&E process owner / manager	✓	✓	✓	✓	✓		✓
Malcolm Smith, QDAF Plant Breeder	RD&E practitioner (MC16000 lead)	✓	✓	✓	✓	✓	✓	✓
Grant Bignell QDAF Principal Research Scientist, Horticulture and Forestry Science	RD&E practitioner (related research)	✓				✓	✓	✓
Steve McLean, Macadamia Allsorts, Grower and consultant	Industry stakeholder						✓	✓
Graham Wessling, CL Macs Manager	Industry stakeholder						✓	✓
Chris Fuller, Nutworks, Grower Liaison	Industry stakeholder						✓	✓
Jarrah Coates, Coates Horticulture Agronomist	Industry stakeholder	✓					✓	✓
MACQ Nursery	Industry stakeholder						✓	✓
Seabreeze Macadamias	Industry stakeholder						✓	✓
Wide Bay Macadamia Seedlings	Industry 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

CRRDC Council of Rural Research and Development Corporations

RD&E Research, Development and Extension

SIP Strategic Investment Plan

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Appendix A. Macadamia industry projections

Macadamia new plantings

From the current 41,000 hectares of macadamia orchards reported in the Australian Tree Crop Map Dashboard (AARSC, 2024), newly developed macadamia orchards were assumed to continue to grow the total industry area until around 2030 before plateauing at approximately 45,000 hectares (Stakeholder consultation). Annual replanting was also assumed to occur for older trees becoming unproductive. Industry stakeholders said there is no established age for replacing older macadamia trees. Benchmarking data (QDAF 2023) shows tree productivity (saleable kernel yield) peaks at 20-24 years. It was assumed in discussion with stakeholders that trees would be replaced at 35 years (tested between 30-40 years). This replacement age was then applied to the industry tree age data (QDAF 2022 & 2023b) to generate the annual replacement area. Annual plantings are shown in Figure 5, with the total new plantings (from 2023) shown in Figure 6.

Figure 5 Annual macadamia plantings

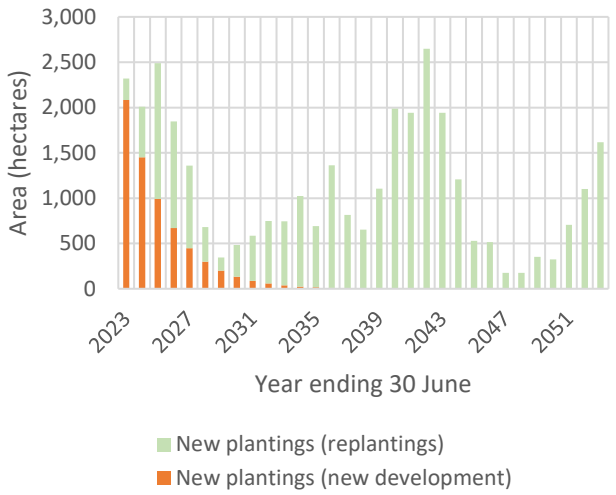
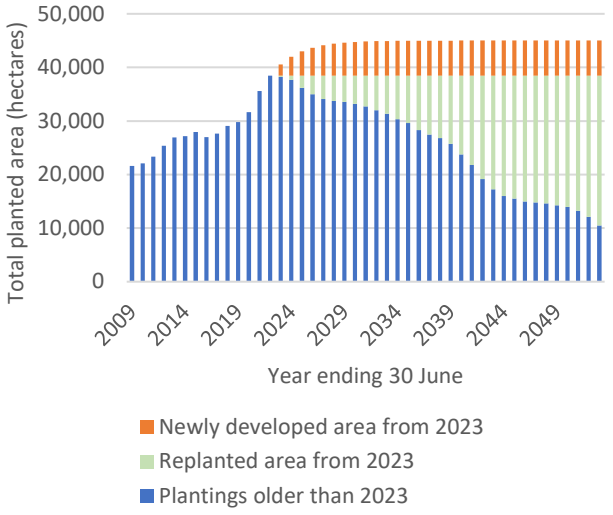


Figure 6 Total macadamia plantings



Macadamia yield and prices

The annual yield growth of new plantings (and yield benefit of the new rootstock) was based on tree age data from (QDAF 2010 & 2023b) with a maximum mature tree yield of 3.08 t/ha (NIS) (Figure 7). NIS prices were projected based on industry consultation (Figure 8). It was assumed that the current low prices of approximately $3.2/kg NIS would recover over the five years to 2029 to be within the range of $3.5/kg to $5.5/kg (average $4.5/kg).

Figure 7 Baseline macadamia yield by tree age

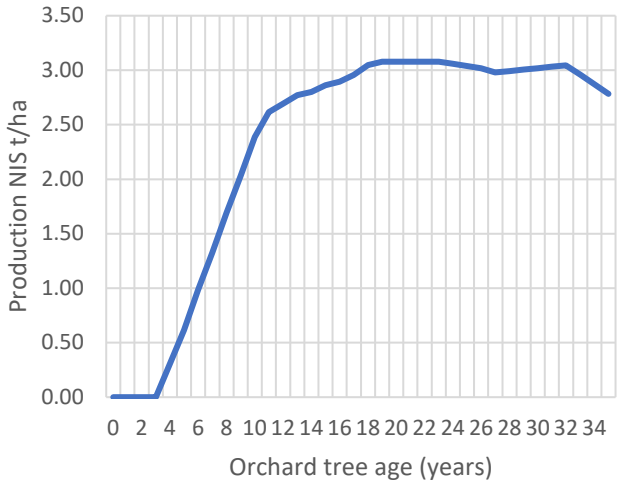
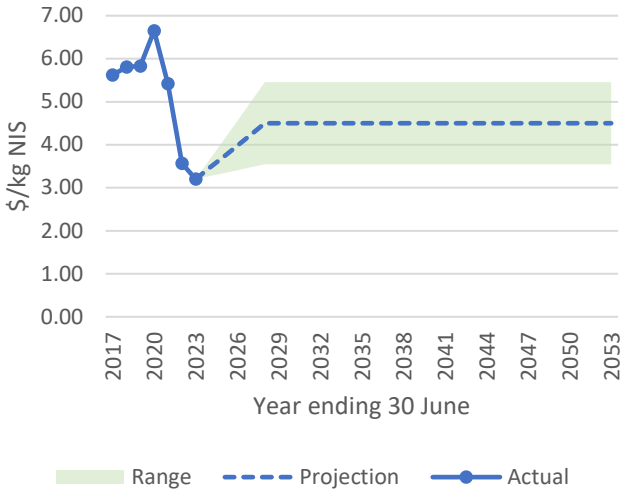


Figure 8 Macadamia NIS price $/kg



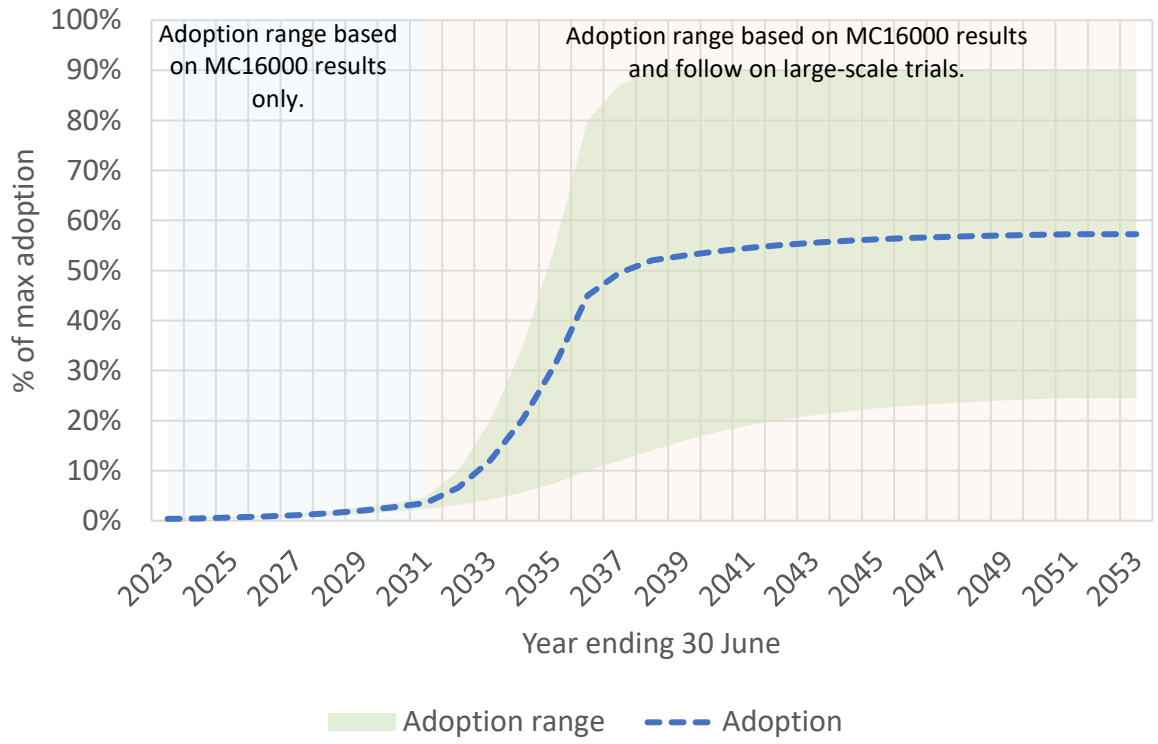
Appendix B. Diffusion and adoption using the ADOPT framework

Appendix B includes the data inputs for the ADOPT model (Kuehne et al 2017) used in this analysis. The results were tested for sensitivity of the adoption rate and level by adjusting answers relating to the key adoption and diffusion parameters of the new varieties and trial results.

Results and recommendations to trial the new rootstocks ('A268', 'Own Venture' and 'A4') were provided through MC16000 from 2023. Small scale farm and nursery trials were recommended but stakeholder consultation indicates these have been limited by the risk presented before larger scale (increased replication) trials are complete (reflected as "small increase in risk" in Q21 in the ADOPT framework), and to a lesser extent by the availability of the new rootstock planting material. Results from the larger scale trials are estimated to be delivered from 2029 to 2034 once trees reach maturity. While the MC16000 trials showed the new rootstocks to yield +23% compared to existing rootstocks, uncertainty remains regarding the extent to which these results will be validated by larger scale trials, so a baseline gain of 11% was applied (50% or the MC16000 results, difference due to rounding), with a range of 0% yield improvement and 23% improvement (reflected in Q16 of the ADOPT framework). Once the results of the large-scale trials start to become available, growers and agronomists will have increased certainty as to the relative performance of the new rootstocks, resulting in a potential step up in propagation and planting from 2033.

The estimated diffusion and adoption curve is shown in Figure 9.

Figure 9 Macadamia NIS price $/kg



1. What proportion of farms have maximising profit as a strong motivation?

A majority have maximising profit as a strong motivation

2. What proportion of farms has protecting the natural environment as a strong motivation?

About half have protection of the environment as a strong motivation

3. What proportion of farms has risk minimisation as a strong motivation?

About half have risk minimisation as a strong motivation

4. On what proportion of farms is there a major enterprise that could benefit from the technology?

Almost all of the target farms have a major enterprise that could benefit

5. What proportion of farms have a long-term (greater than 10 years) management horizon for their farm?

A majority have a long-term management horizon

6. What proportion of farms are under conditions of severe short-term financial constraints?

A minority currently have a severe short-term financial constraint

7. How easily can the innovation be trialled on a limited basis before a decision is made to adopt it on a larger scale?

Very easily trialable

8. Does the complexity of the innovation allow the effects of its use to be easily evaluated when it is used?

Slightly difficult to evaluate effects

9. To what extent would the innovation be observable to farmers who are yet to adopt it when it is used in their district?

Not observable at all

10. What proportion of advisors are capable of providing advice relevant to the innovation?

Almost all use a relevant advisor

11. What proportion of growers/advisors participate in groups that enable discussion relevant to the innovation?

Almost all participate in groups that enable discussion relevant to the innovation

12. What proportion of growers/advisors will need to develop substantial new skills and knowledge to use the innovation?

Almost none will need new skills or knowledge

13. What proportion of growers/advisors would be aware of this innovation in their district?

Almost all are aware of the innovation being trialled in the Bundaberg region

14. What is the size of the up-front cost of the investment relative to the potential annual benefit from using the innovation?

No initial investment required (new rootstocks are used in place of old rootstocks with no net change in costs)

15. To what extent is the adoption of the innovation able to be reversed?

Difficult to reverse due to the long period before reaching maturity (opportunity cost) as well as the direct cost of removal.

16. To what extent is the use of the innovation likely to affect the profitability of the farm business in the years that it is used?

Small to large profit advantage in years that it is used

17 To what extent is the use of the innovation likely to have additional effects on the future profitability of the farm business?

No profit advantage or disadvantage in the future

18 How long after the innovation is first adopted would it take for effects on future profitability to be realised?

6-10 years

19. To what extent would the use of the innovation have net environmental benefits or costs?

No environmental advantage

20. How long after the innovation is first adopted would it take for the expected environmental benefits or costs to be realised?

Not applicable

21. To what extent would the use of the innovation affect the net exposure of the farm business to risk?

Small increase in risk (before large scale trial data is available), and nil-small reduction in risk (once large scale trial data is available).

22. To what extent would the use of the innovation affect the ease and convenience of the management of the farm in the years that it is used?

No change in ease and convenience

Appendix C. Total Program costs

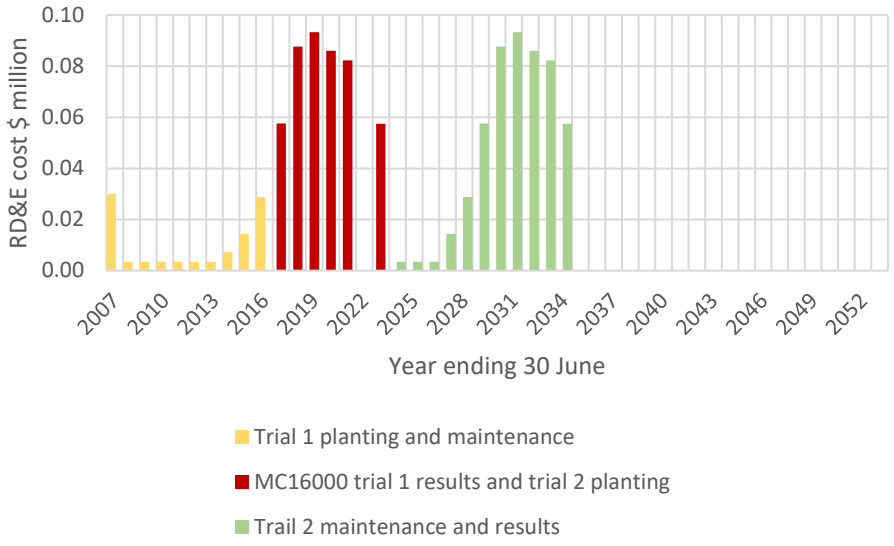
Three stages of investment were identified as part of the program to deliver new macadamia rootstocks. The cost share of MC16000 (in present value (PV) terms) was used to attribute a share of the total program benefits to the project (Table 7 and Figure 10).

- **Trial 1 planting and maintenance (2007 to 2016)**. QDAF initially planted the 2,044 tree (204 different rootstocks) commercial trial site in 2007 due to recognising the need for rootstock research in macadamias. The planting was funded by QDAF at an estimated $15/tree, with subsequent maintenance undertaken as part of normal commercial operations with limited QDAF resource requirements of approximately 3 staff for 1 week per year, increasing as trees reached maturity.
- **MC16000 rootstock trials (2017-2022)**. Final trial data collected and data evaluated. MC16000 planted a selection of best performing rootstocks in a higher replication trial (across 651 trees with 14 rootstocks) at no additional research cost.
- **Trial 2 maintenance and research results (2023 to 2034)**. Trial maintenance undertaken as part of normal commercial operations with limited additional resource requirements (reflecting Trial 1, above). Trial performance data assumed to be collected from 2029 to 2034 as the trees mature. Costs for trial performance data was based on a combination of Trial 1 maintenance and data collection, and MC16000 data collection and evaluation.

Table 7 Total program cost by investment stage

Investment stage	Total PVC ($m)	% Total PVC	Years	Annual PVC
Trial 1 planting and maintenance	0.27	20%	10	0.03
MC16000 trial 1 results and trial 2 planting	0.70	49%	7	0.10
Trail 2 maintenance and results	0.45	32%	11	0.04
Total program	1.42	100%		

Figure 10 Total program cost by investment stage



Ends.