Final Report

Project title:

Horticulture Impact Assessment Program:

Appendix 6: Macadamia Second Generation Breeding and Conservation (MC14000 Impact Assessment)

Impact analyst:

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Delivery partner:

AgEconPlus and Agtrans Research

Project code:

MT18011

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Executive Summary

What the report is about

This report presents the results of an impact assessment of a Horticulture Innovation Australia Limited (Hort Innovation) investment in *MC14000: Macadamia Second Generation Breeding and Conservation.* The project was funded by Hort Innovation over the period January 2015 to December 2019.

Methodology

The investment was first analysed qualitatively within a logical framework that included activities and outputs, outcomes, and impacts. Actual and/or potential impacts then were categorised into a triple bottom line framework. Principal impacts identified were then considered for valuation in monetary terms (quantitative assessment). Past and future cash flows were expressed in 2019/20 dollar terms and were discounted to the year 2019/20 (year of evaluation) using a discount rate of 5% to estimate the investment criteria and a 5% reinvestment rate to estimate the modified internal rate of return (MIRR).

Results/key findings

The investment in MC14000 has continued priority research in the Australian macadamia improvement program. Outputs from the investment in MC14000 have contributed an increased rate of genetic gain for the macadamia breeding program that, in turn, is likely to result in increased productivity and/or profitability for Australian macadamia producers through more rapid development and commercialisation of new and improved macadamia cultivars. Further, the investment has increased the efficiency and/ effectiveness of future investment in macadamia breeding RD&E.

Investment Criteria

Total funding from all sources for the project was $6.70 million (present value terms). The investment produced estimated total expected benefits of $39.23 million (present value terms). This gave a net present value of $32.54 million, an estimated benefit-cost ratio of 5.86 to 1, an internal rate of return of 20.0% and a modified internal rate of return of 8.4%.

Conclusions

A number of environmental and social impacts identified were not valued within the scope of the current assessment, therefore the investment criteria reported are likely to be an underestimate of the performance of investment in MC14000.

Given the long timeframes and significant past investment in macadamia breeding in Australia, the positive results of the assessment of the investment in MC14000 reflect the potential gains from the macadamia breeding program and should be viewed positively by Hort Innovation, the Australian government, other funding partners, the macadamia industry, and other key stakeholders.

Keywords

Impact assessment, cost-benefit analysis, macadamia breeding, macadamia improvement program, macadamia, genetic gain

Introduction

Horticulture Innovation Australia Limited (Hort Innovation) required a series of impact assessments to be carried out annually on a number of investments in the Hort Innovation research, development, and extension (RD&E) portfolio. The assessments were required to meet the following Hort Innovation evaluation reporting requirements:

- Reporting against the Hort Innovation's current Strategic Plan and the Evaluation Framework associated with Hort Innovation's Statutory Funding Agreement with the Commonwealth Government.
- Annual Reporting to Hort Innovation stakeholders.
- Reporting to the Council of Rural Research and Development Corporations (CRRDC).

Under the impact assessment program (Project MT18011), three series of impact assessments were conducted in calendar 2019, 2020 and 2021. Each included 15 randomly selected Hort Innovation RD&E investments (projects). The third series of impact assessments (current series) was randomly selected from an overall population of 56 Hort Innovation investments worth an estimated $38.9 million (nominal Hort Innovation investment) where a final deliverable had been submitted in the 2019/20 financial year.

The 15 investments were selected through a stratified, random sampling process such that investments chosen represented at least 10% of the total Hort Innovation RD&E investment in the overall population (in nominal terms) and was representative of the Hort Innovation investment across six, pre-defined project size classes.

Project *MC14000: Macadamia Second Generation Breeding and Conservation* was randomly selected as one of the 15 investments under the third series for MT18011 and was analysed in this report.

General Method

The impact assessment follows general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including Research and Development Corporations, Cooperative Research Centres, State Departments of Agriculture, and some universities. The approach includes both qualitative and quantitative descriptions that are in accord with the impact assessment guidelines of the CRRDC (CRRDC, 2018).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, outcomes, and impacts. The principal economic, environmental, and social impacts were then summarised in a triple bottom line framework.

Some, but not all, of the impacts identified were then valued in monetary terms. Where impact valuation was exercised, the impact assessment uses cost-benefit analysis as its principal tool. The decision not to value certain impacts was due either to a shortage of necessary evidence/data, a high degree of uncertainty surrounding the potential impact, or the likely low relative significance of the impact compared to those that were valued. The impacts valued are therefore deemed to represent the principal benefits delivered by the project. However, as not all impacts were valued, the investment criteria reported for individual investments potentially represent an underestimate of the performance of that investment.

Background & Rationale

Background

Macadamia is an Australian native nut that grows in tropical and sub-tropical regions. Australia is the leading producer of macadamias and contributes more than 30% of the global crop with over 70% of Australian production exported annually (Australian Macadamia Society (AMS), n.d.).

The Australian macadamia industry currently is made up of around 700 growers with approximately 6.2 million trees planted across 22,000 hectares (AMS, n.d.). Macadamias are predominantly grown along the eastern seaboard of New South Wales (NSW) and Queensland (QLD) from Nambucca Heads (NSW) to Mackay (QLD). Approximately 56% of production is grown in QLD and 44% in NSW (AMS, n.d.).

Macadamia trees typically reach commercial yields from 6 to 7 years of age. A well-managed orchard of standard planting density (approximately 312 trees per hectare) currently is expected to yield a peak of 3.5 to 4 tonnes of in-shell nuts per ha (around 12-13 kilograms per tree) at maturity (Agricultural Marketing Resource Centre, 2017). Table 1 provides a summary of production statistics for the Australian macadamia industry for the three-year period from 2017/18 to 2019/20.

Table 1: Australian Macadamia Industry Statistics for the Period 2015/16 to 2019/20

Year (ended 30 June)	2018	2019	2020	3-Year Average
Total Trees (no.)[(a)]	5,570,536	6,157,906	6,353,815	6,027,419
Bearing Trees (no.)[(a)]	5,018,922	5,257,610	5,195,835	5,157,456
Production area (ha)[(b)]	19,750	19,750	19,750	19,750
Production (in-shell) (t) [b)]	49,300	42,900	45,200	45,800
Yield (t/ha)[(c)]	2.50	2.17	2.29	2.32
Gross Value ($m)[(b)]	297.3	193.9	245.1	245.4

Data Sources:
(a) Derived from ABS data from Agricultural Commodities Statistics (Series 7121.0
(b) Australian Horticulture Statistics Handbook 2017/18 to 2019/20 (Hort Innovation, various years)
(c) Derived based on total production and production area.

Rationale

Industry funding for an Australian macadamia breeding program commenced in 1996, initially led by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Topp, et al., 2016). More recently the macadamia breeding program had been led by the QLD Alliance for Agriculture and Food Innovation (QAAFI) at the University of QLD, with funding from Hort Innovation and the QLD Department of Agriculture and Fisheries (DAF) under Hort Innovation Project MC09021 (Macadamia Breeding and Conservation). This five-year breeding project (MC09021) ran from 2009 to 2013 and concentrated on finishing the evaluation of trials set up by CSIRO.

Project MC14000 (*Macadamia Second Generation Breeding and Conservation*) was funded to continue the macadamia breeding program. More specifically, MC14000 was funded to take the elite cultivar selections from the first generation (developed under previous projects) and use them as parents to deliver second generation genetic improvements, and another productivity step, for the Australian macadamia industry.

Project Details

Summary

Project Code: MC14000
Title: *Macadamia Second Generation Breeding and Conservation*
Research Organisation: QAAFI (University of QLD)
Project Leader: Bruce Topp
Period of Funding: January 2015 to December 2019

Objectives

The objectives of the breeding project MC14000 were to:

- Create new seedling populations and reduce the cost of breeding using multiple breeding strategies,
- Introduce genomics to reduce the breeding cycle time,
- Exploiting wild germplasm to increase genetic diversity, and
- Generate/ evaluate rootstocks for high performance.

Logical Framework

Table 2 provides a detailed description of the project in a logical framework.

Table 2: Logical Framework for Project MC14000

Activities	*Second generation of progeny* • Two pollination methods (hand pollination and a polycross progeny breeding strategy) were used to produce second generation macadamia cultivar progeny. • Hand pollinated progeny field trials were conducted at the QLD Bundaberg Research Station from 2012 to 2016. • Three distinct populations of progeny seedlings were developed and trialled. • Screening of progeny was conducted. This involved harvesting and weighing all nuts from each tree from years three to seven, as well as measurement of nut drop pattern in year six along with kernel recovery (KR) and tree size. • Traits were combined in a selection index to enable selection of elite cultivars. • Elite cultivars then were identified. These plants then were cinctured and grafted onto standard rootstock (H2) for planting in Regional Variety Trials (RVTs) being conducted under project MC17006 (Macadamia RVTs series 4). • Polycross progeny breeding was undertaken at the Maroochy Research Facility (MRF), Nambour (QLD). • Three trials were conducted for the polycross progeny: 1) Precocity trial, 2) Polycross progeny planted at growers' properties, and 3) High density population. • For the precocity trial, progeny were evaluated for early growth, flowering, yield, and nut characteristics. Selection was made at year five (in 2016) using a selection index. • In the second trial, seedling progeny were planted in four growers' trial sites at Childers, Alloway, Pine Creek and Emerald (QLD) between 2017 and 2018.

	• Yields were visually scored on a 0 (none) to 10 (high) scale in January and February of each year. Sample harvesting then was used to calibrate the rating scale. • Further evaluation of the trees was to be undertaken under the RVTs (MC17006) with final evaluation planned for 2024 and 2025. • For the high-density trial, progeny were planted in 2018 at MRF at 5,000 trees per hectare (ha). This was thought to potentially be the highest density fruiting orchard in the world at the time. • The high-density trees are expected to flower in 2022 and the resulting crop will be evaluated in 2023 for KR and all non-fruiting trees will be culled. • Progeny with KR over 40% will be evaluated using genomic selection for nut-in-shell (NIS) yield (and other traits). These elite trees then will be propagated in 2023 for secondary testing on grower properties. • Hand pollination experiments were conducted on 19 elite selections from the series 3 RVTs. • Cross-compatibility combinations were evaluated in the 2016 and 2017 growing seasons. • All trees under evaluation for cross-compatibility also were evaluated for nut setting under open pollination. • Selection strategies using yield component traits and genomics were explored in a PhD project (PhD student: Katie O'Connor) to reduce the lengthy and laborious selection cycle involved in breeding. • Genetic markers associated with nut characteristics and trunk circumference were identified, and a genomic model was developed to predict yield and yield stability. • Genetic gain was compared among traditional breeding methods and genomic selection methods. *Rootstocks and reduced tree size* • This component of the project was conducted with related project AI13004 (Transforming subtropical tree crop productivity). • 30 genotypes of seedings and cuttings from a range of origins were propagated between April and October 2014. • Under MC14000, in July 2016, a commonly grown scion 'HAES741' was grafted onto the rootstocks, and a trial was planted in April 2017. • The scion and rootstock both were phenotyped for growth characteristics and flowering in November 2017, May 2018 and May 2019. • Phenotyping was planned to continue until final measurements taken at year seven in 2024. • An investigation of tree vascular systems also was undertaken to identify vascular traits associated with reduced tree size. *Economic analysis and extension to growers* • A financial planner for macadamia (developed by DAF) was used to compare the relative economic performance of recent releases from the macadamia breeding program and RVTs. • 20-year cash flow forecasts were used to compare both annual net cash flow and cumulative cash flow for four recently released varieties (known as G, J, P and R) and compare these to established varieties (A16 and 741). • Irrigation establishment and operating costs were included in some scenarios.

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A communication strategy was developed at the beginning of the project to maximise growers' understanding of the breeding program and increase adoption of improved cultivars.
The strategy incorporated a range of communication methods including:
a) presentations at industry meetings,
b) field days and farm walks at breeding sites,
c) targeted articles in industry media,
d) evaluation surveys, and
e) direct communication with growers, consultants and members of the Macadamia Industry Variety Improvement Committee (MIVIC).
A survey of previous grower co-operators involved in progeny field trials was carried out in 2016. Eight owners and/or managers were surveyed about their experiences with breeding progeny field trials under their management.
The owners/ managers also were asked about their willingness to participate in future trials and, if so, how such trials could be better organised to suit their needs.

Pathology and entomology breeding research

In 2017, the precocity breeding trial was converted to a husk spot (Pseudocercospora macadamiae) disease-screening nursery.
Experiments were conducted in October 2017 and October 2018.
Husks were collected from diseased trees and hung over trees chosen to be evaluated.
Overhead sprinklers were used to create a moist environment to ensure spreading and infection of the disease to developing husks.
Knots in infected trees then were assessed for chlorotic flecking and premature nut drop.
A second PhD research project, supported by a Commonwealth scholarship, commenced in January 2019 to further investigate husk spot genomics (student: Jasmine Nunn).
Entomology breeding research was removed from the project activities in consultation with Hort Innovation and AMS due to budget constraints.

Wild germplasm trials and development

Materials used in the wild germplasm trials were originally collected in 2000 and 2001 from two ex situ germplasm field trials in Tiaro, QLD and Alstonville, NSW.
Wild accessions were genotyped for molecular markers by Diversity Arrays Technology (DArT), and 540 trees were phenotyped for various nut, flower and tree growth traits from 2017 to 2019.
A genetic diversity and population structure was conducted on all the accessions genotyped.
A genome-wide association study was performed to identify molecular markers associated with key breeding traits.

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<tr><td>Outputs</td><td>
Second generation of progeny

A total of 8,828 progeny were produced from second generation breeding.
From the hand pollination trials, and based on early performance data and selection indices, five elite cultivars were selected in 2019 for further testing.
The five elite varieties were planted in the series four RVTs (project MC17006).

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	• The five selected elite progeny (selected for precocity, KR, reduced growth and yield performance) showed potential for producing between 35% and 200% higher yields at age six to seven than that of existing precocious variety A4. • The selections were expected to contribute to early farm profitability at more than 35% than existing commercial varieties. • From the polycross breeding trials, 18 precocious progeny from the first trial were selected and propagated. • The 18 selected progeny (selected for precocity, KR, and reduced height) were expected to increase farm profitability by more than 30% through early production, high KR and reduced management costs. • Further, in the high-density trial (third trial), the project was able to reduce the nursery management costs by planting seedlings within six months of germination (rather than the conventional 24 months). • The project also was successful at reducing evaluation costs by approximately 80% through high density planting and shortening the progeny evaluation cycle by half (five years). • The project identified that 14 out of 19 selections from the series three RVTs showed some degree of self-compatibility and four of them had a significant level of self-compatibility. • The highly significant self-compatible elites were “K”, “Q”, “D” and “A”. • In 2016, Howell et al. presented a poster at the International Horticultural Congress. • One article on nut-setting has been published in Acta Horticulturae. • Katie O’Conner’s completed her PhD in 2019. Katie’s research found that none of the yield component traits studied were effective for indirectly selecting for high yield. • A genomic model was created to predict yield and yield stability in Australian macadamia orchards. • The identification of Quantitative Trial Loci for key traits is a useful resource and may provide input towards marker-assisted selection in the future. • The PhD study was the first to assess the prospect of employing genomic selection in macadamia. *Rootstocks and reduced tree size* • Under aligned project AI13004, data were generated on the effect of rootstocks on scion productivity, precocity and vigour. • Based on the study of macadamia vascular systems, it was hypothesised that the size of xylem vessel could explain variability in plant size. • Further investigation on a large number of genotypes and on the mechanism of xylem vessel mediated vigour control was recommended. *Economic analysis and extension to growers* • An economic analysis of the breeding program was completed. • The analysis compared the net present value (NPV), internal rate of return (IRR), annual net cash flow, and yearly cash balance of recently released varieties (G, J, P and R) with industry standard varieties (A16 and 741). • The analysis identified the new varieties’ long-term economic potential compared with industry standard varieties.

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A project communication strategy was developed and delivered including a wide range of published scientific and industry materials, presentations, field days/walks, etc.
A survey of eight grower co-operators was completed.
The survey identified potential trial sites for future progeny trials and a number of ways that researchers could improve communication and management protocols for future trials.

Pathology and entomology breeding research

105 accessions representing 17 cultivars and 28 progeny families were evaluated in the 2017-2018 fruiting season. In the 2018-2019 season, 385 plants (representing 32 families and 25 parents) were evaluated.
Data were generated on the variability of husk spot susceptibility in a large number of macadamia genotypes.
Screening for resistance on 212 wild accessions was ongoing and due to be completed in 2021.
Jasmine Nunn commenced PhD research into the genetics of resistance to macadamia husk spot.

Wild germplasm trials and development

The genome-wide study was conducted and completed. Results were peer reviewed and published (Bruce Topp, pers. comm., 2021).
A total of 304 wild accessions were genotyped for molecular markers by DArT, and 540 trees were phenotyped for various nut, flower and tree growth traits.
The research was presented at two international conferences.

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<tr><td>Key Outcomes</td><td>

Investment in project MC14000 focused on developing 20-30 advanced selections with superior genetics for evaluation under the RVTs Program. The investment was focused on accelerating genetic gain (Vino Rajandran, pers. comm., 2021).
Nuts produced from the pollination experiment are being used in a Hort Innovation ‘naturally nutritious’ project (HN15001).
Based on Katie O’Connor’s PhD research, a new progeny trial of 1,600 trees was planted at MRF to trial the new genomic selection model (under subsequent macadamia breeding project MC19000). The trees have been planted at 4m x 0.5m, making it one of the highest density plantings of a fruiting orchard recorded.
Katie’s research was an important step in the introduction of genomic tools into the macadamia breeding program and was part of a planned process to test the applicability of genomic methods. The work on genomics now has led to an Advance Queensland fellowship submission by Dr Mobashwer Alam on “Fast-track” breeding (Bruce Topp, pers. comm., 2021).
The genomics tools produced are likely to lead to more rapid release of cultivars to industry in the future through the selection of elite candidates several years earlier than previously possible using traditional phenotyping techniques.
Elite progeny identified and selected under MC14000 have been incorporated into ongoing RVTs (currently series four, Project MC17006) and are likely to provide the basis for new and improved commercial macadamia varieties in the future.

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Xylem vessel size in macadamia trees now may be used as a tool of early selection of breeding progeny.
Economic analysis of recently released varieties (G, J, P, and R) generated information that is likely to enhance adoption of the new varieties by growers.
Findings from the grower co-operator survey have been used to identify new grower trial sites and improve trial communication and management.
Early findings from the wild germplasm research are being used to inform the ongoing macadamia breeding program.
The findings of the genome-wide study have been used to form the basis for further RD&E investment to accelerate genetic gain (Vino Rajandran, pers. comm., 2021).
It is likely that wild germplasm will remain a key source of genetic diversity with the potential to introduce improved characteristics to future commercial varieties.
The breeding strategies, elite progeny and associated data generated by Project MC14000 are being used to:
a) Develop new and improved macadamia cultivars for the Australian industry to enhance productivity, profitability and international competitiveness, and
b) Inform the ongoing breeding program to ensure advances continue to be made,
c) Reduce costs associated with maintaining and evaluating progeny field trials through higher density planting, new breeding strategies and shortening the progeny evaluation cycle.
The Australian macadamia breeding program is ongoing under project MC19000 (National macadamia breeding and evaluation program).

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<tr><td>Potential Impacts</td><td>

[Economic] Increased average productivity and/or profitability for some Australian macadamia growers driven by:

The breeding program’s primary purpose, to produce elite selections for trial in the RVTs leading to the development of new, improved macadamia varieties (increased rate of genetic gain) (Bruce Topp, pers. comm., 2021).
Improved breeding strategies and tools leading to more rapid development of elite selections (reduced breeding cycle time).
Some contribution to the future release of new and improved macadamia cultivars selected for precocity, kernel recovery, reduced height and other key traits.
Some contribution to increased adoption of new and improved macadamia varieties because of improved grower engagement and communication and demonstration of the benefits of new varieties.
Contribution to reduced orchard management costs in the future (because of new varieties with improved precocity, better tree architecture, reduced disease pressure and enhanced resource use efficiency (Vino Rajandran, pers. comm., 2021)).

[Economic] Increased efficiency and/or effectiveness of resource allocation for macadamia breeding RD&E through:

Improved genomic models/tools leading to more rapid release of cultivars to industry (reduced breeding cycle time).
Improved selection of elite breeding progeny through use of new information and tools (e.g. xylem vessel size) (increased rate of genetic gain).

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	- Reduced nursery management costs through implementation of new breeding strategies such as higher density planting and planting seedlings within six months of germination rather than the conventional 24 months. This, in turn, results in up to an 80% reduction in progeny maintenance and evaluation costs. [Environmental] Some contribution to reduced on-farm chemical use in the future through the development of varieties with increased pest and disease resistance. This may lead to improved environmental outcomes such as increased beneficial biodiversity and reduced chemical export off-farm. [Social] Increased scientific knowledge and research capacity associated with macadamia breeding. [Social] Some contribution to enhanced future regional community wellbeing through spillover benefits associated with a more productive and/or profitable Australian macadamia industry.

Project Investment

Nominal Investment

Table 3 shows the annual investment made in Project MC14000 by Hort Innovation and other funding partners.

Table 3: Annual Investment in Project MC14000 (nominal $)

Year ended 30 June	HORT INNOVATION ($)	DAF[(a)] ($)	QAAFI[(a)] ($)	TOTAL ($)
2015	190,000	215,395	121,134	526,529
2016	68,000	77,089	43,353	188,442
2017	390,000	442,126	248,644	1,080,770
2018	400,000	453,463	255,020	1,108,482
2019	450,800	511,052	287,407	1,249,259
2020	489,489	554,912	312,073	1,356,475
Total	**1,988,289**	**2,254,037**	**1,267,632**	**5,509,958**

Source: MC14000 Executed Research Agreement and Contract Variation documents supplied by Hort Innovation 2021

(a) Derived based on the total DAF/ QAAFI contribution multiplied by the proportion of total Hort Innovation investment by financial year.

Program Management Costs

For the Hort Innovation investment the cost of managing the Hort Innovation funding was added to the Hort Innovation contribution for the project via a management cost multiplier (x1.162). This multiplier was estimated based on the share of 'payments to suppliers and employees' in total Hort Innovation expenditure (3-year average) reported in the Hort Innovation's Statement of Cash Flows (Hort Innovation Annual Report, various years). This multiplier was then applied to the nominal investment by Hort Innovation shown in Table 3.

For the DAF and QAAFI investment costs, it was assumed that management and administration costs were already built into the budget figures provided in Table 3. Therefore, a multiplier of 1.0 was applied to DAF and QAAFI costs.

Real Investment and Extension Costs

For purposes of the investment analysis, the investment costs of all parties were expressed in 2019/20 dollar terms using the Implicit Price Deflator for Gross Domestic Product (ABS, 2020). No additional extension costs were incorporated as the project included a high level of extension and communication through the MC14000 communication strategy.

Impacts

Table 4 provides a summary of the principal types of impacts delivered by the project, based on the logical framework. Impacts have been categorised into economic, environmental, and social impacts.

Table 4: Triple Bottom Line Categories of Principal Impacts from Project MC14000

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<tr><td>Economic</td><td>

Increased average productivity and/or profitability for some Australian macadamia growers driven by:

The breeding program's primary purpose, to produce elite selections for trial in the RVTs leading to the development of new, improved macadamia varieties (increased rate of genetic gain) (Bruce Topp, pers. comm., 2021).
Improved breeding strategies and tools leading to more rapid development of elite selections (reduced breeding cycle time).
Some contribution to the future release of new and improved macadamia cultivars selected for precocity, kernel recovery, reduced height and other key traits.
Some contribution to increased adoption of new and improved macadamia varieties because of improved grower engagement and communication and demonstration of the benefits of new varieties.
Contribution to reduced orchard management costs in the future (because of new varieties with improved precocity, better tree architecture, reduced disease pressure and enhanced resource use efficiency (Vino Rajandran, pers. comm., 2021)).

Increased efficiency and/or effectiveness of resource allocation for macadamia breeding RD&E through:

Improved genomic models/tools leading to more rapid release of cultivars to industry (reduced breeding cycle time).
Improved selection of elite breeding progeny through use of new information and tools (e.g. xylem vessel size) (increased rate of genetic gain).
Reduced nursery management costs through implementation of new breeding strategies such as higher density planting and planting seedlings within six months of germination rather than the conventional 24 months. This, in turn, results in up to an 80% reduction in progeny maintenance and evaluation costs.

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<tr><td>Environmental</td><td>

Some contribution to reduced on-farm chemical use in the future through the development of varieties with increased pest and disease resistance. This may lead to improved environmental outcomes such as increased beneficial biodiversity and reduced chemical export off-farm.

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<tr><td>Social</td><td>

Increased scientific knowledge and research capacity associated with macadamia breeding.
Some contribution to enhanced future regional community wellbeing through spillover benefits associated with a more productive and/or profitable Australian macadamia industry.

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Public versus Private Impacts

The impacts identified from the investment are both public and private in nature. Private impacts are likely to accrue to macadamia growers through increased future productivity/ profitability from adoption of new and improved macadamia varieties. Increased efficiency of resource allocation for macadamia breeding RD&E will impact both private and public stakeholders that fund such research (e.g. macadamia levy payers and state government departments). Also, some other public benefits may be produced in the form of increased capacity and spillovers to regional communities from enhanced industry performance.

Distribution of Private Impacts

Private impacts will be distributed between growers, processor/packers, wholesalers, exporters, and retailers. The share of impact realised by each component of the macadamia supply chain will depend on both short- and long-term supply and demand elasticities in the macadamia market.

Impacts on Other Australian Industries

No direct impacts to other Australian industries were identified. However, it is possible that increased scientific knowledge and research capacity may lead to spillover impacts for other Australian tree/nut crop industries.

Impacts Overseas

Though the Australian macadamia breeding program is focused on RD&E and breeding varieties specific to Australian growers and conditions, improved breeding strategies and genomic models/tools may have relevance to other macadamia growing regions such as the United States of America, southern Africa and China (International Nut and Dried Fruit Council, 2019).

Match with National Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table 5. The project outcomes and impacts are likely to contribute to Rural RD&E Priority 1 and 4, and to Science and Research Priority 1.

Table 5: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities (est. 2015)	**Science and Research Priorities (est. 2015)**
1. Advanced technology 2. Biosecurity 3. Soil, water and managing natural resources 4. Adoption of R&D	1. Food 2. Soil and Water 3. Transport 4. Cybersecurity 5. Energy and Resources 6. Manufacturing 7. Environmental Change 8. Health

Sources: (DAWE, 2019) and (Australian Government, 2015)

Alignment with the Macadamia Strategic Investment Plan 2017-2021

The strategic outcomes and strategies of the Australian macadamia industry are outlined in the Macadamia Industry's Strategic Investment Plan (SIP) 2017-2021[1] (Hort Innovation, 2017). Project MC14000 primarily addressed Outcome 1 through Strategy 1.5: 'Commit to long-term research to improve the understanding of the physiology of the macadamia, an Australian native with a relatively short history of domestication.'

[1] For further information, see: https://www.horticulture.com.au/hort-innovation/funding-consultation-and-investing/investment-documents/strategic-investment-plans/

Valuation of Impacts

Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly where some uncertainty was involved. Sensitivity analyses were undertaken for those variables where there was greatest uncertainty or for those that were identified as key drivers of the investment criteria.

Two economic impacts were valued:

1) Increased average productivity and/or profitability for some Australian macadamia growers.
2) Increased efficiency and/or effectiveness of resource allocation for macadamia breeding RD&E.

Impacts Not Valued

Not all of the impacts identified in Table 4 could be valued in the assessment. Those not valued included:

- Some contribution to reduced on-farm chemical use in the future through the development of varieties with increased pest and disease resistance. This may lead to improved environmental outcomes such as increased beneficial biodiversity and reduced chemical export off-farm.
- Increased scientific knowledge and research capacity associated with macadamia breeding.
- Some contribution to enhanced future regional community wellbeing through spillover benefits associated with a more productive and/or profitable Australian macadamia industry.

These impacts were not valued due to a lack of evidence and/or data to support credible assumptions. Further, as the impacts not valued represent environmental and social impacts, it was difficult to define the precise linkages between the investment and the impacts. Also, estimating monetary values for environmental and social impacts can be complex and require the application of resource intensive non-market valuation methods that were beyond the scope of the current assessment.

Valuation of Impact 1: Increased average productivity/ profitability for macadamia producers

Project MC14000 is likely to have contributed to increased average future productivity and/ or profitability for the Australian macadamia industry through:

a) The breeding program's primary purpose, to produce elite selections for trial in the RVTs leading to the development of new, improved macadamia varieties (increased rate of genetic gain) (Bruce Topp, pers. comm., 2021).
b) Improved breeding strategies and tools leading to more rapid development of elite selections (reduced breeding cycle time).
c) Some contribution to the future release of new and improved macadamia cultivars selected for precocity, kernel recovery, reduced height and other key traits.
d) Some contribution to increased adoption of new and improved macadamia varieties because of improved grower engagement and communication and demonstration of the benefits of new varieties.
e) Contribution to reduced orchard management costs in the future (because of new varieties with improved precocity, better tree architecture, reduced disease

pressure and enhanced resource use efficiency (Vino Rajandran, pers. comm., 2021)).

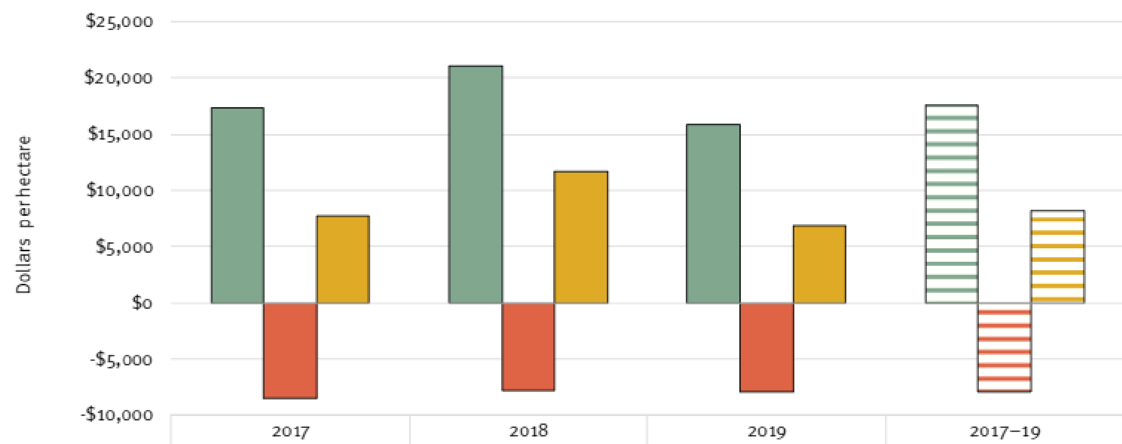
Current macadamia varieties are only two generations from their wild ancestor and the industry is considered to be behind in terms of efficient conversion of inputs to outputs (Vino Rajandran, pers. com., 2021). Increasing productivity and profitability for the Australian macadamia industry is a key priority in the Macadamia Industry SIP (Hort Innovation, 2017).

The performance of new varieties should be measured based on production values on a per tree or per ha basis to quantify the genetic gain (Vino Rajandran, pers. comm., 2021). However, as the primary focus of Project MC14000 was to accelerate genetic gain which, in turn, will contribute to the more rapid delivery of new and improved varieties in the future, the valuation of increased average net profitability (Impact 1) was based on a net increase in the average gross margin for new plantings of macadamia.

A long-term benchmarking study of the Australian macadamia industry, funded through the macadamia levy by Hort innovation (Projects MC15005 and MC18002), has provided data on macadamia production and profitability since 2009 (DAF, 2020). Figure 3 shows the median income, operating costs and gross margins per bearing hectare for mature farms that provided cost data for the 2017-2019 period. Medians are shown to identify the middle point of the sample and provide an estimate of what is typical within the benchmark pool. Income is estimated using a base price of $5.50/kg NIS @ 10% moisture content. The base price is adjusted for each farm according to the actual saleable kernel recovery achieved. The median of these adjusted prices for each season is shown in the table. Levies are also subtracted from the income figures shown. Operating costs include cash as well as unpaid labour, which has been imputed at a standard rate of $30 per hour. The gross margin is calculated for each farm by subtracting operating costs from income (DAF, 2020).

Specific assumptions for the valuation of Impact 1 are described in Table 6.

Figure 1: Median Income, Operating Costs and Gross Margins per Bearing Hectare for Mature Farms 2017-2019



	2017	2018	2019	2017–19
Income	$17,345	$21,065	$15,868	$17,587
Costs	$8,507	$7,773	$7,912	$7,912
Gross margin	$7,737	$11,637	$6,872	$8,242
KR adjusted price	$5.94	$6.07	$5.66	$5.88

Valuation of Impact 2: Increased efficiency/ effectiveness of resource allocation for macadamia breeding RD&E

The total investment in macadamia breeding since it began in Australia in 1996 was uncertain. However, based on the funding for Project MC14000, approximately $5.51 million (nominal dollars) was spent on macadamia breeding RD&E by Hort Innovation and its funding partners between January 2015 and December 2019 (approximately a five-year period).

Project MC14000 is likely to have increased the efficiency and/ or effectiveness of resource allocation for macadamia breeding RD&E through:

a) Improved genomic models/tools leading to more rapid release of cultivars to industry (reduced breeding cycle time).
b) Improved selection of elite breeding progeny through use of new information and tools (e.g. xylem vessel size) (increased rate of genetic gain).
c) Reduced nursery management costs through implementation of new breeding strategies such as higher density planting and planting seedlings within six months of germination rather than the conventional 24 months.

For the valuation of Impact 2, it was assumed that future macadamia breeding RD&E investments would be made in a more efficient manner than it would have been otherwise, in part because of the findings of Project MC14000. It was assumed that there would be an efficiency dividend equivalent to 5% of macadamia breeding RD&E spending over a 10-year period. That is, the same outcomes and impacts would be achieved with a 5% reduction in the RD&E spending that would have occurred without project MC14000.

Specific assumptions are described in Table 6.

Summary of Assumptions

A summary of the key assumptions made is provided in Table 6.

Table 6: Summary of Assumptions for Impact Valuation

Variable	Assumption	Source/Comment
Impact 1: Increased average gross margin for some Australia macadamia growers (mature farms)		
Estimated average gross margin for Australian macadamia producers	$8,242/ha	See Figure 1 (DAF, 2020)
Estimated current macadamia production area	19,750 ha under planting 85% of which is assumed to be of bearing age based on the average number of bearing trees relative to the total number of trees planted.	See Table 1
New area of macadamia planted annually	500 ha p.a.	Analyst assumption – conservative estimate based on the average conservative and optimistic forecast number of new trees planted between 2014 and 2026 (MC15009 Report, Appendix 1; Adam Briggs, pers. comm., 2021) at a density of 312

		trees/ha (DAF, 2020)
Maximum potential area for macadamia plantings	40,000 ha	Analyst assumption – assumes approximately a doubling of the total area planted to macadamia trees
Proportion of new plantings benefiting from the increased rate of genetic gain and release of new varieties	90%	Analyst assumption – assumes some producers continue to plant current/ old varieties in the short-term
First year of impact attributable to MC14000	2025/26	See Table 7
Total area of new macadamia plantings benefiting from genetic improvement attributable to the investment in Project MC14000	11,700 ha between 2026/27 and 2033/34	90% of 500 ha p.a. new area from with a max. potential area of 40,000 ha
Net increase in gross margin for macadamia producers adopting breeding program outputs	20%	Analyst assumption - conservative estimate based on findings from Project MC14000 where selected elite progeny (selected for precocity, KR, reduced growth and yield performance) showed potential for producing between 35% and 200% higher yields at age six to seven than that of existing precocious variety A4.
Risk Factors and Other Variables		
Probability of output	100%	Based on successful completion of MC14000 and ongoing investment in the macadamia breeding program.
Probability of outcome	100%	Based on existing adoption of new varieties and other outputs from the breeding program (level of adoption already accounted in 90% assumption above).
Probability of Impact	90%	Analyst assumption – accommodates the risk that exogenous factors may prevent the predicted impact from being achieved (e.g. adverse climate years).
Attribution of benefits to MC14000	See Table 7	Analyst assumption.
Counterfactual for Impact 1		
It was assumed that, without the Hort Innovation investment in MC14000, investment in		

macadamia improvement would not have continued[(a)].		
Impact 2: Efficiency Gains in Australian Macadamia Breeding RD&E Resource Allocation		
Estimated total average annual expenditure on macadamia breeding RD&E by Hort Innovation and other funding partners	$1.102 million p.a.	Based on $5.51 million over five years for Project MC14000
Efficiency dividend	20%	Analyst assumption - based on significantly useful findings from Project MC14000 (see items (a) through (c) listed under the description of Valuation of Impact 2 above)
RD&E saving with Project MC14000	$220,400 p.a.	20% x $1.102million p.a.
Year of first impact.	2019/20	First year of new investment in subsequent macadamia breeding RD&E (Project MC19000)
Last year of impact	2038/39	20-years after first year of impact – assumes diminishing relevance of outputs of MC14000 over time and a long (est. 10 year) breeding cycle for macadamia
Risk Factors and Other Variables		
Probability of output	100%	Based on successful completion of MC14000 and ongoing investment in the macadamia breeding program
Probability of outcome	100%	Based on existing adoption of new varieties and other outputs from the breeding program (level of adoption already accounted in 80% assumption above)
Probability of Impact	90%	Analyst assumption – accommodates the risk that exogenous factors may prevent the predicted impact from being achieved (e.g. adverse climate years)
Attribution of benefits to MC14000	100%	Analyst assumption
Counterfactual for Impact 2		
It was assumed that, without the Hort Innovation investment in MC14000, the efficiency dividend benefit would not have occurred.		

(a) Based on feedback from Project MC14000 Principal Investigator Professor Bruce Topp.

Attribution of Benefits for Impact 1

Breeding for tree crops typically takes significant time and long-term investment because of the growth rate of the crop. The research, development, trials, and commercialisation of new and improved macadamia varieties was estimated to currently take approximately 20 years. This assumption was based on the beginning of the macadamia improvement program under CSIRO in 1996 and the release of a first series of new macadamia varieties, (known as G, J, P and R) in 2017 (Hardner, Costa e Silva, Williams, Meyers, & McConchie, 2019).

The ongoing development of improved breeding strategies and techniques, and the continued future release of new and improved macadamia cultivars, is likely to be partially attributable to previous years of investment. To estimate the attribution of benefits from the ongoing adoption of outputs from the macadamia breeding program, and in particular, the attribution of benefits to the specific investment in MC14000, the following attribution table was developed (Table 7).

Table 7: Estimated Attribution of Benefits to Annual Macadamia Breeding Program Investment(a)(b)

Relevant Investment Period(c)	Year of Cultivar Release/ Adoption of Breeding Program Outputs(c)													
	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
2007														
2008														
2009														
2010														
2011														
2012														
2013														
2014														
2015		I	I	I	I	I	I	I						
2016			I	I	I	I	I	I	I					
2017				I	I	I	I	I	I	I				
2018					I	I	I	I	I	I	I			
2019						I	I	I	I	I	I	I		
2020							I	I	I	I	I	I	I	
2021														
Attribution of Benefits to Annual Investment	0.0%	6.7%	13.3%	20.0%	26.7%	33.3%	40.0%	40.0%	33.3%	26.7%	20.0%	13.3%	6.7%	0.0%

(a) Green shading indicates approximate seven-year period of breeding investment cycle for macadamias (e.g. investment in Project MC14000). Blue shading indicates the eight-year investment period for RVTs to release new varieties based on elite selections from the breeding program investment (testing plus propagation lag) excluding the year of cultivar release (based on breeding cycle information provided by Bruce Topp, pers. comm., 2021). Overall a 15-year breeding cycle to commercialisation.

(b) An "I" indicates a year of investment between 2014/15 and 2019/20 (duration of Project MC14000) relevant to the future release of new varieties/ adoption of breeding program outputs (horizontal axis).

(c) Year ended 30 June.

Note: Attribution of benefits is based on a similar attribution framework developed for evaluation of mungbean breeding RD&E investment (Chudleigh, Hardaker, & Abell, 2019).

Results

All costs and benefits were discounted to 2019/20 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. All analyses ran for the length of the project investment period plus 30 years from the last year of investment (2019/20) as per the CRRDC Impact Assessment Guidelines (CRRDC, 2018).

Investment Criteria

Tables 8 and 9 show the investment criteria estimated for different periods of benefits for the total investment and the Hort Innovation investment alone.

Table 8: Investment Criteria for the Total Investment in Project MC14000

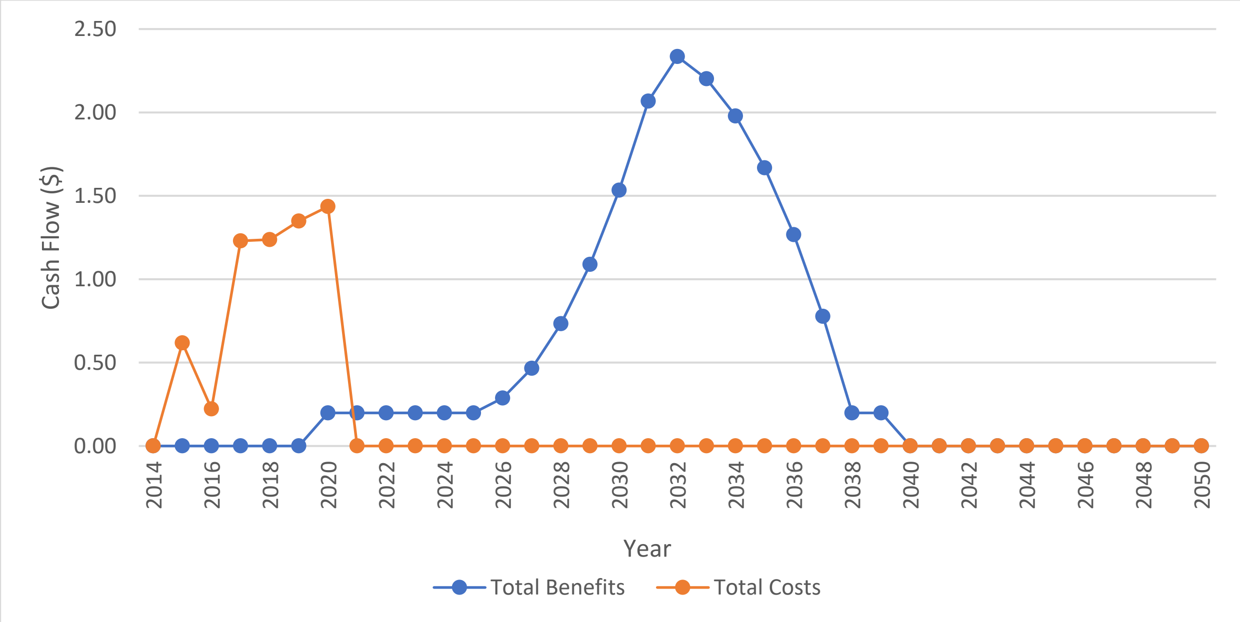
Investment Criteria	Years after Last Year of Investment						
	0	5	10	15	20	25	30
Present Value of Benefits ($m)	0.20	1.06	3.74	9.22	10.30	10.30	10.30
Present Value of Costs ($m)	6.70	6.70	6.70	6.70	6.70	6.70	6.70
Net Present Value ($m)	-6.50	-5.64	-2.96	2.52	3.60	3.60	3.60
Benefit-Cost Ratio	0.03	0.16	0.56	1.38	1.54	1.54	1.54
Internal Rate of Return (%)	negative	negative	negative	7.8	8.6	8.6	8.6
MIRR (%)	negative	negative	negative	6.2	5.4	4.3	3.6

Table 9: Investment Criteria for the Hort Innovation Investment in Project MC14000

Investment Criteria	Years after Last Year of Investment						
	0	5	10	15	20	25	30
Present Value of Benefits ($m)	0.08	0.42	1.48	3.65	4.08	4.08	4.08
Present Value of Costs ($m)	2.65	2.65	2.65	2.65	2.65	2.65	2.65
Net Present Value ($m)	-2.58	-2.23	-1.17	1.00	1.43	1.43	1.43
Benefit-Cost Ratio	0.03	0.16	0.56	1.38	1.54	1.54	1.54
Internal Rate of Return (%)	negative	negative	negative	7.8	8.6	8.6	8.6
MIRR (%)	negative	negative	negative	6.2	5.4	4.3	3.6

The annual undiscounted total benefit and cost cash flows for the duration of the MC14000 investment plus 30 years from the last year of investment are shown in Figure 2.

Figure 2: Annual Cash Flow of Undiscounted Total Benefits and Total Investment Costs



Sources of Benefits

Table 10 shows the relative contribution to the total Present Value of Benefits (PVB) for each of the two impacts valued in the assessment.

Table 10: Sources of Benefits (Present Value Terms)

Impact Valued	PVB ($m)	Proportion of Total PVB (%)
Impact 1: Net increase in average gross margin of macadamia production	7.70	74.8
Impact 2: Increased efficiency of breeding RD&E resource allocation	2.60	25.2
Totals	10.30	100.0

Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate. The analysis was performed for the total investment and with benefits taken over the life of the investment plus 30 years from the last year of investment. All other parameters were held at their base values. Table 11 presents the results. The results show a moderate to low sensitivity to the discount rate reflecting the lag between project cost and the generation of maximum project benefits.

Table 11: Sensitivity to Discount Rate (Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present Value of Benefits ($m)	17.99	10.30	6.27
Present Value of Costs ($m)	6.09	6.70	7.37
Net Present Value ($m)	11.89	3.60	-1.10
Benefit-cost ratio	2.95	1.54	0.85

Given that the estimated benefits for Impact 1 dominated the total PVB (74.8% of the total PVB), a sensitivity analysis then was undertaken for the net increase in the average macadamia gross margin assumed. Results are provided in Table 12. The investment criteria showed a moderate sensitivity to the assumed increase in gross margin.

A break-even analysis for this variable indicated that, holding all other assumptions at their base values, the investment criteria remain positive (benefit-cost ratio of 1:1) when the net increase in the average gross margin was 10.65%.

Table 12: Sensitivity to Increase in Average Gross Margin (Total investment, 30 years, 5% discount rate)

Investment Criteria	**Increase in Average Gross Margin**		
	10%	**20% (base)**	**30%**
Present Value of Benefits ($m)	6.45	10.30	14.15
Present Value of Costs ($m)	6.70	6.70	6.70
Net Present Value ($m)	-0.25	3.60	7.45
Benefit-cost ratio	0.96	1.54	2.11

A final sensitivity analysis tested the sensitivity of the investment criteria to the new annual area of macadamia plantings as this was considered a key driver of the investment criteria. The results (Table 13) show that the investment criteria were moderately sensitive to the annual area of new plantings assumed. As benefits from ongoing genetic improvement will primarily accrue to new plantings of macadamia, the total potential new area planted over time will be a key factor underpinning the realisation of the impacts of the breeding program.

Table 13: Sensitivity to the Assumed Annual Area of New Plantings Benefitting from Genetic Improvement (Total investment, 30 years, 5% discount rate)

Investment Criteria	**Annual Area of New Macadamia Plantings**		
	140 ha p.a.[(a)] (with a max. potential area of 66,000 ha)	**500 ha p.a. (with a max. potential area of 40,000 ha) (base)**	**800 ha p.a.[(b)] (with a max. potential area of 40,000 ha)**
Present Value of Benefits ($m)	4.75	10.30	14.92
Present Value of Costs ($m)	6.70	6.70	6.70
Net Present Value ($m)	-1.95	3.60	8.22
Benefit-cost ratio	0.71	1.54	2.23

(a) Based on the average conservative forecast number of new trees planted in MC15009 between 2014 and 2026 (MC15009 Report, Appendix 1) at a density of 312 trees/ha.
(b) Based on the average optimistic forecast number of new trees planted in MC15009 between 2014 and 2026 (MC15009 Report, Appendix 1) at a density of 312 trees/ha.

Confidence Rating

The results produced are highly dependent on the assumptions made, some of which are uncertain. There are two factors that warrant recognition. The first factor is the coverage of benefits. Where there are multiple types of benefits it is often not possible to quantify all the benefits that may be linked to the investment. The second factor involves uncertainty regarding the assumptions made, including the linkage between the research and the assumed outcomes.

A confidence rating based on these two factors has been given to the results of the investment analysis (Table 14). The rating categories used are High, Medium and Low, where:

High: denotes a good coverage of benefits or reasonable confidence in the assumptions made

Medium: denotes only a reasonable coverage of benefits or some uncertainties in assumptions made

Low: denotes a poor coverage of benefits or many uncertainties in assumptions made

Table 14: Confidence in Analysis of Project

Coverage of Benefits	Confidence in Assumptions
Medium-High	Medium

Coverage of benefits valued was assessed as medium to high as the two key economic impacts (net increase in gross margins and increased efficiency of breeding RD&E resource allocation) were valued.

Confidence in assumptions was rated as medium. Key data and assumptions were based on credible publicly available data and expert opinion (see Acknowledgments). However, as the exact benefits of future varieties produced and attributable, in part, to the investment in MC14000 were unknown, a moderate level of uncertainty still existed.

Conclusion

The investment in MC14000 has continued priority research in the Australian macadamia improvement program. Outputs from the investment in MC14000 have contributed an increased rate of genetic gain for the macadamia breeding program that, in turn, is likely to result in increased productivity and/or profitability for Australian macadamia producers through more rapid development and commercialisation of new and improved macadamia cultivars. Further, the investment has increased the efficiency and/ effectiveness of future investment in macadamia breeding RD&E.

Total funding from all sources for the project was $6.70 million (present value terms). The investment produced estimated total expected benefits of $10.30 million (present value terms). This gave a net present value of $3.60 million, an estimated benefit-cost ratio of 1.54 to 1, an internal rate of return of 8.6% and a modified internal rate of return of 3.6%.

A number of environmental and social impacts identified were not valued within the scope of the current assessment, therefore the investment criteria reported are likely to be an underestimate of the performance of investment in MC14000.

Given the long timeframes and significant past investment in macadamia breeding in Australia, the positive results of the assessment of the investment in MC14000 reflect the potential gains from the macadamia breeding program and should be viewed positively by Hort Innovation, the Australian government, other funding partners, the macadamia industry, and other key stakeholders.

Glossary of Economic Terms

Cost-benefit analysis:	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.
Benefit-cost ratio:	The ratio of the present value of investment benefits to the present value of investment costs.
Discounting:	The process of relating the costs and benefits of an investment to a base year using a stated discount rate.
Internal rate of return:	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.
Investment criteria:	Measures of the economic worth of an investment such as Net Present Value, Benefit-Cost Ratio, and Internal Rate of Return.
Modified internal rate of return:	The internal rate of return of an investment that is modified so that the cash inflows from an investment are re-invested at the rate of the cost of capital (the re-investment rate).
Net present value:	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.
Present value of benefits:	The discounted value of benefits.
Present value of costs:	The discounted value of investment costs.

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Abbreviations

ABS	Australian Bureau of Statistics
AMS	Australian Macadamia Society
CRRDC	Council of Rural Research and Development Corporations
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAF	Department of Agriculture and Fisheries (Queensland)
DArT	Diversity Arrays Technology
Ha	Hectare
Hort Innovation	Horticulture Innovation Australia Ltd
IRR	Internal Rate of Return
KR	Kernel Recovery
MIRR	Modified Internal Rate of Return
MIVIC	Macadamia Industry Variety Improvement Committee
MRF	Maroochy Research Facility
NIS	Nut-in-Shell
NPV	Net Present Value
NSW	New South Wales
PVB	Present Value of Benefits
QAAFI	Queensland Alliance for Agriculture and Food Innovation
QLD	Queensland
RD&E	Research, Development and Extension
RVT	Regional Variety Trial
SIP	Strategic Investment Plan