Hort Innovation

Final Report

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Horticulture Impact Assessment Program:

Appendix 7: Macadamia Genomic Development (MC15008 Impact Assessment)

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Delivery partner:

AgEconPlus and Agtrans Research

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What the report is about

This report presents the results of an impact assessment of a Horticulture Innovation Australia Limited (Hort Innovation) investment in MC15008*: Establishing an open-source platform for unravelling the genetics of Macadamia: integration of linkage and genome maps.* The project was funded by Hort Innovation over the years ending June 2016 to June 2019.

Methodology

The investment in MC15008 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).

Results/key findings

The investment in this macadamia genomic study has been successful in that it has already contributed to the macadamia breeding program by supplying linkage maps for use in their breeding activities. However, the principal impacts of the investment will be delivered after further development of genomic information relevant to macadamia breeding. This further development will most likely lead to future productivity and profitability improvements delivered to the Australian macadamia industry at some time in the future.

Investment Criteria

Total funding from all sources for the project was $185,000 (nominal $ terms) over four years. Hort Innovation contributed 93% of the total and Southern Cross University 7%.

The principal contribution of the MC15008 investment will be as an input to advancement of the future use of genomic technology in Australian macadamia breeding initiatives. However, the extent of the MC15008 contribution, while important, will be only one input to future macadamia breeding performance aided by genomics.

A number of uncertainties prevented any reasonable assumptions to be made regarding the attribution of the investment in Project MC15008 to the eventual useful application to macadamia breeding performance.

Due to the difficulties in making realistic assumptions, a decision was made not to attempt a valuation of the contribution of investment in MC15008 to any future impact from the use of genomic technologies in macadamia breeding. Hence, the Present Value of Investment Costs was estimated at $0.24 m, but the Present Value of Benefits was not estimated.

Conclusions

The investment in MC15008 has contributed to increased knowledge associated with the macadamia genome. This knowledge will undoubtedly be useful in the future as macadamia breeders utilise increased knowledge from Australian and overseas investment that further explore the macadamia genome.

Keywords

Impact assessment, benefit-cost analysis, genomics, macadamia genome, genome association studies, linkage maps, macadamia breeding

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 impact assessment program MT18011, the first series of impact assessments were conducted in 2019 and included 15 randomly selected Hort Innovation Research, Development and Extension (RD&E) investments (projects). The second series of impact assessments, undertaken in 2020, also included 15 randomly selected projects worth a total of approximately $7.11 million (nominal Hort Innovation investment). The third series of projects (current series) was 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 MC15008: Establishing an open-source platform for unravelling the genetics of Macadamia: integration of linkage and genome was randomly selected as one of the 15 investments under 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 actual and/or potential 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 used 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

Industry Background

Macadamia, an Australian native plant, is commercially grown in Australia, predominantly in Queensland and New South Wales, with minor production in Western Australia.

From 1975 macadamia production increased substantially, probably due to a combination of key factors influencing the industry in the early 1960s, including the involvement of CSR providing confidence in the industry, the availability of Hawaiian cultivars and technology, and improved grafting techniques (Wood et al, 1994).

Latest statistics from Hort Innovations suggest there are currently about 19,750 ha of macadamias planted in Australia. A five year time series for production, production value, and export value as published by Hort Innovation is provided in Table 1.

A longer time period of production and price published by Australian Macadamia Society, based on information provided by the Australian Macadamia Handlers Association, is provided in Table 2.

Table 1: Hort Innovation Statistics for Macadamia Industry 2016-2020

Year Ended 30 June	Area (ha)	Production (t)[(a)]	Value of Production ($m)	Export Value ($m)
2016	19,000	15,558	247.3	253.2
2017	19,000	15,329	255.5	291.0
2018	not available	16,629	207.8	190.1
2019	19,750	14,157	193.9	257.2
2020	19,750	14,916	245.1	233.9

(a) Production statistics above refer to Kernel Weight Equivalents

Table 2: Australian Macadamia Society Statistics for Macadamia Industry 2013-2019

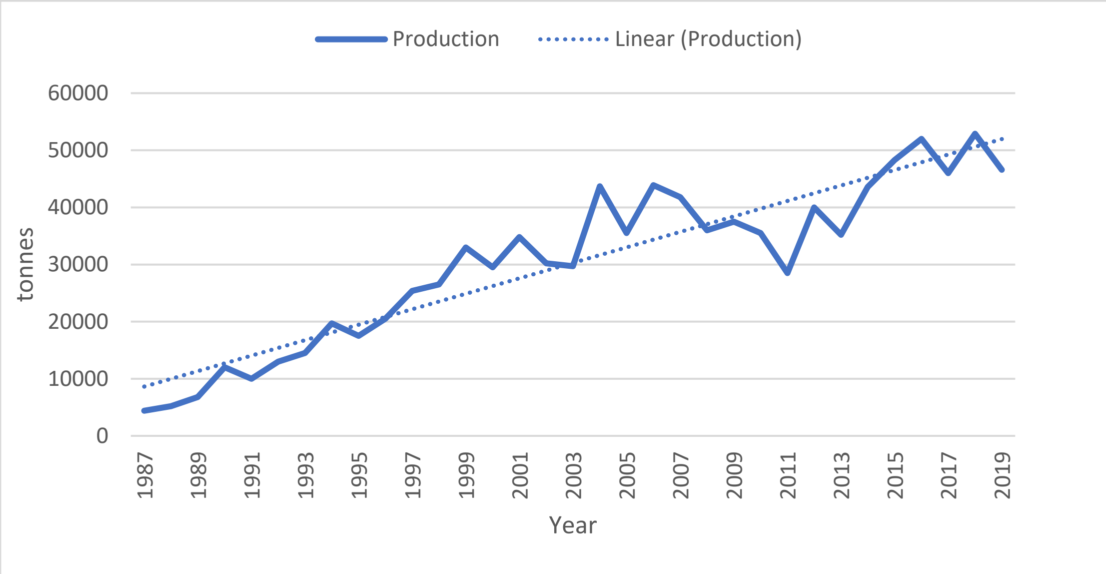
Year Ended 30 June	Production (t) (in shell)	Average Price (In shell) ($/kg)	Sound Kernel Recovery (%)
2013	35,200	3.00	31.81
2014	53,600	3.83	33.66
2015	48,300	5.09	33.64
2016	52,000	5.51	33.32
2017	46,000	5.62	34.33
2018	52,900	5.81	34.85
2019	46,600	5.83	33.78

Source: Australian Macadamia Society (2020)

In shell production volume at 10% moisture from 1987 to 2019 is provided in Figure 1; this Figures shows the production increase over the past 30 years up to 2019. The linear trend shows an increase of over 7,000 tonnes per annum. However, the production increase cannot be split into the contributions by area and yield.

The 2021 Australian macadamia crop is predicted to reach over 50,000 tonnes in-shell @ 3.5% moisture (54,440 tonnes in-shell @ 10% moisture), according to a forecast from scientific modelling from the Queensland Department of Agriculture and Fisheries. Macadamia imports into Australia are very small, for example 188 tonnes in 2020.

Figure 1: Australian Macadamia Production 1987-2019



Rationale for the Investment

While new plantings of macadamia trees have increased in Australia over the past decade, so too has the demand for high quality planting material. The project described in this evaluation has been directed in the long term at improving the performance of new planting material via new plant breeding technology. Better understanding the genetics of the macadamia tree can contribute to making improved crosses in the macadamia breeding program.

The macadamia breeding program currently is carried out by the Queensland Alliance for Agriculture and Food Innovation (University of Queensland) with funding assistance from Hort Innovation. End point targets include those of nut yield, kernel yield, kernel quality and tree performance.

Given such target traits, genome-wide associations between genes can be used to identify and better understand the causal genetic associations between traits in different prospective macadamia lines. Traits of most interest would include such traits as nut yields.

Developing trees with improved nut yields under traditional breeding takes time and is costly. This is because macadamia trees produce nuts only after a number of years, so considerable resources need to be applied. Genome-wide association studies are promising methods to reduce evaluation and selection cycles by identifying genetic markers linked with key traits, potentially enabling early selection through marker-assisted selection (O'Connor et al, 2020).

Project Details

Summary

Project Code: MC15008
Title: *Establishing an open-source platform for unravelling the genetics of Macadamia: integration of linkage and genome maps*
Research Organisation: Southern Cross University
Principal Investigator: Catherine Nock, Research Fellow, Southern Cross Plant Science, Southern Cross University
Period of Funding: 5 November 2015 to April 2019

Objectives

The project involved a team of geneticists and bioinformaticians and built on prior data and macadamia genomics research carried out by the project team. A PhD candiadate was also supported by the project. The overall objective of the investment was to build on previous investment carried out at Southern Cross University (SCU) that addressed the development of the first genome sequence data for macadamia. The objective of MC15008 was to develop a genetic linkage map for macadamia for the purpose of genome anchoring (Catherine Nock, pers. comm., June 2021).

A genetic linkage map is a map that identifies the relative locations of genes or genetic markers on the chromosomes. The linkage idea has significance in that the closer two genes are to each other on the chromosome then there is a greater probability that they will be inherited together.

Logical Framework

Table 3 provides a description of Project MC15008 in a logical framework format.

Table 3: Logical Framework for Project MC15008

Activities	• Populations of macadamias were developed specifically for the project by the Australia macadamia breeding program team and SCU. • Development of sequence defined genetic markers was carried out using next generation sequencing and bioinformatics techniques. • Screening of segregating mapping populations was undertaken, including self-pollinated, bi-parental and open-pollinated populations with HAES 741 parent. • Creation of a high density genetic linkage map for macadamia using single nucleotide polymorphism (SNP) and previously identified sequence-based markers, and anchoring of genetic sequence assemblies to chromosomes. • A PhD candidate (Kirsty Langdon) was supported by the project.
Outputs	• Early in the project macadamia genome assemblies were developed. • Mapping populations with cultivar HAES 741 parentage were developed and DNA paternity analysis was conducted. • An open source platform was developed to identify markers and genes linked to important crop traits, such as local adaptation, pest and disease resistance and improved productivity and profitability. • Genetic linkage maps were constructed for a number of cultivars; each linkage map comprised 14 linkage groups. • The genome assemblies, linkage maps, gene predictions and the assembled database provide an informative platform for improving macadamia genetics. • A PhD thesis by Kirsty Langdon was submitted in April 2020 and conferred in October 2020.

	• A number of peer-reviewed scientific publications were produced by the project team (see Reference list). • Communication of progress to the industry was made through presentations at conferences and articles in the Australian Macadamia Society Newsletter.
Outcomes	• All output data have been deposited in publicly available repositories. • Katie O'Connor used the 741 genome assemblies during her PhD research (O'Connor et al. 2019, 2020). • The breeding program team requested linkage map data from data repository and co-analysed DArT (SNP) data from our study with their data (including that collected by Katie O'Connor and Thuy Mai for their PhD research) (Catherine Nock, pers. comm., June 2021). • Hence, the macadamia breeding program has commenced using the genome and linkage maps in their breeding activities • The 741 assemblies were the first for macadamia (Nock et al. 2016, Nock et al. 2020). Genomic sequencing technologies and bioinformatic pipelines continue to advance rapidly making genome assembly and resequencing now relatively much simpler and cheaper than at the time the project commenced in 2015. • Improvement of the 741 genome and resequencing of other cultivars is currently happening through Hort Innovation National tree genomics program (AS17000) led by the University of Queensland (Catherine Nock, pers. comm., June 2021). • Also, Catherine Nock is collaborating with an international team that have developed a chromosome-scale assembly for 344 (under review). Separate teams in Hawaii and South Africa are assembling other genomes of interest. • Once there are several high quality genome assemblies and reassembled genomes, then extending the genomic selection work initiated by Katie O'Connor should identify genes/markers associated with important traits to accelerate selective breeding. • Further improvement of the 741 genome assembly would be beneficial as would comparative genome sequences from other important industry cultivars. • As this project (MC15008) represented only a relatively small investment, is it likely that there will be further investment required in genomic analyses before macadamia breeders can use genomic information most effectively in their breeding program. • Once genomic information is used widely by breeders, it will allow them to accelerate selective breeding and produce varieties superior to the varieties that they would have produced without the genomic information.
Impacts	• A contribution to the recent macadamia breeding program investment (Project MC14000) via the production of the linkage map data. • Potentially, the future Australian macadamia industry will benefit from the use of improved genomic information in breeding of new varieties that will lead to productivity and profitability gains by growers. • Any Australian prospective future productivity gains based on genomic information will be likely to maintain or increase the Australian competitive advantage over macadamia production in other countries. • Potentially, improved regional community wellbeing will be delivered from spillover benefits from any future increases in macadamia grower and supply chain profitability. • The project has made a contribution to increased skills and knowledge of scientists and macadamia breeders working with the macadamia genome.

Project Investment

Nominal Investment

Table 4 shows the annual investment (cash and in-kind) in project MC15008 by Hort Innovation and Southern Cross University.

Table 4: Annual Investment in the Project MC15008 (nominal $)

Year ended 30 June	Hort Innovation ($)	Southern Cross University ($)	Total ($)
2016	45,000	3,819	48,819
2017	50,000	4,244	54,244
2018	35,000	2,971	37,971
2019	40,526	3,440	43,966
Totals	170,526	14,474	185,000

Source: MC15008 Project Research Agreement supplied by Hort Innovation 2021

Program Management Costs

For the Hort Innovation investment the cost of managing and administration of funding was added to the Hort Innovation contribution for the project via a management cost multiplier (1.162). 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 4.

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 costs of extension were included as the project itself heavily involved the industry and was totally industry oriented.

Impacts

Table 5 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 5: Triple Bottom Line Categories of Principal Impacts from Project MC15008

Economic	• A contribution to the recent macadamia breeding program investment (Project MC14000) via the production of the linkage map data. • Potentially, the future Australian macadamia industry will benefit from the use of improved genomic information in breeding of new varieties that will lead to productivity and profitability gains by growers. • Any Australian prospective future productivity gains based on genomic information will be likely to maintain or increase the Australian competitive advantage over macadamia production in other countries.
Environmental	• Nil
Social	• Potentially, improved regional community wellbeing will be delivered from spillover benefits from any future increases in macadamia grower and supply chain profitability. • The project has made a contribution to increased skills and knowledge of scientists and macadamia breeders working with the macadamia genome.

Public versus Private Impacts

The impacts identified from the investment are predominantly private impacts that will be captured by macadamia growers and their supply chains from new plantings of macadamias. However, some public benefits have been produced in the form of increased scientific capacity and increased value of spillovers to regional communities.

Distribution of Private Impacts

The private impacts on future macadamia growers will be distributed along the relevant macadamia supply chains. The share of impact realised by supply chain participants will depend on both short-and long-term supply and demand elasticities that are experienced along the various linkages in the macadamia supply chains.

Impacts on Other Australian Industries

It is likely that most impacts will be confined to the Australian macadamia industry, including their input and output supply chains.

Impacts Overseas

It is unlikely that there will be any direct spillover impacts to overseas industries.

Match with National Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table 6. The project outcomes and related impacts will contribute primarily to Rural RD&E Priorities 1 and 4, and to Science and Research Priority 1.

Table 6: 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, 2021) 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 2017-2021[1] (Hort Innovation, 2017). Project MC15008 primarily addressed the following outcome "Improved production systems including plant breeding, intensive orchards and novel technologies" through the following strategy "Develop noverl technologies that facilitate improved production systems".

[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/ not Valued

While the contribution of Project MC15008 was recognised in the latest macadamia breeding project (MC14000, this was not the principal purpose or impact of MC15008). Furthermore, the extent of the contribution of linkage map data from MC15008 was not readily available and therefore no attribution to any input from MC15008 was considered.

Rather, the key benefits of the MC15008 investment will be in contributing to the advance of the future use of genomic technology in future Australian macadamia breeding initiatives.

However, the extent of the MC15008 contribution, while important, will be only one input to future macadamia breeding performance aided by genomics. The various uncertainties that prevent any reasonable attribution to the impact of future macadamia breeding performance from MC15008 may include such factors as:

- The timing of release of new future macadamia varieties influenced by genomic technologies,
- The extent of the contribution to such releases e.g. kernel yield,
- The cost and timing of additional investment in genomics required,
- The achievement of macadamia genomic research that is proceeding in other locations, such as, for example, in Hawaii and South Africa.

Hence, due to the nature and extent of these uncertainties, a decision was made not to attempt a valuation of the future impact from the investment in Project MC15008.

Results

All costs were discounted to 2019/20 using a discount rate of 5%. As no impacts from this project were valued the investment criteria results are limited to the reporting of the Present Value of Costs.

Investment Criteria

Tables 7 and 8 show the Present Value of Costs estimated for different periods for the total investment and the Hort Innovation investment alone.

Table 7: Present Value of Costs for Total Investment in Project MC15008

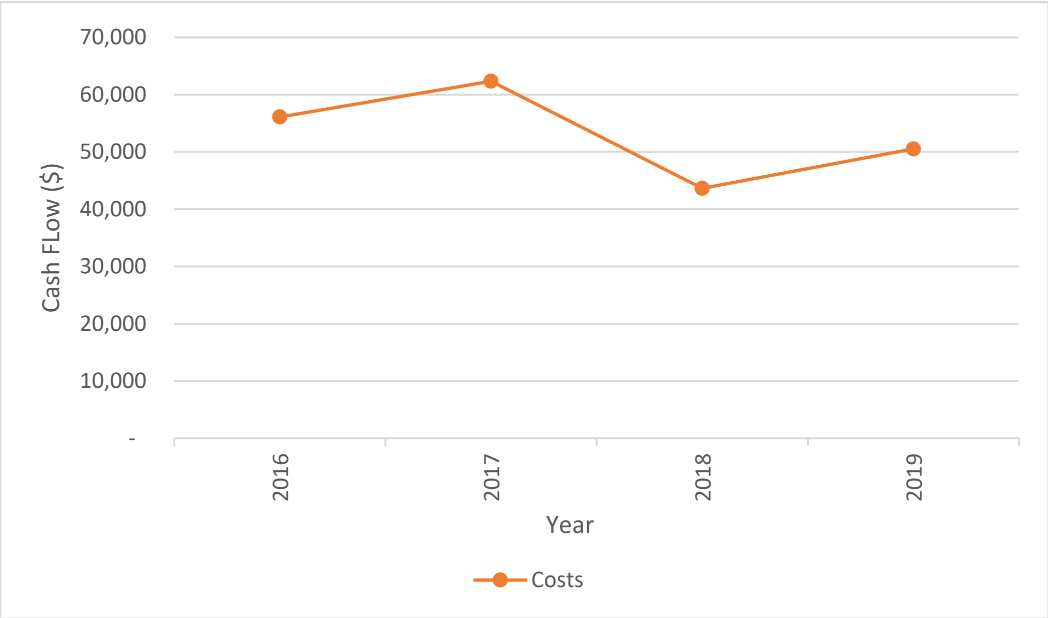
Investment Criteria	**Years after Last Year of Investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present Value of Costs (m$)	0.26	0.26	0.26	0.26	0.26	0.26	0.26

Table 8: Present Value of Costs for Hort Innovation Investment in Project MC15008

Investment Criteria	**Years after Last Year of Investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present Value of Costs (m$)	0.24	0.24	0.24	0.24	0.24	0.24	0.24

The annual undiscounted cost cash flows for the total investment for the duration of the MC15008 investment are shown in Figure 1.

Figure 1: Annual Cash Flow of Undiscounted Total Investment Costs



Conclusion

The investment in MC15008 was only a small strategic investment at $0.26 m in present value terms. The investment is likely to contribute positively to the advancement of the use of genomic information in future macadamia breeding. However, it was not possible to estimate the extent of such a contribution in the future and therefore no other investment criteria have been reported for the evaluation of MC15008.

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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Catherine Nock, Research Fellow, Southern Cross Plant Science, Faculty of Science and Engineering, Southern Cross University

Abbreviations

CRRDC	Council of Research and Development Corporations
DAWE	Department of Agriculture, Water and the Environment (Australian Government)
$m	million $
R&D	Research and Development
RD&E	Research, Development and Extension
SCU	Southern Cross University
SNP	Single Nucleotide Polymorphism
t	tonnes