Impact assessment of the investment:

Improved tree and fruit nutrition for the Australian apple industry (AP14023)

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Previous page image courtesy of https://www.applesoils.com/.

Disclaimer:

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Executive summary

What the report is about

Ag Econ conducted an independent analysis to determine the economic, social, and environmental impact resulting from the delivery of the apple and pear project *AP14023 Improved tree and fruit nutrition for the Australian apple industry*. The project was funded by Hort Innovation over the period November 2015 to October 2021 using the apple and pear research and development levy and contributions from the Australian Government.

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

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

Research background

The project conducted trials and research to gain an improved understanding of apple orchard nutrient and irrigation management leading to improved recommendations and resources for industry. The project also conducted a range of communication and extension activities to support industry awareness and adoption. The *Strategic Irrigation and Nitrogen Assessment Tool for Apples* (SINATA) decision support tool (DST) developed in AP14023, is undergoing further development through follow-on research (AP19006), but was already at a point to support initial adoption.

Key findings

The nominal investment cost of $1.4 million was adjusted for inflation (ABS, 2023) and discounted (using a 5% real discount rate) to a present value (PV) of costs equal to $2.1 million (2022-23 PV).

The analysis found a clear impact pathway for AP14023, with the updated recommendations on nitrogen (N) fertiliser application supporting reduced farm fertiliser costs (economic impact), and reduced N losses through runoff, leaching and greenhouse nitrous oxide emissions associated with nitrogen fertiliser application (socio-environmental impact). These two impacts were quantified, with a PV benefits to $3.63 million (over 30 years with 5% discount rate).

Compared to the PV research costs of $2.15 million (5% discount), this generated a baseline impact with a benefit cost ratio (BCR) of 1.69:1 attributable to AP14023.

Sensitivity testing gave a high level of confidence that AP14023 would generate a positive impact (benefits greater than costs) with 86% of simulated results having a BCR greater than 1. The was a relatively narrow range for the results, with 90% of simulated results falling between 0.80:1 and 2.72:1. The results were most sensitive to changes in the post-harvest N uptake efficiency (NupE), which also had a large potential value range, and which drove the benefits of switching to the more efficient pre-harvest fertiliser application. The relatively low contribution of avoided nitrous oxide emissions was due to the relatively low level of carbon dioxide equivalent (CO_2-e) emissions per unit of fertiliser, combined with a relatively low value of CO_2-e emissions ($34/tonne in 2023) relative to the cost of N fertiliser ($1665/t in 2023). The carbon price was projected to grow at a faster rate than that of N fertiliser potentially reaching $100/t by 2030; however this did not have a material impact on the results given the relatively low level of emissions per unit of fertiliser and the declining attribution for impacts beyond 2030 due to likely ongoing changes in production systems, N products, and recommendations.

Several other social and environmental impacts are expected to be realised from the investment , but were not quantified as a result of data limitations. As such the quantified impacts represent a conservative estimate of the total potential impact that would be realized through optimized nutrition management practices for the apple industry supported by the project.

The key findings of the AP14023 impact assessment are summarized in Figure 1 below.

Keywords

Impact assessment, cost-benefit analysis, apple, nitrogen uptake efficiency, tree nutrition, soil profile, irrigation, fertigation

Figure 1. Summary of impact assessment findings

AP14023 Improved tree and fruit nutrition

RD&E activities

RD&E costs:

- $1.4 million (nominal value)
- 43% R&D levy and Government matching, and 57% Tasmanian Institute of Agriculture in-kind.

Research activities:

- Fertigation trials investigating nutrient and irrigation efficiency
- Industry wide soil characterization
- Develop Decision Support Tool (DST): *Strategic Irrigation and Nitrogen Assessment Tool for Apples* (SINATA)

Extension activities:

- Deliver SINATA to growers and advisors in key regions
- 10 industry fact sheets and articles
- 16 industry training events (field days, workshops, interviews)

Outcomes

Outcomes:

- Improved knowledge, skills and resources relating to best practice nutrient and irrigation management in apple production, including through the SINATA DST.

Industry adoption:

- Transition nitrogen (N) application from post-harvest to pre-harvest, increasing N uptake efficiency (NUpE).
- Estimated adoption of 85% by 2031 supported by ongoing refinement of SINATA in AP19006.

Impacts

Economic impacts:

- Reduced fertiliser input costs

Environmental impacts:

- Reduced fertiliser leaching, runoff and emissions

Social impacts:

- Sustainable domestic apple supply supporting consumption with health benefits.
- Improved community resilience and wellbeing.

Total impact:

- $3.63 million benefit over 30 years
- Net Present Value of $1.48 million
- Benefit cost ratio (BCR) of 1.69:1, with a 90% confidence of a BCR between 0.80:1 and 2.72:1

Introduction

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

Reflecting its commitment to continuous improvement in the delivery of levy funded research, development and extension (RD&E), Hort Innovation required a series of impact assessments to be carried out annually on a representative sample of investments of its RD&E portfolio. Commencing with MT18011 in 2017-18, the impact assessment program consisted of an annual impact assessment of 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).

Project *AP14023 Improved tree and fruit nutrition for the Australian apple industry* was randomly selected as one of the 15 investments in the 2021-22 sample. This report presents the analysis and findings of the project impact assessment. The report structure starts with the general method of analysis used, followed by the RD&E background and an outline of the impact pathway in a logical framework, then describes the approach used to quantify the identified costs and benefits including any data gaps and limitations to the analysis, presents the results including from the sensitivity analysis, and finally discusses any implications for stakeholders.

General method

The impact assessment built on the impact assessment guidelines of the CRRDC (CRRDC, 2018) and included both qualitative and quantitative analysis. The general method that informed the impact assessment approach was 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 stakeholders (see *Stakeholder Consultation*)
3. Through a logical framework, qualitatively map the project's impact pathway, including, activities, outputs, outcomes and the principal economic, environmental, and social impacts.
4. Collect available data to quantify the impact pathway and estimate the attributable impacts using cost-benefit analysis (over a maximum 30 years with a 5% discount rate), and then sensitivity test the results to changes in key parameters.
5. Discuss the implications for stakeholders.

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

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.

Two Stakeholder Case Studies (Victoria and South Australia) were developed to compliment this impact assessment and illustrate how the identified impacts have been realised in a practical setting. The case studies can be accessed via the Hort Innovation project page [Horticulture Impact Assessment Program 2020/21 to 2022/23 (MT21015)](). A more detailed discussion of the method can be found in the *MT21015 2021-22 Summary Report* also on the Hort Innovation project page.

Project background

Since 2009 the Australian apple industry has invested in a collaborative research program focusing on developing orchard productivity with a focus on: irrigation; tree and pest management; soil and nutrition specific to Australian conditions. The "PIPS" (Productivity, Irrigation, Pests, Soils) program was developed to support the ongoing competitiveness of Australian growers amidst a global operating environment characterised by innovative and low cost producers. The first phase of PIPS concluded in 2015 and established several research foundations, including the development of a research trial which focused on nutrition management through fertigation and irrigation (project AP12006). This research supported a simple protype nitrogen (N) budget by quantifying the nitrogen uptake efficiency (NupE) that accounted for the flow of N from key sources of fertigation and mineralisation, though outputs of drainage, prunings and fruit removal, and storages of tree remobilisation and soil N content.

The learnings from project AP12006 in conjunction with industry feedback identified the opportunity to further develop grower understanding of nutrition and irrigation management to support productivity. Project AP14023 was developed in response to this opportunity and was initiated through the subsequent PIPS2 program. The specific objectives of AP14023 were to:

- Define a complete N budget to inform fertiliser management for commercial application by apple growers.
- Develop a grower decision-tool to enable growers and advisors to optimise irrigation and fertiliser strategies and management practices, based on underlying soil types and climates.

Project AP14023 was completed in during the Apple and Pear 2017-2021 Strategic Investment Plan, through which it aligned to Outcome 1: *Industry profitability and global competitiveness is improved by reducing the average cost per carton*.

Project details

The Tasmanian Institute of Agriculture was selected as the lead delivery partner, with the project running from 2015 to 2021 (Table 1).

Table 1. Project details

Project code	AP14023
Title	Improved tree and fruit nutrition for the Australian apple industry
Research organization	The University of Tasmania, Tasmanian Institute of Agriculture (TIA) Plant and Food Research, New Zealand (PFR)
Project leader	Nigel Swarts
Funding period	November 2015 to October 2021
Objective	Support strategic on farm irrigation and nutrient management decisions for apple growers to optimise productivity

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

Fertigation Trials

- Continue fertigation trials from AP12006 at Lucaston across two seasons (2016 and 2017) focusing on rate and timing of N application in context of varying irrigation on fruit quality and productivity.
- Conduct a ^{15}N (stable N isotope used to track N movement) trial in 2017-18 to investigate the affect of timing of N application (pre and post harvest) on uptake, allocation, and remobilization.
- Operate a nitrogen phosphorus and potassium (NPK) fertigation trial in 2018-19 to determine NPK interactions at different application rates.
- A soil mineralization trial in 2015 and 2018 to predict the ability of the soil to supply N through laboratory incubation.
- Incorporate data into the Soil Plant Atmosphere System Model (SPASMO) to adapt for Australian production conditions.

Development of a Decision Support Tool (DST): *Strategic Irrigation and Nitrogen Assessment Tool for Apples (SINATA)*

- Detailed soil chemical, physical, structural and morphological assessments were completed on 40 orchard blocks from five growing regions across Australia.
    - Soil characterisation data was incorporated into the Soil Plant Atmosphere System Model (SPASMO), in collaborative with Plant and Food Research New Zealand (the SPASMO developers) to provide the backbone for the DST.
- Develop an excel based DST by incorporating the soil characterisation, in conjunction with data from the nitrogen fertigation trials, and tree water use (sap flow) research, the Bureau of Meteorology, and general data from the OrchardNet Focus Orchards
- DST testing and verification of DST performance using data from project trials.
- Deliver DST training through Future Orchards (AP15005) (8 regions in total during 2020).

General communication and extension activities covering research progress, findings, and outputs

- 10 industry fact sheets and articles
- 16 industry training events (field days, workshops, interviews)

RD&E outputs

- Final reports on trial data findings and recommendations.
- An online resource (with support from RMCG) for stakeholders to access the multi-site soil parameterisation (http://www.applesoils.com/)
- An excel based irrigation and nutrition DST (SINATA) made available to industry in the 2021-22 season..
- Industry communication and extension activities/outputs as above

Outcomes

- Improved knowledge, skills and resources relating to best practice nutrient and irrigation management in apple production, including through the SINATA DST.
    - The research identified that pre-harvest N (and other nutrients) was taken up by trees much more efficiently (NupE of 32%) compared to post-harvest N (which was the previous industry recommendation and standard practice with a NupE of 17%) with no yield or quality changes. As such, the research advocated for a much lower rate of fertigated N applied pre-harvest to maximize uptake. While available for broad industry use, the SINATA DST was focussed primarily at agronomists to support their advice to growers. Further, at the time of this analysis, the excel based DST was undergoing development into a real time grower facing tool through AP19006, with expectations it would be available to industry in the 2024-25 season.

Impacts

- [Economic] Adoption of the SINATA DST and associated recommendations for irrigation and nitrogen management, helping to improve orchard resource use efficiency and productivity (outputs per unit of irrigation or N input). In particular, the recommendations relating to pre-harvest N application supports increased nutrition application efficiency (i.e. reduced system losses) in turn supporting reduced fertiliser application and cost with no penalty in income.
- [Socio-environmental] Optimised use of fertiliser inputs (e.g. N) reducing associated risk of environmental runoff, leaching, and nitrous oxide (N_2O) emissions.
- [Environmental] Improved irrigation efficiency supports responsible water use, contributing to reducing the overall water footprint of commercial apple production.
- [Socio-economic] Increased contribution to regional community wellbeing from more profitable apple growers.
- [Socio-economic] Increased economic sustainability of the supply of fresh and affordable domestic apple produce, supporting consumption with associated health and wellbeing benefits.

Project costs

The project was funded by Hort Innovation, using the apple and pear research and development levy and contributions from the Australian Government, with additional funding from TIA (Table 3). Where relevant, overhead costs were added to the direct project cost to capture the full value of the RD&E investment.

Nominal investment

Table 3. Project nominal investment

Year end 30 June	Hort Innovation project costs ($)	Hort Innovation overheads[1] ($)	TIA In-Kind[2] ($)	Total nominal cost ($)
2016	160,000	27,207	56,634	243,841
2017	200,000	29,912	70,793	299,704
2018	180,000	34,737	63,713	278,450
2019	170,000	23,429	60,174	253,602
2020	35,000	5,915	12,389	53,304
2021	180,000	29,238	63,713	272,951
2022	Final payment incurred in FY21			
Total	**925,000**	**149,437**	**327,416**	**1,401,853**

1. The overhead and administrative costs were calculated from the Financial Operating Statement of the Hort Innovation Apple and Pear Fund Annual Reports, averaging 16.3% for the AP14023 funding period (2016-2021).
2. Other funds from TIA 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 of $1.40 million identified in Table 3 was adjusted for inflation (ABS, 2023) into a real investment of $1.69 million (2022-23 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 $2.15 million (2022-23 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 was evaluated against available data to determine if the impacts could be quantified with a suitable level of confidence. From this process, two impacts were able to be quantified.

Impacts valued and valuation framework

[Economic] Reduced N fertiliser cost from increased application efficiency and reduced application. The adoption of the SINATA DST and associated recommendations for irrigation and nitrogen management supports improved orchard resource use efficiency and productivity (outputs per unit of irrigation or N input). In particular, the recommendations relating to pre-harvest N application support increased nutrition application efficiency (i.e. reduced system losses) in turn supporting reduced fertiliser application and cost with no penalty in income. Potential grower savings were identified by comparing existing post-harvest application of N with the reduced pre-harvest N application recommended in the project. This was scaled up to an industry level by estimating an adoption and diffusion curve using stakeholder feedback and project data to inform inputs into the CSIRO ADOPT framework (Kuehne et al 2017). The adoption curve considered initial (lower) adoption of the excel based DST developed in AP14023, with later higher adoption as a result of the further development into a more user friendly app through AP19006. The attribution of the full results was considered in relation to contributing investment costs through projects AP12006 and AP19006, and a suitable outcome attribution factor was applied. Finally, the potential for the research to have been conducted without levy investment was also considered, with results adjusted down by an estimated R&D counterfactual factor.

[Socio-environmental] Reduced nitrous oxide emissions from lower N fertiliser application. Optimised use of fertiliser inputs (e.g. N) would reduce the associated risk of N_2O emissions with associated greenhouse gas (GHG) effect. The project research found that the N_2O emissions from apple orchards were very low on an area basis, with a corresponding low contribution to global warming potential. The research also found a lack of correlation between the rate of N fertiliser application and the magnitude of subsequent N_2O emissions. The project found that while the rate of N fertiliser clearly increases the risk of N_2O emissions, the actual emissions are more closely associated with soil environmental conditions than the quantity of fertiliser. AP14023 did note; however, that N_2O emissions are higher in warmer months, and with typical post-harvest application of N fertiliser occurring during the warmer summer–autumn months when soil temperatures are at their highest, there was a potential to mitigate emissions through improved N application practices such as moving to pre-harvest application as recommended in the project. The impact of the reduced N_2O emissions associated with improved NUpE and reduced N application was calculated by estimating the rate of emissions per unit of applied N fertiliser (from Swarts et al 2016 in Annex 1 of AP14023 final report). This was then applied to change in applied N as a result of moving from a higher post-harvest rate to a recommended lower pre-harvest N rate. The avoided emissions were valued by converting N_2O to carbon dioxide equivalent (CO_2-e) and valuing this at the current and projected market price for carbon (Jarden 2022).

Impacts unable to be valued

[Economic and environmental] Improved irrigation efficiency supports responsible water use, contributing to reducing the overall water footprint of commercial apple production. The analysis of water application rates was conducted in the context of the primary goal of improved NUpE. The SINATA DST provides recommendations on both water and fertiliser application (rates, timings), potentially improving irrigation efficiency; however, data gaps relating to water variables (such as soil moisture monitoring and site/orchard specific climate data) reduce the confidence in outcomes (adoption for informing irrigation decisions resulting in a change in irrigation water use) relative to the N fertiliser recommendations. The data gaps are being addressed in AP19006, one of four projects that form PIPS 3. Once the potential for water savings are known, any estimated impact assessment (e.g. of AP19006) should include attribution to AP14023.

[Socio-economic] Increased contribution to regional community wellbeing from more profitable apple growers. The CIE (2023) highlighted the broader socio-economic effects of the apple industry for Australian production regions. The industry contributed over $0.5 billion in valued added (contribution to gross domestic product) and directly supported 1,818 full time employees primarily in regional economies. While this impact assessment is a first step in understanding and quantifying the direct effects on industry production and value, the flow-on effects require additional analysis in economic models that capture regional and national linkages, which are beyond the scope of the R&D impact assessment program (CRRDC 2018). However, the analysis and results from this impact analysis will provide an important input into any future regional or national economic impact modelling.

[Socio-economic] Increased economic sustainability of the supply of fresh and affordable domestic apple produce, supporting consumption with associated health and wellbeing benefits. Fresh, affordable, and locally grown are three of the key drivers in Australian consumer purchasing behaviour for fruit, vegetable and nuts (Kantar, 2022). Further, there is a recognised link between health and wellbeing benefits and apple consumption (APAL, 2023; Hort Innovation, 2020) and fruit and vegetable consumption more broadly (Angelino et al, 2019, Mujcic et al, 2016). A more sustainable supply of domestic produce therefore supports consumption and associated health and wellbeing outcomes. However, to quantify this in the context of cost benefit analysis requires a clear relationship between unit consumption and unit health and wellbeing, as well as a dollar value for unit health and wellbeing changes. A lack of available data or stakeholder estimates meant that these relationships and values could not be estimated.

Data and assumptions

For the impacts where valuation was possible, the necessary data was collected from the project documents and other relevant resources. 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. Where estimates were used, a data range was considered to reflect underlying risk and uncertainty, which was further analysed through in sensitivity testing (see Results). A summary of the key data, assumptions and sources made in the assessment is provided in Table 4.

Table 4. Summary of assumptions for impact valuation

Variable	Assumption	Source / comment
Discount rate	5% (± 50%)	CRRDC Guidelines (2018)
First year of adoption	2022	The Strategic Irrigation and Nitrogen Assessment Tool for Apples (SINATA) decision support tool was available for apple growers in the 2021-22 season. The refined real time grower facing tool is currently under development with Swan Systems through AP19006 and is likely to be available in the 2024-25 season.
Affected production volume (t)	303,126 (-280,273, +315,183)	5 year production volume average (Hort Stats Handbook 2023). Low and high values tested for sensitivity.
Adoption level (% of annual production volume)	51% (± 20%) or 85% (- 20%, 10%)	The CSIRO ADOPT framework was used (See Appendix A) to reflect the baseline adoption from AP14023 as well as the additional adoption that supported through a real-time grower facing DST that is currently under development through AP19006. The maximum adoption without the grower facing tool (output from AP14023 only) was 51%.
Time to maximum adoption speed (years)	9 years	CSIRO ADOPT framework (See Appendix A).
Cost attribution (AP14023) (%)	65%	AP14023 research outputs leveraged legacy AP12006 research, which initiated the N field trials. The contribution of AP14023 was reflected by applying an attribution factor based on the cost share of AP14023 compared with the total investment value.
Cost attribution (AP19006 component) (%)	61%	From 2024-25 the updated DST app will be available to industry, likely increasing the adoption and impact from that point. As the updated DST is to be completed in AP19006, the contribution of that project is considered in the analysis. The contribution of AP14023 to the final updated DST was reflected by applying an attribution factor based on the cost share of AP14023 compared with the total investment value. As only a small investment was allocated for this purpose in AP19006, the attribution to AP14023 did not significantly decrease.
Attribution period	Full attribution 10 years	A full attribution period of 10 years was assumed, followed by a compounded decline of 10% per year for the remaining 20 year analysis period. This reflects the likely need for further research to provide updated knowledge and resources concerning apple nutrition management, reducing the relevance of AP14023 findings over time.

R&D counterfactual (%)	75% (± 30%)	It is considered unlikely that the research would have proceeded without Hort Innovation supporting the coordination of the stakeholders and research priorities. As such, a high R&D attribution is applied.
Reduced N fertiliser cost from increased application efficiency and reduced application		
Recommended NUpE with pre harvest application (%)	32.0% (-30%, +32%)	Project data. Tested to one standard error.
Recommended N rate (kg N/t)	0.08	Project recommended pre-harvest N application (35 kg calcium nitrate/ha with calcium nitrate containing 16% N) to achieve 70t/ha of production, with a baseline pre-harvest NUpE of 32%.
Counterfactual NUpE with post harvest application (%)	17.2% (-14%, +21%)	Project data. Tested to one standard error.
Counterfactual post-harvest N rate (kg N/t)	0.14	Scaled up fertiliser application to reflect the lower pre-harvest NUpE compared to pre-harvest NUpE (17%/32% = 54% in the baseline, meaning 86% more fertiliser required to allow the same tree uptake = 0.08 kg N/t x 1.86 = 0.14 kg N/t
Calcium Nitrate fertiliser cost ($/kg)	$1.67 in 2023 changing to $1.77 by 2052 (± 48%)	Historical imported calcium Nitrate prices (TradeMap, 2023) adjusted to retail prices based on a retailer survey (n=3), adjusted to real prices (ABS, 2023), and projected based on 10-year trend (upper), 10-year average (lower) and a midpoint. See Appendix B.
Reduced nitrous oxide emissions from lower N fertiliser application		
N2O emissions (g N_2O/kg applied N)	25 (± 70%)	Calculated from AP14023 data for apple orchards in Tasmania and NSW showing applied N (40kg and 15kg respectively) and N2O emissions (300g and 600g), with a midpoint used in the baseline.
Value of avoided N_2O emissions ($/tonne CO_2-e)	$33.8 in 2023 to $62 from 2030 (± 40%)	1 tonne of N_2O is equal to 298 tonne CO_2-e. CO_2-e was valued using carbon spot prices (Jarden, 2023). An upper range of $100/tonne by 2030 was based on European carbon prices (Jarden 2023), with a lower range was based on the 10 year average real ACCU spot price (Jarden 2023), with an average of these two levels used in the baseline. See Appendix B.

Results

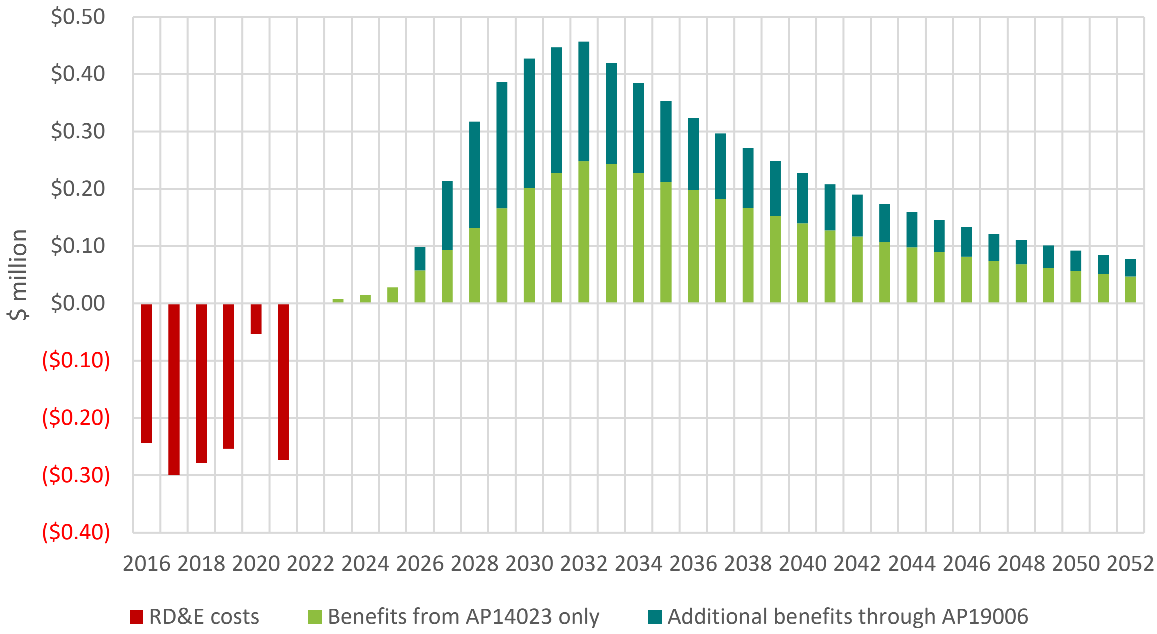
The analysis identified a PV costs (PVC) from all sources of $2.15 million (2022-23 PV) between 2015-16 and 2020-21, and estimated PV benefits (PVB) of $3.63million (2022-23 PV) accruing between 2022-23 and 2051-52 (Table 5). When combined, these costs and benefits generate a net present value (PV) of $1.48 million, an estimated benefit-cost ratio (BCR) of 1.69 to 1, an internal rate of return (IRR) of 9% and a modified internal rate of return (MIRR) of 7%.

Table 5. Impact metrics for the total investment in project AP14023

Impact metric	Years after last year of investment						
	0	5	10	15	20	25	30
PVC ($m)	2.15	2.15	2.15	2.15	2.15	2.15	2.15
PVB ($m)	0.00	0.31	1.74	2.74	3.25	3.50	3.63
NPV ($m)	-2.15	-1.84	-0.40	0.60	1.10	1.35	1.48
BCR	0.00	0.14	0.81	1.28	1.51	1.63	1.69
IRR	Negative	-18%	3%	7%	8%	8%	9%
MIRR	Negative	-12%	4%	6%	7%	7%	7%

Figure 2 shows the annual undiscounted benefit and cost cash flows for the total investment of AP14023. Cash flows are shown for the duration of the investment plus 30 years from the last year of investment. Figure 2 highlights the attributable impact generated directly through AP14023 (65% of total), as well as the additional impact generated from the development of the improved SINATA tool (in AP19006) that can be attributed to the work done in AP14023 (45% of total). Through the improved DST, there is an improved “ease of use” for the AP14023 recommendations, supporting a higher level of adoption and therefore impact. Of the total benefits, 95% were generated from reduced on farm fertiliser costs, and 5% were generated from the reduced socio-environmental cost of greenhouse gas emissions, with the difference due to the low levels of emission per unit of fertiliser, combined with low price (social value) of emissions compared to fertiliser prices.

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

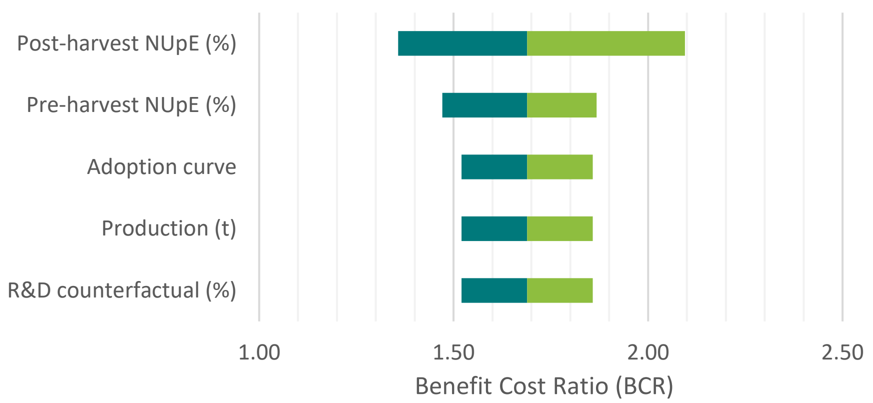


Sensitivity analysis

Given the risk and uncertainty associated with a number of underlying modelling inputs (particularly due to the forward projections inherent in the impact assessment process), the results were tested for sensitivity to changes in variables where a potential value range was identified (Table 4).

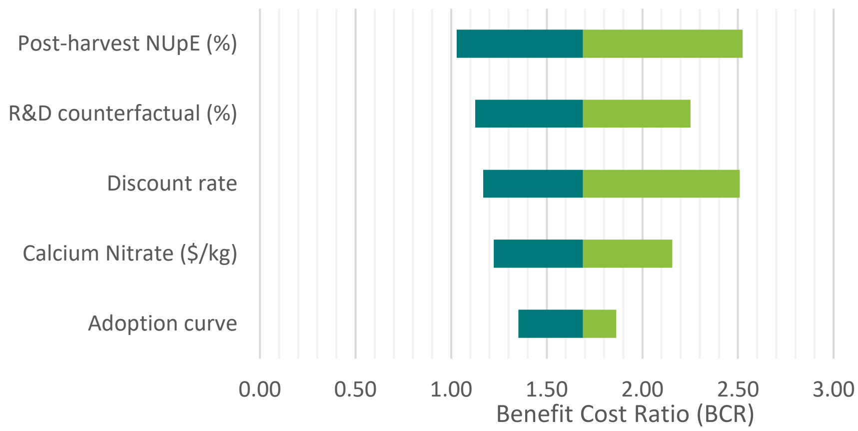
Results were first tested for sensitivity to uniform 10% change in underlying variable values. Figure 3 presents the five variables to which the results were most sensitive to a 10% change. The variable most sensitive to a 10% change in underlying value was the baseline post-harvest NUpE, which drives the post-harvest fertiliser application rate. The remining four most sensitive variables to a 10% change in their underlying value were the pre-harvest NUpE, the adoption curve for the improved N practices, the level of industry production (also driving adoption), and the R&D counterfactual. Of note, the results remained positive to 10% changes in all underlying variables.

Figure 3. Benefit-cost ratio sensitivity (10% change in variable)



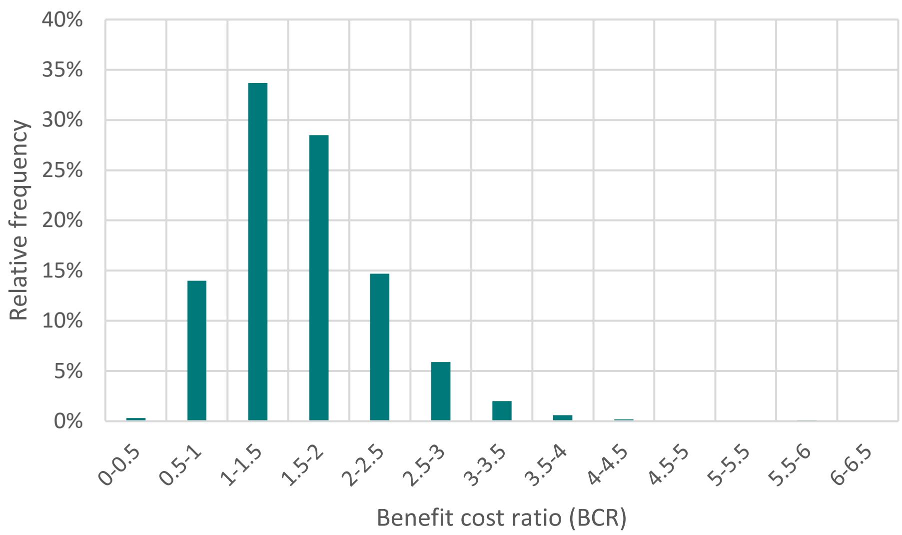
Results were also tested for sensitivity to the identified full range of potential variability for relevant data inputs (from Table 4). This again highlighted the significance to the "without AP14023" post-harvest NUpE, given the sensitivity of the results to any changes (Figure 4) and the wide potential range identified through the project trials. While the results were sensitive to changes in the "with AP14023" pre-harvest NUpE, this had a narrower potential range identified in the project, so this become less significant to the results. The results are also highly sensitive to the discount rate, particularly on the upside. The other variables with the greatest potential to influence the results were the R&D counterfactual, the Calcium Nitrate price, and the adoption curve.

Figure 4. Benefit-cost ratio sensitivity (full range of potential variability)



Finally, the full range of potential impact was estimated using @Risk stochastic modelling to incorporate the combined changes in potential variable ranges over 1000 simulations (Figure 5). This process showed an impact (BCR) range of between 0.38 and 5.5, with 90% of simulations falling between 0.80 and 2.72 (i.e. excluding the low probability tails) and 86% of the simulations generating a BCR higher than 1. These results give a high confidence that the investment will generate a positive impact given potential variations in the underlying variables.

Figure 5. Benefit-cost ratio impact histogram (1000 simulations)



Implications and learnings

The analysis found a clear impact pathway for AP14023. The project conducted trials and research to gain an improved understanding of apple orchard nutrient and irrigation management leading to improved recommendations and resources for industry. The project also conducted a range of communication and extension activities to support industry awareness and adoption. The SINATA DST, is undergoing further development through follow-on research (AP19006), but was already at a point to support initial adoption.

A key finding from the research that was quantified in this analysis was that pre-harvest N (and other nutrients) were taken up by trees much more efficiently (32% NUpE) than post-harvest N (being the previous industry recommendation and standard practice) with no yield or quality changes. As such, the research advocated for a much lower rate of fertigated N applied pre-harvest to maximize uptake.

The impact of this updated knowledge and recommendations was quantified for both economic and environmental benefits.

Economic benefits were derived from growers being able to take advantage of improve NUpE to reduce overall N inputs and cost. Environmental benefits were derived from the reduced N fertiliser application with associated reductions in N_2O emissions, with N_2O being a powerful greenhouse gas.

The total potential fertiliser savings as a result of realising this increased efficiency were calculated as 2.78 kg of calcium nitrate per tonne of apple production, equating to an annual cost saving of $4.62 per tonne of fruit at 2023 prices for calcium nitrate. For every kg of N fertiliser, avoided N_2O emissions of 25 g could be realised, equal to 7.4 kg CO_2-e. With calcium nitrate containing 16% N, the total avoided emissions from the improved N management was equal to 3.2 kg CO_2-e per tonne of fruit, or $0.1 per tonne of fruit at 2023 prices for carbon.

Through the CSIRO ADOPT framework, industry adoption of the excel based SINATA DST and associated recommendations for N management developed in AP14023 was modelled at 51% of industry production, generating present vale (PV) benefits of $2 million over 30 years (5% discount rate). The model also considered a later step-up to higher adoption reflecting the further development of SINATA into a more user-friendly web app through AP19006. By adjusting the ADOPT model to account for increased trialability, reduced complexity, and increased ease of use, the level of adoption increased from 51% to 85% of industry production, thereby increasing the PV benefits to $3.63 million (over 30 years with 5% discount).

Compared to the PV research costs of $2.15 million, this generated a baseline impact of (BCR) of 1.69:1 attributable to VG14023. Sensitivity testing gave a high level of confidence that AP14023 would generate a positive impact (benefits greater than costs) with 86% of simulated results having a BCR greater than 1. The was a relatively narrow range for the results, with 90% of simulated results falling between 0.80:1 and 2.72:1. The results were most sensitive to changes in the pose-harvest NUpE, which also had a large potential value range, and which drove the benefits of switching to the more efficient pre-harvest fertiliser application.

The relatively low contribution of avoided N_2O emissions to the total benefits was due to the relatively low level of emissions per unit of fertiliser, combined with a relatively low value of CO_2-e emissions ($34/tonne in 2023) relative to the cost of N fertiliser ($1665/t in 2023). The carbon price was projected to grow at a faster rate than that of N fertiliser potentially reaching $100/t by 2030; however this did not have a material impact on the results given the relatively low level of emissions per unit of fertiliser and the declining attribution for impacts beyond 2030 due to likely ongoing changes in production systems, N products, and recommendations.

Overall, the investment in AP14023 was found to have delivered a positive impact both to the apple industry and the environment by supporting reduced N fertiliser application with associated reduced costs and emissions.

Additional social and environmental impacts are expected to be realised from the investment, but were not quantified as a result of data limitations. As such the quantified impacts represent a conservative estimate of the total potential impact that would be realized through optimized nutrition management practices for the apple industry supported by the project.

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**
Adrian Hunt, Hort Innovation R&D Manager	RD&E process owner / manager	✓	✓	✓	✓	✓		
Nigel Swarts, Tasmanian Institute of Agriculture	RD&E practitioner (project lead)	✓	✓	✓	✓	✓	✓	✓
David Finger, Vernview	RD&E beneficiary and levy payer				✓		✓	✓
Robert Green, Oakleigh Orchards	RD&E beneficiary and levy payer				✓		✓	✓
Elders, Goulburn Valley	RD&E Stakeholder							✓
IK Caldwell, Goulburn Valley	RD&E Stakeholder							✓
GV Crop Protection, Goulburn Valley	RD&E Stakeholder							✓

Glossary of economic terms

Benefit-cost ratio (BCR)	The ratio of the present value of investment benefits to the present value of investment costs.
Cost-benefit analysis (CBA)	A conceptual framework for the economic evaluation of projects and programs in the public sector. It differs from a financial appraisal or evaluation in that it considers all gains (benefits) and losses (costs), regardless of to whom they accrue.
Direct effects	Impacts generated for the funding industry as a result of adoption of the RD&E outputs and recommendations, typically farm level outcomes relating to productivity and risk.
Discounting (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).
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

ADOPT Adoption and Diffusion Outcome Prediction Tool

APAL Apple & Pear Australia Ltd

CO_2-e Carbon dioxide equivalent

CRRDC Council of Rural Research and Development Corporations

CSIRO The Commonwealth Scientific and Industrial Research Organisation

DST Decision Support Tool

N Nitrogen

N_2O Nitrous Oxide

NUpE Nitrogen Uptake Efficiency

RD&E Research, Development and Extension

SINATA The Strategic Irrigation and Nitrogen Assessment Tool for Apples

SIP Strategic Investment Plan

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Appendix A. Adoption and diffusion using the ADOPT framework

Appendix A includes the data inputs for the ADOPT model (Kuehne et al 2017) used in this analysis which were estimated based on stakeholder consultation and available data. The results were tested for sensitivity of the adoption rate and level by assuming a proportional shift to the adoption levels by a 20% lower bound and 10% upper bound factor. Two separate adoption profiles were estimated: (1) initial influence of the desktop SINATA strategic decision support tool guiding grower nutrition management practice change from AP14023; and (2) subsequent influence of the grower-facing real time decision support tool under development through AP19006 drawing directly from the results of the AP14023 project.

The initial influence of the desktop SINATA strategic decision support tool was found to generate a moderate level of industry adoption of moving from a post-harvest application of N to a pre-harvest application of N. A maximum adoption of 51% of total production volume would be supported by this practice after 14 years from initial research findings from AP14023 being utilised by growers in 2022-23. Following the release of the grower facing decision support tool through AP19006 which is expected to occur in 2024-25, the ADOPT tool was updated to reflect the new basis by which growers could be informed around nutrition management best practices applicable on their property in real time. The variables changed to reflect this were are listed below:

- (Q7) Trialability: Moderately trialable (AP14023); Very easily trialable (AP19006)
- (Q8) Complexity of evaluation: Moderately difficult (AP14023); Slightly difficult (AP19006)
- (Q12) New skill and knowledge development: Almost all growers (AP14023); Minority of growers (AP19006)
- (Q13) Awareness of trial in district: Minority (AP14023); About half (AP19006)
- (Q22) Ease and convenience of farm management: No change (AP14023); Moderate increase (AP19006)

An updated ADOPT curve reflecting the adoption profile of the new management practice following the availability of the grower facing real time decision support tool through AP19006 resulted in a maximum adoption rate of 85% being realised after 7 years. As the real time tool is expected to delivered available to growers in 2024-25, the maximum adoption is estimated to be reached by 2030-31.

For the purposes of the impact assessment, a "combined" adoption curve was used that first utilised the adoption level only from the AP14023 desktop tool applicable for the first two years to 2024-25, before switching to the adoption curve estimated associated with the real time tool from AP19006 becoming available. Figure 6 presents the adoption curves estimated from the outputs generated through AP14023 and AP19006 in addition to the combined adoption curve that was applied to the economic impact assessment.

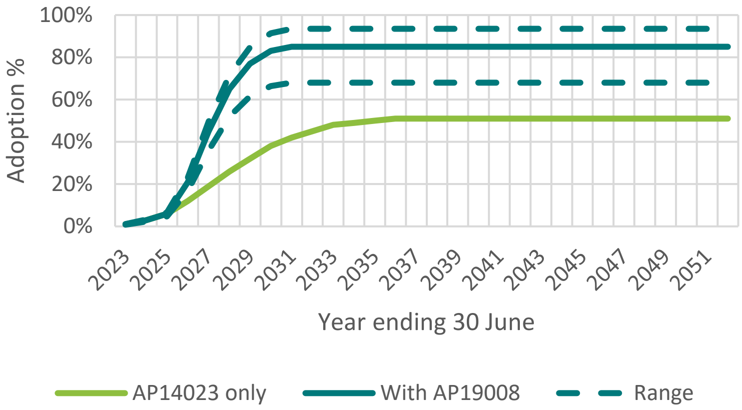

Figure 6. Change in adoption and diffusion curve for outputs delivered through AP14023 and AP19006

ADOPT inputs for AP14023 (alone and through AP19006)

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

Almost all 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?

A majority 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?

About half 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?

Moderately trialable (AP14023)

Very easily trialable (AP19006)

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

Moderately difficult to evaluate effects of use due to complexity (AP14023)

Slightly difficult to evaluate effects of use due to complexity (AP19006)

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

Difficult to observe

10. What proportion of growers use paid advisors capable of providing advice relevant to the innovation?

A majority use a relevant advisor

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

About half are involved with a group that discusses farming

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

Almost all need new skills and knowledge (AP14023)

A minority will need to develop substantial new skills and knowledge (AP19006).

13. What proportion of growers would be aware of the use of trialling of this innovation in their district?

A minority are aware that it has been used or trialled in their district (AP14023)

About half are aware that it has been used or trialled in their district (AP19006).

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

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

Very easily reversed

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 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?

Small profit advantage in the future

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

Immediately

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

Small environmental advantage

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

Immediately

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

No increase in risk

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 (AP14023)

Moderate increase in ease and convenience (AP19006)

Appendix B. Nitrogen and carbon price projections

This section shows the key data projections for the N fertiliser price (as calcium nitrate) (Figure 7), and carbon price (Figure 7).

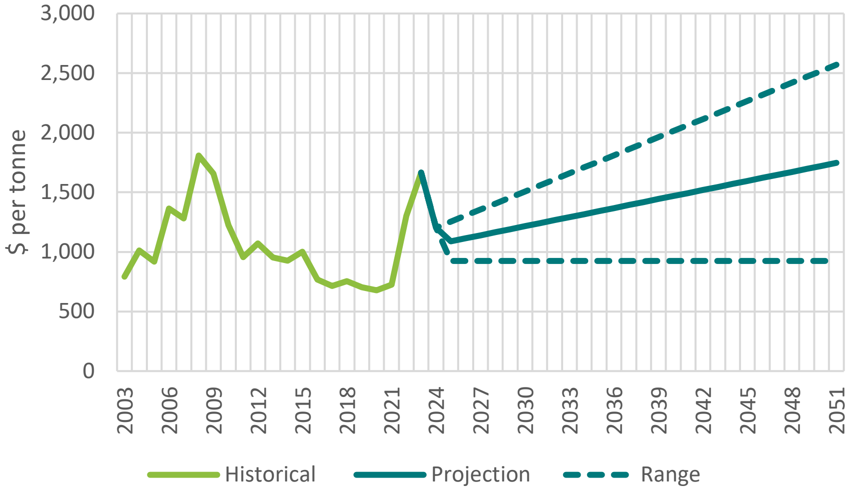

Figure 6. Historical and projected range for real (inflation adjusted) Australian farm calcium nitrate prices. Based off historical imported calcium nitrate prices (TradeMap 2023) adjusted for inflation (ABS 2023) and to farmgate prices through a retailer survey (n=3) and projected based on the ten year trend growth (upper), flat ten year average (lower), and midpoint as baseline.

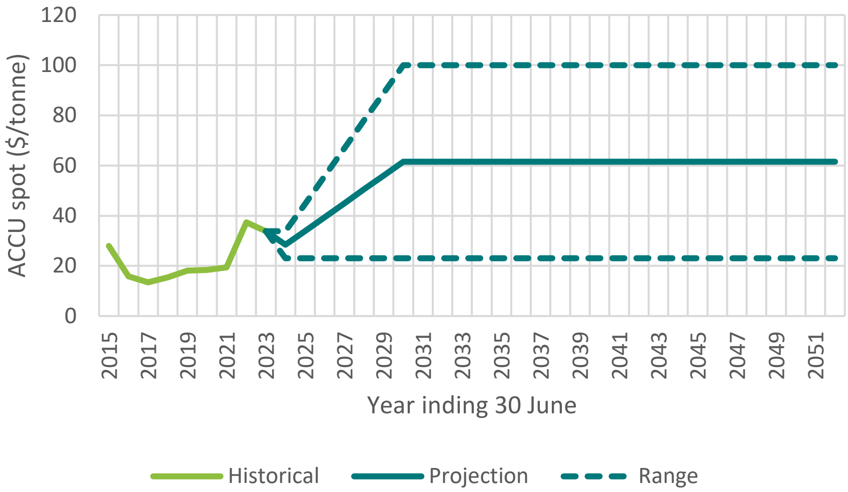

Figure 7. Historical and projected range for real (inflation adjusted) ACCU spot prices, projected to an upper range $45/tonne by 2030 (Reputex 2021) before returning to 10 year trend growth to 2052, a lower range of $21/tonne (10 year average), and a midpoint of these two levels.

Ends.