Impact assessment of the investment:

A strategic approach to weed management for the Australian Vegetable Industry (VG15070)

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Hort Innovation

Previous page image courtesy of VG15070 project reporting.

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Summary

What the report is about

Ag Econ conducted independent analysis to determine the economic, social, and environmental impact resulting from delivery of the vegetable project *VG15070 A strategic approach to weed management for the Australian Vegetable Industry*. The project was funded by Hort Innovation over the period August 2016 to October 2021 using the vegetable 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.

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

From 2016 to 2021, VG15070 researched key weed species relevant to Australian vegetable production, including their economic impact, and a range of integrated weed management (IWM) options. The project delivered economic case studies and weed management guides to assist growers to identify the most suitable IWM practices for their operation.

Key findings

The nominal investment cost of $1.3 million was adjusted for inflation (ABS, 2023) and discounted (using a 5% real discount rate) to a present value (PV) of costs equal to $1.9 million (2022-23 PV).

The impact pathway linking the project's activities and outputs, and their assessed outcomes and impacts was laid out in a logical framework. This highlighted the key outcome of increased industry adoption of innovative IWM practices as a result of the RD&E conducted in VG15070.

The VG15070 farm case studies highlighted the potential for improved whole farm operating profit (WFOP) as a result of adopting IWM practices. Drawing on the case studies, and discussion with industry stakeholders, the total industry benefit was estimated for six vegetable crops: radish, iceberg lettuce, parsley, broccoli, carrot, and rocket. The impact assessment also considered the broader impacts of the research beyond these case study crops, including other field grown vegetables that fall under the vegetable levy fund as well as vegetable crops that sit outside the vegetable levy fund such as potato (fresh and processed), sweet potato, onions and asparagus.

From this approach, the analysis estimated total expected benefits of $7.2 million (2022-23 PV) accruing between 2022 and 2052. When compared to the total funding from all sources of $1.3 million (2022-23 PV), the results showed a positive RD&E impact with a net present value (NPV) of $5.3 million, an estimated benefit-cost ratio (BCR) of 3.7 to 1, an internal rate of return of 19% and a modified internal rate of return of 9%.

Additional impacts were also identified relating to potential price premiums (by supporting a move towards organic production), reduced risk of pesticide resistance, and improved environmental outcomes relating to off target chemical impacts and improved soil health. While these additional impacts were not able to be quantified due to data gaps, the analysis highlighted the data gaps to support future R&D and impact analysis in the future.

The key findings of the VG15070 impact assessment are summarized in Figure 1 below.

Keywords

Impact assessment, cost-benefit analysis, vegetable, integrated weed management, yield, input cost, management cost, radish, lettuce, parsley, broccoli, carrot, rocket

Figure 1. Summary of impact assessment findings

VG15070 A strategic approach to weed management

RD&E activities

Total RD&E costs:

- $1.3 million (nominal value)
- 79% R&D levy and Government matching, and 11% UNE in-kind.

Research activities:

- Literature reviews on 11 key weeds and 8 supplementary weed management practices.
- Weed seed bank assessment
- Field and pot trials to study the effects of cover cropping.

Extension activities and outputs:

- Integrated Weed Management (IWM) manual for the Australian vegetable and potato industries, including guides for the 11 high priority weeds.
- Economics of weed management report and case studies of 19 vegetable farms in NSW, Tas, Vic and WA.
- Field days, webinars, videos, and fact-sheets.

Outcomes

Outcomes:

- Increased industry awareness of the benefits of strategic IWM, and knowledge and skills relating to the application of IWM options.
- Increased research capacity through engagement with complimentary research and extension programs.

Industry adoption:

- Estimated 3% of field vegetable production area to date (2022-23).
- Expected total adoption of 17% by 2029-30

Impacts

Economic impacts:

- ↑ Gross yield
- ↓ Input costs
- ↓ Weed resistance to chemicals

Environmental impacts:

- ↓ Chemical use with off-target impacts.
- ↓ Soil runoff with negative soil health and waterway impacts.

Social impacts:

- More reliable supply of fresh and affordable vegetables with associated health and wellbeing benefits.
- ↑ contribution to regional community wellbeing.

Quantified impact:

- Present value (PV) of RD&E costs of $1.95 (5% real discount rate).
- PV benefits of $7.22 million over from 2022 to 2052, giving a net present value (NPV) of $5.27 million.
- Benefit cost ratio (BCR) of 3.71:1, ranging from 1.7:1 and 6.3:1 with 100% of simulations having a BCR greater than 1:1.

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).

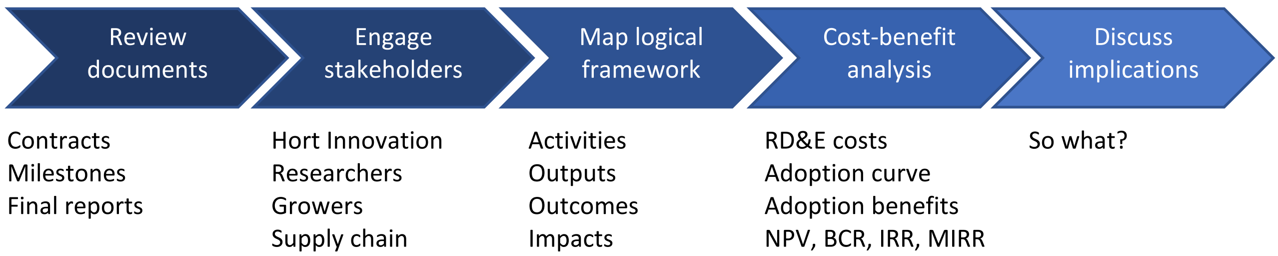
Project *VG15070 A strategic approach to weed management for the Australian Vegetable Industry* was randomly selected as one of the 15 investments in the 2021-22 sample. This report presents the analysis and findings of the project impact assessment.

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 Council of Rural Research and Development Corporations (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 to identify the principal economic, environmental, and social impacts realised through the project
4. Collect available data to quantify the impact pathway and estimate the attributable impacts using cost-benefit analysis (over a maximum 30 years with a 5% discount rate), and then sensitivity test the results to changes in key parameters.
5. Discuss the implications for stakeholders.



The analysis identified and quantified (where possible) the direct and spillover impacts arising from the RD&E. The results did not incorporate the distributional effect of changes to economic equilibrium (supply and demand relationships) which was beyond the scope of the MT21015 impact assessment program. A more detailed discussion of the method can be found in the *MT21015 2021-22 Summary Report* on the Hort Innovation project page [Horticulture Impact Assessment Program 2020/21 to 2022/23 (MT21015)](#).

A Stakeholder Case Study was developed to compliment this impact assessment and illustrate how the identified impacts on integrated weed management (cover cropping) have been realised in a practical setting. The Case Study can also be accessed via the Hort Innovation MT21015 project page link above.

Project background

Weeds are a persistent problem for many vegetable producers in Australia due to favourable growing conditions, regular soil disturbance and limited registered herbicides for selectively control of broadleaf weeds. Weeds reduce crop yield and quality, interfere with sowing and harvesting, may host pests and diseases, and increase grower management costs, which impact both productivity and profitability of vegetable production.

Recommendations for developing integrated weed management (IWM) approaches for the vegetable industry were initially identified in a 2013 Plant Health and Crop Protection RD&E Plan (VG12048), where industry feedback identified an emerging risk regarding diminishing availability of chemical control options. Combining biological, cultural and chemical control methods in a systematic manner was identified as an important knowledge gap to support growers manage and control weeds in their production system.

The project VG13079 *Weed Management for the Vegetable Industry* identified that growers commonly used a range of methods for managing and controlling weeds as no single technique alone could provide suitable control. In addition to identifying and characterizing the most common weeds encountered by vegetable growers, VG13079 identified knowledge gaps around strategic application of integrated weed management practices.

Project VG15070 therefore sought to improve the vegetable industry's understanding of the burden of weeds and how to manage them most effectively, expanding the knowledge and resources available to vegetable growers to encourage and facilitate adoption of current best practice IWM. The specific objectives of VG15070 were to:

- Develop integrated management strategies for high priority weeds in vegetable production, including understanding germination and early growth, timing, and optimizing herbicide effectiveness.
- Quantify the role of the weed seed banks on vegetable farms, link weed lifecycles to farming practices and incorporate this information into weed management strategies for vegetable growers.
- Evaluate the effectiveness of a range of supplementary cultural methods, particularly as they relate to high priority weeds.
- Conduct robust economic analyses of the on-farm costs and benefits of weed management using farm-level data.
- Develop a comprehensive IWM manual for vegetable producers based on products used in other agricultural sectors.
- Enhance extension resources for wed management in vegetable production (including multi-lingual resources).

With a focus on developing management strategies and delivering industry extension to support weed control and management, project VG15070 aligned with the Vegetable 2017-2021 Strategic Investment Plan (Hort Innovation 2017) Outcome 3: *Increased supply chain integration and development through improved supply chain management, development of collaborative models and partnerships* and Outcome 5: *Improvements in industry capability*.

Project details

The University of New England (UNE) was selected as the lead delivery partner, with the project running from 2016 to 2021 (Table 1).

Table 1. Project details

Project code	VG15070
Title	*A strategic approach to weed management for the Australian Vegetable Industry*
Research organization	University of New England (UNE)
Project leader	Paul Kristiansen
Funding period	August 2016 to October 2021
Objective	Improve weed management options and information available to Australia's vegetable growers.

Logical framework

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

Table 2. Project logical framework detail

RD&E activities

Integrated Weed Management (IWM) in high priority weeds.
- Identify eleven priority weed species guided by VG13079 and industry consultation: Amaranth, Blackberry, Chickweed, Common sowthistle, Dwarf nettle, Fat hen, Marshmallow, Nutgrass, Pigweed, Potato weed, Wild radish
- Literature review on each priority weed species.

Seed bank management
- Literature review to identify methods of paddock sampling and weed seed bank enumeration.
- Weed seed bank assessment in for a site each in NSW, QLD, Vic, Tas, WA, SA and NT informed by a review of paddock sampling and weed seed bank enumeration.
- Assess the weed seed bank for each site against paddock management practices.

Supplementary weed management practices
- Literature reviews on eight supplementary weed management methods, including cover crops, crop rotation, hand and robotic weeding, irrigation management, crop orientation, tillage, thermal weed control, organic herbicides.
- Field and pot trials undertaken to study the implications of cover cropping on weed seed banks and weed burden.

Economics of weeds and their management
- Literature review of farm level economics of weeds and their management
- Using a partial budget and case study approach, evaluate the farm level economics of the identified priority weeds and the supplementary weed management practices, and explore grower perceptions of collective action (area wide management). 19 vegetable farms were evaluated across NSW, Tas, Vic and WA, being the first time in which the cost of weeds at the individual vegetable crop level has been explored in Australia

Industry communication and extension
- Re-engage with industry stakeholders from predecessor project VG13079.
- Gather vegetable industry feedback on findings and information needs through engagement at extension events.
- Collate information into weed management guides for each priority species.
- Translate management guides to Vietnamese, Chinese and Khmer.
- Develop articles, videos and fact sheets focusing on preliminary findings and industry implications.
- Promote findings through vegetable industry development officers and the Soil Wealth and Integrated Crop Protection seminar series.
- Develop online presence included a Facebook page, web page and YouTube video channel.

RD&E outputs

- Project commencement media release.
- 7 regional stakeholder feedback meetings (2017).
- IWM manuals for Australian vegetable and potato production, including IWM guides for the 11 high priority weeds (2019).
- Economics of weed management report and case studiesof 19 vegetable farms in NSW, Tas, Vic and WA.
- Project web page.
- Facebook page (reaching 455 followers).
- YouTube channel.
- 9 videos (2018 to 2020) (average 260 views per video by project end)
- 3 fact sheets ((2019 to 2020)
- 10 industry newsletter articles (2017 to 2020)
- 4 webinars (2016 to 2021) (average 37 attendees and 269 online views)
- 4 field days (Tas, Vic, NSW, WA) (2018 to 2019) (average 32 attendees)

Outcomes

- Increased vegetable grower and advisor awareness of the economic and environmental benefits of strategic IWM, and knowledge and skills relating to the application of IWM options, thereby supporting increased industry confidence to adopt.
- Industry has baseline data on weed seed banks on Australian vegetable farms, showing 63 weed species, and cross references against weed management practices, supporting future research
- Increased research capacity and goodwill through engagement with complimentary research and extension programs (e.g. cover cropping [VG16068], VegNET, and soil wealth and integrated crop protection [VG16078]).

Impacts

- [Economic] Increased adoption of relevant IWM practices including supplementary methods for weed management and seed bank management, to address 11 high priority weeds, thereby supporting improved farm productivity and profitability through increased gross yields, or reduced weed management costs or both.
    - Across the 19 farms evaluated, the weighted average reduction in whole farm operating profit (WFOP) per hectare due to weeds was found to be $2,090 per hectare. This was comprised of $1,403 per hectare net costs due to weeds, and $687 per hectare revenue lost due to weeds.
    - In 16 case studies across the 19 farms, VG15070 showed that the introduction of the new IWM practices generated a positive economic impact in 11 cases (with WFOP increasing from $7/ha to $152,199/ha), negative in 5 cases (WFOP decreasing from $45/ha to $5,586/ha). In four of the five negative cases, additional benefits were noted that could not be valued in dollar terms, including helping to move towards organic production with market premium potential, as well as longer term benefits of improved soil health from cover cropping, and reduced herbicide resistance through increased use of non-chemical control options. In two of the five negative cases, yield data was not collected so changes in revenue could not be assessed.
    - Some of the new management options had high initial costs (e.g. purchasing specialised inter-row tillage or thermal control equipment, or upfront hand weeding).
- [Social] Increased economic sustainability (relating to WFOP as identified above) of vegetable production supporting a more reliable supply of fresh and affordable vegetables, in turn supporting consumption (Kantar 2022) with associated health and wellbeing benefits (Angelino et al, 2019, Mujcic et al, 2016).
- [Social] Increased contribution to regional community wellbeing from more profitable vegetable growers(The CIE 2023).
- [Environmental] Reduced reliance on chemical herbicides and fumigation weed control options, thereby decreasing the chance of off target chemical impacts (Australian Gov, 2021).
- [Environmental] Reduced risks of soil erosion and increased soil microbial activity supported by cover cropping weed management practices (AHR & RMCG 2017).

Project costs

The project was funded by Hort Innovation, using the vegetable research and development levy and contributions from the Australian Government, with additional funding from research partners UNE) (Table 3). 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 ($)	Hort Innovation overheads[1] ($)	UNE In-Kind[2]	Total nominal ($)
2017	260,242	37,620	81,058	378,921
2018	150,000	29,201	46,721	225,922
2019	150,000	24,950	46,721	221,671
2020	160,000	27,811	49,836	237,647
2021	180,060	26,958	56,084	263,102
Total	**900,302**	**146,540**	**280,420**	**1,327,262**

1. The overhead and administrative costs were calculated from the Statement of Comprehensive Income in the Hort Innovation Annual Report 2016-17, and the Vegetable industry's Fund Annual Report 2017-18 to 2020-21, averaging 16.6% for the VG15070 funding period (2016-2021).
2. Other funds from UNE were provided in the contract as a lump sum, so were apportioned yearly based on Hort Innovation cash costs.

Present Value of investment

The nominal total investment cost of $1.33 million identified in Table 3 was adjusted for inflation (ABS, 2023) into a real investment of $1.58 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 $1.95 million (2022-23 PV). The results were sensitivity tested changes in the discount rate between 2.5% and 7.5%.

Project impacts

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

Impacts quantified

[Economic] Improved farm productivity and profitability. The VG15070 research reports and discussions with stakeholders provided sufficient data to quantify the direct farm-level economic impact of IWM relating to improved productivity and profitability. The magnitude of farm-level economic changes was informed through the results of project case studies that developed partial farm budgets to identify the effect of IWM on WFOP ($/ha). From the 16 case studies, a sub-set of six were selected as there was sufficient data on plantings for national adoption and impact to be estimated. The six case studies selected were sheet steam weeding (radish); stale seed bed and trickle fertigation (lettuce); inter-row push sprayer for glyphosate (parsley); strip tillage (broccoli); cover cropping (carrot); hand weeding (rocket). For these six case studies, results were scaled up to an industry level by identifying a total production area for each case study vegetable crop and estimating an adoption and diffusion curve using stakeholder feedback and project data to inform inputs into CSIRO ADOPT framework (Kuehne et al 2017) (see Appendix A). While the case studies provided data for six vegetable crops, the VG15070 research also highlighted that the IWM principles are applicable to broader field grown vegetable production. As such, a multiplier was applied to the quantified impact to reflect the adoption of the IWM practices across field grown vegetable production more broadly . The attribution of the results was considered in relation to the contribution of earlier and concurrent R&D to develop the IWM recommendations, as well as the contribution of follow-on RD&E to continue to refine the research and extend it to industry. 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.

Impacts not quantified

[Economic] Longer term productivity benefits. The VG15070 case studies highlighted an expectation of longer term productivity benefits relating to improved soil health (such as from cover cropping) and reduced chemical resistance in weeds. Quantifying these benefits was assessed to require additional data (such as the likely timeline and magnitude of changes) that was not identified through the project data or discussions with stakeholders.

[Socio-economic] Improved health and wellbeing. 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 vegetable consumption (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 changes, 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.

[Socio-economic] Greater resilience for local economies and communities. The CIE (2023) highlighted the flow-on (spillover) effects of the vegetable industry for regional economies. Quantifying the flow-on effects requires the direct impacts identified in this impact assessment to be incorporated into economic models that capture regional and national linkages, and which is beyond the scope of the R&D impact assessment program (CRRDC 2018).

[Environmental] Reduced chemical use with associated negative externalities. There is a recognised link between farm chemical use and harmful off-target effects on rivers, the ocean, the atmosphere, animals and plants if not managed safely (Australian Gov, 2021). Decreased on-farm chemical use reduces these potential environmental impacts. However, no data was identified to link per unit changes in chemical use with a quantifiable unit change in environmental quality, so this impact was unable to be valued.

[Environmental] Reduced risks of soil erosion and increased soil health. There is a recognised relationship between IWM practices such as cover cropping and improved waterway health (from reduced runoff) and increased soil health (including increased carbon sequestration) (for example see AHR & RMCG 2017); however, these benefits were only identified qualitatively with insufficient data to allow quantification.

Data and assumptions

To quantify the improvement in farm productivity and profitability, the necessary data was collected from the project documents and other relevant resources. Where available, empirical data was used, with estimates applied for any data gaps and projections into the future. Estimates were based on appropriate analytical techniques, or stakeholder estimates, or both. Where estimates were used, a data range was also considered to reflect underlying risk and uncertainty, which was further analysed through sensitivity testing (see *Results*). A summary of the key data, assumptions and sources is provided in Table 4.

Table 4. Summary of data for impact valuation

Variable	Value	Source / comment
Discount rate	5% (± 50%)	CRRDC Guidelines (2018).
Field production area (ha)	Radish 121 (±20%) Lettuce 7,422 (± 1 st. dev) Parsley 1,777 (±20%) Broccoli 7,326 (± 1 st. dev) Carrot 5,351 (± 1 st. dev) Rocket 638^ (±20%)	Estimated field production area (Stakeholder Consultation) applied to industry total production area (ABS 2022): Radish 100% field grown applied to 2013-14 production data (most recent); lettuce, 75% field applied to 5-year average area to 2021-22; parsley 50% field and 2013-14 only; broccoli 100% field and 5-year average; carrot 100% field and 5-year average; and rocket 50% field and 2013-14 only.
First year of adoption	2022	VG15070 research concluded in 2022.
Adoption level (% of potential production area)	17% (±32%) over 9 years	Developed through the CSIRO ADOPT framework (See Appendix A)
Change in radish WFOP $/ha	6,027 (±30%)	Result from VG15070 economic case study partial farm budgets. The trial results tested for ±30% to reflect a potential wide variation at an individual farm level.
Change in lettuce WFOP $/ha	222 (±30%)	
Change in parsley WFOP $/ha	180 (±30%)	
Change in broccoli WFOP $/ha	353 (±30%)	
Change in carrot WFOP $/ha	7 (±30%)	
Change in rocket WFOP $/ha	1,780 (±30%)	
Outcome attribution (%) (change in WFOP)	70% (50%, 90%)	Estimated from VG15070 findings and discussions with stakeholders. The research demonstrated a strong link between the adoption of the IWM practices researched and extended in the project, and the change in WFOP, with some support having been contributed from complimentary projects (e.g. Cover cropping VG16068 and Soil Wealth Phase 2 VG16078). This full attribution was estimated to decline by 10% per year (tested 5% and 15%) following project completion, reflecting the continued RD&E into improved IWM practices and adoption such as through MT22004 (Soil Wealth Phase 3).

R&D counterfactual (%)	70% (50%, 90%)	Detailed research into supplementary and integrated weed management practices would have been unlikely to have proceeded without Hort Innovation levy funding and support in coordinating the stakeholders and research priorities. As such, a high R&D attribution is applied.
Impact multiplier to other relevant vegetable crops	4.09 (±1%)	Project case studies were only available for 6 conventional vegetable crops. However the researched IWM practices were targeted at field produced vegetable crops more broadly. The farmgate value of total field grown vegetable production[1] was compared to the 6 case study crops (above) using Hort Stats Handbook data (Hort Innovation 2022), generating a 5-year average multiplier of 4.09 (±1%).

Results

The analysis identified PV costs (PVC) of $1.95 million (2022-23 PV) between 2016-17 and 2020-21, and estimated PV benefits (PVB) of $7.22 million (2022-23 PV) accruing between 2021-22 and 2051-52 (Table 5). When combined, these costs and benefits generate a net RD&E impact of $5.27 million (NPV), an estimated benefit-cost ratio (BCR) of 3.70 to 1, an internal rate of return (IRR) of 19% and a modified internal rate of return (MIRR) of 9%.

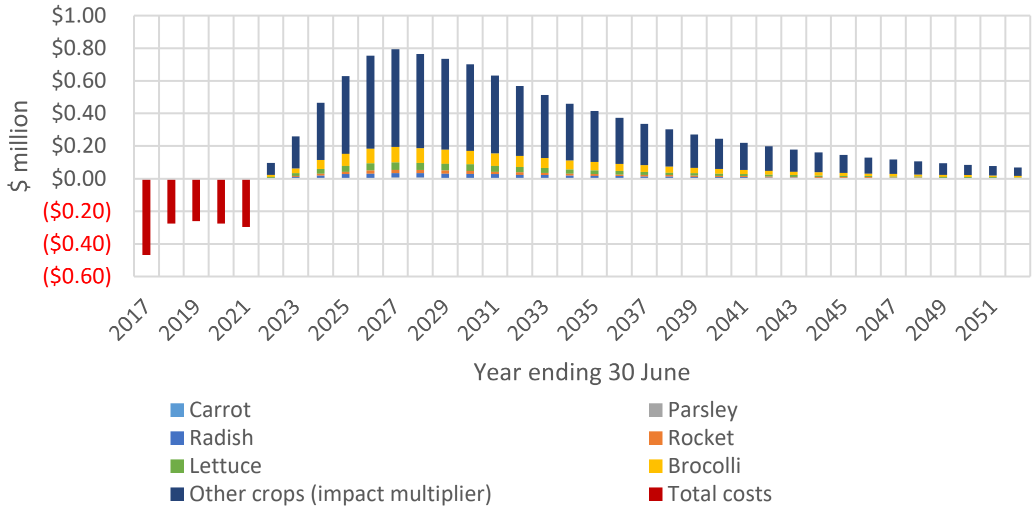
Table 5. Impact metrics for the total investment in project VG15070

Impact metric	Years after last year of investment						
	0	5	10	15	20	25	30
PVC ($m)	1.95	1.95	1.95	1.95	1.95	1.95	1.95
PVB ($m)	0.36	3.28	5.43	6.45	6.92	7.13	7.22
NPV ($m)	-1.59	1.33	3.49	4.50	4.97	5.19	5.27
BCR	0.18	1.69	2.79	3.31	3.55	3.67	3.71
IRR	Negative	10%	18%	19%	19%	19%	19%
MIRR	Negative	8%	12%	11%	10%	10%	9%

Figure 1 shows the annual undiscounted benefit and cost cash flows for the total investment of VG15070. Cash flows are shown for the duration of the investment plus 30 years from the last year of investment. In the baseline results, the six case study crops made up 24% of total benefits: carrots made up less than 1% of benefits (reflecting the low case study change in WFOP/ha despite a large production area; parsley made up 1% reflecting a moderate change in WFOP/ha but a small production area; radish and rocket both made up 3% reflecting a high change in WFOP/ha but a small production area; lettuce made up 6% reflecting a moderate change in WFOP/ha and a large production area; and broccoli made up 12% reflecting a moderate change in WFOP/ha and a large production area. The remainder (76%) of benefit was made up of the remainder of field grown vegetable crops[1] through the application of the impact multiplier as discussed in Table 4.

[1] Field grown vegetable production estimated at 80% (Future Food Systems 2020) of total vegetables: artichokes, asparagus, beans, beetroot, broccoli, brussels sprouts, cabbage, capsicums, carrots, cauliflower, celery, chillies, cucumbers, eggplant, spinach/silverbeet/kale, fresh herbs, garlic, ginger, leavy Asian veg, leafy salad veg, leeks, head lettuce, onions, parsnips, peas, potatoes, pumpkins, sweet potatoes, zucchini, and other veg not specific.

Figure 1. Annual cash flow of undiscounted total benefits and total investment costs

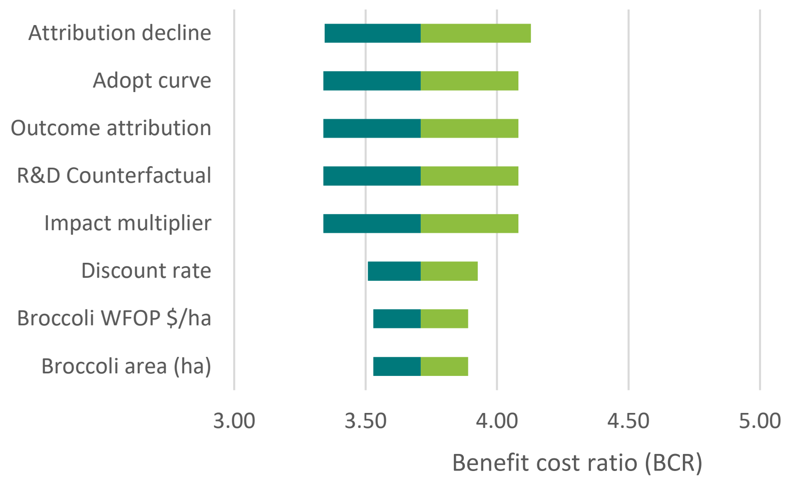


Sensitivity analysis

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 the variable where a potential value range was identified (in Table 4).

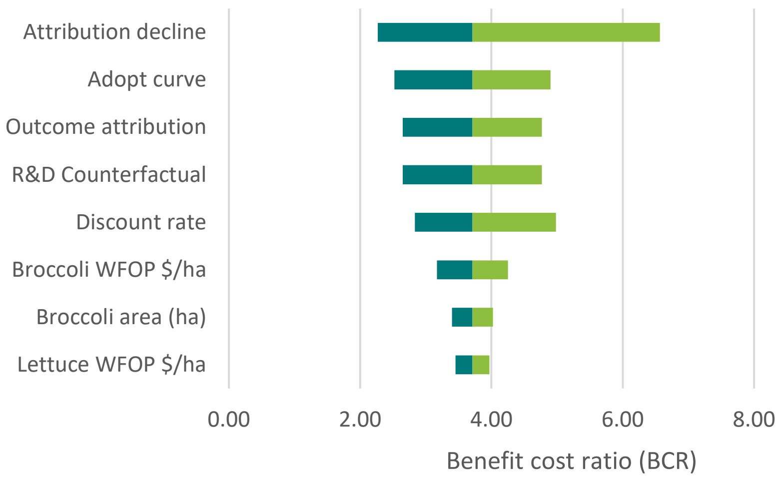
Results were first tested for sensitivity to uniform changes in underlying variables to reflect their relative influence on the modelling results. The eight variables to which the results were most sensitive are shown in Figure 2. These included the decline in attribution (reflecting ongoing research to refine and extend IWM recommendations), the estimated adoption curve, the outcome attribution (extent to which the estimated WFOP/ha can be attributed to VG15070 research and extension), the R&D counterfactual (extent to which the research would have been undertaken without vegetable levy funding), and the impact multiplier (benefit for vegetable crops beyond those identified in VG15070 case studies).

Figure 2. Sensitivity of the results to a uniform 10% change in variables



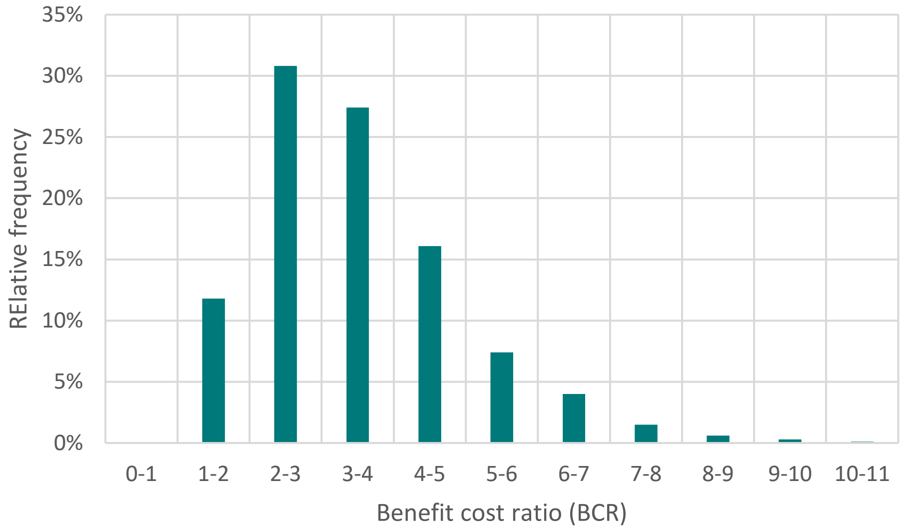
Results were also tested for sensitivity to the identified full range of potential variability for relevant data inputs (Figure 3). This showed that the rate of attribution decline had the largest potential effect on the results, which highlights the uncertainty regarding the extent to which the findings conducted in VG15070 will be improved upon or made redundant by future research into IWM or other innovations in vegetable production. This variable had a particularly large impact on the upside as the decline was calculated as a compounding figure. For the same reason, the discount has a larger upside potential. Other variables of significance were the adoption curve, the outcome attribution and R&D counterfactual.

Figure 3. Sensitivity of the results to the estimated full range of data variability



Finally, the full range of potential impact was estimated using @Risk stochastic modelling software to incorporate the combined changes in potential variable ranges over 1000 simulations. This process showed an impact (BCR) range of between 1.0:1 and 10.5:1, with 90% of results falling between 1.7:1 and 6.3:1 (i.e. excluding the low probability tails) (Figure 4). 100% of simulations resulted in a BCR less than 1. These results give a high level of confidence that the investment will generate a positive impact.

Figure 4. Range of impact results over 1000 simulations



Conclusions and implications

The analysis quantified the immediate on-farm economic impacts of IWM practices realised through reduced weed management input costs, combined with increased yield. The analysis was strongly supported by the detailed economic data collected through the VG15070 case studies that demonstrated the impacts of innovative IWM practices across different crops. Impacts generally related to reduced chemical, machinery, and labour inputs, and increased yield. Overall, 11 of the 16 case studies showed a positive economic impact from the innovative IWM practices. In two of the five negative cases, yield data was not collected so changes in revenue could not be assessed. Across all case studies, additional impacts relating to price premiums (by moving towards organic production), reduced risk of pesticide resistance, and improved environmental outcomes were also identified but were not able to be quantified due to a lack of data. These qualitative and quantitative research results, as well as discussions with stakeholders demonstrated a strong link between adoption of IWM and improved WFOP.

While the case studies reflected a sub-set of field grown vegetable production, the impact assessment considered the broader impacts of the research. These included other field grown vegetables that fall under the vegetable levy fund (and who therefore funded this RD&E), as well as vegetable crops that sit outside the vegetable levy fund such as potato (fresh and processed), sweet potato, onions and asparagus. The benefits to these non-funding industries represent spillover impacts.

Beyond these farm level benefits, the impact assessment also identified other spillover socio-economic benefits. These include a more sustainable vegetable industry supporting community resilience and increased vegetable consumption and associated health benefits, and environmental benefits from reduced chemical use and soil-runoff. While these additional impacts were not able to be quantified due to data gaps, the analysis highlighted the data gaps to support future R&D and impact analysis in the future. Opportunities for data collection include the vegetable and onion industries benchmarking program (currently MT22009). Despite these data gaps, the baseline impact (BCR) of 3.71:1, combined with sensitivity testing showing a likely impact (BCR) range of between 1.7 and 6.3, gives a high level of confidence in a positive RD&E impact.

Stakeholder engagement

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 theme						
Stakeholder and organisation	Stakeholder type	Related research	Research inputs	Research outputs	Research immediate outcomes	Follow on research	Stakeholder adoption	Impact areas and data
Araz Solomon, Hort Innovation	Funding organisation	✓	✓	✓	✓	✓		✓
Paul Kristiansen and Michael Coleman, UNE	Research organisation	✓	✓	✓	✓	✓	✓	✓
Darren Long, MG Farms	Target beneficiary and levy contributor						✓	✓
Maureen Dobra, The Loose Leaf Lettuce Company	Target beneficiary and levy contributor						✓	✓

Glossary of economic terms

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

Abbreviations

CRRDC Council of Rural Research and Development Corporations

CSIRO The Commonwealth Scientific and Industrial Research Organisation

IWM Integrated Weed Management

RD&E Research, Development and Extension

SIP Strategic Investment Plan

UNE University of New England

VegNET The national vegetable industry extension program funded through the vegetable industry R&D levy

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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. The adoption of IWM practices will vary across vegetable growers, influenced by planted crops, existing weed management practices and weed burden, and enterprise size. The adoption and diffusion of the VG15070 RD&E were estimated using the CSIRO ADOPT framework (Kuehne et al 2017) and drawing on project reporting and stakeholder consultation. From this approach, a maximum adoption of 17% of relevant vegetable planted area after 10 years was estimated with adoption starting from the release of the initial IWM resources being available to growers in 2020-21. The maximum adoption was tested at ±32% to test the results for sensitivity to changes in this variable. Figure 5 shows the adoption diffusion profile used for the impact assessment's cost benefit analysis.

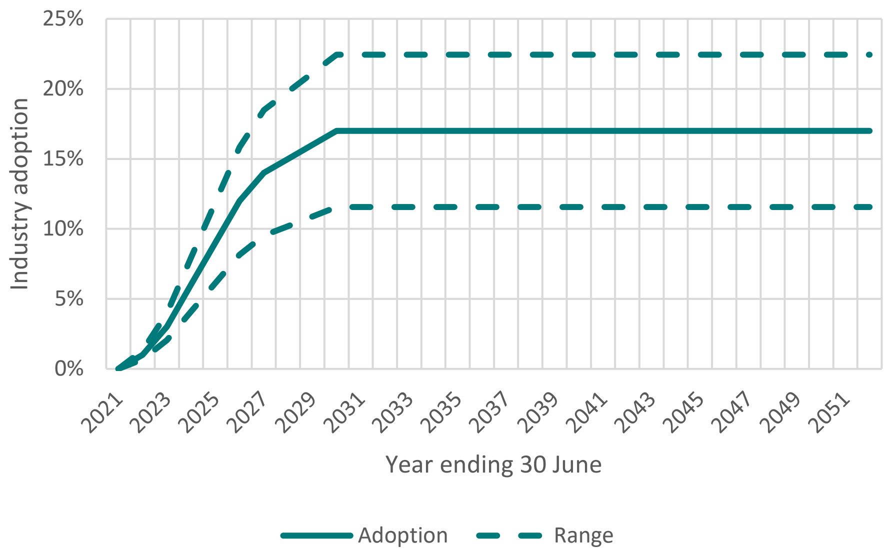

Figure 5. Adoption and diffusion curve applied to IWM practices for relevant vegetable crops

ADOPT inputs for integrated weed management

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

A majority 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?

About half have risk minimisation as a strong motivation

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

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

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

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?

Very easily trialable

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

Not at all difficult to evaluate effects of use due to complexity

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

Easily observable

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?

A majority 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?

About half will need new skills and knowledge

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

About half are aware that it has been used or trialled in their district

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

Minor initial investment

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 future years

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

1 - 2 years

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

Moderate environmental advantage

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

1 - 2 years

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?

Small decrease in ease and convenience

Ends.