Hort Innovation

Final Report

Independent Program Coordination for Apple and Pear Productivity Program

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Delivery partner:

RMCG

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AP14022

Project:

Independent Program Coordination for Apple and Pear Productivity Program AP14022

Disclaimer:

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Content

Summary

The Productivity, Irrigation, Pests and Soils (PIPS) program has efficiently delivered meaningful research outcomes and extended these to industry through the Future Orchards (FO) program. It has achieved this by:

- Aligning and leveraging investment,
- Enhancing cooperation between organisations, and
- A focus on delivering industry relevant results.

The PIPS program is the apple and pear industry's premier research and development (R&D) program designed to combine research activity and provide a connection to industry through co-investment and shared management. The first PIPS program ran from 2009 to 2014 with the second phase (PIPS2) running from 2015 to 2020. PIPS2 comprises six projects delivered by a range of organisations. The objective, deliverer and time-lines are detailed in Table 1 below.

Table 1: PIPS2 Projects

TOPIC	OBJECTIVE	WHO	When
Crop load management.	Improvement of crop load management and fruit quality through artificial spur extinction (ASE).	Dr Sally Bound (TIAR).	2009 – 2017 (100% complete).
Managing new pear varieties.	Assess orchard management systems to maximise and sustain productivity of high-quality red-blushed pears.	Dr Ian Goodwin (DEDTJR).	2012 – 2018 (100% complete).
Integrated pest and disease management.	Assessment of *Mastrus ridens* effectiveness as a biological control agent for codling moth.	David Williams (DEDTJR).	2015 – 2019 (100% complete).
Independent program coordination.	Facilitation of communication and collaboration across PIPS2 and the broader apple and pear industry, and provision of project M&E.	Dr Kristen Stirling and Dr Anne-Maree Boland (RMCG).	2015 – 2019 (100% complete).
Nutrition.	Understanding of, and development of tool to manage nitrogen use in apples.	Dr Nigel Swarts (TIAR).	2015 – 2020 (75% complete).
Crop load management.	Clarification of how flowering in apple is inhibited or promoted by changes in gene expression and metabolic signals formed within the plant in response to ontogeny, plant resources, cultural practices and environmental cues.	Dr Dario Stefanelli (DEDTJR) and Prof Jens Wunsche (UoH).	2015 – 2020 (75% complete).

PIPS2 addresses key gaps in our understanding of orchard productivity through integrated and efficient R&D. Technical excellence, adaptive management, and efficient leveraging of funds have been key strengths of the PIPS2 program. Independent coordination and integration with Apple and Pear Australia Limited (APAL) to effectively communicate and engage with industry have also been important aspects of successful delivery.

A mid-term review of the PIPS2 program highlighted strengths of the program including:

- An ability to adaptively manage research activity to mitigate risks
- Ensuring outcomes are relevant to industry needs
- Providing 'value for money' through leveraging of investment and collaboration
- Effectively communicating research outcomes through APAL and FO
- Demonstrating potential industry impact.

Particular achievements of individual projects include:

Improved management of biennial bearing in apple orchards through better understanding of thinning techniques and the internal factors impacting on flowering.	Sally Bound has shown that Artificial Spur Extinction (ASE) offers a new technology to precisely manage crop load. ASE eliminates the need for chemical thinning and has the added advantages that it is not weather dependent and removes the negative impact that most chemical thinners have on fruit size and shape. With its simplified hand-thinning and high fruit quality, ASE reduces both time and cost to the grower. The outcomes of Sally's work have been communicated to industry via 3 APAL speed updating presentations, seven industry articles (three in the Australian Fruit Grower (AFG) magazine and four in other magazines), one case study in a book chapter, three technical presentations to agronomists, four field walks, one media interview, a demonstration video produced by APAL, presentations to Victorian and Tasmanian growers, and participation in the PIPS2 video.
	Dario Stefanelli and Jens Wunsche (University of Hohenheim, Germany) have worked collaboratively to understand how crop load affects the internal plant processes that determine flowering and ultimately fruit set in apple. The project has already identified genes, metabolites and proteins involved in the initiation of flowers in both biennial and non-biennial apple cultivars. The Australian component of the project has made significant progress in simplifying and validating the MaluSim model so that it can be used under Australian conditions for making crop thinning decisions. The outcomes of Jens and Dario's work has been communicated to industry via seven research papers, attendance at an international symposium, three APAL speed updating presentations, two field walks, one article in the AFG magazine and participation in the PIPS2 video.
Improved management of key pests	David Williams has demonstrated the effectiveness of *Mastrus ridens* as a biological control agent of codling moth in Australian apple orchards. *Mastrus* offers industry the ability to control codling moth at all stages of its life cycle, and in combination with other techniques, provides comprehensive coverage. Improved management of codling moth will not only reduce cost and impacts on the environment but also facilitates access to key export markets. The outcomes of David's work have been communicated to industry via three technical presentations to agri-chemical companies, participation in the PIPS2 video, three articles in the AFG magazine, three APAL speed updating presentations, presentations at the 2017 northern loop of the Future Orchard walk, Pome Zone 2016 and to Gippsland growers.
Improved management of nitrogen within apple and pear orchards	Nigel Swarts has developed a strong team of plant physiologists, soil scientists and modellers to describe what happens to nitrogen both during and between seasons in apple trees. This information (along with soil characterisation) is being fed into a model that will assist growers to strategically manage their nitrogen inputs and a more productive orchard. The outcomes of Nigel's work have been communicated to industry via participation in the PIPS2 video, three articles in the AFG magazine, two APAL speed updating presentations, presentations at the 2016 southern loop of the Future Orchard walk, Pome Zone 2016 and to key growers involved in testing the model.
	Ian Goodwin has also investigated nitrogen use efficiency in pear orchards including remotely sensing tree nitrogen status. The team at the Pear Field Laboratory determined the most productive planting configurations and tree training, which rootstocks and cultivars deliver the best yields, most effective irrigation regimes and effects of shading on red blush development. The outcomes of Ian's work have been communicated to industry via nine conference presentations, more than thirty field walks, one masterclass, eleven videos, four seminars, three conference posters, eight refereed journal papers, one refereed conference paper, eighteen industry articles, five technical reports, one Agnote and three press releases.

The independent coordination of PIPS2 has been a key factor in its success and has facilitated the delivery of achievements discussed above. The coordinators (Anne-Maree Boland and Kristen Stirling) have achieved this by integrating research and development (R&D) across sub-projects within PIPS2 and improving the communication of R&D outcomes to growers by expanding the collaborative model of research across sub-programs, agencies, and boundaries (Australian States and Trans-Tasman).

The coordinators have built research capacity and mitigated research silos facilitating greater awareness of research activity and increased the uptake of research outputs by advisors and growers.

Keywords

R&D, program coordination, productivity, pests, soils, irrigation, apple, pear.

Introduction

In 2010, Apple and Pear Australia Ltd (APAL) endorsed a new strategic plan for the apple and pear industry (New Horizons 2015)[1]. This plan highlighted a number of key challenges facing the industry including:

- Consumer dissatisfaction with fresh fruit
- Competition with other products or imports
- The imminence of imports
- Environmental impact pressures.

To best direct resources into addressing these challenges, a five-year (2010-2015) Apple and Pear Industry Research, Development and Extension (RD&E) Investment Plan ("Innovation making a difference")[2] was developed. This plan set out seven integrated priority investment areas; Productivity and Supply Chain, Climate Change, Germplasm Improvement, Market Access and Biosecurity, Market Research, Industry Development and Portfolio Management.

The Apple & Pear Industry Productivity, Irrigation, Pests and Soils (PIPS) Program was one of ten projects under the Productivity and Supply Chain priority investment area. The first phase of the PIPS Program, completed in December 2014, was designed to provide integrated RD&E to support gains in efficiency within the apple and pear orchard while providing orchardists with the tools to assist the long-term sustainability of their orchards. The first phase of the PIPS program comprised five research projects (Tree structure, Integrated pest and disease management (IPDM), Soils, water and nutrients, Precision fertigation Profitable pears and Intensive Pear Production) and an industry communications project (for example, via Future Orchards fact sheets, APAL National Conferences and Australian Fruit grower articles)[3].

An independent review of the first phase of the PIPS Program was completed by Roberts Evaluation in 2013 to assess the extent to which the program met its objectives, identify gaps and provide recommendations for future programs[4].

A key recommendation from this review was to employ a suitably experienced independent program manager to drive the sharing of results and communication between and within sub-programs operating in different geographic locations and across different organisations. AP14022 was commissioned to coordinate the individual research projects within PIPS2 and facilitate communication of research outcomes via the industry communications and Future Orchards programs.

Achievements

The coordinators of PIPS2 have successfully provided oversight of the Apple & Pear Productivity Program, which has:

- Enabled ongoing integration of research, extension and communication activities for the apple and pear industry
- Driven improvements in communication between stakeholders across all geographic regions, sub-projects and organisations
- Allowed for coordinated selection of appropriate research projects that meet the needs of all growers
- Fostered the uptake of research outputs by end users using multiple channels of communication
- Ensured that the Apple & Pear Productivity Program design is flexible enough to adapt existing research to maximise benefits to end users and be responsive to emerging research needs.

[1] *New Horizons 2015* – apple and pear industry plan (APAL)

[2] Apple and Pear Industry RD&E Investment Plan 2010-2015 – *"Innovation making a difference"*

[3] See http://apal.org.au/research-development-extension/projects/productivity-irrigation-pests-and-soils-pips/

[4] An independent review of the PIPS program, Dr. Daniel Healy, Roberts Evaluation Pty Ltd, 2013

Methodology

The coordination of the PIPS2 program was delivered in three phases to allow some flexibility in approach.

The three phases included:

1. Program design and establishment (Year one)
2. Program delivery and engagement (Years two to five)
3. Program evaluation and finalisation (Years two to five).

These are described in greater detail below.

Phase 1

Phase 1 was undertaken in the first year and focused on the robust design and establishment of the program. During this phase the coordinators worked closely with APAL and Hort Innovation to ensure that appropriate linkages were made and that the program meet the needs of industry.

Foundational activities to design the research program included:

Activity	Task
Review of program deliverables, milestones and reporting.	• Desktop analysis of relevant documents • Determine extent of alignment between current project deliverables, milestones, reporting and program objectives • Clearly identify current research gaps and opportunities for future research.
Project selection process.	• Using updated sub-program tender selection process (proforma, criteria etc.) • Work in consultation with HAL, APAL, R&D sub-committee and external experts to run the selection process.
Develop and award contracts, including milestones and sub-contractor agreements (in conjunction with HAL).	• Facilitate procurement processes (e.g. setting up contracts, reporting processes).
Develop sub-project work plans including milestones.	• Identify key implementation steps • Develop activity schedule • Communication processes.
Develop Program Logic and MERI Framework for the whole program.	• Identify project activities, outputs, outcomes at the program level • Identify suitable indicators to measure success at the program level.
Support development of sub-project MERI Plans.	• Assist projects to identify project activities, outputs outcomes at the program level • Assist projects to identify suitable indicators to measure success at the program level.

Phases 2 and 3

Phases 2 and 3 were delivered during Years two to five of the program (August 2014 to September 2019).

Phase 2 and 3 activities included:

Focus	Activity
Program delivery and engagement.	Providing strategic oversight and leadership to drive coordinated Program delivery through: • Maintaining links with current industry research and knowledge • Responding to and facilitating the communication of emerging research needs • Maintaining program cohesiveness.
	Providing support for project leaders to maximise the potential of projects through: • Facilitating linkages between and within sub-Programs • Ensuring delivery of milestones • Discussing issues arising with sub-program managers • Providing sub-project managers with updates on other projects • Ensuring sub-program managers delivered against their contractual obligations.
	Maintaining oversight of individual projects, including: • Mid-term review of individual projects • Coordinating data collection for evaluation and reporting purposes • Managing project communication processes.
Coordination of program engagement processes.	• Presenting to and liaising with the Apple and Pear Strategic Industry Advisory Panel (SIAP) • Regular communication with Hort Innovation, Future Orchards and the APAL communications team • Coordinating twice yearly program meetings.
Facilitate the effective uptake of research outputs by end users.	• Newsletter and magazine articles, website updates, fact sheets • Coordinate opportunities for growers to access research outputs • Presentations, expert speakers.
Evaluating the impacts.	• Data collection in line with the MERI framework • Facilitate data collection in line with MERI Framework (against the different levels of the program logic - activities, outputs, outcomes) • Collect data to highlight challenges and successes • Drive adaptive management processes • Collation of information throughout the Program to ensure continuous improvement • Present key lessons at relevant meetings.
Reporting	• Manage and deliver against reporting requirements • Communication summaries (start and end of program) • Submission of Hort Innovation standard six-month reports • Facilitate reporting against project outputs and outcomes (linked to program logic and MER framework) • Facilitate milestone reporting (linked to program logic and MER framework).

Outputs

The key outputs of the coordinator's role were focused on:

1. Facilitating the communication of research outcomes
2. Monitoring and evaluating the performance of individual research projects within PIPS2
3. Coordinating the individual projects and facilitating greater collaboration and integration.

The outputs from these activities are discussed below.

1. Communications

Magazine articles

A communication schedule was established to ensure that one article per year based on the activities and outcomes from each of the research projects was published in the Australian Fruit grower (AFG) Magazine. The AFG magazine is distributed to 950 readers across Australia. The researchers were encouraged to provide additional articles at other times of the year and through other communication avenues however the schedule ensured there was a consistent flow of information from research projects out to industry (via the primary industry magazine). The schedule was broadly aligned with the milestone outputs for each project. During 2016 – 2018 an edition of the AFG was published every two months. In 2019 the magazine was published every quarter.

The Coordinators provided a role in organising the submission of articles, advising on content and editing prior to submission to APAL. Articles produced during the program can be found at:

Year	Author	Edition	Weblink
2016	Nigel Swarts	February/March	http://apal.org.au/precision-fertigation-improve-apple-orchard-productivity/
	Kristen Stirling and Anne-Maree Boland		http://apal.org.au/introducing-pips2/
	Ian Goodwin	April/May	http://apal.org.au/nitrogen-management-red-blushed-pears/
	David Williams	August/September	http://apal.org.au/codling-moth-control/
	Sally Bound	October/November	http://apal.org.au/chemical-thinners-necessary/
	Nigel Swarts		http://apal.org.au/strategically-managing-water-nitrogen/
2017	Dario Stefanelli and Jens Wunshe	December/January	http://apal.org.au/finding-triggers-biennial-bearing-apple/
	Ian Goodwin	February/March	http://apal.org.au/drones-deployed-assess-nitrogen-needs-red-blushed-pears/
	Sally Bound	August/September	http://apal.org.au/precision-crop-load-management-without-chemicals/
	Ian Goodwin	October/November	http://apal.org.au/exploring-plant-growth-regulator-use-new-pears/
2018	Nigel Swarts	December/January	http://apal.org.au/what-becomes-nitrogen-orchard/
	Sally Bound	February/March	http://apal.org.au/save-time-and-money-with-a-smart-crop-load-management-choice/
	David Williams	June/July	http://apal.org.au/killer-wasps-and-better-pheromones-target-codling-moth/
	Ian Goodwin	August/September	http://apal.org.au/planting-systems-blush-pears/
	Dario Stefanelli and Jens Wunshe	October/November	https://apal.org.au/secondary-thinning-service/
2019	Dario Stefanelli	Autumn	Effects of crop load on apple fruit maturity (Autumn 2019 edition) https://apal.org.au/wp-content/uploads/AFG-Autumn19-final.pdf
	Nigel Swarts	Winter	Harvesting the benefits of fruit nutrition science for

Year	Author	Edition	Weblink
			a consumer driven future https://apal.org.au/wp-content/uploads/AFG-Winter19.pdf
	Ian Goodwin Nigel Swarts	Spring	Water deficits and apple productivity Soil characterization and water use in Australian apple orchards https://apal.org.au/wp-content/uploads/2019/09/APAL_Fruit-Grower_DD_FA_Low-Res.pdf
	Jens Wunsche David Williams Dario Stefanelli	Summer	Articles planned for this edition (*not yet published*) include: • Update on the biennial bearing project focusing on research conducted in Germany • Outcomes of the *Mastrus ridens* project • Assessing fruit maturity and quality.

As new research articles are published from the PIPS2 program they are also included on the PIPS2 webpage at https://apal.org.au/programs/more-industry-programs/pips2/ and also at https://apal.org.au/news-and-resources/research-and-statistics/.

Updates

In the absence of an established advisory committee, discussions and updates have been provided to APAL via Angus Crawford (and Alison Barber post Angus' departure) and Hort Innovation via Byron De Kock. At a project level, individual research project leaders engage with industry participants directly.

APAL distribute a weekly e-newsletter called 'Industry Juice' to a distribution list of 1200 providing an update on current events, news and topics of interest. The researchers within the PIPS2 program were contacted on a monthly basis to identify any news items from the research projects suitable for inclusion in APAL's e-newsletter 'Industry Juice'. The e-newsletter has also been used to promote communication products such as the PIPS2 videos or to highlight the achievements of the researchers within the program (such as receiving industry awards).

Presentation at APAL Industry Events

The coordinators have liaised with the APAL communication team to highlight the research conducted within the PIPS2 program. Researchers within the program have participated in the 'Speed Updating' events held prior to Hort Connections from 2016 – 2019. These events have provided an opportunity to discuss research outcomes from their projects with industry members and to also seek feedback from industry on research objectives. Anne-Maree Boland also provided an overview of the PIPS2 program at the 2016 National Horticulture Convention. This provided a valuable opportunity to update industry members on the research occurring within the PIPS2 program and enabled us to seek feedback from industry. There was considerable interest in the program and what the findings from each project may mean for growers.

Videos

During the program the coordinators explored avenues to extend the reach of the current PIPS2 communication activities (e.g. AFG articles, papers, conferences, social media). In discussion with the PIPS2 team it was agreed that videos have proven to be a useful and effective way to achieve this. A great example of this was the response to the video prepared by APAL for Sally Bound on Artificial Spur Extinction.

In 2017 an introductory PIPS2 video was prepared in partnership with APAL. The purpose of this video was to introduce each of the researchers and their projects to a broader audience. Preparation of the video involved each researcher recording a short 30-40s clip, where they:

- Introduced themselves
- Provided a brief overview of their research project
- Described how their project and its outcomes will benefit growers.

The final version of the video can be accessed here: https://youtu.be/M-GkLyQaPuI.

The video was circulated by APAL through their various communication channels including Industry Juice, social media and used to promote the upcoming Speed Updating event.

Videos showcasing the achievements of three PIPS2 projects were developed in 2018. An opportunity to film the researchers was identified and realised during the APAL speed updating event. In particular, the presence of Jens Wunshe at the speed updating event provided the rare opportunity to meet and discuss the biennial bearing project face to face. The videos provided industry with a snapshot of progress and research outputs to date and an understanding of the potential impact and value for industry once research has been completed. Footage of interviews were interspersed with images and video taken in the field.

The first video featuring Dario Stefanelli and Jens Wunsche was included in the 254th edition of Industry Juice on the 15 August and is located on the PIPS2 page at https://apal.org.au/understanding-biennial-bearing-in-apples-2018-update/.

The other two videos featuring Sally Bound discussing the outcomes of the Artificial Spur Extinction project, and Bi Tan and Nigel Swarts discussing their research on understanding nitrogen movement through apple orchards and the development of the SINATA model are available on the PIPS2 webpage at https://apal.org.au/programs/more-industry-programs/pips2/.

A final video showcasing the outcomes of David Williams' project on *Mastrus ridens* was developed in 2019 using footage from the field, laboratory and discussion with David. The video will be promoted through Industry Juice and is located on the PIPS2 webpage at https://apal.org.au/programs/more-industry-programs/pips2/.

A video of Ian Goodwin's project was not made as DEDTJR have made numerous videos on the key outputs of this project which are available on the Horticulture Industry Network website at http://www.hin.com.au/networks/blush-pear-research/pear-planting-systems-trials, with links also provided on the PIPS webpage.

Websites

The PIPS webpage located on the APAL website (https://apal.org.au/industry-info/pips/) has been a useful platform for showcasing the individual projects within the PIPS program and providing online access to resources associated with the projects. The page was updated in 2016 to reflect the changes in the program from PIPS to PIPS2, which included reviewing and updating the text and inclusion of new photos.

In 2018 the webpage was reviewed and the need to update the resources and individual project summaries identified. The coordinators met with the communications team at APAL to discuss options for updating the page to make it a more useful and engaging resource for the program. As a consequence, in conjunction with an overhaul of the whole of the APAL website, the page was re-designed to display content according to topic area rather than projects and update and provide better links to the resources associated with these topic areas.

The coordinators also liaised with each of the project leads to identify the most relevant resources and links for inclusion on the webpage. This included the publication of more detailed scientific papers on the website which had been a recommendation from industry members. These papers can be found at https://apal.org.au/news-and-resources/research-and-statistics/.

A key component of Nigel Swarts' project has been the collection of data on common apple growing soils in South Eastern Australia. This data included characterization of soil types including the collection and analysis of data relating to the morphology, chemistry and hydrology of over twenty different soil types. This information will be used to support and inform the decision support tool SINATA which will assist growers in making decisions around nitrogen management in their orchards. This information is of interest and value to those in the apple and pear industry seeking to better understand their soil and how the characteristics of their soil impacts on irrigation and nutrition management. To improve the visibility and communication of this information the Coordinators developed a website enabling industry members to engage far more easily with the data and apply to their own situations. A link to the website is included on the PIPS webpage on the APAL website. The website will be promoted through industry juice and will be featured in a presentation by Nigel Swarts at the Industry R&D Updates in November 2019. This website could be extended (in future programs) by incorporating simple irrigation calculation tools to enable industry to make informed decisions regarding water use depending on their soil types and crop demands.

Factsheets

In view of the dry conditions in 2019 the coordinators liaised with Ian Goodwin (AgVic) and Alison Barber (APAL) to update and republish information developed on managing orchards during dry conditions through various irrigation approaches. This information was published in the Spring 2019 edition of the Australian Fruit Grower magazine and a fact sheet on Regulated Deficit Irrigation (RDI) in pears was also developed and can be viewed on the PIPS webpage. The information in the fact sheet and magazine articles was based on research conducted by Ian Goodwin during Phases 1 and 2 of the PIPS program.

2. Monitoring and Evaluation

Development of Project Logics and MERI Frameworks

At the start of the program the coordinators worked with each of the project leaders to develop program logics and a Monitoring, Evaluation, Reporting and Improvement (MERI) framework. These are important tools in monitoring the performance of projects and identifying opportunities for improvement. The program logics and MERI frameworks were used during the mid-term review to guide data collection and evaluate outputs and outcomes.

Milestone Monitoring

Monitoring of milestone achievements within each of the PIPS2 research projects occurred throughout the program. Researchers were contacted four weeks prior to the due date of the milestone report to assess progress and identify any potential problems/risks. We also requested copies of the milestone reports once they were sent to Hort Innovation to identify potential communication opportunities and data to assist with the monitoring and evaluation.

These reports (minus appendices) were also provided to AgFirst to facilitate the extension of research outcomes through the Future Orchards programs. The reports remained confidential and cannot be distributed without the permission of the authors.

Mid-term review of three of the PIPS2 research projects

As the independent program coordinator for the Apple and Pear Productivity Program, RMCG conducted a mid-term evaluation of the following three research projects within the PIPS2 program:

- Integrated pest and disease management – Phase 2 (AP15001)
- Physiological, metabolic and molecular basis of biennial bearing in apple (AP15002)
- Improved tree and fruit nutrition for the Australian apple industry (AP14023).

The evaluation collected data through desktop review and interviews to assess the effectiveness of project activities to date in achieving desired project outcomes.

Semi-structured interviews were conducted with participants that were intensively engaged in project activities with the intention of directly influencing practice change. To successfully measure impact, these interviews sought participant's views on their current levels of awareness, knowledge and skills/experience as well as their current practices which can be analysed over time to determine change.

Based on the findings of the evaluation, RMCG made a number of recommendations on maintaining, and potentially improving project performance.

The review was funded out of the existing budget for AP14022 and conducted from November 2017 to April 2018. A report discussing the findings of the review is provided in Appendix 1.

3. Coordination

Research Leader Biannual Meeting

During the program the Coordinators organised and facilitated six-monthly meetings between the research leads, Hort Innovation, APAL and Future Orchards. The purpose of these meetings was to:

- Update all team members of current progress and achievements of each research project
- Discuss commonalities and opportunities for integration
- Flag any risks/challenges associated with projects.

These meetings also provided an important opportunity for the communications team and the Future Orchards representative (Ross Wilson) to understand research outputs/outcomes and to extend this to industry.

Championing of researchers within the program

During the program the coordinators identified opportunities to champion the activity of the research projects and their leaders. This helps build the reputation of the research conducted within Australia for the apple and pear industry. A key opportunity was identifying researchers whose work had real impact for the apple and pear industry and therefore worthy of the APAL award for researcher of the year.

In 2018 David Williams and Sally Bound were nominated and received a research of the year award and a lifetime achievement award. In 2019, Nigel Swarts was nominated and received the researcher of the year award.

An article was written on the general success of the PIPS program and in particular those of Dr Sally Bound and David Williams, who both received an APAL industry excellence awards at Hort Connections in June 2018. This article was included in the Industry Juice newsletter: https://apal.org.au/pips-researchers-awarded-for-excellence-and-achievement/.

Assessing the future of the PIPS program

In 2018 the PIPS team considered it important to begin identifying the research focus areas for the next phase of PIPS and discuss this with the A&P Strategic Investment Advisory Panel (SIAP) to gain their input. Discussion occurred during the biannual research leader meeting as to what the next phase of PIPS could look like. This was then formalised and documented in a paper 'Future Options for PIPS' and provided to the A&P SIAP for consideration. Nigel Swarts and Kristen Stirling then presented to the A&P SIAP in October 2018 to:

- Inform them on the achievements of PIPS2 to date both in terms of content (research) and approach (coordinated program)
- Determine what they think has worked well and what we could do better
- Outline the team's ideas for future research priorities and seek their feedback on this.

Feedback from the presentation to the A&P SIAP was that they felt that the program had provided value for money and there was agreement that in principle the program should be continued.

At the next PIPS2 program coordination meeting (June 2019) the team focussed on progressing the concept proposal for the next phase of PIPS. The SIAP members were invited to attend this meeting to provide their input and feedback on proposed future R&D activity to address issues associated with productivity, irrigation, pest and soil management.

The coordinators facilitated a workshop session with both the researchers and the SIAP members to ensure that the design of the concept proposal for PIPS3 was further advanced. Preparation for this meeting required ongoing liaison between the coordinators, Hort Innovation, APAL and the project leads.

Based on the outcomes of that workshop session a concept proposal was developed and provided to the SIAP at their September 2019 meeting.

Future Orchards Program

The Coordinators developed strong relationships and liaised continuously with the AgFirst team to ensure an effective flow of information out of the PIPS2 team for extension to industry through the Future Orchards program. This was achieved by initial meetings with Ross Wilson in 2016 to discuss how the PIPS2 program and Future Orchards could best work together to promote research outcomes to industry. Based on the outcomes of this meeting:

- Opportunities for the PIPS2 researchers to present on their research projects during FO walks were identified
- Ways for the PIPS2 program to work/liaise through Ross to ensure that PIPS2 information was disseminated at all of the FO walks was discussed
- AgFirst was provided with information of other apple and pear research occurring within Australia and how they might be able to involve other researchers within the FO program.

AgFirst provided a preliminary schedule for the FO Walks and their annual themes for these walks. During the next biannual PIPS2 meeting opportunities for each of the researchers to be involved in the FO Walks was discussed to ensure a continuous flow of apple and pear research through this extension avenue.

The following schedule was developed:

Date	Topic	Northern Loop	Southern Loop
Jan 2016	PIPS2 nutrition research specifically nitrogen its role, movement in the soil and need in the plant.		Nigel Swarts.
September 2016	PIPS2 Research Update.	Brett Feehan.	Brett Feehan.
March 2017	IPM and Mastrus ridens.	David Williams.	
June 2017	PIPS2 Research Update. ASE.		Ross Wilson. Sally Bound.
September 2018	PIPS2 Research Update.		Ross Wilson.
June 2019	PIPS2 Research Update.		Ross Wilson.
November 2019	SINATA nutrition and water.	Nigel Swarts.	
June 2020	PIPS2 Update.	Ross Wilson.	Ross Wilson.
September 2020	Wrap up of the biennial bearing project.		Dario Stefanelli and/or Jens Wunsche.

At each of the Future Orchard Walk Loops either a PIPS2 researcher would present as a guest speaker or AgFirst would provide an overview of the PIPS2 research program and recent outcomes. This presentation was developed based on information provided by the research team at the six-monthly research meetings.

The coordination team met with Angus Crawford and Brett Feehan after the presentation of the first PIPS2 Update by AgFirst to debrief on the experience. Brett and Angus felt the overview presentation was a useful way to raise general awareness with growers about the PIPS2 research currently underway. Presenting the overview to industry also generated some useful feedback on the delivery of PIPS2 extension through the Future Orchards project.

Key points included:

- Focus on research projects that are at an advanced stage in the short-term
- Specifically define the recommendations for growers
- Provide enough detail to allow growers to make informed decisions e.g. trigger points, decision tools
- Provide links to technical resources and further information.

These lessons informed the design and delivery of PIPS2 research at future Orchard Walks. Ross Wilson (AgFirst) acted as the extension agent for the PIPS2 program during future Orchard Walks. In preparation for the PIPS2 presentation the sharing of milestone reports was negotiated with Hort Innovation and Ross worked with individual researchers and attended the biannual research leaders' meetings to develop a thorough understanding of the progress of the individual research projects.

The Coordinators attended several of the Orchard Walks to gain a better understanding of the structure and delivery format, to contribute to the continuous improvement of the PIPS2 and Future Orchards extension partnership. Insights included:

- Involving the Research Leader in the Orchard walks was positive as it allowed direct access for growers. This meant that specific and detailed questions about the research could be answered on the spot.
- Focusing on a research project that was at an advanced stage provided more practical and useful information for growers.
- Providing technical resources, further information and an opportunity for growers to get involved in the research was useful for those growers seeking further interaction with the researcher and project.

Outcomes

The Apple & Pear Productivity Program Manager role has improved communication and engagement both within the PIPS2 research team and across industry.

This has been achieved through delivery of activities which have focussed on:

- *Improving internal program communication and engagement*. The coordinators have facilitated communication between subprogram researchers/consultants (via informal and formal, written and verbal communication) and industry representatives. Specifically:
    - Ensuring sharing of results via clear lines of communication
    - Facilitating discussions on adapting to the existing research (research workshops to identify new themes), including mid-term reviews scheduled within contracts
    - Ensuring latest industry knowledge is captured and incorporated across subprograms, as it becomes available (i.e. from those RD&E projects outside of the Productivity Program)
    - Providing quarterly reporting of results and activities to internal program staff.
- *Improving external program communication and engagement. The coordinators have facilitated the extension of R&D outcomes to wider industry users and non-program participants, such as Government/state agencies, via regular targeted articles in coordination with APAL and Future Orchards program. Specifically:*
    - Raising awareness and advising on new tools/outputs via 6-monthly reporting (at least) of outputs to growers and industry in multiple forms (e.g. Website, industry magazines, newsletters, APAL publications)
    - Ensuring a high level of industry engagement - inclusion of all relevant stakeholder groups in program implementation and improvement via facilitated workshops and events.
- *Improving program governance and reporting. The coordinators have delivered on contractual reporting and evaluation arrangements including regular reporting of program updates to Hort Innovation and mid-term reviews, as well as ongoing informal evaluation of projects via milestones and regular contact to ensure meeting contractual requirements).*

Monitoring and evaluation

One of the key functions of this project (program coordination) was to provide monitoring and evaluation of the individual projects within the program. This occurred throughout the project and included the establishment of program logics, MERI plans and a mid-term review of three of the projects. There was however no formal plan for monitoring and evaluation of this project (program coordination). Informally the coordinators sought regular feedback from key members of the program (including Future Orchards, APAL and lead researchers) to ensure that the project was meeting their needs and to identify if improvements could be made. Feedback from program members was positive and where possible modifications were made to project delivery to ensure that outcomes were of value.

Recommendations

Without the PIPS program, research activity conducted for the apple and pear industry would occur in isolation, have potential for duplication and potentially lose the ability to recognise the 'whole of orchard' system. Communication between the research community, and with industry, would be reduced and ultimately the competitiveness of the apple and pear industry could be diminished.

Based on the outcomes of the mid-term review conducted by the coordinators a number of recommendations are provided to facilitate the efficient management of, and effective delivery of outcomes from, future R&D programs for the apple and pear industry. These include that:

- Research projects need to identify and respond (through adaptive management) to issues or risks which may impact on project performance and the achievement of long-term outcomes
- Research projects and program coordinators capitalise on communication and extension opportunities
- Program coordinators need to have a productive working relationship with the APAL communication and Future Orchards teams to:
    - Highlight communication and extension opportunities
    - Appropriately schedule communication and extension opportunities with the release of research outcomes
    - Identify new and/or modified approaches to extension and communication that will extend reach.
- Reporting of research outcomes could be more effective and have greater impact on industry if milestone reports were simplified and better aligned with program logics (developed at the start of the project)
- Future research projects need to demonstrate how the outputs/outcomes will be extended to industry (where topics/activity doesn't align with the Future Orchards program). For example, two of the projects within PIPS2 will develop models which can be used to guide important crop management decisions, however one on one work with orchardists will be required to facilitate an understanding of why and how the models can be used. It is recommended that an extension component is included in the next phase of PIPS to ensure that the valuable outputs generated by these projects are taken up by industry.

While two of the existing PIPS2 projects will continue beyond 2019, the majority of research activity will be completed by the end of 2019 providing the opportunity to identify and develop new projects to address key knowledge gaps. The coordinators have worked extensively with the lead researchers, Future Orchards and APAL to identify priorities and potential research activities for a third phase of PIPS. The projects and guiding principles of PIPS3 are discussed in greater detail in Appendix 2.

The objective of the PIPS3 program would be to provide industry with the tools and knowledge to develop orchards of the future that:

- Use resources efficiently and sustainably.
- Focus on biological and cultural management solutions (reducing pesticide dependence).
- Drive quality through access to better information along the supply chain (through use of new technology such as IoT and blockchain.

These orchards will ensure the apple and pear industry has social license to produce now and in the future through the environmentally-sound and sustainable production of apple and pears, that will continue to meet consumer demands and inspire public confidence.

It is recommended that the PIPS3 program be structured as follows:

- Four projects – with separate leaders and individual contracts with Hort Innovation focused on:
    1. Orchard systems (apple and pear)
    2. Soil health and nutrition
    3. Biological/cultural control of pests & diseases
    4. Supply chains of the future.
- Coordination – independent coordination to encourage integration of projects and a systems approach (key activities could include involvement in the initial contracting phase to ensure alignment between projects, facilitating regular meetings between project leaders and ensuring ongoing liaison between all members of the program).
- Performance management - with stop/go points and adaptive management based on Program Reference Group and Hort Innovation feedback.
- Communication and extension – via APAL, Future Orchards, FLAs, partnership network and demonstrations focusing on adoption and change in practice.
- Delivering benefit – clearly describing the benefit to industry either through adoption or awareness of more basic type research.

Intellectual property, commercialisation and confidentiality

No project IP, project outputs, commercialisation or confidentiality issues to report.

Appendices

RMCG

MAY 2018

Mid-term review of PIPS2

Final report

Hort Innovation

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Executive summary

The Productivity, Irrigation, Pests and Soils (PIPS) program coordinates different organisations to undertake orchard research for the apple and pear industry. PIPS research, development and extension aims to enhance orchard productivity and management by developing:

- More profitable and efficient production
- Efficient and responsible use of resources, and
- Adoption of good management practices.

To assess the effectiveness, relevance, process appropriateness, efficiency and impact of three of the current PIPS2 research projects at their mid-point of implementation a review was conducted. The outcome of this review provides Hort Innovation with insight on the current performance of the PIPS2 program. The three projects evaluated as part of the mid-term review were:

- Integrated pest and disease management (AP15001)
- Physiological, metabolic and molecular basis of biennial bearing (AP15002)
- Improved tree and fruit nutrition for the Australian apple industry (AP14023).

The evaluation utilised program logics developed for each individual research project at the start of the PIPS2 program to provide a framework. Data for the evaluation was collated from a desktop review of relevant material (such as milestone reports, presentations and communication material) and interviews with the research team and relevant industry members. This information was analysed to determine the likely success of achieving project outcomes and impact on industry.

Findings for each of the research projects are discussed in detail in Section 3, 4 and 5. Conclusions and recommendations for the future effective management of the program is provided in Section 6. Based on the outcome of this evaluation it is concluded that:

- The three research projects are on a trajectory that is likely to result in the achievement of all short-term outcomes by project completion
- Issues or risks which may impact on project performance and the achievement of long-term outcomes have been identified and responded to
- The research remains highly relevant to the intended beneficiaries (i.e. growers, advisors and the broader apple and pear research community)
- Significant effort has been made to provide ‘value for money’ from the funds invested in this research
- Research outputs have been effectively communicated to the scientific community and industry using the main industry communication avenues and integration into the extension program Future Orchards.

Recommendations to facilitate the on-going management of, and effective delivery of outcomes from, the PIPS2 program include:

- On-going identification and response (through adaptive management) to issues or risks which may impact on project performance and the achievement of long-term outcomes
- Capitalising on communication and extension opportunities over the remainder of the project term. As the research projects mature practical outcomes that are readily extendable will be realised during this period
- Maintaining productive working relationships with the APAL communication and Future Orchards teams to:

  - Highlight communication and extension opportunities
  - Appropriately schedule communication and extension opportunities with the release of research outcomes
  - Identify new and/or modified approaches to extension and communication that will extend reach
- Research projects and the project coordination team should continue to work together to:
  - Simplify the content of Milestone Reports and align reporting with the outcomes for each research project (presented in the program logic)
  - More formally and consistently document the assumptions that occur between the different levels of the program logic (short-term outcomes $\rightarrow$ medium-term outcomes$\rightarrow$ long-term outcomes)
- The inclusion of an extension component in the next phase of PIPS to ensure that the valuable outputs generated by these projects are taken up by industry.

1 Introduction

1.1 PROJECT BACKGROUND

The Productivity, Irrigation, Pests and Soils (PIPS) program coordinates different organisations to undertake orchard research for the apple and pear industry. The first PIPS project ran from 2009 to 2014 with the program being refunded in 2015 as PIPS2.

Two of the five PIPS2 projects commenced prior to the second phase of the program. These two projects which are *Investigating apple tree structure* and *Maximising the productivity and quality of new pear varieties* are not included in the mid-term project evaluation as they are due for completion in the next 12 months.

The remaining three projects commenced in 2015 and are approximately 50% complete. The following projects are evaluated as part of the mid-term review:

- Integrated pest and disease management (AP15001)
- Physiological, metabolic and molecular basis of biennial bearing (AP15002)
- Improved tree and fruit nutrition for the Australian apple industry (AP14023).

1.2 PURPOSE OF THE EVALUATION

The purpose of this evaluation is to:

- Review the outcomes to date of each of the three research projects (above), as well as other unintended outcomes that may have given additional benefit to industry participants
- Assess the lessons learned in relation to program approach and general implementation, and
- Provide recommendations for the completion of the three research projects.

The evaluation of these projects has been based on the program logics established at the start of the project (Appendix 1, 2 and 3) and included consultation with each of the research teams and industry members to assess the progress and performance of each project.

1.3 PROJECT OUTCOMES

The key outcome of this project is a report documenting the effectiveness, relevance, process appropriateness, efficiency and impact of three of the current PIPS2 research projects at their mid-point of implementation (this report). This information will provide Hort Innovation with insight on the current performance of the PIPS2 program.

Based on the information collated during the evaluation, a series of recommendations have been provided on how the program can be most effectively and efficiently managed into the future.

1.4 PURPOSE AND STRUCTURE OF THIS REPORT

The purpose of this report is to document the findings of the mid-term review. The report is structured as follows:

- **Section 1:** outlines the purpose of the evaluation and provides a brief project background
- **Section 2:** details the evaluation approach including program logic, key evaluation questions and monitoring, evaluation and reporting (MER) framework

- **Section 3-5:** presents the findings and discussion based on the data collected and analysed
- **Section 6:** provides conclusions and recommendations.

2 Approach

2.1 OVERVIEW

RMCG, as the independent program coordinator for the Apple and Pear Productivity Program, conducted the mid-term evaluation of the following three research projects within the PIPS2 program:

- Integrated pest and disease management – Phase 2 (AP15001)
- Physiological, metabolic and molecular basis of biennial bearing in apple (AP15002)
- Improved tree and fruit nutrition for the Australian apple industry (AP14023).

The evaluation team collected data through a number of processes (including desktop review and interviews) to assess the effectiveness of project activities to date in achieving desired project outcomes. Based on the outcomes of the evaluation, recommendations on maintaining, and potentially improving, project performance have also been developed.

2.2 PROGRAM LOGIC

The evaluation utilised program logics developed for each individual research project at the start of the PIPS2 program.

Program logic outlines the anticipated cause-and-effect relationships between project outputs and outcomes or its 'theory of change'. Program logic also documents any assumptions that are made about the transition from one level of the logic to the next. Framing the mid-term review on the program logics enabled rigorous testing and review of the processes taken by the projects to achieve their short-term outcomes.

The program logics were developed in consultation with each research team at the start of their projects (Appendix 1, 2 and 3).

2.3 EVALUATION PLAN

An evaluation plan for each individual research project was developed to provide a logical approach to the review (and are provided in Appendices 4, 5 and 6). The evaluation plan is suitable for assessing the merit of each research project at both the mid-term and end-of-term evaluation points. The focus for the mid-term evaluation will be on assessing whether progress towards desired outcomes is following a trajectory that will result in their achievement at the end of the implementation phase.

Given that each of the research projects is only at 50% completion, it is likely that data will be incomplete against some of the identified key evaluation questions (e.g. impact).

Each plan sets out project specific key evaluation questions against the five evaluation domains as shown in Table 2-1.

Table 2-1: Evaluation domains

EVALUATION DOMAINS	DEFINITION	OVERARCHING KEY EVALUATION QUESTIONS
Effectiveness	The extent to which an intervention (a project) has attained (or is expected to attain) its intended end-of-project outcomes.	To what extent has the project achieved its expected outcomes?
Relevance	The extent to which the expected outcomes of an intervention (a project) are consistent with beneficiaries' requirements, government priorities, etc.	How relevant was the project to the needs of intended beneficiaries?
Process appropriateness	The extent to which a project/program is operating as intended.	How well have intended beneficiaries been engaged in the project?
		To what extent were engagement processes appropriate to the target audience/s of the project?
Efficiency	The extent to which an intervention (a project) produces outputs and outcomes without wasting time, money, effort or other resources.	What effort did the project make to improve efficiency?
Other (Impact)	The extent to which an intervention (a project) has contributed to its longer-term outcomes (including SIP outcomes).	To what extent have the end-of-project outcomes contributed to medium-term outcomes?
		To what extent have the end-of-project outcomes contributed to long-term outcomes?

2.4 DATA GATHERING

DESKTOP ANALYSIS OF RELEVANT DOCUMENTATION

Background information and documentation was reviewed for each research project to gather evidence against key evaluation questions. This information was drawn from:

- Milestone reports
- Peer-reviewed publications
- Magazine articles and other communication outputs.

ENGAGEMENT OF APPLE AND PEAR INDUSTRY AND INTERVIEWS WITH RESEARCH TEAMS

Qualitative data was collected via interviews with industry members for each research project and the research project team.

Interviews were semi-structured and of approximately 45 minutes in length. Semi-structured interviews allow open-ended exploration of key concepts and the opportunity for the participant to contribute detailed and insightful qualitative data against key evaluation questions. This is particularly important in relation to identifying areas for improvement to the delivery of management actions that would enhance the achievement of the programs objectives.

Interviews were conducted face to face and via telephone. The interview guides are provided in Table 2-2 and Table 2-3. A full list of interviewees is also provided in Appendix 7.

Table 2-2: Interview guide for research team

EVALUATION DOMAINS	INTERVIEW QUESTIONS
Effectiveness	▪ What are the most significant achievements of the project to date? Why? ▪ To what extent have the short-term outcomes (end-of-project) been achieved? ▪ Are the short-term outcomes achievable by the end of the project period?
Relevance	▪ How relevant is the project to the needs of intended beneficiaries? ▪ What is the perceived value of the project? ▪ Are there any emerging or changing needs the projects should address?
Process appropriateness	▪ How well have intended beneficiaries been engaged in the project? ▪ To what extent were engagement processes appropriate to the target audience/s of the project? ▪ What are the strengths, weaknesses, opportunities and threats to the project?
Efficiency	▪ What effort did the project make to improve efficiency?
Other (Impact)	▪ Has the project made a contribution to Medium and Long-term outcomes? How? ▪ To what extent were these changes directly or indirectly produced by this project? ▪ What, if any, unanticipated positive or negative outcomes have resulted from the project? ▪ What legacy will be left by this project?

Table 2-3: Interview guide for industry members

EVALUATION DOMAINS	INTERVIEW QUESTIONS
Effectiveness	▪ How have you been involved in the project to date? ▪ What is your understanding of what the project is trying to achieve? ▪ Do you feel the outputs from this project will be useful for your business into the future? ▪ Can you suggest any opportunities for improvement for the future?
Relevance	▪ How relevant is this work for your business?
Process appropriateness	▪ Have you read or heard about the project through any other communication channels e.g. industry events, industry publications?
Other (Impact)	▪ What impact do you think this information will have on your business (e.g. management practices, profitability, efficiency, resource use)?

2.5 PROJECT ANALYSIS AND REPORTING

Data from the desktop review was triangulated with the qualitative data gathered through semi-structured interviews and analysed based on the program logic to address the key evaluation questions.

The findings and discussion are presented for each project with recommendations particular to that project provided at the end of each section. Discussion and recommendations for improving the delivery of the PIPS2 program as a whole are provided in Section 6.

Recommendations were formulated on the future direction, approach and management of the PIPS2 project to facilitate a lasting impact on the capacity of the apple and pear industry.

3 Findings and discussion – AP15002

3.1 INTRODUCTION

AP15002 is a five-year project investigating the physiological, metabolic and molecular basis of biennial bearing in apple. The major goal of this project is to advance knowledge on the key molecular and physiological processes involved in flower bud induction in apple which may cause biennial bearing. This involves testing specific working hypotheses by functional analysis of flower inhibiting or promoting signals (such as phytohormones, carbohydrates and gene expression) formed within the plant in response to ontogeny, plant resources, crop management and climate. Specific goals are to induce regular and uniform flowering by manipulating gene expression as well as hormone and carbohydrate concentrations within plant tissue.

The underlying mechanisms of flower bud induction and initiation are being investigated in two (biennial versus non-biennial) apple cultivars in Australia and Germany. In Australia the study focuses on the application of crop load gradient to trees in a commercial orchard of the biennial bearing cultivar Nicoter (marketed as Kanzi®) and the non-biennial bearing cultivar Rosy Glow (marketed as Pink Lady™) in the Yarra Valley. The Australian component of this project is led by Dr Dario Stefanelli (DEDTJR). In Germany the project is focused on field experiments using Royal Gala and Fuji and laboratory work to determine the genes, specific compounds and inhibitory/promoting signals involved in flower initiation. The German component of the project is led by Professor Jens Wunsche (University of Hohenheim).

The project is also investigating a simplified approach to determining tree carbon balance status with a focus on providing advice for the application of chemical thinners. If this simplified approach is found to be appropriate, connecting a model to weather forecast information will streamline the process, allowing an avenue for a service to be constructed relatively quickly and cost effectively for Australian growers.

3.2 EFFECTIVENESS

The project is progressing well towards its expected outcomes through the delivery of a range of field experiments and laboratory analysis. The two short-term outcomes for the project are:

- Improved knowledge by researchers and industry on key plant processes that regulate flowering in apple and impact on biennial bearing
- Development of practical approaches (including model and substances) to avoid alternate bearing in pome production.

Activities which contribute to the delivery of Outcome 1 consist primarily of field work conducted both in Germany and Australia and laboratory analysis conducted in Germany. The development of practical approaches (Outcome 2) has involved the assessment of a carbon balance model (MaluSim) and the ability to digitally collect and analyse tree physiology. The delivery of activities and outputs to meet these outcomes are discussed in further detail below.

OUTCOME1: IMPROVED KNOWLEDGE BY RESEARCHERS AND INDUSTRY ON KEY PLANT PROCESSES THAT REGULATE FLOWERING IN APPLE AND IMPACT ON BIENNIAL BEARING

Activity: Field Work

A range of field experiments (both in Germany and Australia) are being conducted to elucidate the responses of apple trees to crop load treatments. The effects of these treatments are assessed (measured) in the field with representative samples taken from trees and sent to laboratories in Germany where they are further analysed.

Germany

In Germany two field sites were established during the Spring of 2016. This included the establishment of the 'Spencer Seedless' field site at the Horticulture Research Centre (HRC) at the University of Hohenheim (UHOH), Stuttgart. Samples of buds, seeds, fruit flesh and fruit diffusates were taken at weekly intervals during the growing season and then prepared for analysis. This included collection of:

- 1620 buds and 1350 fruit for histology, gene expression, proteomics and metabolomics during the 2015 growing season
- 832 buds and fruit for histology, gene expression, proteomics and metabolomics during the 2016 growing season.

The second cultivar field site was established at Lake Constance using a biennial (Fuji) and non-biennial (Royal Gala) apple cultivar. Samples of buds, seeds, fruit flesh and fruit diffusates were taken at weekly intervals during the growing season and then prepared for analysis. This included collection of:

- 7200 buds for proteomics and metabolomics (40 per tree), gene expression (5 buds per tree) and histology (2 buds per tree) in 2015
- 50 spur buds from 2-year-old wood from each tree at each time point (2 for histology work, 5 buds for RNA extraction and gene expression analysis, 5 buds for RNA sequencing and 40 buds for proteomic and metabolomics profiling). 12000 buds were collected in total during 2016.

Australia

In Australia a site for crop load experiments was identified during the 2015/16 season. Application of crop load treatments and the collection of buds and data are outlined by season below.

2015/2016 Season

During the 2015/16 season crop load experiments were conducted on 30 Kanzi and 30 Pink Lady trees. For each treatment applied:

- Six shoots per tree were selected to monitor growth during the growing season for each treatment and cultivar. Measurements were collected twice during the growing season. Assessments were made on:
  - Growth (shoot growth, light interception, gas exchange)
  - Yield (normal quality, maturity and pack out).
- Nine fruit per tree were monitored weekly for maturity with the DA-Meter starting mid-January.
- Fruit were harvested and counted from each tree in the experiment to identify average fruit weight. A subsample of 20 fruit per tree was brought back to AgriBio for the quality analyses. Size (diameter and height), soluble solids content (SSC), firmness, colour and maturity were measured the next day.
- Buds were sampled weekly for 15 weeks starting 4 weeks after full bloom (new sets of 4 trees per cultivar each time).

- Twenty buds per week were frozen for molecular analysis and 8 buds were placed in fixing solution for histological analysis.
- At the end of the collection period a total of 120 buds for histological analysis and 300 buds for molecular genetic analysis were shipped to Germany for analysis.

2016/2017 Season

For the 2016/17 season it was agreed that of the 30 trees in the trial half of them would receive the same crop load as the previous year while the other half would receive the reversed of the original crop load. Measurement and sampling of the experimental trees included:

- Collection of buds for the new season molecular analyses at UHOH. Buds were collected from the trees in the same orchard but not from the experimental trees due to their young age. Eight buds per tree from 4 trees (total of 32) were frozen immediately using dry ice (frozen CO_2) for the molecular analysis and kept at -80°C and 3 buds per tree from 3 trees were collected weekly and placed in fixing solution for the histological analysis and kept at 4°C, as per the protocol defined by UHOH. Samples were stored at the AgriBio building and sent to Germany at the end of the collection period.
- Four shoots per tree were selected to monitor growth during the growing season for each tree and cultivar. Measurements were collected three times during the growing season.
- Leaf conductance (as an indirect measurement of photosynthesis and treatment sink) was measured twice during the season.
- Six fruit per tree were monitored regularly for maturity with the DA-Meter starting 4 to 8 weeks prior to harvest for Nicoter and Rosy Glow, respectively.
- Non-structural carbohydrates (starch and soluble sugars) were measured by enzymatic digestion and spectrophotometric quantification on 2016 winter wood.

2017/2018 Season

The effect of crop load treatments applied to the experiment trees during the 2016/17 season was measured by determining:

- The size (diameter and weight), soluble solids content (SSC), firmness, colour and maturity of 20 fruit per tree.
- Shoot and fruit growth during the growing season for each tree and cultivar (using a sub-sample of four shoots and fruits).
- Light interception and stomatal conductance (measured using a porometer) was recorded when weather conditions permitted on measurement days.
- Flower cluster number during full bloom in all trees to evaluate effects of crop load on return bloom.

Three buds per tree were also collected each week from 4 weeks after full bloom for a period of eight weeks. Two buds were frozen for molecular analysis and one bud fixed for histological analysis. Buds collected last season were sent to Germany for analyses. Crop load treatments (same as 2016/17 season) were applied to trees within three weeks of full bloom.

Activity: Lab Work

Samples collected from the field experiments conducted in Germany and Australia (outlined above) were subjected to a series of analyses to identify:

- Candidate genes which can be used as molecular markers for future breeding activities
- Specific compounds that modulate flowering behaviour
- Inhibitory/promoting signals for flowering.

The activities (analyses) used to deliver these outputs included:

- Measurement of maximum height and width of the bud meristem following the transition of the apical meristem from a flattened to a domed shape in 180 buds. The data from this histological analysis is now being statistically evaluated, interpreted and converted into a logistic regression model for predicting apple bud initiation
- RNA sequencing (gene expression) of 84 bud samples
- Metabolomic profiling of 96 samples (use of mass-spectrometry to profile metabolites)
- Proteomic profiling of 96 samples (use of mass-spectrometry to analyse proteins).

Output: Identification of floral bud initiation

The timing of floral bud initiation has been identified with the results of the histological analysis suggesting that floral bud initiation is related to crop load, with 'on' trees having fewer floral buds than 'off' trees. The transition time from vegetative to floral meristems in apple buds differed markedly depending on variety and treatment. The first signs of floral bud initiation were detected for 'Fuji' at 70 and 120 days after full bloom (DAFB) for 'off' and 'on' trees, respectively, and for 'Royal Gala' at 99 DAFB for both treatments. Consequently, buds from 'Fuji-off' trees committed to flowering about 1 month earlier than those from 'Royal Gala-off' trees. In contrast, flower initiation of buds from 'Royal Gala-on' trees occurred 21 days earlier when compared to those from 'Fuji-on' trees.

Output: Identification of candidate genes which can be used as molecular markets for future breeding activities

RNAseq raw reads have been mapped to a 'Golden Delicious' genome that is accessible in the portal of The National Center for Biotechnology Information (NCBI) and the data has been standardized for the various statistical analyses. As a result of read alignment, more than 50 thousand genes have been identified in the analyzed apple buds. In collaboration with bioinformatics specialists from the Quantitative Biology Center (QBiC) at the University of Tübingen, Germany, and FEM in San Michele, the statistical model to evaluate RNAseq data is being developed. A preliminary evaluation of the dataset revealed 10,905 genes that are differentially expressed between 'On' and 'Off' treatments during at least one sampling date. The complete RNAseq data set is planned to be aligned with the new 'Golden Delicious' genome that was released in 2018 by the research institute FEM, San Michele, Italy.

Output: Identification of specific compounds that modulate flowering behaviour

45 metabolites in extracts of apple buds from 'Royal Gala' and 'Fuji' and around 30 compounds in apple diffusates from 'Spencer Seedless' have been detected. The identified metabolites represent a wide range of flavonoids. Several substances among them are known to influence hormonal signalling pathways which could play a regulatory role in the flower induction process. To aid compound identification, a metabolic apple database is necessary, which is currently under construction. Metabolite analysis of both apple buds and fruit diffusates commenced in the first quarter of 2018.

Output: Identification of inhibitory/promoting signals for flowering

Preliminary experiments identified 3,011 proteins, of which 1,309 are related to approximately 200 pathway maps retrieved from the Kyoto Encyclopaedia of Genes and Genomes (KEGG) and used for in-depth biological interpretation. 81 proteins were significantly upregulated in floral buds and 100 proteins in vegetative buds. All proteins that were mapped to flavonoid biosynthesis were significantly upregulated in floral buds. Time-series analyses prior to and during flower initiation will further expose proteins linked to the development of floral apple buds. Based on preliminary computations, it is expected that the project will identify up to 7,000 proteins in each apple bud sample. After successful protein identification in the bud extracts, the project plans to perform

mass spectrometry analysis of apple diffusates. By comparing proteins from buds and diffusates, mobile signals that either promote or inhibit flower bud formation can potentially be detected.

OUTCOME2: DEVELOPMENT OF PRACTICAL APPROACHES (INCLUDING MODEL AND SUBSTANCES) TO AVOID ALTERNATE BEARING IN POME PRODUCTION

Activity: Field Work

The field experiments discussed under the first outcome provide both the samples for analysis in the laboratory and also the response functions to crop load entered into the MaluSim model. As discussed above the crop load experiments are progressing well and providing consistent trends (detailed further in the Outputs section).

Activity: Model Validation

Response functions to application of crop load have been incorporated into a carbohydrate balance model called 'MaluSim'. This model is being simplified and validated to assess its ability to be used under Australian conditions to assist orchardists with decisions relating to crop load management. Activities conducted to simplify and validate the model have included:

- Use of climate data from weather station at the field experiment
- Assessment of the ability to simplify MaluSim using software program R
- Analysis of the model for the first 80 days after green tip to investigate early season responses using the 2014/15 season data at Tatura
- Examination and refinement of the three key features of MaluSim (photosynthesis, respiration and carbon allocation)
- Photosynthesis was simulated (from green tip to 90 days after green tip) at four different sites and during different seasons to determine the accuracy of the R version of MaluSim against the model written in Stella®. The sites were located in Victoria, NSW and New York (USA).

Output: Identification of ability to digitally collect tree growth data

To identify the ability to digitally collect tree growth data, ten optical methods and approaches were investigated. A stereo camera system was then set up to collect pictures for the image analysis to identify flowering, fruit set, growth and canopy size. Daytime and night-time pictures were collected regularly starting from bud break.

Assessment of tree growth is important for determining how much fruit will be present at harvest. The ability to collect and analyse this information digitally would provide growers with a major time saving. This component of the project was identified as a potential PhD project. Unfortunately, identification of a suitable candidate took longer than expected and the enrolled student has now stopped working on the PhD. While the project will try to engage another student to complete this component of work it is likely that the scope of works will be reduced from that originally determined.

Before ceasing his employment, the student did identify that the preferred method of picture collection and subsequent analysis is simulating stereo vision (different angles to simulate eye vision) to be later reconstructed in a 3D image. Night-time pictures will be used to help tree separation from the background and to improve tree 3D reconstruction and segregation in the day time pictures. In addition, to further help in tree segregation and background separation of the trees in the front row of the open Tatura system from the trees in the back row, the use of variable insertion angles and different colour intensity of the trellis wires in the pictures has been proposed.

Output: Data for development of MaluSim model suitable for Australian conditions

The trees within the field experiments are responding to crop load treatments as expected and displaying consistent trends. Research results have shown that:

- Shoot growth is inversely proportional to crop load for both cultivars
- Trees with lower crop loads transpired less, independent of the growing season
- High crop loads resulted in later maturing of fruit
- All fruit quality variables were found to have an inverse correlation with crop load with fruit from high crop loads demonstrating a lower SSC content, firmness, size and colour
- Return bloom was found to be inversely proportional to the applied crop loads for both cultivars. In general, the number of clusters on the trees were proportionally higher than the previous year which could be due to both a combination of tree growth and being an "on" year
- No significant differences in starch concentration were found between trees with different crop loads in either cultivar. There was a direct correlation between crop load and the concentration of total soluble non-structural sugars, mostly fructose and to a lesser extent glucose, in both cultivars. No significant effect of crop load on sucrose concentration was found for either cultivar.

Once statistical analysis of the research results has been conducted, the project team feel that they will have a "*good story to tell industry*" regarding the effect of crop load on return bloom and fruit development.

Simplification of the MaluSim model, originally developed in the USA, has progressed well indicating that it could be a suitable tool for providing thinning advice. Early results showed small root mean square errors and confidence has now been gained that the algorithms in R derived for daily photosynthesis, carbon demand, and leaf and wood respiration represent those in Stella® well. Testing of the model has shown however that it performs differently under Australian conditions due to the differing environmental conditions (to that experienced in New York). In Australia it appears that climatic conditions (number of days between bud break and the day you want to thin) have more of an impact on subsequent crop load than number of fruit. To further assess this impact:

- Larger climate data series from Ithaca will be sourced. These will be compared with key Australian growing sites to illustrate similarities and differences (solar radiation and temperature) and indicate the applicability of a carbon balance model such as MaluSim for thinning procedures.
- Identification and collation of key information required for secondary thinning decisions (e.g. temperature, radiation) will be conducted for important growing areas in Australia. This will provide a baseline of the historical range in conditions and allow for comparison of growing areas and provide scope to use forecasts for in-season conditions.

3.3 RELEVANCE

This project is of great relevance to apple growers in Australia and around the world. It is estimated that about 30% of commercial apple cultivars are susceptible to some level of biennial bearing, causing an annual financial loss to growers of about $30 to $50 Million Euro in Germany. Similar value losses are likely occurring in Australia. Considering that the value of apple production is estimated over $500 million, it is expected that increasing orchard efficiency will improve business profitability by 5% to 10%, translating to a total improvement of around $25 to $50 million AUD.

New non-biennial bearing apple varieties are a long-term solution given breeding timeframes. To help growers in the medium term, the project aims to identify if specific compounds that, upon application to a biennial cultivar in an 'on' or 'off' year prior to seasonal flower induction, reduce or increase flowering gene activity, and thus keep the tree relatively balanced in its annual fruit load. This would provide industry with an excellent horticultural tool to modulate crop levels. It is also hoped that through a better understanding of the processes

involved in biennial bearing it will be possible to identify more effective crop management practices that reduce biennial bearing in different susceptible apple cultivars.

3.4 PROCESS APPROPRIATENESS

The benefits of this project apply to both the science community and apple industry members. Due to the highly technical nature of this project, communication and training to date has focussed on the communication of scientific results to the research community.

This has included the publication of several technical articles in peer reviewed journals as discussed including:

- Milyaev A., Kofler J., Stefanelli, D., Flachowsky H., Hanke M.-V., Wünsche J.-N. Apple bud histology: A tool to study floral bud development in relation to biennial bearing. Submitted to Acta Horticulturae journal in July 2017
- Kofler J., Milyaev A., Pfannstiel J., Stefanelli, D., Flachowsky H., Hanke M.-V., Wünsche J.- N. Biennial bearing in apple: Proteomic profiling of developing buds. Submitted to Acta Horticulturae journal in July 2017
- Wünsche J.-N., Milyaev A., Kofler J., Stefanelli, D., Flachowsky H., Hanke M.-V. Physiological, metabolic and molecular basis of biennial bearing in apple. Submitted to Acta Horticulturae journal in July 2017
- Flachowsky H., Weigl, K., Djurić, G., Mićić, N., Garkava-Gustavsson, L., Zborowska, A., Si- Ammour, A., Asquini E., Sotiropoulos, T., Wünsche J.-N., Hanke M.-V. A European study on the time of flower induction in apple. Submitted to Acta Horticulturae journal in July 2017
- Milyaev A., Kofler J., Pfannstiel J., Stefanelli, D., Flachowsky H., Hanke M.-V., Wünsche J.-N. Histological and proteomic approaches to study floral bud induction in relation to biennial bearing in apple
- Dario Stefanelli, Tim Plozza, Henryk Flachowsky and Jens Wünsche. Response of young apple trees to crop load. Submitted to Acta Horticulturae journal in July 2017
- Rebecca Darbyshire, Wai Yan Kyaw San, Dario Stefanelli, Tim Plozza, Brian C. Lovell, Henryk Flachowsky and Jens Wünsche. An innovative approach to estimate carbon status for improved crop load management in apple. Submitted to Acta Horticulturae journal in July 2017.

In addition, members of the project team were invited to become contributing authors to an article collection on "Flowering Phenology in Trees: from Molecular Control to Mathematical Models" in collaboration with the journal Frontiers in Plant Science, section Plant Physiology. The aim of this article collection is to bring together international experts to provide a comprehensive view of this topic. The team members agreed to participate in the project by preparing a manuscript on ‘Identification of the onset of floral bud induction in apple: A prerequisite for uncovering the physiological and molecular mechanisms of biennial bearing’.

A number of the researchers within the project also attended the most recent ISHS International Symposium on Flowering, Fruit set and Alternate Bearing in June 19-23, 2017 in Palermo, Italy where they had the opportunity to present results from the project. Attendance at the symposium also provided the German and Australian team members with the opportunity to meet and discuss project progress.

Communication and delivery of research outcomes has been coordinated by the program coordinators (RMCG). This has included the delivery of information to APAL’s e-newsletter ‘Industry Juice’ with a distribution of 1,200 and articles for the national magazine (Australian Fruit Grower) which has a distribution of 950. These two communication products are delivered to all sectors of the apple and pear industry such as producers, supply chain members, and service providers. RMCG have also liaised with AgFirst to ensure that research outcomes are included in the Future Orchard Walks program.

More industry focused communication and training has included:

- Presentations on research outcomes at the APAL speed updating sessions in 2015 and 2017

- Participation in a video developed by RMCG and APAL to introduce the PIPS2 projects
- Presentation on the project during an orchard walk organised by the farm owner, to an audience comprised of apple growers, farm and chemical consultants and one DEDJTR Biosecurity and Agriculture Services (BAS) representative. A total of 35 people from the Goulburn and Yarra Valleys and Gippsland attended the event
- Engagement of growers to seek feedback on thinning practices and challenges and whether a service similar to the USA would be helpful. Grower engagement occurred at the Batlow Future Orchards walk (27 June 2017) and the Sydney basin growers meeting in Bilpin (19 October 2017)
- Publication of an article in the Australian Fruit Grower Magazine on 'Finding the triggers of biennial bearing in apples".

While the project has made a concerted effort to communicate research outcomes it is likely that engagement by industry will come later when more of the field and laboratory analysis has been completed, and the project has more information to provide industry on how to manage biennial bearing.

Further discussion on the appropriateness of methods used to extend research outcomes to industry is provided in Section 6.

3.5 EFFICIENCY

The project has demonstrated 'value for money' through the:

- Establishment of partnerships for delivering the project
- Coordination of the delivery of activities
- Implementation of procurement processes to ensure both quality and quantity from investment, and
- Leveraging investment from other sources.

These are discussed in further detail below.

Establishment of partnerships for delivering the project

A notable feature of the team members is that they are involved in research that stretches across the entire continuum from fundamental and underpinning science through to applied research and technology transfer to growers. This will facilitate the application of research findings (regarding plant mechanisms) and services (crop management tools) to alleviate flowering constraints, leading to enhanced orchard productivity and management (long-term outcome). The amalgamation of researchers in Australia and Germany also allows the project to utilise the strengths of each team. The German team have greater access to skills and experience within the academic realm while the Australian team have greater contact and liaison with industry allowing for grower input and feedback into the project. The collaboration between the research teams in Germany and Australia has worked well allowing realisation of the key strengths between the two teams. The German and Australian components have sufficient scope to operate independently but effective communication between the two has fostered great collaboration. Open and regular communication has been facilitated by email/ skype correspondence, travel between the research sites, and attendance at international events.

Coordination of the delivery of activities between Germany and Australia

Conducting field experiments in both Germany and Australia will allow for the eventual amalgamation of the two treatment regimes. In Germany the field experiments are focused on a total "on" or "off" regime which facilitates the identification of promoting and inhibitory signals. The field experiment in Australia employs a more graduated crop load treatment which will ultimately be a more practical and realistic application within commercial operations. Once the inhibitory/promoting signals have been identified by the German experiments these can then be assessed within the more commercially applicable scenario being tested in Australia.

Resourcing

To increase efficiency of resourcing, the project planned to provide capacity-building opportunities for students and professionals in both Germany and Australia. This would include the involvement of one Postdoc candidate and two PhD students to be involved in the outlined research work packages by taking responsibility for the planning and execution of the various research components. Unfortunately, the use of a PhD student to complete the image analysis and field measurements in Australia has not been successful which will ultimately increase resource costs within the project.

Leveraging investment from other sources

Investment of funds into this project have been leveraged by additional fuds provided by the Agriculture Victoria Research Division of the Victorian Government's Department of Economic Development Jobs Transport and Resources.

Adaptive management

Efforts have been made to quickly adopt and utilise modern analytical techniques that have become readily available throughout the project, such as RNA sequencing, proteomics and metabolic profiling. Mass spectrometry (MS) is an analytical technique that has become widely available to determine the elemental or isotopic signature of a sample, the masses of particles and of molecules, and to elucidate the chemical structures of molecules, such as peptides and other chemical compounds. The project team have also been utilising this emerging technique in an attempt to identify the metabolite(s) and protein(s) associated with the biennial bearing habit of apple cultivars.

3.6 OTHER (IMPACT)

The activities and outputs of the project are contributing to the achievement of the medium and long-term outcomes (as specified in the Program Logic). Genes, metabolites and proteins involved in flowering in apple have been identified from analysis of samples from field experiments conducted in Germany and Australia. However, it is likely that more research and engagement with industry will be required to translate these outputs into the development of new varieties and inhibitory/promoting substances that could be used in commercial apple production management.

Similarly, the simplification and validation of the MaluSim model for Australian conditions has progressed well and is likely to provide a valuable tool for making crop thinning decisions however, the extension and adoption of this tool to industry will be a component of work outside the scope of this current project. The key end of project outcome for this project will be the completion of a rigorous scientific body of work which provides information to the research community to build on to develop practical solutions for the apple industry.

The assumptions used to develop the program logic and working hypothesis for this project remain true and correct. In that:

- Improved understanding of what makes one cultivar biennial and another one not, may also lead to understanding how the amplitude of biennial bearing can be reduced, therefore establishing consistent cropping potentials
- Identification of genes or alleles that trigger biennial bearing, may lead to breeding of new cultivars with a reduced biennial bearing behaviour
- Identification of compounds from apple that affect floral integrator gene activity and thus regulation of the transition to flowering in apple trees, may also lead to demonstration that this substance can be applied to trees to regulate flowering without having any other negative effects on trees, humans and the environment.

The value of the MaluSim model and digital collection of tree growth data has been tested with industry during the project to ensure that its application to Australian production systems is viable. Feedback from growers indicated that while factors such as previous season's performance, flowering thinning effectiveness, chemical choice and biennial patterns were important, carbon imbalance was not an important factor. In discussing thinning strategies, fruit counts were noted as a useful measure for facilitating secondary thinning decisions. The digital collection of tree data (and potentially an app to facilitate the use of this data) could be useful to industry and validates the importance of progressing the image analysis component of this project.

> *"At the moment the model is not being taken up by growers because the data needed to inform the model (fruitlet numbers) is too labour intensive to collect. Model is accurate if you do 100% of the counting but not as accurate if you do less counting. Collecting the data digitally would be a huge help. It should be one of the tools for tomorrow – this is where the future is heading". Kevin Sanders (Orchardist)*

3.7 CONCLUSIONS

AP15002 has progressed well in the delivery of activities and outputs and is expected to deliver on the identified short-term outcomes by the end of the project. A large amount of laboratory analysis and field experimentation has been completed to date, which has led to the identification of numerous compounds, genes and signals involved in the initiation of flowers in both biennial and non-biennial apple varieties. Response to crop load experiments in the field have been consistent allowing for the identification of clear trends. The development of practical approaches (use of a model and digital tree analysis) has progressed well however the lack of a PhD student to complete this work may impact the scope of this output.

The project is efficient, with significant effort made to provide 'value for money' from the funds invested into this research. This has included leveraging of investment from other sources, identification of efficiency gains and sound project management. Research outputs have been effectively communicated to the scientific community and industry using the main industry communication avenues and integration into the extension program Future Orchards. Greater engagement by industry will come later once the more practical outputs have been realised.

Discussion with industry has confirmed the importance of this work.

> "*We lose 20 – 30% of our income every year due to biennial bearing. The ability to even out biennial bearing would be extremely valuable and assist with industry wide planning" (Orchardist).*

This project will provide a rigorous scientific body of work which facilitates the development of practical solutions for the apple industry.

4 Findings and discussion - AP15001

4.1 INTRODUCTION

AP15001 builds on the outputs from the original 5-year national Orchard Productivity R&D program PIPS which had an Integrated Pest and Disease Management (IPDM) sub-project that achieved approval to import and release a biocontrol agent (*Mastrus ridens*) against codling moth to supplement pheromone-mediated mating disruption. The parasitoid was released into one orchard in the Goulburn Valley in 2014 to establish a nursery site and to provide a field site in which establishment issues such as dispersal, predation, and hyper-parasitism could be studied.

Phase II of the IPDM sub-project (AP15001) aims to release *Mastrus ridens* into sites in Queensland (QLD), New South Wales (NSW), South Australia (SA), Tasmania (TAS) and Southern Victoria. David Williams, principal research scientist at DEDTJR, is leading this project.

4.2 EFFECTIVENESS

The project is progressing well towards achieving its expected outcomes. This has been achieved through completion of a number of the key activities and development of outputs. There are three key outcomes for this project. Progression of activities and outputs which contribute to these outcomes are discussed below.

OUTCOME 1: IMPROVED AWARENESS BY INDUSTRY OF THE EFFECTIVENESS OF *MASTRUS RIDENS* AS A BIO-CONTROL AGENT FOR CODLING MOTH IN AUSTRALIAN POME FRUIT ORCHARDS

To assess the effectiveness of *Mastrus ridens* as a bio-control agent for control of codling moth in Australian pome fruit orchards it is necessary to raise, distribute and release codling moth larvae parasitised with *Mastrus ridens*. This output is progressing well and is on track to meet performance objectives by the end of the project as discussed below.

Output: Establishment of *Mastrus ridens* in pome fruit orchards in QLD, NSW, VIC, TAS and SA

A number of key activities have been progressed which will enable the establishment of *Mastrus ridens* in pome fruit orchards in QLD, NSW, VIC, TAS and SA. These key activities include:

- The culture of codling moth and *Mastrus ridens* colonies of sufficient size and quality to enable release at nursery sites. Current volumes of production are 7,000 codling moth larvae per week, 2,600 diapausing codling moth larvae per week and 1,300 *Mastrus ridens* adults per week. The parasitised larvae can be stored for 4 months without loss of quality.
- The release of *Mastrus ridens* into ten nursery sites. This is achieved by using sentinel bands which contain codling moth larvae which have been parasitised by *Mastrus ridens*. To date 220 bands have been deployed and inspected (with approximately 190 *Mastrus ridens* emerging from each band).
- *Mastrus ridens* was released at two sites in VIC and two sites in QLD during the 2015/16 season and at five sites in NSW and TAS during the 2016/17 season. Assessment of establishment of *Mastrus ridens* has occurred at the sites in VIC and QLD with assessment of the NSW and TAS sites to occur next month.
- The level of establishment of *Mastrus ridens* has been mixed in VIC and QLD. *Mastrus ridens* have been detected on the sentinel bands located in orchards in Northern Victoria in the season following release but to date there has been no detection of *Mastrus ridens* in Queensland orchards in the season following

release. This may have been due to unusually high temperatures in the season following the release of *Mastrus ridens*.

The project will complete releases of *Mastrus ridens* in SA and Southern Victoria and continue to monitor and assess the establishment of *Mastrus ridens* in QLD, NSW and TAS. Assessment of *Mastrus ridens* establishment has been hampered by a high level of predation by earwigs and ants. The research team are investigating ways to overcome this issue (as discussed below for Outcome 2). If detection of the establishment of *Mastrus ridens* continues to be an issue this could impact on the ability to increase industry awareness of the effectiveness of Mastrus ridens as a bio-control agent for codling moth.

OUTCOME 2: IMPROVED KNOWLEDGE OF HYPER-PARASITES AND IMPACT OF COMMONLY USED PESTICIDES THAT COULD INHIBIT THE SUCCESS OF CODLING MOTH BIO-CONTROL BY *MASTRUS RIDENS*

To identify factors that could inhibit the success of *Mastrus ridens* (such as hyper-parasites and pesticides) the research team is conducting on-going assessment of the impact of commonly used pesticides on *Mastrus ridens* survival and have also surveyed release sites for evidence of hyper-parasites. These outputs are progressing well and are on track to meet performance objectives by the end of the project as discussed below.

Output: Identification of pesticides that impact the survival of *Mastrus ridens*

The project is currently assessing nine pesticides for their potential level of toxicity to *Mastrus ridens*. The products tested were chosen as they are newer and most widely used at the moment. Assessment has looked not only at the direct effects of pesticides on *Mastrus ridens* survival but also at the fecundity of future generations (sub-lethal side effects). Initially a set of protocols for the assessment of sub-lethal side effects was developed as none were currently available. Avatar and Samurai were shown to be highly toxic to *Mastrus ridens* and no further testing was done on these products. Pesticides that had low to moderate contact toxicity were then tested for sub-lethal effects. While a number of the pesticides are not suitable for use within an integrated pest management program (due to toxicity to *Mastrus ridens*) the testing has shown that there are a number of viable options that orchardists will be able to use in conjunction with *Mastrus ridens* leading to a more integrated approach to the management of codling moth.

The project will continue to assess the lethal and sub-lethal effects of common pesticides in order to identify a suite of compatible “soft” options for management of codling moth. This information will be provided to industry as part of the guide developed for the use of *Mastrus ridens* as a control agent for codling moth.

Output: Identification of hyper-parasites that could inhibit the success of codling moth bio-control by *Mastrus ridens*

The project has surveyed all release sites for evidence of hyper-parasitism and at this stage no hyper-parasites have been detected, although there has been predation by ants and earwigs. The predation of *Mastrus ridens* by ants and earwigs has been heavier than expected and has created some issues in detecting the establishment levels of *Mastrus ridens* at release sites. To counter the predation the project team are releasing higher numbers of diapausing larvae at each release site and also looking at the use of an aggregation pheromone which would lure *Mastrus ridens* into traps (facilitating assessment of establishment).

OUTCOME 3: IMPROVED AWARENESS BY INDUSTRY OF HOW TO MANAGE CODLING MOTH USING AN INTEGRATED APPROACH

To improve industry awareness of how to manage codling moth using an integrated approach it is planned to develop guidelines for commercial supplies of bio-control agents to assist them in the mass rearing of *Mastrus ridens* and to also develop guidelines for use by growers. These two outputs will be developed towards the end of the project when the majority of laboratory and field work has been completed. There have however been steps taken towards the completion of each of these outputs as discussed below.

Output: Guidelines for commercial suppliers of bio-control agents

No guidelines for commercial suppliers of bio-control agents have been developed yet as it is too early in the project for this to be feasible, however commercial suppliers such as Bugs for Bugs have been informed of project progress through regular meetings and site visits at both Agribio and Tatura. During the project, methods for increasing the efficiency of mass rearing of *Mastrus ridens* have been identified (both from personal experience and from international research) and these will be included in the manual provided to bio-control agent (BCA) suppliers.

Output: Guidelines for growers on managing codling moth in apple orchards

This will be an output delivered towards the end of the project once successful establishment of *Mastrus ridens* has been achieved. The establishment of *Mastrus ridens* and its impact on codling moth will be developed as a case study to demonstrate how codling moth can be controlled using an integrated management approach. The case study will be featured within a manual and training course being developed as part of an integrated pest and disease management program within apple orchards.

4.3 RELEVANCE

Apple and pear producers require pesticides to manage insects and diseases within their orchards and produce fruit that meets customers quality expectations. In particular, pesticides are an important tool in controlling outbreaks and reducing high pest pressure populations. The use of pesticides however, and the range of available activity groups, will become increasingly limited in the future due to restrictions imposed by reaction to expectations of consumers, export and domestic market MRLs, current use patterns driving development of resistance, and costs. Advances in biological control, enhanced resistance traits and biorational (ecologically benign, highly selective or behaviour modifying) techniques integrated with agronomic practices provide opportunities for more stable pest, disease, and crop management.

Codling moth is a major pest for the apple industry and can reduce access to key export markets such as China and Korea. Biological control agents such as *Mastrus ridens* are a potential tool that producers can incorporate into an integrated pest management system to give them enhanced control of pests such as codling moth while reducing reliance on pesticides. This project will provide industry with valuable information on the effectiveness of *Mastrus ridens* as a biocontrol agent against codling moth and identify factors (such as pesticide toxicity and hyper-parasites) that may impact on the success of *Mastrus ridens* as a biocontrol agent.

Research using classical biological control methods has become increasingly rare due to increasing aversion to risk by the Australian government. This type of research (which introduces natural predators from the pest's country of origin) has demonstrated remarkable success in managing pests in a range of horticultural industries however it tends not to be well publicised or acknowledged.

> *"The Mastrus ridens project is a great example of classical biological control and there should be more projects like this funded" (BCA supplier).*

4.4 PROCESS APPROPRIATENESS

While this project is of relevance to apple and pear producers, at this point in time the key industry stakeholders are crop protection advisors and the companies currently producing biological control agents. Crop protection advisors need to be aware of the options for control of codling moth (and how their products may impact its survival) and biological control companies will take on the production of *Mastrus ridens* for commercial use if it's effectiveness in controlling codling moth under Australian conditions is proved.

To this end, a number of the training events have focussed on engaging with technical staff at crop protection and biological control companies. This has included presentations to ADAMA and Bayer CropScience field and technical staff at:

- AgriBio - 13 May 2016 (on evolution of IPM to students and researchers)
- The Regional Innovation Forum - 18 May 2016
- The Adama Cormoran Field Launch.

Communication and delivery of research outcomes has been coordinated by the program coordinators (RMCG). This has included the delivery of information to APAL's e-newsletter 'Industry Juice' with a distribution of 1,200 and articles for the national magazine (Australian Fruit Grower) which has a distribution of 950. These two communication products are delivered to all sectors of the apple and pear industry such as producers, supply chain members, and service providers. RMCG have also liaised with AgFirst to ensure that research outcomes are included in the Future Orchard Walks program.

The project has also increased awareness and engaged with industry at the main industry events including:

- Presentations at Stathorpe, Orange, Batlow and Shepparton during the northern loop of the Future Orchards Walks during 2017
- APAL research speed updating in 2016 and 2017 (average 100 attendees)
- Presentations at Pome Zone 2016
- Presentations to Gippsland growers on management options for codling moth and Queensland Fruit Fly.

While the project has made a concerted effort to communicate research outcomes it is likely that engagement by industry will come later when higher levels of establishment are achieved, and the project has more information to provide industry on how to use *Mastrus ridens* as part of an integrated management approach.

Further discussion on the appropriateness of methods used to extend research outcomes to industry is provided in Section 6.

4.5 EFFICIENCY

AP15001 has demonstrated 'value for money' by:

- Making efficiency gains where possible to the rearing of *Mastrus ridens*. This has included:
  - Assessing the method used to rear codling moth to determine if the cost and time required to rear the larvae could be reduced. The rearing methods have been optimised so that smaller numbers of larvae are produced but quality is enhanced resulting in the production of more *Mastrus ridens* per larvae.
  - Assessing the ability to automate some components of the codling moth larvae rearing and the development of manual equipment which speeds up the process.
- Using a student to assist with pesticide toxicity assessment reducing project labour costs.
- Leveraging investment from the Agriculture Victoria Research Division of the DEDJTR which provided 50% of the total project costs.
- Adaptively managing the project (demonstrated by seeking an aggregation pheromone to lure *Mastrus ridens* into traps to enable better detection of *Mastrus ridens* numbers after release).

- Participation in PIPS2 program coordination meetings to identify opportunities for coordination and collaboration with other PIPS2 research projects and the Future Orchards program.

4.6 OTHER (IMPACT)

At this stage of the project it is difficult to make an assessment of how the project has contributed to the achievement of medium and long-term outcomes (as stated in the program logic). The project activities are contributing to the short-term outcomes, in particular Outcomes 2 and 3 and this has been achieved primarily through the assessment of factors (such as hyper-parasites and predation) that could negatively impact on *Mastrus ridens* survival and the assessment of pesticide toxicity.

The achievement of Outcome 1 will require better assessment of *Mastrus ridens* establishment at each of the release sites. The project team have identified options for improving how *Mastrus ridens* is detected at the release sites (such as the use of the aggregation pheromone). At this point it would appear that the assumptions made at the start of the project still hold true i.e. that the determination of *Mastrus ridens* as a viable control option for codling moth will lead to enhanced orchard productivity and management. This has been confirmed through discussion with industry:

> *"When people use bio-control agents as an improved pest management strategy they won't save money but they will be more sustainable. In the scheme of things growers don't spend that much on pest management so if we were to reduce costs by 50% it doesn't mean that much but if we can help them produce a better product, preserve the chemicals they can use and open export markets then that is a good result. (BCA supplier)*

4.7 CONCLUSIONS

AP15001 has progressed well in the delivery of activities and outputs and is expected to deliver on the identified short-term outcomes by the end of the project. A number of issues have been identified which may impact on project performance however, the project has identified solutions which will help to mitigate these.

Significant effort has been made to provide 'value for money' from the funds invested into this research. This has included leveraging of investment from other sources, identification of efficiency gains and sound project management.

Research outputs have been effectively communicated to industry using the main industry communication avenues and integration into the extension program Future Orchards. Engagement and uptake of *Mastrus ridens* as a bio-control agent for codling moth management will depend in part on:

- The ability to successfully establish *Mastrus ridens* in orchards
- The cost effectiveness of commercially rearing Mastrus ridens, and
- Increasing the confidence of industry to use *Mastrus ridens* through support provided by guidelines, training and informed advisors.

5 Findings and discussion - AP14023

5.1 INTRODUCTION

AP14023 is a five-year project that builds on the outputs from the original 5-year national Orchard Productivity R&D program PIPS, specifically the sub-project 'Precision fertigation for improved apple orchard productivity (AP12006)'. This project investigated how efficiently apple trees use both water and nitrogen and how growers can manipulate the timing and rate of these to consistently produce high quality fruit. AP14023 builds on findings from this past research and aims to develop a multi-season N budget underpinned by fertigation research and a decision support tool that will guide advisor/grower optimisation of irrigation and fertigation application for all major growing regions across Australia. The project, led by Dr Nigel Swarts from the Tasmanian Institute of Agriculture (TIA) is a fully-integrated and collaborative effort between TIA and Plant and Food Research, New Zealand (PFR).

Fertigation research includes the continuation of a major ongoing nitrogen and irrigation trial at Lucaston Park Orchards in Southern Tasmania. This trial was established for AP12006 and fertigation and irrigation treatments have continued creating one of the longest intensive nutrition trials ever completed in the pome fruit industry. Undertaking litter decomposition studies, labelled nitrogen (N) research and monitoring tree performance and N leaching will enable a complete N budget for commercial apple production. This research will provide an understanding of how fertiliser application approach, rates and timings can be managed to best satisfy the tree's N requirements, mitigate leaching and optimise productivity without a cost to fruit quality.

The decision support tool backed by a meta-model incorporating data from field N fertigation trials, multi-site regional soil parametrisation, climate and tree physiological datasets aims to provide growers with a reliable assessment of their orchard's soil, water and nutrient status based on their irrigation and fertiliser inputs. Growers and advisors will be trained in the usage of the decision support tool enabling them to explore different irrigation and fertiliser strategies and management practices for different soil types and climates in order to optimise yield achievement without cost to quality.

5.2 EFFECTIVENESS

The project is progressing well towards achieving its expected outcomes. This has been achieved through completion of a number of the key activities and outputs. There are three outcomes for this project. Progression of activities and outputs which contribute to these outcomes are discussed below.

OUTCOME 1: IMPROVED GROWER/ADVISOR UNDERSTANDING OF TOTAL NITROGEN INPUTS, ACCUMULATION, RECYCLING AND LOSS

Output: Multi-season nitrogen budget for commercial apple production

There are four activities which contribute to the development of a multi-season nitrogen budget for commercial apple production. Activities include (i) nitrogen and irrigation (fertigation) trials, (ii) multi-season ^{15}N trials, (iii) N, P and K uptake trials and (iv) laboratory analysis on N mineralisation rates, decomposition and nutrient release rates.

The delivery of these activities is progressing well as discussed below.

- The Lucaston Fertigation trial has now been running for five years (3 years completed under AP12006 and 2 years completed under AP14023). This will be one of the longest running irrigation/fertiliser trials in an

Australian apple orchard. The findings to date have demonstrated the influence of pre-harvest N application on fruit colour with reduced red colouration and greener background colour associated with greater pre-harvest N supply. Irrigation rate so far has had limited influence on fruit quality outcomes with trends towards smaller fruit with greater soluble solid content under reduced irrigation quantities.

- The methodology for the ^{15}N trial has been developed and presented (Milestone 105). The objective of this trial is to determine the uptake efficiency, partitioning and remobilisation of nitrogen in mature apple trees over two seasons using ^{15}N enriched fertiliser. The field trial will compare the impact of three full rate fertiliser application timings (spring, summer, and 50-50 split applications) on nitrogen use efficiency and partitioning of nitrogen through the tree. The trial is multi-season and commenced in 2017 (2017 Post harvest – treat 8 trees – complete, 2018 Pre-harvest only – treat 8 trees, 2018 Pre and post-harvest - treat 8 trees). No results from this trial have been presented yet. Fruit quality outcomes from two seasons will be reported in Milestone 106.
- The methodology for the NPK trial has been developed and presented (Milestone 105). The objective of this trial is to investigate the interaction between different application rates of mineral nutrients (N, P, K) on fruit production and quality. The trial will run over one season with variables measured at harvest and post-harvest. During 2018, the legacy of previous NPK applications will be erased from the trial site via rinse and drain. Application will commence next season (2018/2019).
- The results from laboratory analysis on N mineralisation rates have been presented (Milestone 105). Soil was collected from the Lucaston apple fertigation experiment in December 2015 from the 50% pre- and post-harvest N medium irrigation treatments to test and refine the component model for mineralisation of the soil organic matter. The comparison between measured mineralisation rate and modelled outputs showed a reasonable fit to the data for each of the soil samples (tree row, alley, and alley subsoil) using the measured fraction of labile C to estimate a parameter value for the fraction of stabilised OM. Simple modelling seems to work, at least for the high/optimum moisture content. A better understanding of N mineralisation will be achieved from leaf litter and pruning decomposition trials over the next two seasons that have been highly enriched with ^{15}N. This forms part of PhD student Bi Tan's research and includes PFR's Roberta Gentile.

OUTCOME 2: IMPROVED GROWER/ADVISOR UNDERSTANDING OF HOW TO MATCH FERTILISER APPROACH, RATES AND TIMING TO APPLE TREE NITROGEN REQUIREMENTS

AP14023 aims to achieve Outcome 2 through the development of SINATA (Strategic Irrigation and Nitrogen Assessment Tool for Apples). This decision support tool will guide advisors and growers on optimisation of their irrigation and fertigation application. The focus of SINATA is on nitrogen, and to understand how irrigation and fertiliser application (types, rates, timings) can be managed to satisfy the tree's water and nitrogen requirements, mitigating leaching and optimising productivity without cost to fruit quality.

The core component of SINATA is Plant and Food Research's SPASMO model (Soil Plant Atmosphere System Model) which has already been parameterized for Australian apple orchards and verified against field data collected under the PIPS project. Development of the SPASMO meta-model (which will form the basis of SINATA) requires further refinement and improvement of the model code, significant investment in soil parameterisation, model validation and incremental model improvement based on current and on-going research.

Required enhancements of the tool include (1) integration of national soil parameterisation, (2) integration of a 2D soil module to accommodate the point-source application of water and nutrients via a line of drippers or sprinklers, and (3) the integration of an existing 3D tree-canopy module, with leaf processes linked to local microclimate, that can accommodate differences in tree variety, size, spacing, as well as the soils, slope and aspect of the orchard.

Whilst the decision support tool (SINATA) is only in the early phases of development, significant effort has gone in to refining the SPASMO model which forms the backbone of SINATA. The delivery of these activities and outputs are progressing well as discussed below.

Output: Multi-site regional soil parameterisation

- The methodology for soil characterisation has been developed and presented in milestone reports. Delays in sampling have resulted due to the need to obtain biosecurity approval for the UTAS soil physics laboratory (obtained in April 2017), and upgrades to analytical equipment (completed September 2017). Soil characterisation has now been completed in two apple production areas (Huon Valley, Gippsland and Yarra Valley). Analysis of soil physical properties is proceeding. All core samples have been analysed for the 'wet end' soil water retention properties using the KuPf device. Analysis of the 'dry end' properties by high pressure chamber commenced in January 2018 due to a backlog of other samples. Soil samples were sent for chemical analysis in December 2017.
- Soil series with the requisite hydraulic and physical properties have been assembled into a soils database to assist with SINATA program development. Some soil series being used for program development are from New Zealand. This will be replaced with Australian data as it becomes available.

Output: Development of climate and tree physiology dataset

- In the SINATA model, a standard crop-coefficient approach is used to relate tree water use to the prevailing microclimate and physiological time of development. Daily values of global radiation, air temperature, relative humidity and wind speed are required for this calculation. Data from 22 climate stations (where long-term climate data, 1986-2012 is available) have been assembled from records downloaded from the Australian Bureau of Meteorology (BOM) database (http://www.bom.gov.au/). The climate database has been a key input for SINATA program development.
- As described above, the SINATA model uses a standard crop-coefficient approach. The crop coefficient, *K*c, relates actual tree water use to the potential evaporative demand. This factor is a crucial input parameter for the water balance component of SINATA. A value for *K*c has been derived from the ratio of transpiration (ETc, mm/day), derived from sap flow measurements in the tree trunk (completed under PIPS and PIPS2 projects), and the reference evapotranspiration (ETo, mm/day), derived using data from a local climate station.
- Sufficient data has been assembled to run the 3D canopy model simulations. 3D model inputs include tree dimensions (spacing, height, canopy width, leaf area density), leaf response functions (for stomatal conductance and leaf photosynthesis), and site details (location, slope, aspect). Outputs from the 3D model will be used to parameterize SINATA for many of the crucial inputs where we have no data such as radiation use efficiency, which is a parameter that converts incoming solar radiation to whole-tree photosynthesis. The development of more detailed models for the below-ground environment (2D) has also commenced.
- A 2D model of the soil and root system has been formulated to enable investigation of the implications of different application methods and rates (e.g. nutrient application via broad-cast vs fertigation methods, and irrigation via drippers or sprinklers) on water and nutrient movement through the soil, and uptake by the trees and the grassed alleyways. The 2D model will enable simulation of irrigation and nutrient use efficiencies under different management strategies and to assess other aspects of orchard production such as the competition for water and nutrients between the tree crop and the grass sward.

Output: Refined SPASMO model to form back-bone for SINATA

- The preceding two outputs outline the progress towards refinement of the SPASMO model as the back-bone for SINATA. As described in the introduction for Outcome 2, required enhancements include (1) integration of national soil parameterisation, (2) integration of a 2D soil module to accommodate the point-source application of water and nutrients via a line of drippers or sprinklers, and (3) the integration of an

existing 3D tree-canopy module, with leaf processes linked to local microclimate, that can accommodate differences in tree variety, size, spacing, as well as the soils, slope and aspect of the orchard.

Output: Strategic management tool for advisors and growers to aid nutrition and irrigation management

- Program development of SINATA is progressing well as more data becomes available. Feedback from the inception workshop has been incorporated into the design, e.g. it was agreed the model should display a soil water balance that can be tested against field data and it should present outputs, such as fruit growth and 'quality attributes' that can be benchmarked against experience and data from other years or other scenarios.
- As described in the preceding outputs, whilst the decision support tool is only in the early phases of development, significant effort has gone in to refining the SPASMO model which forms the backbone of SINATA.

Output: Communication and training

- Outcomes of the research to date have been communicated to industry using key industry communication publications (The Australian Fruitgrower Magazine and Industry Juice), events (Speed Updating) and extension programs (Future Orchards).
- To date AP14023 has published two articles in the AFG magazine ("Strategically managing water and nitrogen" Oct/Nov 2016 and "What becomes of Nitrogen in your Orchard", Dec 2017/Jan 2018), participated in the Future Orchards southern loop February 2016 (presentations in VIC, SA, TAS and WA) and a presentation at the APAL research speed updating in 2017.

OUTCOME 3: GROWERS/ADVISORS KNOW HOW TO USE THE DECISION SUPPORT TOOL TO TEST FERTILISER AND IRRIGATION APPROACHES SPECIFIC TO THEIR ORCHARD

Output: Communication and training

- On the 9th November an inception workshop was held at the Grove Research Station to discuss SINATA with growers and advisors. The purpose of the workshop was to identify key outcomes required of the decision support tool. The event was attended by thee growers, two advisors, two representatives from the Tasmanian Fruit Growers Association and three TIA staff. Overall the meeting was very positive with excellent contribution made by both growers and advisors. There was strong desire for the tool, acceptance and understanding of its limitations and ideas provided for its functionality and useability.
- As the decision support tool (SINATA) is still in the development phase, the remaining communication and training activities/outputs have not yet commenced. These include:
  - Decision support tool grower user manual
  - Decision support tool training sessions
  - Grower and advisor interviews to evaluate performance, functionality and usability of the decision support tool.

5.3 RELEVANCE

How relevant was the project to the needs of intended beneficiaries?

Applying nitrogen fertiliser is a high input cost in apple production. Moreover, nitrogen is often applied at a rate higher than trees demand due to low nitrogen use efficiency and loss via leaching or conversion to nitrous oxide gas. Application rates vary significantly depending on the site and are often determined by soil nitrogen status, an estimation of nitrogen removed by crop harvest and tree pruning, gut feel and possibly a legacy of how things have always been done. AP14023 aims to increase the understanding of nitrogen use by the tree, efficiency of nitrogen uptake and nitrogen's fate following application.

> *"This work is hugely relevant for my business. There has not been a lot of work done on this. We never had much evidence on peak demand periods and where it goes in the tree. The last research of any quality was done in 1958 in peach trees. Most growers have a reasonable feel for it, but there is also a lot of wastage. There are also growers who don't put enough on". Orchadist*

Under improved nitrogen use efficiency scenarios, it is anticipated that up to a 15% increase in fruit quality outcomes (more Grade 1 fruit and increased yield) could be achieved. For example, if a grower is earning $3/kg from a 75t apple crop in one hectare, once nitrogen use efficiency (NUE) is optimised from pre-and post-harvest N applications, it is estimated that this grower will earn an additional $33,750. Coupled with savings from fertiliser use, they are likely to achieve up to $35k/ha additional earnings.

> *"This research project is very relevant for my work and our business. Sometimes when I provide advice, I do wonder if I should be applying nitrogen. It has been a bit gut feel. It will be so nice to have some proper research behind it. Thresholds will be useful (without affecting fruit quality). I do pride myself on never recommending anything that won't do the job for a grower. This will give me a better evidence base to make these decisions". Orchadist*

This project will also have immediate and direct positive environmental outcomes. The optimisation of NUE will lead to reduced N leaching into sensitive waterways and reduced N_2O emissions through a reduction in overall N use from fertilisers. By undertaking research on optimal use of N pre- and post-harvest, growers will receive accurate advice on when to supply N for maximum root uptake and optimal distribution into tree storage organs. This means there will be considerably less wastage or leaching of N and the build-up of N in the soil will contribute to the dangerous emissions of N_2O into the atmosphere.

> *"From an environmental point of view, nitrogen is a touchy nutrient, ask any grower, they don't want to over use for the environment and because of cost". Orchadist*

5.4 PROCESS APPROPRIATENESS

AP14023 has conducted early and targeted engagement with industry (growers and advisors) to help shape and inform the research project, specifically the design, functionality and usability of the decision support tool SINATA. The inception workshop with growers and advisors (described above) has established an informal industry sounding board for the project. The intention is to consult with the sounding board for the duration of the project implementation and track the experiences of industry participants for evaluation purposes. This includes tracking how their awareness, knowledge and skills change over time as a result of their participation in the project, as well as the ultimate goal which is adoption and ongoing use of the decision support tool, SINATA.

> *"I have played an advisory role for this research project. This is ongoing. The researchers use us as a bit of a sounding board to test ideas and ask for feedback".*

Industry engagement has also been a significant outcome of the soil characterisation work. Through the sampling conducted to date in two apple production areas (Huon Valley, Gippsland and Yarra Valley) a total of 14 growers have participated. The feedback from growers involved in this work has been very positive reporting value in both learning more about their soils (through the soils sampling process) and the objectives and progress of the broader research project.

Increasing industry awareness of this project has occurred by using the key communication tools available to the apple and pear industry which include articles in the Australian Fruitgrower magazine (distribution of 950) and highlights in the e-newsletter 'Industry Juice' with a distribution of 1,200. These two communication products are delivered to all sectors of the apple and pear industry such as producers, supply chain members, and service providers.

The project has also increased awareness and engaged with industry at the main industry events including:

- Future Orchards southern loop February 2016 (142 participants in total). Presentations in VIC, SA, TAS and WA
- APAL research speed updating in 2017 (average 100 attendees)
- Presentations at Pome Zone 2016
- Inception workshop with growers and advisors to identify key outcomes required of the decision support tool (10 attendees)
- Participation in a video developed by RMCG and APAL to introduce the PIPS2 projects.

Further discussion on the appropriateness of methods used to extend research outcomes to industry is provided in Section 6.

5.5 EFFICIENCY

What effort did the project make to improve efficiency?

The project has demonstrated 'value for money' through the:

- Establishment of partnerships for delivering the project
- Resourcing
- Utilising existing infrastructure, and
- Leveraging investment from other sources.

These are discussed in further detail below.

Establishment of partnerships for delivering the project

AP14023 has been designed and implemented as a fully-integrated and collaborative partnership between the Tasmanian Institute of Agriculture (TIA) and Plant and Food Research, New Zealand (PFR). The collaboration between researchers in Australia and New Zealand has enabled the establishment of a multi-disciplinary team which brings the required skills and experience to deliver the intended project outcomes.

TIA Tasmanian Institute of Agriculture (TIA) is a unique collaboration between the Tasmanian State Government and the University of Tasmania (UTAS) with a well-recognised history of converting research to practise change through its integration of research, development and extension and education. TIA manage the research project and bring specialist skills in deciduous tree nutrition, tree and fruit physiology and soil hydrology (Dr Nigel Swarts, Associate Professor Dugald Close and Dr Marcus Hardie).

PFR is a New Zealand-based science company providing research and development that adds value to fruit, vegetable, crop and food products. With over 900 people based at sites across New Zealand, as well as in the

USA and Australia, at the heart of PFR is a goal to underpin the growth of plant and marine-based industry through the successful application and commercialisation of research-based innovation. PFR bring specialist skills in soil nutrient management and the development of system models (SPASMO) to tailor management practices to achieve production goals and predict the effect of land use activity on the receiving environment. and (Dr Steve Green, Dr Brent Clothier, Dr Roberta Gentile).

Resourcing

To increase efficiency of resourcing the project has attracted a PhD student. PhD candidate Bi Zheng Tan is conducting research for the project and is setting up new trials in collaboration with Dr Nigel Swarts. Bi will be investigating the conditions in which apple trees use nitrogen most efficiently. The work involves excavating 30 trees over winter 2018 and during the 2019 harvest. It's a technique that allows investigation of the movement of the nitrogen that is applied to the soil through the tree. 50% of Bi's scholarship is funded by the PIPS program and the other 50% is funded by the University of Tasmania.

Utilising existing experimental infrastructure

Ongoing fertigation and irrigation trials through AP14023 have been implemented in a highly efficient manner as they utilised existing infrastructure and treatment history from the previous PIPS project AP12006. This also enabled a seamless transition into the next growing season which maintained the integrity of the longitudinal data that has been collected at the Lucaston trial site. The Lucaston Fertigation trial has now been running for five years (3 years completed under AP12006 and 2 years completed under AP14023). This is one of the longest running irrigation/fertiliser trials in an Australian apple orchard.

Leveraging investment from other sources

The establishment of a quarantine soil laboratory facility at UTAS has significantly increased the efficiency of soil collection and processing for the soil characterisation component of the project. Upgrades to the facility have included obtaining biosecurity approval (which will enable importation of soil samples from interstate to be analysed at UTAS) and additional analytical equipment (which will enable faster processing times).

Investment has been leveraged from multiple sources to complete the soil laboratory upgrades including UTAS internal equipment fund, Tasmanian Institute of Agriculture and CSIRO.

5.6 OTHER (IMPACT)

At this stage of the project it is difficult to make an assessment of the extent to which the project has contributed to the achievement of medium and long-term outcomes (as stated in the program logic). However, the detailed assessment of the effectiveness of AP14023 has demonstrated strong evidence that the project is on a trajectory that will result in the achievement of all short-term outcomes at the end of the project term.

A more detailed assessment of the contribution to medium and long-term outcomes will be possible for the end of project evaluation. Consultation with industry provided some early indicators of longer-term impacts in that:

- Both growers and advisors feel that they will use the decision support tool (SINATA) as an evidence base for more informed decision making on nitrogen and irrigation management into the future
- Both growers and advisors feel that better decision making (supported by SINATA) will result in multiple benefits including:
  - More efficient use of resources (e.g. water and nutrients)
  - Cost savings as a result of reduced input costs
  - Environmental benefits through reduced loss of nutrients to waterways and the atmosphere, and

- Increased profitability through increased yield and fruit quality.

Two important external factors that have the potential to impact the achievement of long-term outcomes were identified in the consultation. These include:

- More nutrient leaching occurring under the orchard than expected in some treatments. This is an unexpected negative outcome that requires further research
- The risk of a fruit fly incursion limiting the appetite of some growers to invest in infrastructure upgrades including highly efficient fertigation systems or soil moisture monitoring platforms.

The research team has these risks front of mind and have begun planning management strategies for the remainder of the project. Management strategies include:

- Gathering further information on nutrient leaching in order to make accurate and reliable recommendations for application approach, rates and timing for optimum environmental outcomes
- Incorporation of scenarios into the decision support tool that require no or limited infrastructure spending
- Further work on Cost:Benefit analysis to clearly explain the pros and cons of optimising nitrogen use efficiency.

5.7 CONCLUSIONS

The detailed assessment of the effectiveness of AP14023 has demonstrated strong evidence that the project is on a trajectory that will result in the achievement of all short-term outcomes at the end of the project term. The results from the consultation also demonstrate that the research remains highly relevant to the intended beneficiaries (i.e. growers, advisors and the broader apple and pear research community).

Research outputs have been effectively communicated to industry using the main industry communication avenues and integration into the extension program Future Orchards. Localised engagement has also been critical for informing the methods and key outputs of the research project (e.g. decision support tool). During the second phase of the project, communication and training will expand to a much broader audience when training on the application and use of the decision support tool commences.

A number of mechanisms have been put in place to ensure the efficiency of project delivery. These include establishment of partnerships, resourcing, utilising existing experimental infrastructure and leveraging investment from other sources.

Consultation with industry provided some early indicators of longer-term impacts of the project. The research team are also demonstrating their ability to adaptively manage the project in order to mitigate risks that have the potential to impact on long-term outcomes.

6 PIPS2 Communication, Extension and Coordination

6.1 COMMUNICATION

PIPS2 communication outputs are coordinated by the program coordinators (RMCG) in collaboration with the communications team at APAL. RMCG and APAL have established a productive working relationship to ensure that research outcomes are communicated to industry in a timely and appropriate manner.

Increasing industry awareness of PIPS2 research projects has occurred using the key communication tools available to the apple and pear industry which include articles in the Australian Fruitgrower magazine (distribution of 950) and highlights in the e-newsletter 'Industry Juice' with a distribution of 1,200. These two communication products are delivered to all sectors of the apple and pear industry such as producers, supply chain members, and service providers.

Key communication outputs are also published on the Apple and Pear Australia Limited (APAL) website.

The PIPS2 related webpages on the APAL website have generated a consistent level of engagement over the period between July 2016 and January 2018. The top five pages in terms of interest include:

- PIPS2 video: Artificial Spur Extinction demonstration (Sally Bound) – total of 846 views between 26 Sep 2016 and 27 Oct 2017 (this has been one of the most popular videos published by APAL)
- 'Advances in codling moth control in orchards' – total of 407 views since release (July 2016)
- 'Are chemical thinners necessary?' – total of 346 views since release (October 2016)
- 'Precision crop load management without chemicals – total of 333 views since release (August 2017)
- 'Drones deployed to assess nitrogen needs of pears' – total of 264 views since release (January 2017).

6.2 EXTENSION

PIPS2 extension outcomes are delivered through Future Orchards. Launched in 2006, Future Orchards provides growers with practical and hands on education to help increase the fruit quality and productivity of their orchards and improve international competitiveness.

Future Orchards holds orchard walks twice a year in each of the eight growing regions around Australia. Orchards walks are the primary extension activity for PIPS2 research outcomes. Involvement of PIPS2 research in Future Orchards is again coordinated by the program coordinators (RMCG) in collaboration with the Future Orchards team (APAL and AgFirst, NZ). RMCG and the Future Orchards team have also established a productive working relationship to ensure that research outcomes are extended to industry in a timely and appropriate manner.

An overview of the effectiveness and appropriateness of the extension model for PIPS2 (delivered through the Future Orchards project) is presented below. The results in this section are informed by an interview with Ross Wilson (AgFirst, New Zealand) who delivers PIPS2 extension through the project's Orchard Walks and Orchard Walk debriefs prepared by AgFirst.

- The model that we are using currently is working well. It is meeting the needs of industry, researchers and the outcomes of the Future Orchards projects. Key components of the current model include:
  - An update to growers on all PIPS2 research every 12 months

- Involvement of PIPS2 researchers as guest speakers on a rotational basis aligned to the release of significant research outcomes for each PIPS2 research project. This program of speakers has been developed in conjunction with the researchers and PIPS2 coordinators
- Practical demonstration of research outcomes wherever possible e.g. demonstration of Artificial Spur Extinction pruning techniques.

- The approach to preparation for the 12 monthly PIPS2 research update has been managed adaptively over time in response to lessons learnt. The process is now operating in a very efficient and effective manner. To prepare for these updates, Ross Wilson is invited to the PIPS2 bi-annual program coordination meeting which is held prior to the scheduled Orchard Walks. Here Ross is able to hear presentations on each of the research project outcomes, ask questions to improve understanding and work with the researchers to prioritise which research outcomes are most important to communicate back to industry. The bi-annual program coordination meeting is then followed by the APAL Speed Updating session which provides a further briefing on key research outcomes for each project. Using the information collated through the bi-annual meeting and the Speed Updating session, Ross prepares his Orchard Walk presentation and provides it back to the researchers for review and approval.
- Positive feedback has been received from growers involved in the Orchard Walks in relation to the way that complex and detailed research outcomes have been communication using plain English and through practical demonstration.

> *"Communication has certainly been better than it has ever has been in the past. The research is certainly not locked up in a science building"*

- Opportunities for the future include:
  - Building on the strengths of the current model by incorporating more practical demonstration of research outcomes as the projects near completion
  - PIPS2 coordinators to keep AgFirst informed of current research project publications such as peer reviewed papers.

6.3 COORDINATION

PIPS2 project coordination is provided by the project coordinators (RMCG). In addition to facilitating the communication and extension of research outcomes (as described above), the project coordinators also provide the following services:

- Monitoring and evaluating the progress and achievement of objectives of the individual research projects within the PIPS2 program, such as the preparation of program logics and this mid-term evaluation report, and
- Delivery of biannual program coordination meetings.

A total of four biannual program coordination meetings have now been convened. The details and key outcomes of each meeting are provided in Table 6-1.

Table 6-1: Biannual research leader meetings

DATE	LOCATION	OUTCOMES
1 December 2015	Victoria	▪ Greater understanding of the: – Roles and responsibilities of the RMCG program coordination role – Structure of the Apple and Pear RD&E program – Individual research projects. ▪ Agreed approach to: – PIPS2 internal communication – Industry communication – Monitoring and evaluation
22 June 2016	National Horticulture Convention, Gold Coast	▪ Generation of key messages from each of the research projects to date ▪ Discussion about the linkages between research projects and the integration of management practices
15 December 2016	Teleconference	▪ Generation of key messages from each of the research projects to date ▪ Discussion about the linkages between research projects and the integration of management practices
24 May 2017	Launceston	▪ Generation of key messages from each of the research projects to date ▪ Discussion around the linkages between projects and the integration of management practices. The program team considered the broader effects of changing practices in one area (e.g. thinning, irrigation, nutrition) on the whole orchard system, specifically: – Opportunity with the SPASMO model to look at pest management, specifically the impact on the tree and yield under different nitrogen/irrigation treatments – Opportunity to investigate the impact of pests and diseases in different ASE/chemical thinning treatments – Opportunity to use state-of-the-art image analysis in other projects e.g. for measurements on fruit position, colour and bud position. ▪ Agreed approach to: – PIPS2 mid-term review
18 December 2017		▪ Generation of key messages from each of the research projects to date ▪ Discussion about the linkages between research projects and the integration of management practices ▪ Identification of need to scope next phase of PIPS with input from the SIAP

7 Conclusions and recommendations

7.1 CONCLUSIONS

Based on the evaluation of the three PIPS2 research projects included in this mid-term review, the following conclusions are provided on the current performance of the PIPS2 program:

- The detailed assessment of the effectiveness of AP15001, AP15002 and AP14023 has demonstrated strong evidence that each project is on a trajectory that will result in the achievement of all short-term outcomes at the completion of the projects
- Each research project has identified and responded (through adaptive management) to issues or risks which may impact on project performance and the achievement of long-term outcomes
- Consultation with industry has:
  - Demonstrated that the research remains highly relevant to the intended beneficiaries (i.e. growers, advisors and the broader apple and pear research community), and
  - Provided some positive early indicators of longer-term impacts of each project
- Significant effort has been made to provide 'value for money' from the funds invested in this research. This has included the establishment of partnerships, efficient resourcing, utilising existing experimental infrastructure, leveraging investment from other sources and adaptive management
- Research outputs have been effectively communicated to the scientific community and industry using the main industry communication avenues and integration into the extension program Future Orchards. Greater engagement by industry will come later once the more practical outputs have been realised.

7.2 RECOMMENDATIONS

Based on the outcomes of the mid-term review a number of recommendations are provided to facilitate the efficient management of, and effective delivery of outcomes from, the PIPS2 program. These include that:

- Research projects continue to identify and respond (through adaptive management) to issues or risks which may impact on project performance and the achievement of long-term outcomes
- Research projects and the project coordination team (RMCG) capitalise on communication and extension opportunities over the remainder of the project term. As the research projects mature practical outcomes that are readily extendable will be realised during this period. Given the significant interest in the Artificial Spur Extinction demonstration video, further production of video should be considered as an additional communication medium for each project during this period
- The project coordination team maintain productive working relationships with the APAL communication and Future Orchards teams to:
  - Highlight communication and extension opportunities
  - Appropriately schedule communication and extension opportunities with the release of research outcomes
  - Identify new and/or modified approaches to extension and communication that will extend reach
- In preparation for the end-of term evaluation, research projects and the project coordination team work together to:
  - Simplify the content of Milestone Reports and align the reporting with the outcomes for each research project (presented in the program logic)
  - More formally and consistently document the assumptions that occur between the different levels of the program logic (short-term outcomes → medium-term outcomes→ long-term outcomes)

- The projects in this review will generate great outcomes for industry however all of the research teams have identified that additional work will be required once the projects are completed to facilitate uptake by industry. Two of the projects will develop models which can be used to guide important crop management decisions, however one on one work with orchardists will be required to facilitate an understanding of why and how the models can be used. It is recommended that an extension component is included in the next phase of PIPS to ensure that the valuable outputs generated by these projects are taken up by industry.

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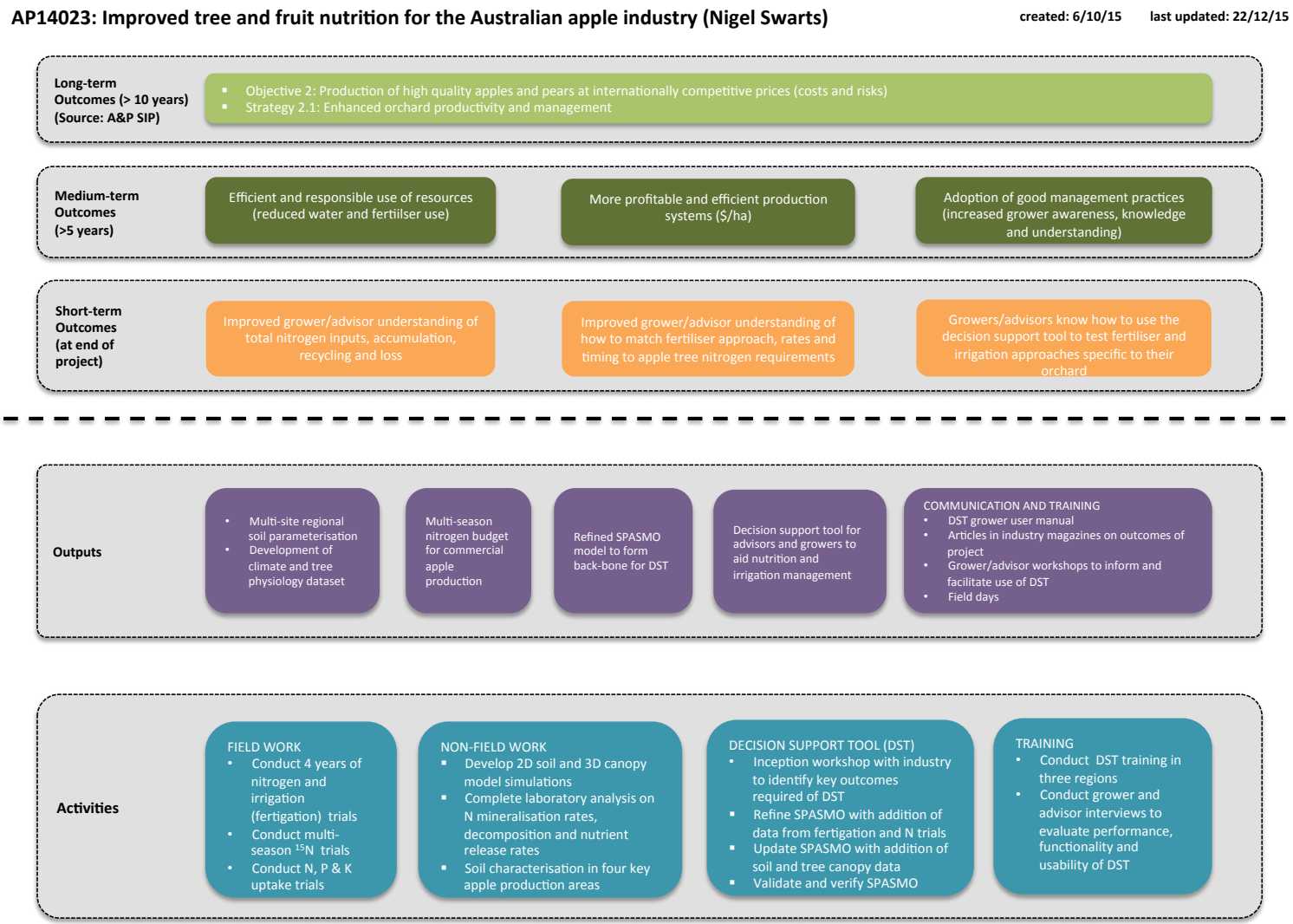
3.0	Final	15/5/18	K. Stirling S. Drum	Project Research Leads A.M. Boland	H. Buck	A.M. Boland	Hort Innovation

Appendix 3: Program logic for AP14023



Appendix 4: Evaluation plan for AP15001

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP15001 "INTEGRATED PEST AND DISEASE MANAGEMENT – PHASE 2"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
Effectiveness	To what extent has the project achieved its expected outcomes?	To what extent is AP 15001 achieving its activities (and associated performance expectations): LAB WORK ▪ Culture of M. ridens and codling moth ▪ Assessment of pesticide impact on M. ridens FIELD WORK ▪ Release of M. ridens at 'nursery sites' ▪ Establishment of sentinel bands (containing codling moth larvae) at 'nursery sites' ▪ Assessment of hyper-parasitism of M. ridens ▪ Assessment of M. ridens establishment and impact on codling moth survival COMMUNICATION ACTIVITIES ▪ Development of guidelines for commercial suppliers of bio-control agents ▪ Nursery sites may potentially be used for demonstration purposes (will depend on grower) ▪ Bio-control producers informed of project and potential to be involved	A comprehensive response to this KEQ will demonstrate the achievement of project activities to date for project AP15001 (refer to activities in Appendix 1: AP15001 Program Logic and MERI Table). The statement will detail how the current achievements are on track to meet performance expectations by the end of the project. The response will identify potential issues preventing the project from meeting its performance expectations by the end of the project. Responses to this question will be based on the measures that are assigned to each activity in the MERI table (refer to activities in Appendix 1: AP15001 Program Logic and MERI Table).	▪ Desktop review of relevant documentation ▪ Industry consultation comprising semi-structured interviews ▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers
		To what extent is AP 15001 achieving its outputs (and associated performance expectations): ▪ M. ridens established in pome fruit orchards in Qld, NSW, Vic, Tas and SA ▪ Identification of pesticides that impact the survival of M. ridens ▪ Identification of hyper-parasites that could inhibit the success of codling moth bio-control by M. ridens	A comprehensive response to this KEQ will demonstrate the achievement of project outputs to date for project AP15001 (refer to outputs in Appendix 1: AP15001 Program Logic and MERI Table). The statement will detail how the current achievements are on track to meet performance expectations by the end of the project. The response will identify potential issues preventing	

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP15001 "INTEGRATED PEST AND DISEASE MANAGEMENT – PHASE 2"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
		▪ Guidelines for commercial suppliers of bio-control agents ▪ Guidelines for growers on managing codling moth in apple orchards	the project from meeting its performance expectations by the end of the project. Responses to this question will be based on the measures that are assigned to each output in the MERI table (refer to outputs in Appendix 1: AP15001 Program Logic and MERI Table).	
		To what extent is AP 15001 achieving its short-term outcomes (and associated performance expectations): ▪ Improved awareness by industry of the effectiveness of M. ridens as a bio-control agent for codling moth in Australian pome fruit orchards ▪ Improved knowledge of hyper-parasites and impact of commonly used pesticides that could inhibit the success of codling moth bio-control by M. ridens ▪ Improved awareness by industry of how to manage codling moth using an integrated approach	A comprehensive response to this KEQ will demonstrate how AP15001 project activities and outputs to date are contributing to achieving each of the short-term outcomes (refer to short-term outcomes in Appendix 1: AP15001 Program Logic and MERI Table). The statement will detail how the current achievements are on track to meet performance expectations by the end of the project. The response will identify potential issues preventing the project from meeting its performance expectations by the end of the project. Responses to this question will be based on the measures that are assigned to each short-term outcome in the MERI table (refer to outputs in Appendix 1: AP15001 Program Logic and MERI Table).	
Relevance	How relevant was the project to the needs of intended beneficiaries?	To what extent is AP15001 meeting the needs of the industry levy payers?	A comprehensive response to this KEQ will demonstrate in a qualitative manner that AP15001: ▪ Aligns with priority research and knowledge gaps of industry levy payers ▪ Is facilitating the achievement of desired outcomes identified by the industry levy payers at the commencement of the project.	▪ Industry consultation comprising semi-structured interviews ▪ Interview with each research leader, and ▪ Interviews with relevant Hort

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP15001 "INTEGRATED PEST AND DISEASE MANAGEMENT – PHASE 2"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
				Innovation R&D managers
Process appropriateness	How well have intended beneficiaries been engaged in the project?	To what extent have the target engagement levels of industry levy payers been achieved?	A comprehensive response to this KEQ will demonstrate in a qualitative manner that AP15001 is utilising communication and extension approaches that are: ▪ Tailored to the industry levy payers ▪ Achieving the desired reach ▪ Resulting in the intended awareness and knowledge change outcomes ▪ Managed adaptively during the delivery of the project in response to changes in the project context ▪ Responding to lessons learnt along the way which improves the delivery approach.	▪ Desktop review of relevant documentation ▪ Industry consultation comprising semi-structured interviews ▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers
		Have regular project updates been provided through linkage with the industry communication project?		
	To what extent were engagement processes appropriate to the target audience/s of the project?	Is the project engaging with industry levy payers through their preferred learning style?		
		How accessible were extension events to industry levy payers?		
Efficiency	What effort did the project make to improve efficiency?	To what extent is AP15001 demonstrating 'value for money' through the: ▪ Establishment of partnerships for delivering the project (pooling resources, using local knowledge and experience) ▪ Coordination of the delivery of activities (e.g. with other projects, in geographic locations) ▪ Implementation of procurement processes to ensure both quality and quantity from investment, and ▪ Leveraging investment from other sources?	A comprehensive response to these KEQs will demonstrate, via qualitative analysis, that AP15001 is: ▪ Delivering the required activities, results and targets within the agreed budget ▪ Addressing 'value for money' criteria ▪ Making efficiency gains where possible ▪ Implementing sound project management ▪ Documenting and where possible, responding to lessons learnt along the way which improves efficiency.	▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers
		How could have resources been used more efficiently?		
		What could have been done differently to maximise impact, at an acceptable and sustainable cost?		
Other (Impact)		What evidence is there that AP15001 is contributing to:		

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP15001 "INTEGRATED PEST AND DISEASE MANAGEMENT – PHASE 2"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
	To what extent have the end-of-project outcomes contributed to medium-term outcomes?	▪ Efficient and responsible use of resources (reduced pesticide use and increased use of IPDM) ▪ Adoption of good management practices (increased grower awareness, knowledge and understanding) ▪ More sustainable production systems?	A comprehensive response to these KEQs will be based on combining the data reported under the effectiveness questions with information about the assumptions included in the program logic. The aim is to determine whether the cause and effect relationships documented in the program logic are valid, and the extent to which evidence shows that anticipated outcomes are being achieved. This process should demonstrate that the AP15001 team: ▪ Is reviewing and testing assumptions documented in the program logic (through review of literature, review of experiences, primary research, investigation etc.) and identifying those that are found to be true and correct. If assumptions are not found to be true and correct, an explanation will be provided. The objective is to be able to describe the achievements of AP15001 all the way from activities to medium-term and long-term outcomes. Case studies or short stories are a very effective way to do this and will be used wherever possible (i.e. a practical demonstration of a path travelled through the logic).	▪ Industry consultation comprising semi-structured interviews ▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers
		To what extent were these changes directly or indirectly produced by AP15001?		
		What, if any, unanticipated positive or negative outcomes have resulted from AP15001?		
	To what extent have the end-of-project outcomes contributed to long-term outcomes?	To what extent is AP15001 contributing to: ▪ Production of high quality apples and pears at internationally competitive process (costs and risks) ▪ Enhanced orchard productivity and management		

Appendix 5: Evaluation plan for AP15002

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP15002 "PHYSIOLOGICAL, METABOLIC AND MOLECULAR BASIS OF BIENNIAL BEARING IN APPLE"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
Effectiveness	To what extent has the project achieved its expected outcomes?	To what extent is AP 15002 achieving its activities (and associated performance expectations): LAB WORK ▪ RNA-seq experiments and bioinformatics on samples from Australia and Germany ▪ Validation of candidate genes using qRT-PCR analyses ▪ Histological analyses (microscopic study) on samples from Australia and Germany ▪ Hormone and carbohydrate analyses using HPLC and RIA FIELD WORK ▪ Crop load experiments – application of cultural interventions with perturbing source-sink interactions applied to a biennial and non-biennial apple cultivar ▪ "Spencer Seedless" experiment ▪ Collection of samples for use in lab work MODEL VALIDATION ▪ Development of response functions to crop load levels and correlation with identified genes and metabolites ▪ Incorporation of response functions into 'MaluSim' ▪ Digital collection of tree growth data ▪ Image analysis validation	A comprehensive response to this KEQ will demonstrate the achievement of project activities to date for project AP15002 (refer to activities in Appendix 2: AP15002 Program Logic and MERI Table). The statement will detail how the current achievements are on track to meet performance expectations by the end of the project. The response will identify potential issues preventing the project from meeting its performance expectations by the end of the project. Responses to this question will be based on the measures that are assigned to each activity in the MERI table (refer to activities in Appendix 2: AP15002 Program Logic and MERI Table).	▪ Desktop review of relevant documentation ▪ Industry consultation comprising semi-structured interviews ▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP15002 "PHYSIOLOGICAL, METABOLIC AND MOLECULAR BASIS OF BIENNIAL BEARING IN APPLE"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
		To what extent is AP 15002 achieving its outputs (and associated performance expectations): ▪ Identification of candidate genes which can be used as molecular markers for future breeding activities ▪ Identification of specific compounds that modulate flowering behavior ▪ Identification of inhibitory/promoting signals for flowering ▪ Identification of ability to digitally collect tree growth data ▪ Data for development of 'MaluSim' model suitable for Australian conditions COMMUNICATION AND TRAINING ▪ Industry communication products (such as factsheets, articles, manuals) ▪ Technical publications (peer reviewed manuscripts) ▪ Industry training events (field days) ▪ Attendance at conferences	A comprehensive response to this KEQ will demonstrate the achievement of project outputs to date for project AP15002 (refer to outputs in Appendix 2: AP15002 Program Logic and MERI Table). The statement will detail how the current achievements are on track to meet performance expectations by the end of the project. The response will identify potential issues preventing the project from meeting its performance expectations by the end of the project. Responses to this question will be based on the measures that are assigned to each output in the MERI table (refer to outputs in Appendix 2: AP15002 Program Logic and MERI Table).	
		To what extent is AP 15002 achieving its short-term outcomes (and associated performance expectations): ▪ Improved knowledge by researchers and industry on key plant processes that regulate flowering in apple and impact on biennial bearing ▪ Development of practical approaches (including model and substances) to avoid alternate bearing in pome production	A comprehensive response to this KEQ will demonstrate how AP15002 project activities and outputs to date are contributing to achieving each of the short-term outcomes (refer to short-term outcomes in Appendix 2: AP15002 Program Logic and MERI Table). The statement will detail how the current achievements are on track to meet performance expectations by the end of the project. The response will identify potential issues preventing the project from meeting its performance expectations by the end of the project.	

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP15002 "PHYSIOLOGICAL, METABOLIC AND MOLECULAR BASIS OF BIENNIAL BEARING IN APPLE"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
			Responses to this question will be based on the measures that are assigned to each short-term outcome in the MERI table (refer to outputs in Appendix 2: AP15002 Program Logic and MERI Table).	
Relevance	How relevant was the project to the needs of intended beneficiaries?	To what extent is AP15002 meeting the needs of the industry levy payers?	A comprehensive response to this KEQ will demonstrate in a qualitative manner that AP15002: ▪ Aligns with priority research and knowledge gaps of industry levy payers ▪ Is facilitating the achievement of desired outcomes identified by the industry levy payers at the commencement of the project.	▪ Industry consultation comprising semi-structured interviews ▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers
Process appropriateness	How well have intended beneficiaries been engaged in the project?	To what extent have the target engagement levels of industry levy payers been achieved?	A comprehensive response to this KEQ will demonstrate in a qualitative manner that AP15002 is utilising communication and extension approaches that are: ▪ Tailored to the industry levy payers ▪ Achieving the desired reach ▪ Resulting in the intended awareness and knowledge change outcomes ▪ Managed adaptively during the delivery of the project in response to changes in the project context ▪ Responding to lessons learnt along the way which improves the delivery approach.	▪ Desktop review of relevant documentation ▪ Industry consultation comprising semi-structured interviews ▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers
		Have regular project updates been provided through linkage with the industry communication project?		
	To what extent were engagement processes appropriate to the target audience/s of the project?	Is the project engaging with industry levy payers through their preferred learning style?		
		How accessible were extension events to industry levy payers?		

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP15002 "PHYSIOLOGICAL, METABOLIC AND MOLECULAR BASIS OF BIENNIAL BEARING IN APPLE"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
Efficiency	What effort did the project make to improve efficiency?	To what extent is AP15002 demonstrating 'value for money' through the: ▪ Establishment of partnerships for delivering the project (pooling resources, using local knowledge and experience) ▪ Coordination of the delivery of activities (e.g. with other projects, in geographic locations) ▪ Implementation of procurement processes to ensure both quality and quantity from investment, and ▪ Leveraging investment from other sources?	A comprehensive response to these KEQs will demonstrate, via qualitative analysis, that AP15002 is: ▪ Delivering the required activities, results and targets within the agreed budget ▪ Addressing 'value for money' criteria ▪ Making efficiency gains where possible ▪ Implementing sound project management ▪ Documenting and where possible, responding to lessons learnt along the way which improves efficiency.	▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers
		How could have resources been used more efficiently?		
		What could have been done differently to maximise impact, at an acceptable and sustainable cost?		
Other (Impact)	To what extent have the end-of-project outcomes contributed to medium-term outcomes?	What evidence is there that AP15002 is contributing to: ▪ Development of varieties that have reduced alternate bearing ▪ Industry adoption of model for management of thinning practices ▪ Industry utilisation of commercially available inhibitory/promoting substances for flower induction	A comprehensive response to these KEQs will be based on combining the data reported under the effectiveness questions with information about the assumptions included in the program logic. The aim is to determine whether the cause and effect relationships documented in the program logic are valid, and the extent to which evidence shows that anticipated outcomes are being achieved. This process should demonstrate that the AP15002 team: ▪ Is reviewing and testing assumptions documented in the program logic (through review of literature, review of experiences, primary research, investigation etc.) and identifying those that are found to be true and correct. If assumptions are not found to be true and correct, an explanation will be provided.	▪ Industry consultation comprising semi-structured interviews ▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers
		To what extent were these changes directly or indirectly produced by AP15002?		
		What, if any, unanticipated positive or negative outcomes have resulted from AP15002?		

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP15002 "PHYSIOLOGICAL, METABOLIC AND MOLECULAR BASIS OF BIENNIAL BEARING IN APPLE"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
	To what extent have the end-of-project outcomes contributed to long-term outcomes?	To what extent is AP15002 contributing to: ▪ Production of high quality apples and pears at internationally competitive process (costs and risks) ▪ Enhanced orchard productivity and management	The objective is to be able to describe the achievements of AP15002 all the way from activities to medium-term and long-term outcomes. Case studies or short stories are a very effective way to do this and will be used wherever possible (i.e. a practical demonstration of a path travelled through the logic).	

Appendix 6: Evaluation plan for AP14023

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP14023 "IMPROVED TREE AND FRUIT NUTRITION FOR THE AUSTRALIAN APPLE INDUSTRY"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
Effectiveness	To what extent has the project achieved its expected outcomes?	To what extent is AP 14023 achieving its activities (and associated performance expectations): FIELD WORK ▪ Conduct 4 years of nitrogen and irrigation (fertigation) trials ▪ Conduct multi-season ^{15}N trials ▪ Conduct N, P & K uptake trials NON-FIELD WORK ▪ Develop 2D soil and 3D canopy model simulations ▪ Complete laboratory analysis on N mineralisation rates, decomposition and nutrient release rates ▪ Soil characterisation in four key apple production areas DECISION SUPPORT TOOL ▪ Inception workshop with industry to identify key outcomes required of DST ▪ Refine SPASMO with addition of data from fertigation and N trials ▪ Update SPASMO with addition of soil and tree canopy data ▪ Validate and verify SPASMO TRAINING ▪ Conduct DST training in three regions ▪ Conduct grower and advisor interviews to evaluate performance, functionality and usability of DST	A comprehensive response to this KEQ will demonstrate the achievement of project activities to date for project AP14023 (refer to activities in Appendix 3: AP14023 Program Logic and MERI Table). The statement will detail how the current achievements are on track to meet performance expectations by the end of the project. The response will identify potential issues preventing the project from meeting its performance expectations by the end of the project. Responses to this question will be based on the measures that are assigned to each activity in the MERI table (refer to activities in Appendix 3: AP14023 Program Logic and MERI Table).	▪ Desktop review of relevant documentation ▪ Industry consultation comprising semi-structured interviews ▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP14023 "IMPROVED TREE AND FRUIT NUTRITION FOR THE AUSTRALIAN APPLE INDUSTRY"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
		To what extent is AP 14023 achieving its outputs (and associated performance expectations): ▪ Multi-site regional soil parameterisation ▪ Development of climate and tree physiology dataset ▪ Multi-season nitrogen budget for commercial apple production ▪ Refined SPASMO model to form back-bone for DST ▪ Decision support tool for advisors and growers to aid nutrition and irrigation management COMMUNICATION AND TRAINING ▪ DST grower user manual ▪ Articles in industry magazines on outcomes of project ▪ Grower/advisor workshops to inform and facilitate use of DST ▪ Field days	A comprehensive response to this KEQ will demonstrate the achievement of project outputs to date for project AP14023 (refer to outputs in Appendix3: AP14023 Program Logic and MERI Table). The statement will detail how the current achievements are on track to meet performance expectations by the end of the project. The response will identify potential issues preventing the project from meeting its performance expectations by the end of the project. Responses to this question will be based on the measures that are assigned to each output in the MERI table (refer to outputs in Appendix 3: AP14023 Program Logic and MERI Table).	
		To what extent is AP 14023 achieving its short-term outcomes (and associated performance expectations): ▪ Improved grower/advisor understanding of total nitrogen inputs, accumulation, recycling and loss ▪ Improved grower/advisor understanding of how to match fertiliser approach, rates and timing to apple tree nitrogen requirements ▪ Growers/advisors know how to use the decision support tool to test fertiliser and irrigation approaches specific to their orchard	A comprehensive response to this KEQ will demonstrate how AP14023 project activities and outputs to date are contributing to achieving each of the short-term outcomes (refer to short-term outcomes in Appendix 3: AP14023 Program Logic and MERI Table). The statement will detail how the current achievements are on track to meet performance expectations by the end of the project. The response will identify potential issues preventing the project from meeting its performance expectations by the end of the project. Responses to this question will be based on the measures that are assigned to each short-term outcome in the MERI table (refer to outputs in Appendix 3: AP14023 Program Logic and MERI Table).	

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP14023 "IMPROVED TREE AND FRUIT NUTRITION FOR THE AUSTRALIAN APPLE INDUSTRY"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
Relevance	How relevant was the project to the needs of intended beneficiaries?	To what extent is AP14023 meeting the needs of the industry levy payers?	A comprehensive response to this KEQ will demonstrate in a qualitative manner that 14023: ▪ Aligns with priority research and knowledge gaps of industry levy payers ▪ Is facilitating the achievement of desired outcomes identified by the industry levy payers at the commencement of the project.	▪ Industry consultation comprising semi-structured interviews ▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers
Process appropriateness	How well have intended beneficiaries been engaged in the project?	To what extent have the target engagement levels of industry levy payers been achieved?	A comprehensive response to this KEQ will demonstrate in a qualitative manner that AP14023 is utilising communication and extension approaches that are: ▪ Tailored to the industry levy payers ▪ Achieving the desired reach ▪ Resulting in the intended awareness and knowledge change outcomes ▪ Managed adaptively during the delivery of the project in response to changes in the project context ▪ Responding to lessons learnt along the way which improves the delivery approach.	▪ Desktop review of relevant documentation ▪ Industry consultation comprising semi-structured interviews ▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers
		Have regular project updates been provided through linkage with the industry communication project?		
	To what extent were engagement processes appropriate to the target audience/s of the project?	Is the project engaging with industry levy payers through their preferred learning style?		
		How accessible were extension events to industry levy payers?		
Efficiency	What effort did the project make to improve efficiency?	To what extent is AP14023 demonstrating 'value for money' through the: ▪ Establishment of partnerships for delivering the project (pooling resources, using local knowledge and experience)	A comprehensive response to these KEQs will demonstrate, via qualitative analysis, that AP14023 is: ▪ Delivering the required activities, results and targets within the agreed budget	▪ Interview with each research leader, and ▪ Interviews with relevant Hort

EVALUATION DOMAINS	KEY EVALUATION QUESTION	SPECIFIC QUESTIONS FOR AP14023 "IMPROVED TREE AND FRUIT NUTRITION FOR THE AUSTRALIAN APPLE INDUSTRY"	EVALUATION REQUIREMENTS	DATA COLLECTION METHODS
		▪ Coordination of the delivery of activities (e.g. with other projects, in geographic locations) ▪ Implementation of procurement processes to ensure both quality and quantity from investment, and ▪ Leveraging investment from other sources?	▪ Addressing 'value for money' criteria ▪ Making efficiency gains where possible ▪ Implementing sound project management ▪ Documenting and where possible, responding to lessons learnt along the way which improves efficiency.	Innovation R&D managers
		How could have resources been used more efficiently?		
		What could have been done differently to maximise impact, at an acceptable and sustainable cost?		
Other (Impact)	To what extent have the end-of-project outcomes contributed to medium-term outcomes?	What evidence is there that AP14023 is contributing to: ▪ Efficient and responsible use of resources (reduced water and fertiliser use) ▪ More profitable and efficient production systems ($/ha) ▪ Adoption of good management practices (increased grower awareness, knowledge and understanding)	A comprehensive response to these KEQs will be based on combining the data reported under the effectiveness questions with information about the assumptions included in the program logic. The aim is to determine whether the cause and effect relationships documented in the program logic are valid, and the extent to which evidence shows that anticipated outcomes are being achieved. This process should demonstrate that the AP14023 team: ▪ Is reviewing and testing assumptions documented in the program logic (through review of literature, review of experiences, primary research, investigation etc.) and identifying those that are found to be true and correct. If assumptions are not found to be true and correct, an explanation will be provided. The objective is to be able to describe the achievements of AP14023 all the way from activities to medium-term and long-term outcomes. Case studies or short stories are a very effective way to do this and will be used wherever possible (i.e. a practical demonstration of a path travelled through the logic).	▪ Industry consultation comprising semi-structured interviews ▪ Interview with each research leader, and ▪ Interviews with relevant Hort Innovation R&D managers
		To what extent were these changes directly or indirectly produced by AP14023?		
		What, if any, unanticipated positive or negative outcomes have resulted from AP14023?		
	To what extent have the end-of-project outcomes contributed to long-term outcomes?	To what extent is AP14023 contributing to: ▪ Production of high quality apples and pears at internationally competitive process (costs and risks) ▪ Enhanced orchard productivity and management		

Appendix 7: Evaluation interviewees

RESEARCH PROJECT	NAME	TYPE OF INVOLVEMENT
AP15001	Dario Stefanelli / Jens-Norbert Wunsche	Research Leader
	Kevin Sanders	Industry (Grower and SIAP member)
AP15002	David Williams	Research Leader
	Dan Papacek	Industry (Biological control specialist)
AP14023	Nigel Swarts	Research Leader
	Peter Morrison	Industry (Grower)
	Andrew Hall	Industry (Advisor)
Overarching	Ross Wilson	PIPS2 Extension Leader for Future Orchards

Scoping Document

Project Title: PIPS3

Context

The Productivity, Irrigation, Pests and Soils (PIPS) program has efficiently delivered meaningful research outcomes and extended these to industry through the Future Orchards (FO) program. The first PIPS program was implemented from 2009 to 2014, with the second phase (PIPS2) running from 2015 to 2020.

The Apple and Pear Strategic Investment Advisory Panel (SIAP) considered future research and development (R&D) priorities for a potential PIPS3 program at their June 2019 meeting.

There was extensive discussion with the PIPS researchers on key research topics, and how these should be approached using lessons learnt from previous projects and the experience of SIAP members.

Discussion focused on what a new program needs to achieve, including:

- Clearly describing the short and long-term expected outcomes (and ensuring projects provide both).
- Providing a portfolio approach of basic and applied research within the program.
- Measuring performance of projects in achieving outcomes.
- Focusing on the communication and extension of research outcomes to generate positive change in practice.
- Demonstrating the value of investment and overall benefits.
- Better integration of research projects to add value to project outcomes.

Objectives

The objective of the PIPS3 program is to provide industry with the tools and knowledge to develop orchards of the future that:

- Use resources efficiently and sustainably.
- Focus on biological and cultural management solutions (reducing pesticide dependence).
- Drive quality through access to better information along the supply chain (through use of new technology such as IoT and blockchain.

These orchards will ensure the apple and pear industry has social license to produce now and in the future through the environmentally-sound and sustainable production of apple and pears, that will continue to meet consumer demands and inspire public confidence.

Key words

- Future orchard systems
- Resource use efficiency
- Biological solutions
- Social license
- Climate variability
- Partnership Network.

Principles

The following principles will be critical to the effective implementation of PIPS3:

Industry Engagement – achieving true practice change within the industry and maximising the investment in R&D of PIPS 1 and 2 is a critical element of PIPS3. To facilitate greater industry involvement, we suggest:

- Ongoing presentation of project messages and outputs at orchard walks using the Future Orchard (FO) model as currently delivered by AgFirst.
- Ongoing communication of messages and outputs through the APAL communication program (including Industry Juice and Australian Fruitgrower magazine).
- Establishment of processes to engage directly with Front Line Advisors (FLAs) and with regional agronomists/consultants, to foster greater regional connections and ensure two-way communication regarding priorities, delivery of messages and outputs.
- Establishment of an industry reference group (including FLAs, growers, consultants, Hort Innovation and APAL) to guide program delivery.

Regional Prioritisation – it is important that the delivery of the program focuses on regional differences and priorities. This will be achieved through FO, FLAs and the reference group.

Collaboration and partnerships – the PIPS3 program will focus more deliberately on collaboration between projects and with industry service providers within the apple and pear industry (such as FLA's, agronomists, chemical re-sellers, IPM advisors) and seek to establish a partnership network (which could be funded as part of PIPS3). The network will encourage exchange of information and focus on broader industry solutions incorporating the latest R&D.

Market driven – the focus of the PIPS3 program will be more explicitly driven by consumer and public sentiment with the consideration of:

- Social license – public and consumer confidence, and trust in the industry to continue to operate in an ethical and sustainable manner.
- Environmental awareness – consideration of the environmental footprint of the industry and means to improve performance.
- Export – there is a need to consider the consumer tastes and regulatory requirements of key export markets.

Systems approach – for R&D to be effective it is critical that a system approach is supported. Any management practice or technology that is adopted will have a potential impact on other aspects within the orchard. Whilst we propose the four R&D projects be managed/contracted separately within the program, these will be coordinated (by an independent coordinator to ensure strong integration of issues). Request for Proposals (RFPs) for PIPS3 should also direct respondents to develop project proposals that consider how R&D outputs will impact on other aspects of orchard management and how they can be integrated to create a systems approach.

Seeing is believing – the demonstration of R&D on-farm is critical to adoption and change in practices. Greater demonstration of practices and technologies through FO and the FLAs is encouraged and could include demonstration of project outcomes on regional trial blocks, which show how the individual project outcomes work together in a systems approach.

Climate variability – all R&D should be considered within the context of a changing climate and increased climate variability.

Existing R&D – it is essential that the program builds on existing information from PIPS 1 and 2, as well as other research, with a focus on filling the research gaps to ensure that existing knowledge is further advanced and extended accordingly.

Program structure – the PIPS3 program will be delivered as follows:

- Four projects – with separate leaders and individual contracts with Hort Innovation focused on:
    1. Orchard systems
    2. Soil health and nutrition
    3. Biological/cultural control of pests & diseases
    4. Supply chains of the future.
- Coordination – independent coordination to encourage integration of projects and a systems approach (key activities could include involvement in the initial contracting phase to ensure alignment between projects, facilitating regular meetings between project leaders and ensuring ongoing liaison between all members of the program).
- Performance management - with stop/go points and adaptive management based on Program Reference Group and Hort Innovation feedback.
- Communication and extension – via APAL, Future Orchards, FLAs, partnership network and demonstrations focusing on adoption and change in practice.
- Delivering benefit – clearly describing the benefit to industry either through adoption or awareness of more basic type research.

Measures of success

The intended outcomes include:

- Delivery of integrated R&D that is effectively extended to industry to promote a sustainable systems approach to apple and pear production.

Deliverables/Outputs

Below are the deliverables (outputs) we envisage for the program/project:

- Program deliverables include program logic, evaluation plan, communication and engagement plan, project reference group, milestones and final reports.
- Each project will have individual deliverables/outputs.

Timeline

What are the key turnaround times for this procurement:

- TBA (however early commencement is advised due to completion of a number of the projects within PIPS2).

Budget

- To be developed with each RFP.

Projects

The following project themes have been developed following discussion with the SIAP.

1. Orchard systems:
    a. Apples
    b. Pears.
2. Soil health and nutrition
3. Biological/cultural control of pests & diseases
4. Supply chains of the future.

For each project, we have considered the high-level outcome to be achieved, the SIP strategy it relates to and possible activities.

1. Orchard systems

Outcome

SIP Strategy 1.1 - Drive orchard reworking with emphasis on preparedness for increased mechanisation/automation/scale.

The desired outcome is to have an orchard production system that maximises quality, yield and labour efficiency.

This project would focus on training systems, pruning, crop load and irrigation to deliver a product that meets consumer expectations related to cultivars, quality, taste, sweetness, size, and colour.

a) Apples

Activities

Activities proposed include:

- Further investigation of crop load optimization and its effects on plant and fruit physiology in new and emerging apple and pear cultivars *(this activity will build on the outcomes from two projects delivered during the PIPS2 program, which are:*
    - *Improvement of crop load management and fruit quality through artificial spur extinction (ASE) (AP09031).*
    - *Clarification of how flowering in apple is inhibited or promoted in response to ontogeny, plant resources, cultural practices and environmental cues (AP15002)).*
- Exploring the future of irrigation automation to determine how automated control systems (artificial intelligence) can impose deficit irrigation strategies, and where to site sensors in orchards.
- Developing orchards to prepare for greater weather variability including high temperature, hail and frosts with evaporative cooling, row orientation, plastics and netting.
- Assessing the benefits of regenerative agriculture in a perennial orchard system.
- Developing tools to improve orchard management (including use of sensing systems) with the ultimate solution being a robotic harvesting system.

As previously described in the principles section the important elements of this project include:

- Consideration of the significant interactions between orchard system management, irrigation, soil health and nutrition, and pest and disease management.
- Understanding how climate variability and extreme heat will change the management of the orchard system with flow on effects to pests and disease and soil health.
- The need to collaborate with irrigation suppliers and orchard infrastructure providers to deliver a commercially appropriate output.

b) Pears

Activities

Activities proposed include:

- Developing smarter pear orchards to maximise quality, yield and labour efficiency through cultivar, tree density, rootstocks, tree training, plant growth regulators, robotic harvesting and other management practices *(this activity will build on the outcomes from the PIPS2 Project - Assessing orchard management systems to maximise and sustain productivity of high quality red-blushed pears – Ian Goodwin).*
- **Activities will be further developed following a meeting between Hort Innovation, Ian Goodwin and SIAP member Peter Hall.**

2. Soil health & nutrition

Outcome

SIP Strategy 1.3 - Improve soil health and increase knowledge of beneficial microbes in orchard management.

The outcome of this project is to achieve more efficient use of resources (nutrients, water and soil) through improved orchard floor management to improve fruit quality outcomes. This project will increase understanding of how soils function with a particular focus on how soil biology contributes to apple and pear production.

The project will also focus on ways to understand and mitigate spatial variation within the orchard and reduce the environmental footprint of apple and pear production.

Activities

Activities proposed include:

- Understanding the role of soil microbes, including mycorrhizal fungi in the uptake of water and nutrients and developing a biological approach to orchard management.
- Investigating and learning to manage soil constraints that affect long term yield, tree growth and fruit quality outcomes by:
    - Assessing the impact of fertiliser application and soil amendments on soil physical structure, soil biology and fruit quality (*this activity will build on the outcomes from PIPS 1 and 2 projects AP12006 and AP14023).*
    - Reducing variation within orchards through mapping and soil characterisation and moving towards precision horticulture. Recognizing the economic and practical constraints and determining when the costs outweigh the benefits (80:20 rule).
- Developing an application guide for SINATA to assist with the volume and timing of nutrient application and irrigation supply to meet tree demand *(this activity is an extension of the PIPS2 project - AP14023).*

As previously described in the principles, the important elements of this project include:

- Building on (not replicating) the significant work already done on irrigation and nutrient management. Growers have extensive knowledge of individual orchards which can be further extended with a greater understanding of how orchard management influences soil biology and function.
- Integration with activities focused on orchard systems, pruning, crop load, pest and disease management.
- Considering the overall increased biodiversity through practices such as intercropping and use of living mulches.
- Working with partners including agronomists, soil experts and precision technology.
- Understanding experiences with precision agriculture in other industries e.g. viticulture and grains.
- Considering the impact of climate variability on the management of soils such as increased soil runoff due to severe rainfall events.

3. Biological/cultural control of pests & diseases

Outcome

SIP Strategy 1.2 - Continue to build the body of knowledge around pest and disease management and prevention, considering both biosecurity risk mitigation and cost reduction.

A practical, cost effective pest and disease management system that reduces reliance on chemicals. The approach would focus on reducing the pesticide load, increasing biologicals and moving towards a chemical free industry.

These solutions are critical in response to public demands and to enable the ongoing production of apples and pears i.e. the Social Licence. In addition, accessing export markets requires control of chemical residues with options becoming increasingly limited.

Activities

Activities proposed will focus on the following key pests:

- Codling moth - a systems approach to management including biological control using *Mastrus ridens (this activity follows on from outcomes of the PIPS2 Project - Assessment of Mastrus ridens effectiveness as a biological control agent for codling moth (AP15001) and should be integrated with the recently funded HI Sterile Codling Moth project AP18001*).
- Fruit fly - biological control rather than reliance on chemicals.
- Apple scab.

As previously described in the principles the important elements of this project include:

- Consultation with industry to determine regional priorities whilst also addressing pests of national importance.
- Integration of pest and disease approaches with activities focused on soil health, nutrition and fruit quality outcomes.
- Consideration of export market requirements regarding chemical residues.
- Assessing the impact of extreme heat on biological options.
- Working with partners including chemical companies, chemical laboratories, plant breeders and exporters.

4. Supply chains of the future

Outcome

SIP Strategy 1.5 - Research IT and data systems that enable better collection and connectivity of orchard and business data at every level of the supply chain.
SIP Strategy 1.6 - Extend Future Orchards® concept to 'Future Pack House' with the aims of both cost reduction and quality improvement.
SIP Strategy 3.1 - Improve quality consistency and percentage of Class 1 fruit per hectare.

Technology and data management is rapidly evolving with the introduction of Internet of Things (IoT) and blockchain technology. Whilst these technologies exist, their application has not been extensive partly due to a lack of understanding of their potential.

Consumers increasingly require assurance on the safe production of their food and the traceability of product is essential to the establishment of trust. In addition, there is increased interest in the provenance of fruit particularly for the high-quality end of the market.

This project will focus on developing technology solutions across the supply chain through working with IT experts.

Activities

Activities proposed will focus on:

- Exploring and testing technology (barcoding) that could be used to track fruit from tree to table to enable product traceability.
- Grading fruit in the orchard at the point of harvest based on colour and maturity (in conjunction with post-harvest assessment) and extending this to robotic harvesters.
- Developing decision support systems, using a team of information technology (IT) people and horticulturists/agronomists.
- Increasing data analysis and the ability to respond to supply chain intelligence.
- Investigating how to make blockchain user-friendly. Advantages of blockchain include providing certainty and reducing time.
- Introducing a national identification scheme and using technology to assess national crop size and assist in crop forecasting.

As previously described in the principles section the important elements of this project include:

- Consultation with supply chain participants and IT experts to more fully understand the available technology and its potential application.
- Integration of agronomic information with IT knowledge.
- Consideration of requirements for traceability and provenance for domestic and export markets.
- Working with partners including IT, supply chain and exporters.