Final report

Project title:

Workshop and Roadmap for the way forward for irregular bearing

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Public summary

This project aimed to create a Roadmap providing strategic direction for industry investments to improve the management of irregular and alternate bearing. The Roadmap was developed through a multi-stage process, starting with a literature review to gather existing scientific information on the issues. Insights were also collected through a survey of Australian avocado growers and input from international contacts about their experiences. A workshop brought together growers, scientists, and other industry participants, featuring presentations from local and international experts, along with discussion and co-design sessions. A draft Roadmap was then created, and industry feedback was sought through a session in Manjimup, Western Australia, as well as a webinar and written feedback following the broad distribution of the draft to industry.

There were a number of important outcomes from these activities. First, there was a high level of consensus during the Roadmap development process around the major problems and issues leading to irregular and alternate bearing and the potential strategies to overcome these issues. There was also consensus among the contributors that the terms 'irregular bearing' and 'alternate bearing' were leading to grower confusion and that it would be more informative to refer to impact areas of floral initiation and development, pollination and fruit set, fruit retention and development and vegetative growth and canopies. Finally, there was consensus amongst the Workshop participants that for many of the impact areas, scientific understanding was still limited and there were often considerable knowledge gaps to fill before grower focused management tools could be developed.

The major output from the work is the "Investment Roadmap for Enhancing Yield Consistency in the Australian Avocado Industry", which is supported by the literature review, Talking Avocados article, grower survey and workshop presentations. These outputs are available on the avocado Best Practice Resource.

Keywords

Avocado; irregular bearing; alternate bearing; yield consistency; crop load; carbohydrates; crop load; floral initiation; floral development; fertilisation; fruit set; fruit retention; vegetative growth

Introduction

Yield per hectare in avocado orchards can vary significantly from year to year. Alternate bearing is a within-tree cycle where a high crop load in one year leads to signalling within the tree that inhibits flowering and fruit set, leading to a low crop load in the following year. Alternate bearing cycles are categorised by clear 'on' and 'off' years of high and low yield, respectively. Irregular bearing can be caused by a range of environmental, management, agronomic or within tree resource allocation factors, generally leading to poor fruit set and retention. Irregular bearing does not necessarily occur in clearly alternating 'on' and 'off' years.

The Australian avocado industry is undergoing a period of significant growth in production, which has changed the dynamics of markets and industry profitability. It is recognised that more consistent and improved yield will improve these dynamics.

The review of avocado alternate and irregular bearing by Whiley (2013) conveyed the complexity of the R,D&E challenge facing the Australian industry. Part of the complexity is due to elevated yield variability being caused by a wide range of factors. This is exacerbated by the geographic diversity within the industry, with avocados being produced commercially from the topics in Far North Queensland to southern temperate regions, with the causal factors for yield variability at times varying between growing regions. Having acknowledged the complexity of the issue, there are likely to be opportunities to identify research themes common amongst irregular and alternate bearing and diverse production regions.

This project to develop the Roadmap was initiated due to the perception of diverse views within the industry regarding the direction of future investments to improve yield consistency. It was recognised that a collaborative process with high levels of industry engagement and a strong scientific foundation be undertaken to develop clarity and consensus on the aims of future investments.

Methodology

The overall aim of this project was to document a pathway for future investments in alternate and irregular bearing that was developed through high levels of industry engagement, with high levels of industry consensus, and based on sound scientific principles. The work involved several steps that encompassed initial information gathering, organising and undertaking the workshop, co-design of the Roadmap and communicating the draft Roadmap for industry feedback. Details of these activities is provided below.

Project Reference Group

A diverse Project Reference Group (PRG) was engaged at the commencement of the project. The purpose of the PRG was to provide input, insights and feedback to the project team on matters of a technical and industry nature and ensure communication and engagement activities were well targeted.

PRG members included:

- Four growers from a range of growing regions, including Jacinta Foley (Western Australia), Clayton Lynch (Far North QLD), Simon Grabbe (Central QLD), Ryan Marr (Tri-State).
- Avocados Australia R&D coordinator, Mary Burton
- Independent horticultural research scientist, Professor Phil Brown, Central QLD University
- Hort Innovation R&D Manager, Tom McCue
- Project team members, John Wilkie, Renata Grunennvaldt and Bridie Carr

The PRG met via webinar three times during the project. Their ultimate role was to endorse the final draft of the Roadmap.

Foundational information gathering

Two activities were undertaken in the early stage of the project to collect scientific and industry information.

The first of these was the surveys. A formal domestic grower survey was conducted, with the aim of gaining insights and perceptions around irregular and alternate bearing from Australian avocado growers. One critical aspect of the survey was that growers from all growing regions would respond to the survey. At the outset of the project, it was decided that a minimum of 30 survey responses were required for a reasonable data set. Survey respondents were asked to consider one of their orchard blocks and answer the questions with respect to this one portion of their orchard. The survey questions and responses are presented in Appendix 2. An informal consultation of international avocado researchers and advisers was also conducted. The purpose of this was to gain their insights and perceptions of irregular and alternate bearing in their regions.

The second information gathering activity was the literature review. The purpose of this was to review factors relating to alternate and irregular bearing in the Australian avocado industry. The review was a core activity for the project. It provided a factual scientific foundation for the project team for subsequent planning of the surveys, workshop focus areas and speaker selection. It was also provided to Workshop participants beforehand to ensure they were aware of current scientific understanding of the topic. A literature review with similar aims was undertaken in 2013 (Whiley, 2013) as part of project AV12030. This was a detailed review and there was no point replicating this work, as such the current review focussed on areas that were not done in great detail in the AV12030 review, where new information had been published since the previous review and we also introduced relevant information from other tree crops. Consequently, it was recommended that both reviews be read concurrently.

Brisbane workshop and Roadmap co-design

The purpose of the Workshop was to create a forum where avocado growers, scientists and other industry participants could be provided with up-to-date information on avocado irregular and alternate bearing, be able to discuss this information and then undertake a co-design process to develop the Roadmap.

The format of the Workshop was clearly specified in the MRT, including the number of participants and whether they were growers, advisers or scientists. However, during the first PRG meeting, the PRG recommended that the number of scientists attending the Workshop be increased.

The selection of Workshop participants was different for participating scientists and participating growers and advisers. The participating scientists were selected by the project team based on the technical areas relating to irregular and alternate bearing that needed to be covered. The selection of grower and adviser participants was undertaken using an expression of interest process. An advertisement requesting expressions of interest for attendance at the Workshop was published in the online industry newsletter Guacamole. The expressions of interest were assessed by the project team based on a desire to have grower and adviser attendees from a broad range of Australian production regions and attendees with high levels of skills and experience.

Based on project team experience from previous avocado industry Workshops, approximately half of the time at the Workshop was dedicated to presentations and half the time dedicated to discussion sessions or co-design sessions. The discussion sessions were scheduled frequently between presentations to allow the group to discuss the information. The co-design activity was the final session of the Workshop.

Communication of draft Roadmap and industry feedback

Following the Workshop and development of the draft Roadmap, a series of communication and feedback activities were undertaken:

1. The project leader visited Manjimup in Western Australia and presented the draft to a group of growers and advisers.
2. The draft Roadmap was presented to industry via a webinar and feedback invited.
3. The draft Roadmap was emailed to industry by the Australian Avocados Limited communications team and written or verbal feedback invited.
4. The draft Roadmap was emailed to all Workshop participants and feedback invited.
5. The draft Roadmap was presented to the avocado SIAP.

Results and discussion

Survey

The report for the 'Irregular and alternate bearing Australian domestic survey' is presented in Appendix 2. There were 52 survey responses in total, with all Australian growing regions being represented. The number of responses for each growing region was not even, for example, 40.4% of responses were from growers in Western Australia and 11.5% of the responses were from growers in far north QLD. The orchard size of the respondents varied from less than 20 hectares (48.1%) to greater than 400 hectares. Over 90% of the respondents were primarily 'Hass' growers.

A very low percentage of survey respondents believed that their orchards were not negatively impacted by either alternate bearing or irregular bearing (Questions 6 and 7) and the majority of respondents believed that their orchards were negatively affected at a medium or high level. These responses were discussed during the Workshop and the participants felt that there may have been some confusion amongst the respondents between effects of alternate bearing and effects of irregular bearing. It may therefore, be most useful to consider the responses to these two questions together. There was some variation between growing regions in the responses, however, there were southern and northern growing regions where a high percentage of respondents believed they have medium and high alternate and irregular bearing impacts (e.g. Western Australian and North QLD).

In years with low production, respondents believed the top three environmental factors (Question 9) were cool weather at flowering, extended wet conditions at flowering and extreme heat and low humidity during flowering and fruit set. The major environmental variable identified was cool weather at flowering (60.4% of respondents) although this was not consistent across growing regions, with North QLD respondents believing extended wet weather was the major environmental factor in their region.

In years with low production, respondents believed the top three management factors or phenomena (Question 10) were very high crop load in the previous year (56%), poor flowering (36%) and late harvesting in the previous year (32%). Interestingly, very high crop load in the previous year was the most frequently or equally most frequently identified reason in every production region.

The was a relatively even spread of plant development stages that the respondents considered to be the main bottleneck to increasing production. The responses ranged from 17% for vegetative growth up to 34% for fertilisation/fruit set.

There was a clear trend in the timing of fruit maturity, with respondents believing that maturity was delayed as the production regions moved from north to south (Question 12). There was a similar trend for the timing of harvest, however, the data indicated that there may tend to be a greater delay between maturity and the completion of harvest in Western Australia than in other regions.

There were a broad range of areas where respondents believed that more knowledge would help them manage irregular and alternate bearing. The top three areas were fruit retention/summer fruit drop, managing nutrition and managing extreme weather. One respondent believed that there is no need for this work as the causes are already known.

The project team also consulted with international avocado industry participants from USA, South Africa, Chile and New Zealand on issues related to irregular and alternate bearing in these countries. In summary, in South Africa, irregular bearing affects about 5% of hot production areas where trees flower but fail to set fruit. In Chile, both irregular and alternate bearing are concerns, with alternate bearing often linked to insufficient flowering. New Zealand also experiences both irregular and alternate bearing, largely driven by climatic conditions, where heavy cropping depletes tree reserves and irregular bearing can exacerbate the issue. Both phenomena occur to a lesser or greater extent depending on microclimates and how well orchards are managed. California faces significant challenges with irregular and alternate bearing, primarily influenced by weather, particularly cold springs, which lead to poor fruit set.

The South African industry has largely mitigated severe alternate bearing through improved orchard management, selective pruning, spraying uniconazole, and the adoption of diverse cultivars, especially in well-suited northern regions. However, in late-harvest areas, alternate bearing can be more pronounced, as prolonged harvest periods can exhaust trees. In Chile, growers aim to minimize alternate bearing through practices such as cincturing branches and applying soil-based plant growth regulators (PGRs) to induce flowering. They also use autumn nitrogen applications to enhance reserves for producing quality flowers and employ PGR sprays during flowering to improve fruit set. In New Zealand, the primary management strategy is flower and structural pruning of orchards. In California, growers focus on optimizing nutrients, particularly nitrogen, during winter to support flowering and fruit set.

While South Africa and California are not conducting active research on alternate and irregular bearing, Chile is exploring PGR timing, nutrition, and the use of bio-stimulants to improve root systems. They are also investigating soil strategies to maintain stomatal conductance in hotter inland regions, as heatwaves pose challenges.

Literature review

The purpose of the literature review was to review factors relating to alternate and irregular bearing in the Australian industry and provide a factual scientific foundation for the project team for subsequent planning of the surveys, workshop focus areas and speaker selection. The review was also provided to Workshop participants to allow them to provide them with up-to-date scientific understanding of the subject prior to the Workshop to facilitate informed discussion.

The review by Whiley (2013) in project AV12030 covered many relevant areas in great detail, including environmental impacts on flower development and fertilisation, effects of pollinators and pollenisers, nutrition management, phytophthora management and carbohydrate management. Given the major guiding principles for the current review were to focus on areas where there was new information or that were not covered in detail by Whiley (2013), it evolved into a review on the physiology of crop load and resource allocation. The review also provided a synthesis of factors likely contributing to alternate and irregular bearing in Australian orchards based on the current review and the review of Whiley (2013).

Workshop

The Workshop was held at the State Library of Queensland in Brisbane on 7 – 9 August 2024. The classification of the participants was as follows:

- 8 growers attended (representing 14% of Australian avocado production).
- 8 scientists (including 2 international scientists that presented via webinar).
- 3 advisers/consultants.
- 4 Hort Innovation and Australian Avocados Limited staff.
- 3 project team members.

The Workshop participants were:

- Ben Norrish (Delroy Orchards, Western Australia),
- Dr Amnon Haberman (DAF QLD),
- Dr Chris Searle (MacAvo Consulting, Central QLD),
- Clayton Lynch (Australian Produce Partners, Far North QLD),
- Drikus Heyns (Costa Group, multiple growing regions),
- Dudley Mitchel (Kurima, Western Australia),
- Gerhard Rossouw (DAF QLD),
- Dr Harley Smith (CSIRO),
- Helen Bensilum (Kureen Farming, Far North QLD),
- Jacinta Foley (Jasper Farms, Western Australia),
- John Tyas (Avocados Australia Limited),
- Lisa Fyffe (Ripe Horticulture, Central QLD grower and Tri-State adviser),
- Mary Burton (Avocados Australia Limited),
- Phillip West (New Zealand Avocado),
- Dr Sally Bound (Mimosa Consulting Pty Ltd),
- Simon Grabbe (Simpson Farms, Central QLD),
- Simon Newett (Consultant, Southern QLD adviser),
- Professor Stephen Trueman (Griffith University),
- Tom McCue (Hort Innovation),
- Gemma Burger (Hort Innovation),
- Dr Inaki Hormaza (CSIC Spain),
- Dr Vered Irihimovitch (ARO Israel).
- Dr John Wilkie (Wilkie Horticulture, project team)
- Dr Renata Grunennvaldt (DAF, project team)
- Bridie Carr (DAF, project team)

The speakers and presentation topics were chosen by the project team to cover the range of topics identified in the literature review, domestic survey and in conversations with industry participants and scientists. The presentations are listed below:

- Irregular bearing – a key industry issue, John Tyas (Avocados Australia Limited)
- Scoping study for avocado alternate bearing research AV12028 2012-2013, Simon Newett (DAF, retired)
- Domestic survey of practices and regional perspectives, Renata Grunennvaldt (DAF)
- Where have all the flowers gone? Inaki Hormaza (CSIC, Spain)
- Highlights and synthesis of current literature review and Tony Whiley's review, John Wilkie (Wilkie Horticulture)
- Avocado pollination, Professor Stephen Trueman (Griffith University)
- An understanding of avocado fruit abscission and opportunities for management, Dr Harley Smith (CSIRO)
- Carbohydrate monitoring, (Drikus Heyns, Costa)
- Carbohydrate allocation and tree reserves: insights for avocado productivity, Dr Gerhard Rossouw
- Pruning flowers and fruit to reduce irregular bearing, Dr Phillip West (New Zealand Avocado)
- Crop load management strategies in apple, Dr Sally Bound (Mimosa Consulting Pty Ltd)

- Framing irregular and alternate bearing, Dr Amnon Habermann (DAF)
- Effects of fruit load on floral induction and inflorescence development in alternate bearing 'Hass' avocado trees, Dr Vered Irihimovitch (Volcani Institute)

Workshop discussions, co-design and Roadmap development

The culmination of the Workshop was the co-design session where the participants integrated the information from the previous presentation and discussion sessions into the initial draft of the Roadmap investment priorities. The co-design process was facilitated by the project team in several ways. First, the project team created a framework in which to organise the identified investment priorities. Early in the project, it was recognised that irregular and alternate bearing may not be the most useful terms to use when identifying key issues, causal factors and potential research strategies to overcome these production problems. Instead, it was proposed that the production issues be organised into four impact areas that represented the direct effects to avocado reproduction. These proposed impact areas were eventually named: floral initiation and development; fertilisation and fruit set; fruit retention and development; vegetative growth and canopies. The project team also sought to separate out the information collected for each of these impact areas into definitions of the issue or problem, potential research gaps and opportunities, and the likely research deliverables. Second, the team provided a simple and practical mechanism for recording of information and ideas that were presented to the group and discussed by the group. Recording boards for each of the impact areas were placed in the room and the participants were prompted to record their ideas on sticky notes and place them on the relevant impact area board. During the co-design session, participants were divided into pre-selected groups that consisted of a balance of growers, scientists and advisers. One impact area was allocated to each group. These groups then discussed the previously recorded ideas and distilled the information into problems and issues, R&D gaps and opportunities and potential R,D&E deliverables. Each group then presented their results to all participants and the information was discussed and amended. This information formed the basis of the Roadmap investment priorities.

Following on from the Workshop, the project team translated the investment priority co-design content and other information collected and discussed during the Workshop into the initial Roadmap draft. The process of translating the investment priority co-design content involved simplifying, clarifying, re-arranging, removing repetition and re-wording the information. However, the intent of the content was retained during this process.

The discussion sessions at the Workshop included technical discussions of the presentations, ideas and issues relating to content for the investment priorities and issues relating to the organisation of the Roadmap. Several of the major discussion points are included below:

- One of the major conceptual challenges of the Roadmap development was the manner in which the range of identified investment priorities would be organised. Discussions leading up to the Workshop between the project team and Dr Harley Smith proposed the idea of categorizing the effect of irregular and alternate bearing into four areas, based on their impact to avocado reproduction. These four 'Impact areas' were: floral initiation and development, fertilisation and fruit set, fruit retention and development and vegetative growth and canopies. The idea of using these Impact Areas was proposed to the Workshop participants and there was strong support for this idea.
- One reason for directly describing the effects on reproduction when discussing issues leading to yield variability is that the traditionally used terms of irregular and alternate bearing can create confusion, often need to be clarified and can be emotive terms for some people. The Workshop participants agreed that these were important issues. Ultimately, the group decided that the Roadmap should use the term 'yield consistency' in the general sense and refer to specific impacts. This led to a suggestion that the title of the Roadmap be changed to 'Investment Roadmap for Enhancing Yield Consistency in the Australian Avocado Industry'.
- The idea of restricting the issues to be considered in the Roadmap was proposed to the participants. It was proposed that avocado production issues that directly affect reproduction should be considered for inclusion in the investment priorities of the Roadmap and issues that only indirectly affect reproduction via stress or tree health should not be considered. The purpose of restricting the breadth of the issues was to minimize the risk of the Roadmap losing focus, because even when the issues are restricted to those that directly affect reproduction, it is still a broad range of issues. The participants agreed that this was a good approach. Examples of issues that are not considered under this framework are irrigation management and phytophthora. Of course, these are extremely important issues in avocado production systems, however, these issues are already being researched in other programs.

Communications and feedback

Following the Workshop and development of the draft Roadmap, a series of communication and feedback activities were undertaken:

1. Manjimup (Western Australia) feedback session – A total of 12 growers, advisers and researchers representing 2.1% of national production attended this session at the Manjimup DPI research institute. The feedback from the group was quite positive during the discussions. One question raised during the discussions was that a broad range of important issues had been identified but how would these issues be prioritised when investment decisions were being made?
2. Webinar - The draft Roadmap was presented to industry via a webinar on 18 September and attended by growers representing 7.5% of Australian avocado production. There were two written feedback responses from the webinar in addition to two responses to the post webinar survey. One comment received in the post webinar survey was "I felt we need more high-level science-based research and need to focus on gene editing that will solve most of the problems. Hass use by date is up.".
3. Responses from Workshop attendees – On 20 September, the draft Roadmap was emailed to all of the Workshop attendees and feedback requested. Two of the presenting scientists provided feedback.
4. Invitation for written responses to the draft Roadmap – The draft Roadmap was emailed out to the wider industry by the AAL communications team on 7 October and feedback on the document requested. One written response was received.
5. Strategic industry advisory panel presentation – The draft Roadmap was presented to the SIAP on 8 October in Brisbane. There was interest in the regional break down of responses to the survey question regarding the severity of impact of alternate and irregular bearing in growers' orchards. The full report, including the breakdown is presented in Appendix 2.

Photos/images/other audio-visual material

Figure 1. Brisbane Workshop participants at the State Library of Queensland.

Outputs

Table 1. Output summary

Output	Description	Detail
Investment Roadmap for Enhancing Yield Consistency in the Australian Avocado Industry	Yield consistency research strategy document.	There was considerable industry and scientific consultation in the development of the Roadmap and in subsequent feedback (see other 'Outputs' for details). The final document will be made available on the Best Practice Resource.
Domestic grower survey	Survey of grower insights and perceptions of alternate and irregular bearing	The survey was completed by 52 growers spread across all Australian production regions. The survey results were presented at the Brisbane Workshop. The survey report is available on the Best Practice Resource.
Literature review	Literature review of factors affecting irregular and alternate bearing in avocado	Provided the Brisbane Workshop participants before the Workshop. Available on the Best Practice Resource
Brisbane Workshop	Alternate and irregular bearing Workshop and Roadmap co-design held in Brisbane in August 2024	Attended by 8 growers, 8 scientists, 3 advisers and 4 AAL/Hort Innovation staff. Used to develop the Roadmap. Survey evaluation data: • Respondents rated the usefulness of the technical presentations 4.9 out of 5. • Respondents rated the usefulness of the co-design session 4.6 out of 5.
Manjimup feedback session	In person session held in Manjimup (WA) where the draft Roadmap was presented to industry and feedback invited.	Attended by a total of 12 growers, advisers and researchers. Survey evaluation data: • Respondents rated the usefulness of the presentation 4.2 out of 5 • Respondents rated the usefulness of the Roadmap in guiding future irregular and alternate bearing investments 4.4 out of 5. • Respondents rated the question of whether they believed the Roadmap covered the irregular and alternate bearing issues relevant to their region 4.4 out of 5.
Feedback webinar	Webinar open to all industry participants where the draft Roadmap was presented and feedback invited.	The recording of this webinar is on the Best Practice Resource. Post webinar feedback survey completed by 2 growers: • Respondents rated the usefulness of the webinar 3.5 out of 5. An additional feedback response was received where the grower suggested specific R&D activities.
Roadmap presentation to SIAP	Project leader was requested to present the Roadmap draft to the	The presentation was made to a combined meeting of the production R&D and the marketing R&D committees.

	SIAP at their Brisbane October 2024 meeting	
Talking Avocados article on Workshop and Roadmap	Article submitted for publication in Talking Avocados on the Brisbane Workshop and some of the key presentations for participants.	The article has been submitted and not published at the time of the submission of this report. It will be available in Talking Avocados. No feedback available on this output.

Outcomes

Table 2. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Sound scientific foundation provided for the co-design of the Roadmap (intermediate outcome)	Outcome 2 Strategy 2	The scientific foundation was provided by sound literature review and attendance by high quality scientists who gave high quality presentations. Fund level: important that the Roadmap was developed using sound and current scientific information	The literature review was reviewed by a DAF scientist. Post-workshop survey indicated the participants gave the usefulness of the technical information a score of 4.9 out of 5.
Broad array of quality information provided for the Roadmap co-design process (intermediate outcome)	Outcome 2 Strategy 2	Information included scientific and non-scientific information. One major input here was the industry survey that provided workshop participants with information from growers from every region. Fund level: important that the Roadmap was developed using current industry intelligence on grower insights and perceptions.	The grower survey was completed by 52 growers that were spread across all growing regions.
Growers from all regions have participated in the co-design of the Roadmap (intermediate outcome)	Outcome 3 Strategy 1	All growing regions were represented at the Workshop except Southern QLD, however a consultant of this region attended the workshop. All other regions either had representatives that grow avocados solely in that region or represented businesses with orchards in multiple regions. The survey was a key input to the Workshop and it was undertaken by growers from all regions. Fund level: Regional representation was important to give stakeholders confidence that the Roadmap would be relevant nationally and not just to a limited number of regions.	The grower survey was completed by 52 growers that were spread across all growing regions.
Draft Roadmap has been broadly communicated to growers and feedback provided (intermediate outcome)	Outcome 3 Strategy 1	Draft Roadmap communicated via a face-to-face session in Manjimup, an industry webinar, email from AAL to entire industry and presentation to the SIAP. Fund level: Broad communication of the draft and opportunities to provide feedback are critical to achieving industry endorsement and giving	Feedback webinar audience represented 7.5% of avocado production Manjimup feedback session audience represented 2.1% of avocado production Brisbane Workshop participants represented

		stakeholders confidence that the Roadmap was developed through broad consultation.	14% of avocado production.
A pathway for future investments in alternate/irregular bearing, co-designed and endorsed by growers (End-of-project outcome)	Outcome 2 Strategy 2	The Roadmap was co-designed by growers and scientists during the Brisbane Workshop. Relevant information was presented to the group but participants proposed their own key points following presentations and discussions. The Roadmap has a high level of legitimacy due to the quality of growers and scientists that developed it. Fund level: Due to this legitimacy, the Roadmap will provide a valid pathway for developing future alternate/irregular bearing investments.	Grower participants at the Workshop represented 14% of Australian avocado production. Post workshop survey indicates that 100% of respondents thought that the approach and framework of the Roadmap was endorsed by participants.
Greater awareness and understanding of the causes and geography of alternate and irregular bearing (End-of-project outcome)	Outcome 2 Strategy 2	The Workshop participants had a significantly improved awareness of the issues relating to alternate/irregular bearing. The survey provided insights into the geographic distribution of inconsistent production. Fund level: The relevance of the industry being more informed of the issues is that this knowledge can be used to develop more targeted irregular/alternate bearing investments.	Post-workshop survey indicated the participants found the usefulness of the technical information a score of 4.9 out of 5. A minimum of 24% of industry production represented in the Workshop and subsequent communication and feedback activities.
Awareness within industry of the existence and content of the Roadmap (End-of-project outcome)	Outcome 3 Strategy 1	The industry has been made aware of the Roadmap through the several communication and feedback activities noted above. Fund level: This is important at the fund level so that industry has confidence that any subsequent investments are based on sound science and industry need.	A minimum of 24% of industry production represented in the Workshop and subsequent communication and feedback activities.

Monitoring and evaluation

Table 3. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
To what extent is the Irregular/alternate bearing R,D&E Roadmap capable of guiding R,D&E investment that will improve consistency of bearing in avocado orchards?	Great extent: Strong scientific foundation (literature review, domestic and international scientific presentations) Strong industry engagement (24% of production across all activities) Strong endorsement of process by Workshop participants	The project performed well within the resource constraints (time, funds). If the project had been larger and longer then it may have been possible to request more detailed feedback from other scientists. This may have been useful.
To what extent will the Roadmap have durable relevance for avocado growers?	Great extent: High level of confidence that the identified problems are real issues. Many of the problems require medium to long time frames for research. Broad range of issues require R,D&E investment	In future, it would be useful for expected lifespans of these kind of guiding industry documents to be discussed during the project development phase or early project phase with a PRG.
To what extent were the target engagement levels of industry levy players achieved?	Great extent: It would be expected that greater than 50% of Workshop participants would have improved understanding of alternate/irregular bearing.	Greater awareness of the Roadmap would have been achieved by additional communication and feedback activities. E.g. presenting the Roadmap at Extension project regional forums.
Were the grower engagement activities (Workshop, survey, feedback opportunities) appropriate for the avocado industry?	Yes Workshop organisation and structure were highly rated by participants. Survey provided useful insights Feedback opportunities were numerous and engaged with a significant percentage of avocado production	Some time was allocated in the Workshop discussion session discussing issues that were of secondary importance. This took some time away from the issues of primary importance. Therefore, discuss issues of primary importance first, if possible. The survey was useful. However, more respondents and more detailed responses would have provided better data. If the project had more resources (time and funds), it would have been useful to undertake a more detailed survey process, possibly as part of the extension project regional forums, however, this would be a significantly larger activity.
What efforts did the project make to improve efficiency?	The Project Reference Group were chosen to provide strong, unbiased and informed feedback and this	

	helped deliver a sound Roadmap. The DAF project team members were also project team members of the avocado extension program, and this provided significant operational efficiencies due to their knowledge of the industry. The DAF project team have organised several previous Workshops and their experience meant the Workshop budget was accurate and the organisation was efficient. The project team engaged with PRG members to help secure high profile international speakers who gave exceptional presentations.	

Recommendations

- The end-users of the Roadmap are intended to be those developing investments for the avocado industry. This includes stakeholders identifying priority areas for investment and formulating the format of the requested investments. It also includes the research providers that develop proposals. All users of the Roadmap should be aware that the intrinsic nature of reproductive development in tree crops means that crop load development processes interact with each other. For example, the extent and quality of flowering will affect the extent of fruit set and retention, which may subsequently affect fruit size and final yield. Thus, it is important for users of the Roadmap to be aware of the issues/problems in all of the 'Impact areas', not just the Impact area of specific interest to that investment.
- This Roadmap development project had numerous steps and was required to undertake significant amounts of industry communication and consultation. Consideration should be given for future projects that develop Roadmaps and R&D strategies to be of a nine-month duration as opposed to a six-month duration to allow time for the industry consultation and feedback activities.

Refereed scientific publications

Nil

References

Whiley AW (2013) Literature review and gap analysis for the development of research plan into irregular bearing. Final Report (AV12030), Horticulture Australian Limited, Sydney, Australia.

Intellectual property

No project IP or commercialisation to report'

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Project reference group - Professor Phil Brown (Central Queensland University), Mary Burton (Avocados Australia Limited), Jacinta Foley (Jasper Farms), Simon Grabbe (Simpson Farms), Clayton Lynch (Australian Produce Partners), Ryan Marr (Trentham Fresh), Tom McCue (Hort Innovation), Harley Smith (CSIRO).

Workshop presenters and participants - Ben Norrish (Delroy Orchards), Amnon Haberman (DAF QLD), Chris Searle (MacAvo Consulting), Clayton Lynch (Australian Produce Partners), Drikus Heyns (Costa Group), Dudley Mitchel (Kurima), Gerhard Rossouw (DAF QLD), Harley Smith (CSIRO), Helen Bensilum (Kureen Farming), Jacinta Foley (Jasper Farms), John Tyas (Avocados Australia Limited), Lisa Fyffe (Ripe Horticulture), Mary Burton (Avocados Australia Limited), Phillip West (New Zealand Avocado), Sally Bound (Mimosa Consulting Pty Ltd), Simon Grabbe (Simpson Farms), Simon Newett (Consultant), Professor Stephen Trueman (Griffith University), Tom McCue (Hort Innovation), Gemma Burger (Hort Innovation), Dr Inaki Hormaza (CSIC Spain), Dr Vered Irihimovitch (ARO Israel).

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Appendices

Appendix 1: Investment Roadmap for Enhancing Yield Consistency in the Australian Avocado Industry (September 2024)

Appendix 2: Irregular and alternate bearing Australian domestic survey

Appendix 3: Literature review

Appendix 4: Brisbane Workshop evaluation summary

SEPTEMBER 2024

Investment Roadmap for Enhancing Yield Consistency in the Australian Avocado Industry

Developed in partnership with industry through project AV23014

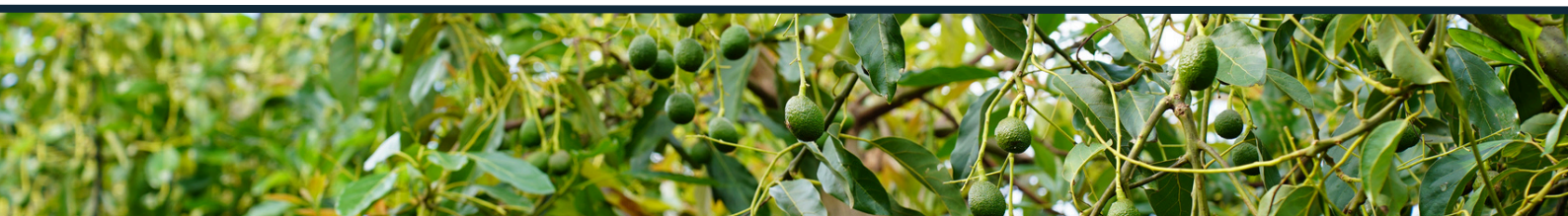
Hort Innovation AVOCADO FUND

Wilkie Horticulture

Queensland Government

Table of Contents

The project 'Workshop and roadmap for the way forward for irregular bearing' (AV23014) has been funded by Hort Innovation, using the avocado research and development levy, co-investment from the Queensland Department of Agriculture and Fisheries, and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian Horticulture



Introduction

The Australian avocado industry is undergoing a period of significant growth in production, which has changed the dynamics of markets and industry profitability. It is widely accepted that inconsistent production and availability of fruit to markets has significant negative impacts on profitability.

This Roadmap was developed because there was a perception that there were wide-ranging views within the industry on the direction future investments to improve yield consistency should take. A Workshop and co-design process exposed participants to high quality scientific information, encouraged rigorous discussion and was successful in generating consensus on the critical issues for yield consistency in Australia.

This Roadmap will inform and support avocado industry investments aiming to improve yield consistency (minimise the effects of irregular and alternate bearing). It is anticipated that this Roadmap should have a lifespan of at least 10 years. These investments will help achieve:

- The Hort Innovation avocado industry strategic plan (Outcome 2)
- Avocados Australia strategic plan (1.1 Encourage consistent supply to the domestic market)
- Australian Avocados Export Strategy (Section 2)
- Australian Avocado Extension Strategy (High priority practice change area 12)

The intended users of the Roadmap are those evaluating investment decisions, including the avocado Strategic Investment Panel and Hort Innovation. It is also intended that the Roadmap be used by research providers designing projects aimed at improving yield consistency.

The Roadmap has been developed with two key principles in mind. First, that the process be undertaken with high levels of industry input and consultation. Second, that strong and broad scientific expertise be used to develop the Roadmap.

The Roadmap is a research strategy that has identified key issues, likely strategies to overcome these issues and potential deliverables. The Roadmap is not intended to be a research proposal.

Project summary

This roadmap is part of the Hort Innovation-funded project (AV23014), which aims to develop a comprehensive and actionable roadmap for research, development, and extension focused on irregular and alternate bearing in the Australian avocado industry, guiding future industry investments.

The Roadmap development process began with a literature review, to provide a strong scientific foundation, and an industry survey, to gain grower insights and understand their perceptions of the issues.

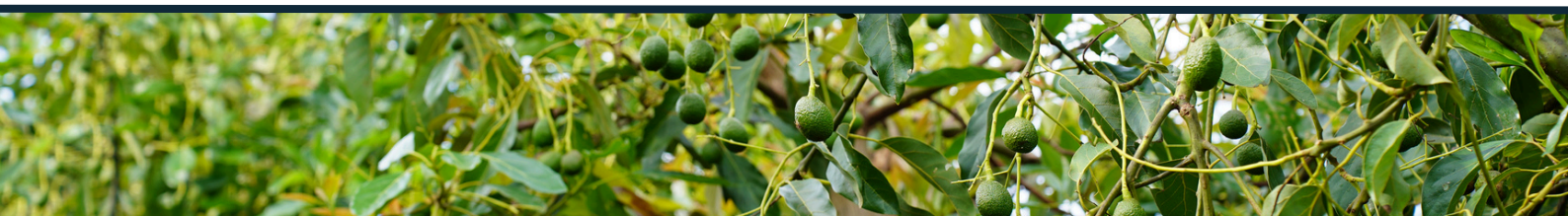
The primary activity was the Workshop in Brisbane, which was attended by leading scientists, advisers and producers from diverse growing regions that represented 14% of Australian production. The program was designed to provide the participants with current scientific information on critical issues around alternate and irregular bearing in avocado, and to allow the group time to absorb and discuss this information. There were a range of important outcomes from the discussion and co-design sessions at the Workshop. First, the group agreed that the traditional terms of 'irregular bearing' and 'alternate bearing' may be leading to confusion and that talking of the issue as one of yield consistency would be more useful.

Second, the factors affecting yield consistency were separated into four clear crop production impact areas. This aided the co-design process and is intended to aid investment decisions:

1. Floral initiation and development
2. Pollination and fruit set
3. Fruit development and retention
4. Vegetative growth and canopies

Third, there was consensus that for many of the issues affecting yield consistency, scientific understanding is in its infancy and many areas require research to develop underlying principles, knowledge and understanding before grower tools and management packages could be developed. There are a broad range of issues within the identified Investment Priorities which further demonstrates the breadth of the challenge in improving yield consistency. Some issues were identified to be more severe in certain growing regions, however, many of the issues were accepted to be in common across the industry.

Extensive feedback on versions of the draft Roadmap has been sought, via an additional information session in Western Australia, an industry wide webinar and an opportunity for written responses following online access to the draft roadmap.



Purpose and scope of the Roadmap

The purpose of the Roadmap is to inform and guide future avocado industry investment decisions aimed at improving consistency of production.

These investments will help achieve:

- The Hort Innovation avocado industry strategic plan (Outcome 2)
- Avocados Australia strategic plan (1.1 Encourage consistent supply to the domestic market)
- Australian Avocados Export Strategy (Section 2)
- Australian Avocado Extension Strategy (High priority practice change area 12)

Many factors affect yield in avocado orchards. We are not including certain aspects of avocado production systems in the investment priorities of this Roadmap:

- Factors that indirectly affect avocado reproductive development via tree health or by inducing stress in the tree, are not considered in this Roadmap.
- Examples of factors that are not included in the investment priorities are Phytophthora and irrigation. We are not saying these issues are unimportant, they are not included as areas for research in this Roadmap because research on these issues is conducted in other programs.

The terms 'irregular bearing' and 'alternate bearing' have traditionally been used to describe different forms of variability in avocado yield. The workshop participants agreed that these terms may be leading to confusion and are not ideal. The group instead agreed to refer to impacts on:

1. Floral initiation and development – including the induction, initiation and development of inflorescences and flowers up until the point that the flowers open.

2. Pollination and fruit set – encompassing all of the processes from flower opening until a fruit has been set. This includes the quality of the flowers, the transfer of pollen and all of the processes affecting successful fertilisation of the ovary and resultant fruit set.

3. Fruit development and retention – this encompasses the entire period of fruit development from the point of initial fruit set until maturity and includes the processes of fruit growth and fruit abscission.

4. Vegetative growth and canopies – this includes the factors affecting the development of the canopy, ranging from the scale of individual shoot growth up to the whole tree and orchard scale.

The Australian avocado industry operating environment in 2024

- Inconsistent supply of fruit to markets is having a strong negative impact on profitability in all growing regions.
- There has been a significant increase in plantings with some of these plantings yet to come into production.
- The industry is aiming to drive domestic consumption and increase export, both at profitable farm gate prices, but inconsistent fruit supplies are hindering this market development.
- Wide range of growing environments (tropical to temperate), with an associated range of crop phenology.
- The climate is changing. The overall impacts on avocado yield through direct impacts to crop development processes are not fully understood. Nor are the impacts for the different growing regions.

Australian annual avocado production and price

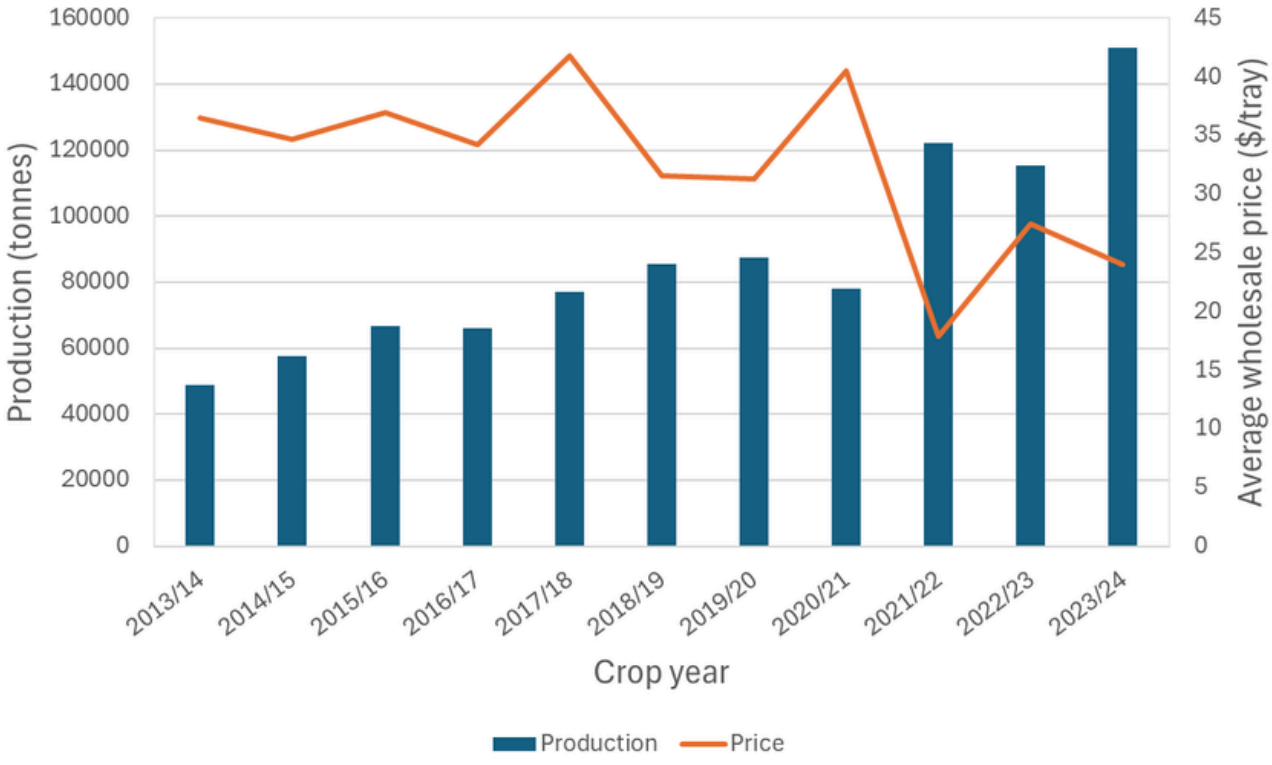


Figure 1: The relationship between Australian national avocado production and average wholesale avocado prices
Source: Data provided by Avocados Australia Limited

Where are we and where do we want to be?

Current state

- Lack of consistency in yield and low productivity is a significant issue in Australian avocado orchards.

- Improved understanding of avocado physiology, factors affecting crop load development and responses to management.
- Better management tools and strategies.
- Greater ability of managers to generate improved crop resilience against severe weather events.

Desired state

- Australian avocado orchards with greater productivity and improved yield consistency
- Greater grower confidence in ability to achieve consistent yields.

The Roadmap development process

Broad industry and scientific contributions were a feature of the Roadmap process:

- A Project Reference Group consisting of growers and scientists was engaged to guide the Roadmap development.
- The Roadmap design workshop was attended by growers representing 14% of Australian avocado production and leading domestic and international scientists.
- The survey had responses from more than 50 avocado businesses with representation from all Australian growing regions.

LITERATURE REVIEW

- Reviewed the factors affecting alternate and irregular bearing, including the influence of growing regions
- Areas that were reviewed in great detail in AV12030 were not duplicated, resulting in a review with a significant focus on tree physiology and resource allocation

PRE-WORKSHOP SURVEYS

- Domestic survey gained an understanding of grower experiences and perceptions across all production regions
- International consultation provided input from researchers worldwide regarding their experiences and perspectives

WORKSHOP

- Featured guest international and domestic speakers and facilitated discussion sessions
- Participants engaged in a co-design process to develop the R,D&E investment priorities

R,D&E ROADMAP

- Information gathered from the literature review, surveys, presentations, workshop discussions and co-design sessions were integrated
- The Roadmap will provide a pathway for future investments in this area, validated through extensive industry consultation
- It is worth noting, however, that the Roadmap is not a research proposal

POST-WORKSHOP FEEDBACK OPPORTUNITIES:

- Webinar
- Feedback session in Western Australia
- Written responses to draft Roadmap

FINAL REPORT

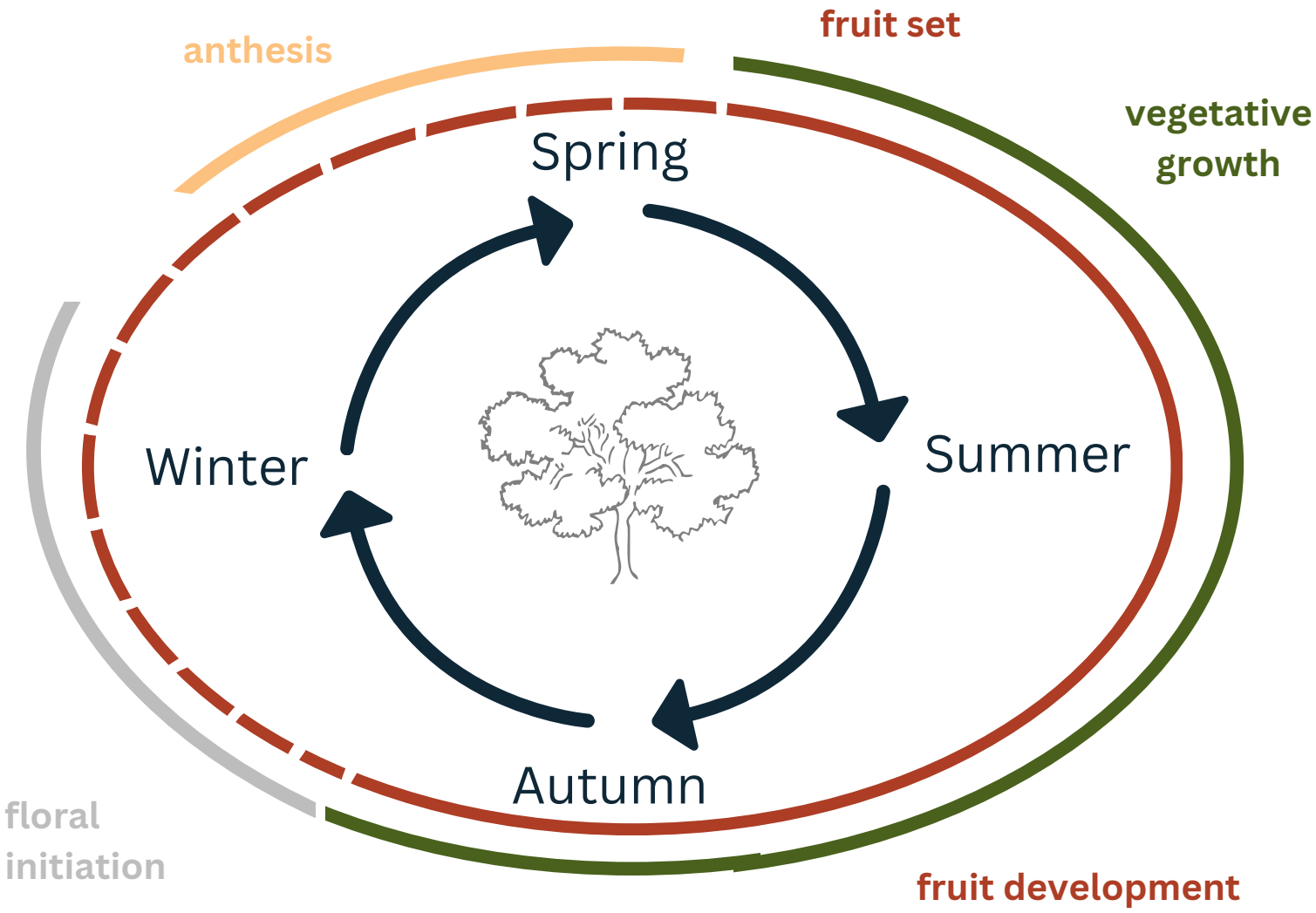
- Summary of all outputs
- Outputs added to Best Practice Resource
- Industry article on the project
- Final Roadmap submitted to Hort Innovation

A note for users of the Roadmap

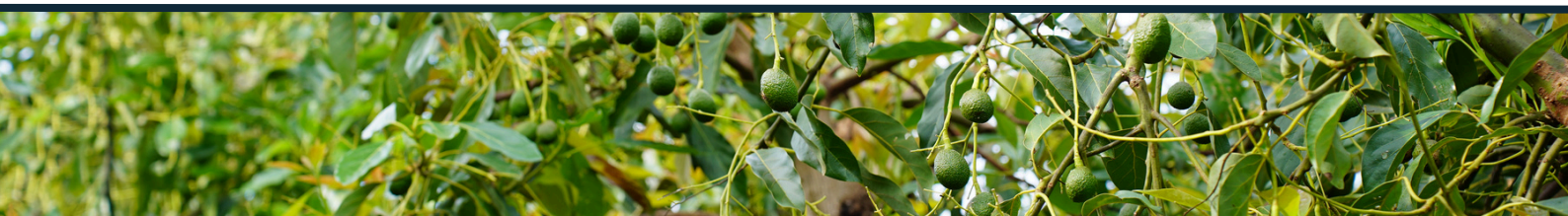
Reproductive development in avocado is complex, because it is a multi-step process, is affected by processes occurring within the tree and by the external environment. Additionally, the previous crop affects the development of the current crop.

This means that critical crop development processes such as floral initiation and development, fruit set and fruit development can be affected by each other or by vegetative growth.

It is therefore important for Roadmap users to consider how their issue of interest may interact with issues in the same or other Impact areas.



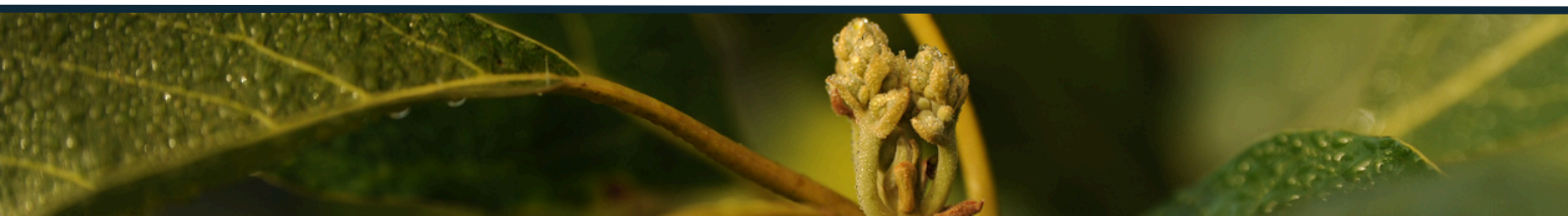
The avocado crop development cycle varies with growing environment. The initiation of flowers occurs when temperatures are cool enough for the expression of flowering genes, and these flowers bloom during late winter or spring. Fruit set and development follow flowering, with fruit maturity and harvest times varying with growing regions, sometimes overlapping floral initiation and bloom, sometimes not. Vegetative growth often occurs in spring, summer and autumn flushes but sometimes these flushes become indistinct.



Investment priorities
Impact 1: Floral initiation and development

Problems/Issues	Strategies	Deliverables
-Poor ability to manage carbohydrate availability and/or allocation.	Improve understanding of carbohydrate partitioning in trees and how it can affect initiation, development and quality of flowers.	New knowledge on carbohydrates to support consistent flowering, including measurement protocols and tissue carbohydrate thresholds (**M**).
Poor flowering: -Insufficient tools and knowledge to manage the impact of high crop loads and late harvesting causing poor flowering.	Investigate strategies to improve regularity of flowering under varying crop loads, including interactions with vegetative growth, timing of harvest, carbohydrate status of the tree and other signals.	New knowledge and tools to support consistent flowering (**M**), including the effects of crop load on vegetative growth, carbohydrates, hormones and other signals.
-Insufficient canopy management strategies.	Improve understanding of canopy architecture and complexity and its impact on flowering and crop production. E.g. light and production of shoots for flowering.	Canopy management strategies and principles to support consistent flowering and production (**S-M**).
	Improve understanding of pruning on subsequent flowering.	Same as above (**S-M**).

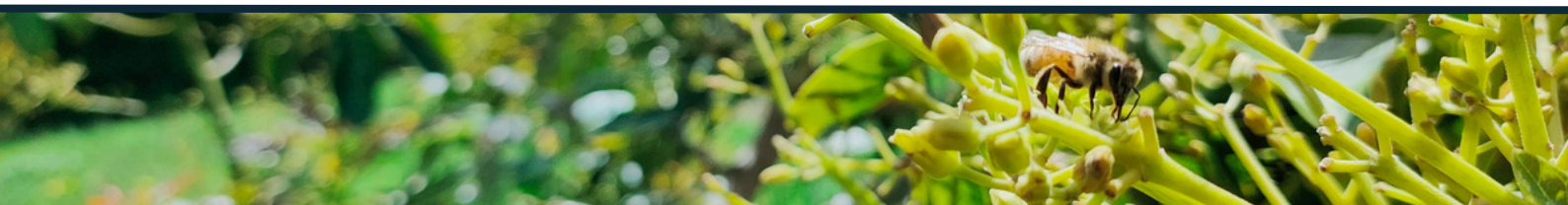
Investment time frame:
***E** = extension; **S** = short, up to 3 years; **M** = medium, 3 to 6 years; **L** = long term, more than 6 years*



Investment priorities
Impact 2: Pollination and fruit set

Problems/Issues	Strategies	Deliverables
Poor flower quality leading to poor fruit set: –Beyond the role of carbohydrate and Boron, there is little understanding of what determines flower quality –Unknown effect of flowering intensity on flower quality –Limited understanding of flower quality at grower level.	Investigate opportunities to manipulate carbohydrate partitioning to improve flower quality, including manipulating flowering intensity.	Understanding of desired carbohydrate levels in flowers and management options to influence this (e.g. via crop load management)
	Develop understanding of what makes a good pollen grain • Attractiveness • Viability • Likely to produce strong fruit	Definition of desirable traits for pollen and management options to influence it (**S–M**).
Negative effect of cool and hot temperatures at flowering. The impact of temperatures at flowering are well understood but there is a lack of tools to manage it.	Investigate the possibility of increasing the length of time flower pistils are viable.	Understanding and management tools to increase flower pistil viability, if possible (**S–M**).
	Investigate options to modify orchard microclimate, including cover crops or other methods.	Understanding of the changes to orchard microclimate achieved through different options (**S–M**).
Insufficient understanding of the impact of pollenisers on productivity and profitability.	Investigate productivity and profitability aspects of polleniser distribution and the best cultivars for each region.	Quantitative understanding of the productivity and profitability impacts of pollenisers (**E,S**).
	Encourage documentation and sharing of local pollination events in relation to climate (e.g. VPD).	Extension of industry standard methods to document pollination events (**E**).
Sub optimal pollen transfer.	Investigate factors affecting nectar and pollen attractiveness and how to influence it.	Understanding and management tools to influence avocado flower attractiveness (**M**).
	Investigate ideal pollinator stocking rates per hectare and ideal hive distributions.	Decision tools on when and how many hives to introduce (**S – M**).
	Investigate options to attract alternate pollinators, including cover crops to promote a habitat and food source.	Understanding and management guidelines on options to increase pollinator diversity for improved pollination, including regional understanding on floral competition and supporting plants (**S – M**).
	Investigate artificial methods of pollination or transfer of cross-pollen.	Proof of concept of artificial pollination/pollen transfer methods in avocado orchards (**S–M**).

*Investment time frame: **E** = extension; **S** = short, up to 3 years; **M** = medium, 3 to 6 years; **L** = long term, more than 6 years*



Investment priorities
Impact 3: Fruit development and retention

Problems/Issues	Strategies	Deliverables
Limited ability to manage fruit retention and development: –Lack of understanding of the relationships between flowering, fruit set and abscission (crop load development cycle).	Develop understanding of reproductive development and the crop load development cycle in different growing regions.	New knowledge on reproductive development (**S**). Foundation for pathway to manage crop load through various methods (**S–M**).
–Lack of tools to manage abscission.	Investigate new tools to manage abscission (e.g. PGR management of abscission currently underway in AV23000).	Management tools developed through AV23000 and beyond (**M–L**).
–Lack of understanding of carbohydrate partitioning, signalling and storage across the phenological cycle.	Develop understanding of these cycles across different growing regions and their relationship with fruit development.	New knowledge and pathway for management of carbohydrates for improved and consistent production (**M–L**).
–When carbohydrate benchmarks are developed, a rapid carbohydrate measurement tool would be needed.	Develop a rapid, scalable, non–destructive carbohydrate measurement method to quantify partitioning of carbohydrates (progress toward this in AV19006).	Carbohydrate measurement method – a tool for management and research (**M**).
–Unknown yield potential (carrying capacity) for each region. Varied grower and regional expectations.	Determine sustainable yield potential/carrying capacities for different growing regions that do not lead to alternation of bearing. Understanding of the physiology underlying regional differences may lead to management strategies to improve yield and consistency.	Sustainable yield potentials (crop loads) identified for differing growing regions, along with an understanding of differences in the underlying physiological drivers of productivity.
Considerable yield variation and production problems with 'Hass'.	Undertake DNA–free gene editing to improve reproductive success of 'Hass'	Proof of concept (**S**). New Hass clones that exhibit more consistent production (**M**).

Investment time frame:
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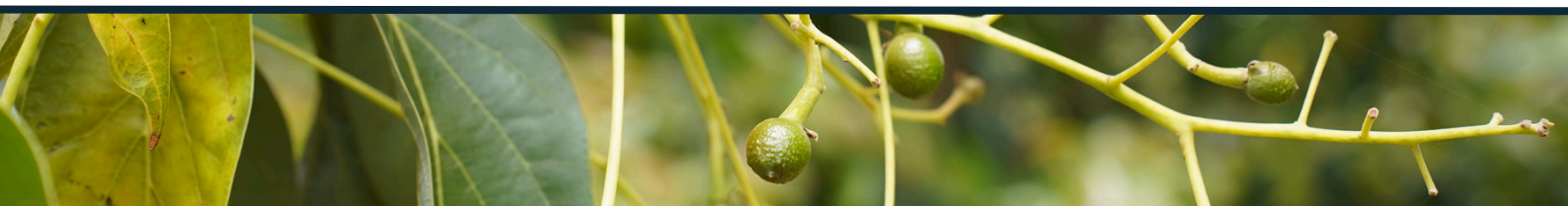

Investment priorities
Impact 4: Vegetative growth and canopies

Problems/Issues	Strategies	Deliverables
Canopy management and light environment impacts on regularity of bearing not well understood. A wide range of current pruning practices.	Develop understanding of pruning strategies for high and consistent production, potentially through better orchard light environment and canopy structures. Develop understanding of effects of canopy structure and light availability on pollinator activity.	Greater understanding of the principles of light, canopy structures and responses to pruning (**M**) Orchard light model and best management practice and solutions for rapid light measurement (**S-M**) Pruning strategies that promote balanced vegetative growth and fruiting (**S-M**)
The effect of nitrogen nutrition on vegetative growth and subsequent reproductive development is poorly understood. Grower nitrogen nutrition practices vary regionally.	Investigate the ability to use nitrogen nutrition to manipulate spring and summer flushes and subsequent floral initiation.	Greater understanding of the effect of nitrogen on the balance between vegetative and reproductive development, with a goal of leading to more consistent production (**S-M**).
	Investigate the effect of crop load on nitrogen requirements in different growing regions. A range of tools are available including isotope studies.	Updated nitrogen guidelines that consider growing environment, crop load, vegetative growth and genetics (**S-M**).
	Investigate the effect of nitrogen nutrition on competition between shoot growth and fruiting	New knowledge on factors affecting fruit to shoot competition to feed into nitrogen guidelines.
Limited ability to manipulate carbohydrate partitioning for desired balance between vegetative growth and reproductive development	Investigate methods to modify allocation of carbohydrate resources with the aim of improving productivity. E.g. PGRs, pruning techniques, nutrition, crop load manipulations.	Improved understanding of factors affecting allocation of resources and competition between sinks in avocado orchards. Improved ability to alter partitioning (**M**).
PGR potential not maximised	Further studies on PGR use strategies to optimise their use.	Updated principles for PGR usage (**S**).
Lack of understanding of leaf function over time, including across the season and during shoot development.	Investigate leaf function and photosynthetic rates, including the effect of light intensity and photoinhibition, during shoot development and as leaves age.	New knowledge on leaf function and carbohydrate production (**M**). Improved understanding of energy production by avocado trees and interactions with reproductive development (**M**).

Investment time frame:
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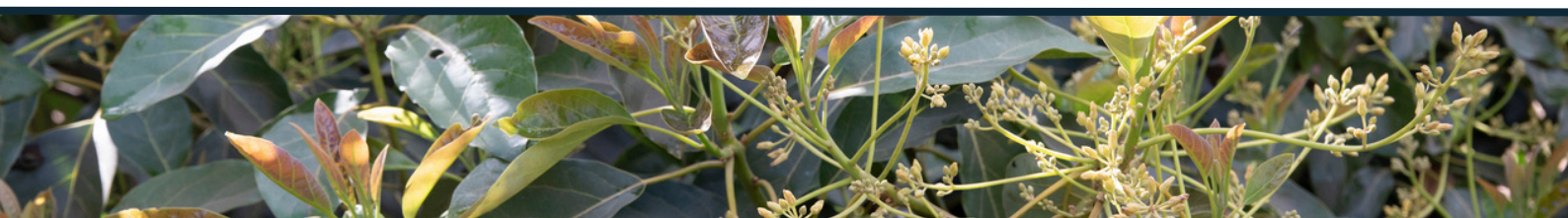

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AV23014 Project Reference Group:

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Hort Innovation AVOCADO FUND Wilkie Horticulture Queensland Government

AUGUST 2024

Irregular and alternate bearing Australian domestic survey

Renata Grunennvaldt, Bridie Carr and John Wilkie
(Department of Agriculture and Fisheries and Wilkie Horticulture)

This workshop and roadmap for the way forward for irregular bearing has been funded by Hort Innovation, using the avocado research and development levy, contributions from the Australian Government and co-investment from the Queensland Government Department of Agriculture and Fisheries. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Hort Innovation AVOCADO FUND Wilkie Horticulture Queensland Government

Domestic Survey Report - Workshop and roadmap for the way forward for irregular and alternate bearing

Contents

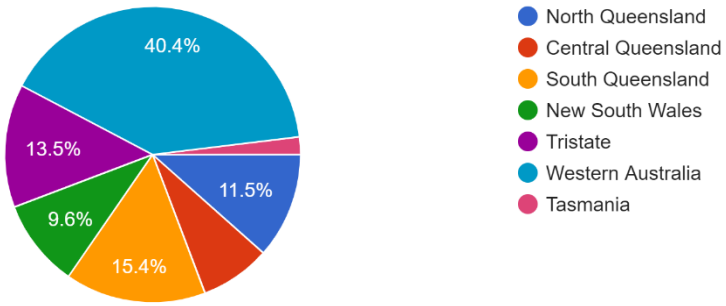
Summary

As part of the AV23024 project—"Workshop and Roadmap for the Way Forward for Irregular and Alternate Bearing"—a domestic survey was developed and submitted for contribution by Australian avocado growers. This survey was designed to gather growers' insights about irregular and alternate bearing issues in avocado production in Australia. Growers were asked to complete the survey by selecting a mature block of trees that is representative of their orchard and to answer the following questions specifically based on this block. Note: They were requested not to choose a block that has been staghorned or pruned severely within the past 3 or 4 years.

The survey aims to measure how alternate and irregular bearing are perceived by growers as issues in avocado production across different regions. The results will be discussed at the Irregular and Alternate Bearing Workshop and will support the development of the Irregular and Alternate Bearing Roadmap, which will guide future industry investments. This report presents the survey questions along with the designated answers provided by the growers.

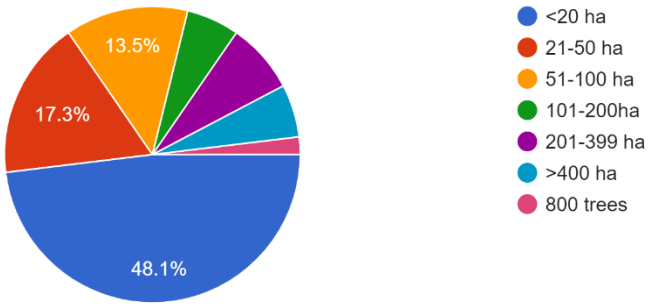
1- What is the region in which you grow avocados?

52 responses



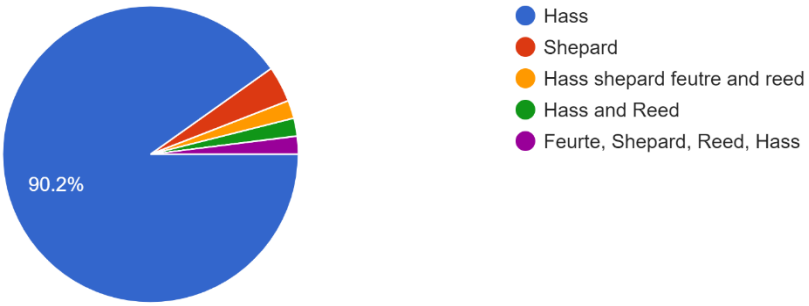
2- How large is your farm (hectares or trees?)

52 responses



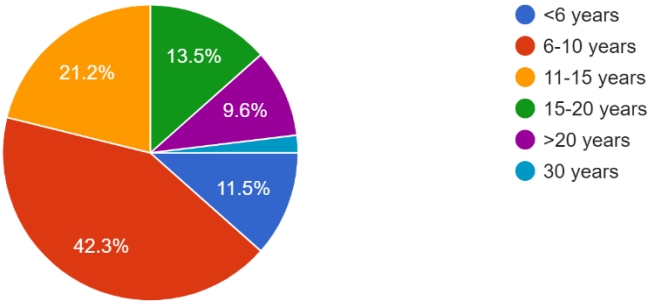
3- What are the main varieties of avocados that you grow?

51 responses



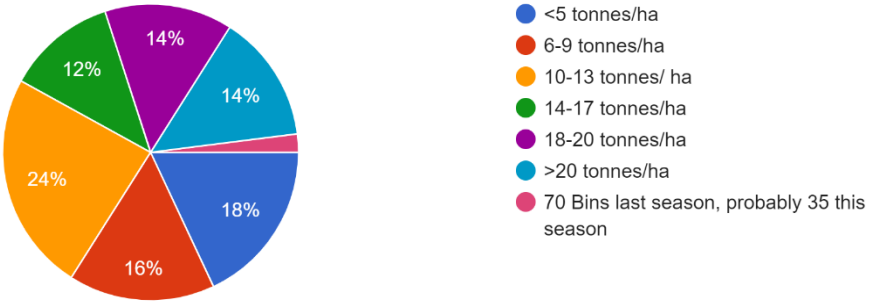
4- What is the predominant age of trees in your orchard?

52 responses



5- What is the average yield per hectare?

50 responses



6- Is your orchard affected by irregular bearing (climatic or management events that impact negatively on fruit-set/crop load regardless of flowering intensity)?

50 responses

7- Does your orchard exhibit alternate bearing (consistent "on"/ "off" flowering/yields from one year to the next)?

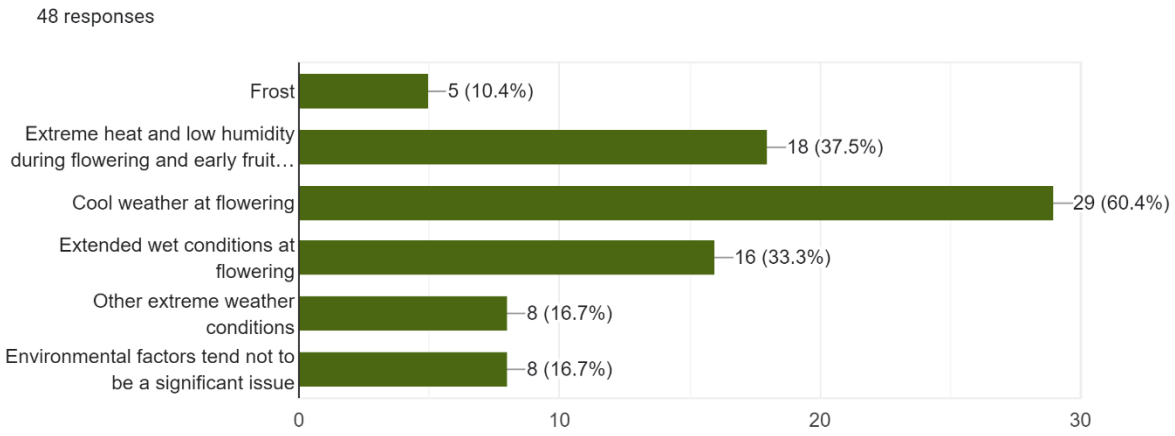
50 responses

8- Table comparing the region and the level of significance of irregular and alternate bearing:

Region	Irregular Bearing Impact	Alternate Bearing Impact
Central QLD (4 responses)	Minor impact (2)	Minor impact (3)
	Medium impact (1)	Yes, due to late harvest or cold at flowering time (1)
	Yes, due to late harvest or cold at flowering time (1)	
NSW (5 responses)		Minor impact (1)
	Medium impact (1)	Medium impact (1)
	High impact (4)	High impact (2)
North QLD (14 responses)	Minor impact (3)	Minor impact ()
	Medium impact (8)	Medium impact (9)
	High impact (3)	High impact (3)
South QLD (8 responses)	Minor impact (1)	
	Medium impact (4)	Medium impact (5)
	High impact (3)	High impact (3)

Tasmania (1 response)	Minor impact (1)	Medium impact (1)
Tristate (7 responses)	Minor impact (2)	Minor impact (3)
	Medium impact (3)	Medium impact (2)
	High impact (1)	High impact (1)
	No (1)	Variation within the patch (1)
WA (21)	Minor impact (2)	Minor impact (1)
	Medium impact (6)	Medium impact (9)
	High impact (11)	High impact (9)
	Didn`t answer (2)	No (2)

9- In years with low production, can you relate the low yield to one of the following environmental factors? (Select the top three)

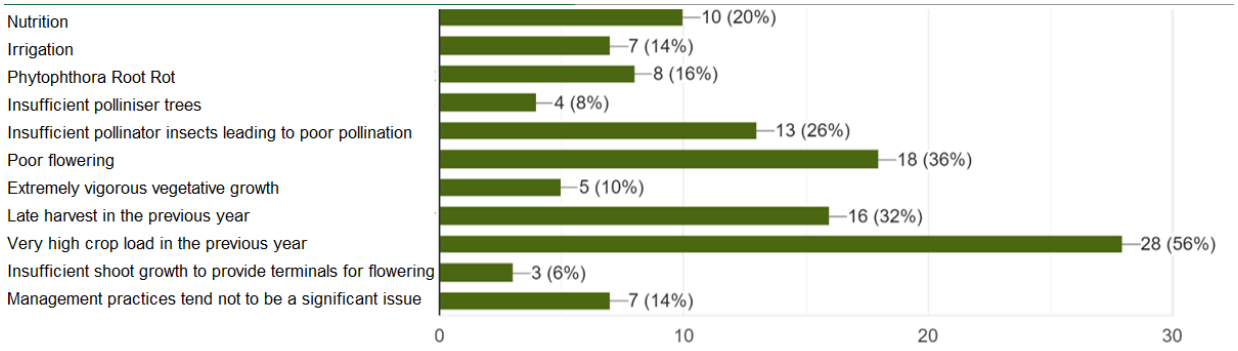


Breakdown by region:

Weather Issue	Central QLD (3)	New South Wales (5)	North QLD (6)	South QLD (8)	Tasmania (1)	Tristate (7)	Western Australia (9)
Cool Weather at Flowering	3	2	1	4	1	7	8
Extreme Heat & Low Humidity During Flowering and Early Fruit Set	1	3	2	2		3	7
Extended Wet Conditions at Flowering		3	6	3			5
Environmental Factors Tend Not to be a Significant Issue		2		1		1	2
Frost		1		1		3	1
Other Extreme Weather Conditions		1		2		2	

10- In years with low production, can you relate the low yield to one of the following management practices and /or phenomenon? (Select the top three)

50 responses

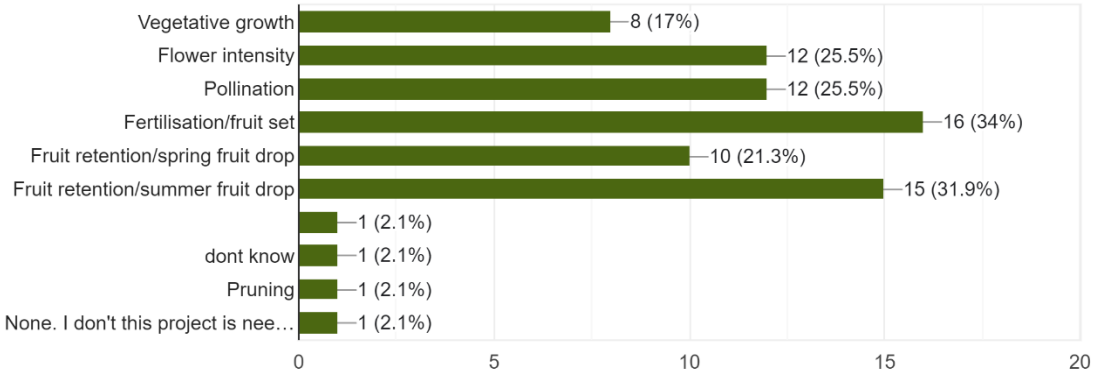


Breakdown by region:

Issue	Central QLD (3)	New South Wales (5)	North QLD (6)	South QLD (8)	Tasmania (1)	Tristate (7)	Western Australia (9)
Insufficient Polliniser Trees	-	-	1	-	-	2	1
Insufficient Pollinator Insects Leading to Poor Pollination	-	4	2	4	1	1	7
Poor Flowering	4	4	1	3	-	4	5
Extremely Vigorous Vegetative Growth	-	2	2	-	1	2	-
Late Harvest in the Previous Year	3	1	1	5	-	3	5
Management Practices Tend Not to Be a Significant Issue	-	2	-	2	1	2	2
Nutrition	3	1	1	3	-	3	3
Irrigation	-	1	-	2	-	2	3
Very High Crop Load in the Previous Year	4	4	5	6	1	5	9
Phytophthora Root Rot	-	1	1	3	-	-	4
Insufficient Shoot Growth to Provide Terminals for Flowering	1	2	-	1	-	-	-

11- What plant development stage do you consider as the main bottleneck to increase production in your orchard?

47 responses



*cont… None. I don't this project is needed. Research and knowledge is already out there.

Breakdown by region:

Issue	Central QLD (4)	New South Wales (5)	North QLD (6)	South QLD (8)	Tasmania (1)	Tristate (7)	Western Australia (9)
Fruit Retention: Spring Fruit Drop	3	3	-	2	-	-	5
Fruit Retention: Summer Fruit Drop	1	3	3	4	-	1	9
Flower Intensity	-	2	1	3	-	3	8
Pollination	-	2	2	-	1	3	7
Vegetative Growth	2	2	2	0	0	-	2
Fertilisation/Fruit Set	-	1	1	5	-	4	9
Other	1 (None)					1 (Don't know)	1 (Pruning)

12- Which month does fruit achieve maturity for harvest in your region? Which months do you pick your crop?

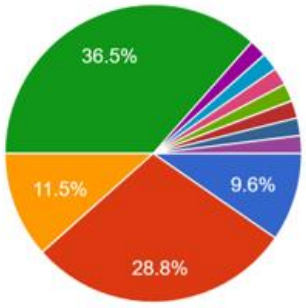
52 responses

Region	Fruit Maturity Month	Harvest Months
Central QLD	March	March to July
	May for Hass	May - August
	March	March - August
	April/May	April, May, June, July, August
NSW	July	July, September
	September	September to December
	June	June to September
	August	August to December
	July	August

North QLD	February	February, March, April
	April	April to July
	April	April/May/June
	End May	May to August
	May	May to July
	March	March/April
South QLD	June	May - October
	April/May	June/July
	May	June, July, August
	June	July, August, September
	June	June
	June/July	August/September
	May	August
	June	June to August
Tasmania	October	January
Tristate	September	August to November
	August	August
	August	July, August, September, October
	August	August to January
	August	August, September, October
	August	August to January
	July/August	July through to February
WA	September	September to March
	November	November to March
	October	October to February
	September – December (Hass)	September to January
	July	July to December
	September	December
	August	August to November
	July	July, August, September
	October	October, November, December, January
	October	October
	September	September to February
	November (Hass), February (Reed)	November to February (Hass), February to May (Reed)
	October	December
	March - August	March to September
	May - September	May -September
	September/October	October/December
	October	October- January & March - May
	October/November	October to February
	August	August
	October	October to December
	October/November	October to March

13- Do you have polliniser varieties interplanted? If yes, which one

52 responses



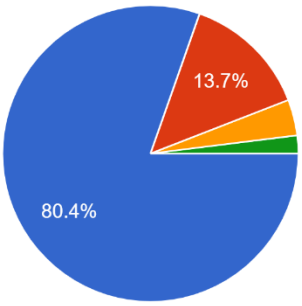
- Yes - separate rows
- Yes - in the same row
- Yes- separate blocks
- No
- As replants
- Some
- Zutano/Ettinger/Edranol
- In separate rows & in same row

1/2

- Probably all the above. We have a small mixed variety orchard, but Sharwill are spread through most blocks
- Surrounded by native vegitation
- Not all blocks and no regular spacing on blocks that we have B varieties

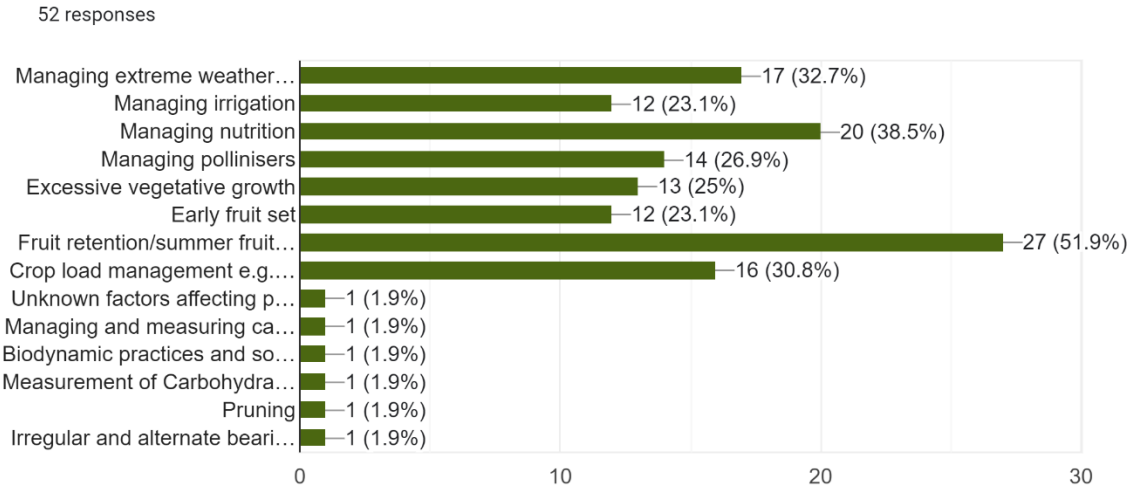
14- Do you apply Boron?

51 responses



- Yes - standard part of the nutrition program
- Yes - only if deficiencies are indicated on leaf and soil analysis
- No
- Not as much as should

15- In which of the following areas would gaining more knowledge help you better manage irregular and alternate bearing? (Select the top three)



Others comments:

- Unknown factors affecting pollenization, fruit set and fruit retention
- Measurement of Carbohydrate levels
- Biodynamic practices and soil improvements to support all of the above
- Irregular and alternate bearing, is caused when you leave a block late to harvest or it drops below 10 degrees at time of flowering. There is no need for this project as we know what causes it. I think this is a waste of levy money!

JULY 2024

Irregular and alternate bearing literature review

Dr John Wilkie
Wilkie Horticulture

This workshop and roadmap for the way forward for irregular bearing has been funded by Hort Innovation, using the avocado research and development levy, contributions from the Australian Government and co-investment from the Queensland Government Department of Agriculture and Fisheries. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Hort Innovation AVOCADO FUND Wilkie Horticulture Queensland Government

Irregular and alternate bearing literature review for the AV23014 industry investment roadmap

Wilkie JD

Wilkie Horticulture

Contents

Summary

Yield per hectare can vary significantly from year to year in avocado orchards. This excessive yield variability has been classified as either alternate or irregular bearing. Alternate bearing is an internal tree cycle where a high yielding 'on' year is followed by a low yielding 'off' year in a repeating pattern. Irregular bearing can be caused by a range of factors and does not necessarily lead to a repeating pattern of 'on' and 'off' production. Avocado production in Australia spans from temperate climates in Southern Australia up to tropical environments in Far North Queensland. These diverse growing environments are accompanied by diverse plant development and phenology.

The purpose of this review is to provide an update on the causal factors and crop development impacts of irregular and alternate bearing in Australian avocado production. This review is designed to be read in conjunction with the review undertaken by Whiley (2013), with this review focussing on work published since 2013 and areas that were dealt with in less detail in the previous review. The outcome of this approach is that this review has a strong focus on avocado tree physiology. First, we review factors affecting the avocado crop load development cycle, including effects on return flowering. We then go on to review the literature associated with allocation of resources within avocado trees, including competition between vegetative and reproductive development and fruit abscission. Third, we review recent work on cross pollination in avocado orchards. Finally, we attempt to synthesis the findings by categorising them according to their impacts on avocado tree development.

Background

Excessive variability in yield per hectare from year to year is a significant issue in a range of temperate and deciduous tree crops (Monselise and Goldschmidt, 1982), including avocado. For avocado, these elevated levels of yield variability are classified as being either alternate bearing or irregular bearing.

Alternate bearing is when an individual tree or an entire orchard develops a cycle of a high yielding 'on' year, followed by a low yielding 'off' year in a repeating pattern. Once the alternate bearing cycle has been entrenched, it persists due to within tree physiological factors. Irregular bearing, as the name suggests, is characterised by variability in yield from year to year without a clear biannual pattern of 'on' and 'off' bearing years. Irregular bearing can be due to a range of causal factors including management (e.g. irrigation or nutrition), weather extremes or undesirable within tree partitioning (excessive summer fruit drop).

Avocado is a subtropical, recurrent flushing horticultural tree. It has been classified as an evergreen tree; having no distinct leafless and dormant phenological stage. It has also been colloquially classified as a 'wintergreen' tree (Whiley 1994), due to its habit of replacing all leaves annually with the canopy partially or, at times, almost fully defoliating before the spring vegetative flush has occurred. The avocado industry in Australia stretches from tropical Far North Queensland down to the temperate regions of southern and Western Australia with associated climatic differences (Table 1), leading to significant differences in phenology and plant development between regions. One of the most notable differences in phenology between the growing regions is the length of time taken for fruit development, with Hass at Childers in Central QLD reaching 24% dry matter during May (ca. eight months after flowering; Whiley at al., 1996) and Hass grown in southern Australia reaching 24% dry matter in October/November (ca. 13 months after flowering).

Table 1. Major Australian growing regions selected climate data*, including monthly mean minimum temperature (Min T), monthly mean maximum temperature (Max T) and Monthly mean 9 am relative humidity (Mean RH).

Location	Min T (°C) Sep.	Max T (°C) Sep.	Min T (°C) Nov.	Max T (°C) Nov.	Min T (°C) Jan.	Max T (°C) Jan.	Mean RH (%) Jan.**
Walkamin (17.13°S)	14.8	27.1	18.6	30.6	20.4	29.9	77
Bundaberg (24.91°S)	13.7	25.7	18.8	28.6	21.5	30.4	70
Alstonville (28.85°S)	12.8	22.4	16.6	25.4	19.5	27.2	79
Renmark (34.17°S)	8.2	20.9	13.2	27.8	16.7	32.5	52
Manjimup (32.25°S)	7.3	16.7	10.1	22.1	13.1	27.3	65

*Data sourced from Bureau of Meteorology long term climate data sets.

The issue of inconsistency of bearing is documented in the avocado industry SIP in Outcome 2, Industry supply, productivity and sustainability to 'develop improved orchard management practices to increase productivity, yield consistency and fruit quality based on improved knowledge or tree physiology"

There have been a number of prior industry R,D&E investments into alternate and irregular bearing, including a GAP analysis a decade ago to identify appropriate research areas to improve the management of irregular and alternate bearing. Most recently, it was recommended that a Roadmap be developed to guide future irregular and alternate bearing R,D&E investment decisions.

The purpose of this review is to document current scientific understanding of the causal factors and within tree physiology that drives irregular and alternate bearing in avocado, drawing on relevant information from other tree crops. Current and potential management options used in avocado and other tree crops are also discussed. The review will help to provide scientific context for the grower and technical expert co-design of the Australian avocado industry irregular and alternate bearing R,D&E roadmap.

The review undertaken by Whiley (2013) presented detailed accounts of many of the factors affecting irregular and alternate bearing, e.g. the effects of extreme temperatures on pollination and fruit set. This review focusses on areas that were not covered in as much detail in Whiley (2013) or areas that have advanced significantly in the previous decade. For example the interaction between crop load, resource allocation and irregular and alternate bearing. The review by Whiley should be read in conjunction with this one.

Crop load in tree crops and the alternate bearing cycle

The development of crop load in tree crops is a cycle. The cycle includes the initiation of flowers, floral development, fruit set and retention, fruit growth, and then floral initiation and fruiting in the following cropping season. The crop load can affect each of the steps in the above cycle. The crop load can also affect the growth and development of the tree in other ways, including effects on vegetative growth and the storage of resources. Across a broad range of temperate deciduous and subtropical/tropical tree crops there is considerable consistency in growth and fruiting responses to crop load.

Floral initiation

A logical point to begin discussing the crop development cycle is with the initiation of flowers (floral initiation). In most subtropical and tropical tree crops, floral initiation occurs in response to a cool temperature stimulus (Wilkie *et al.*, 2008). For avocado, Chaikiattiyos *et al.* (1994) reported that flowering occurred at 23°C/18°C (day/night temperatures), with more flowering at 15°C/10°C and no flowering at 25°C/20°C or greater temperatures, at which only vegetative growth occurred. Cool temperature induction of flowering with critical temperatures in the range of 15°C – 20°C (Wilkie *et al.*, 2008) has also been reported for a range of other subtropical and tropical tree crops including macadamia (Nakata, 1976), lychee (Menzel and Simpson 1995) and mango (Whiley *et al.*, 1989).

In contrast, the temperate deciduous tree crop apple initiates flowers autonomously once the dormant vegetative bud of the current season's growth has produced a 'critical node number' (Bertelsen *et al.*, 2002; McCartney *et al.*, 2001). Environmental conditions affect the extent of floral initiation in apple, for example reduced flowering at low light intensity in shaded portions of the canopy (Cain, 1971), however environmental cues do not appear to provide a floral stimulus (Wilkie *et al.*, 2008).

The timing of floral initiation is also an important consideration. For subtropical and tropical tree crops, floral initiation tends to occur during late autumn or winter in the presence of the above mentioned cool inductive temperatures. For example, for avocado key flowering genes were reported to increase expression during late autumn and early winter, providing very strong evidence for this being the timing of floral initiation (Ziv *et al.*, 2014). Mango is similar to avocado, with the expression of flowering genes increasing with the onset of cool temperatures during early winter (Nakagawa *et al.*, 2012).

The flowering intensity within a tree can vary in a number of ways. First, the proportion of buds capable of flowering may vary. Second, differences in the amount or density of shoots and buds capable of flowering within the canopy. Third, the size and complexity of the inflorescence can vary.

Crop load in the current cropping season

Final yield is often related to the magnitude of flowering (flowering density/flowering intensity/'heaviness' of flowering), although the relationship tends to vary a bit with tree crops. Work undertaken on 'Hass' in Central Queensland, indicated that fruit yield increased linearly as inflorescence density increases from very low levels. As inflorescence density increased to high levels, the authors were unsure whether fruit yield continued to increase linearly with inflorescence density or whether fruit yield began to plateau at the higher levels of inflorescence density (Hofman *et al.*, 2018). For tropical mango and temperate deciduous almond, yield also increased linearly as inflorescence density increased from low levels, but fruit yield plateaued at moderate inflorescence densities with no further increase in yield as inflorescence densities reached very high levels (Orr *et al.*, 2023; Dicenta *et al.*, 2006). For all of the situations mentioned above, low inflorescence density had the potential to limit yield. For mango, almond and probably avocado it appears that once inflorescence density reaches a critical level and the yield plateaus, carbohydrate supply then limits further increases in yield.

Fruit set and retention are also affected by flower density. Work on 'Hass' in Central Queensland created a wide range of inflorescence densities by removing between 0% and 95% of inflorescences from whole trees. The trees with the lowest inflorescence densities set and retained approximately

five times more fruit per inflorescence than the trees with the greatest inflorescence densities (Hofman *et al.*, 2018). Similarly, for 'Hass' in California, heavy flowering 'on crop' trees dropped many more flowers and small developing fruit than low flowering 'off crop trees' (Garner and Lovatt, 2008). The temperate deciduous crop apple is similar, with trees that had their floral bud density reduced to four floral buds per cm^2 of branch cross-sectional area (BCA) retaining 3.8 fruit per BCA compared with the control treatment with 13.3 floral buds per BCA retaining only 1.8 fruit per BCA (Breen *et al.*, 2015). This effect of flower density on fruit set and retention has generally been attributed to competition between setting flowers and young fruit for resources such as carbohydrates. That is, when there are fewer flowers and young fruit competing for limited resources, more of them are able to be retained and develop to maturity.

Final fruit size is also affected by crop load. In the work of Hofman *et al* (2018) undertaken in Bundaberg, the extreme inflorescence thinning and resultant low crop loads of less than one kg fruit per m^3 canopy volume had a mean fruit weight of ca. 340 grams. Where there was little or no inflorescence thinning and crop loads of greater than 10 fruit per m^3 canopy volume, the mean fruit weight was significantly smaller at ca. 250 grams. The effect of crop load on final fruit size is common in diverse tree crops, including mango (Orr *et al.*, 2023), apple (Palmer, 1992), and macadamia (Wilkie, 2010). The effect is consistent with competition between fruit for limited carbohydrates, leading to smaller individual fruit size.

The work above demonstrates that there is plasticity in the avocado crop load development cycle, due to compensation mechanisms. For example, when inflorescence density is low, fruit set per inflorescence can be high, due to greater resource availability for each fruit.

Crop load and vegetative growth

Crop load and shoot growth interact in several ways. There is evidence that heavy crop loads reduce the amount of vegetative growth occurring during the cropping season (Hofman *et al.*, 2018; Ziv *et al.*, 2014). A similar effect is observed across a broad range of subtropical and temperate tree crops (Wilkie, 2010; Berman and Dejong, 2003; Palmer *et al.*, 1992). There is also evidence that strong vegetative growth can reduce fruit set and retention during the spring growth flush (Hofman *et al.*, 2018; Wolstenholme *et al.*, 1990). These ideas will be discussed in the 'Resource allocation within the tree' section, below.

Return cropping and the alternate bearing cycle

The effects of crop load are not confined to one cropping season. In certain situations, the crop load from one cropping season may affect the cropping in the subsequent season. Of course, we are most familiar with this concept as the alternate bearing phenomenon where a heavy 'on' cropping season is followed by a light 'off' cropping season, which continues as a cycle of 'on' and 'off' cropping years. This alternate bearing phenomenon occurs in many tree crops (Monselise and Goldschmidt, 1982).

Alternate bearing is considered to be a significant commercial issue in certain production regions, including New Zealand (Dixon *et al.*, 2008) and California (Garner and Lovatt, 2008). Micklebart (2007) reported extreme variation in yield between 'on' and 'off' years in a rootstock trial in California, with 'off' years having an average of c.a. 55% to 90% less yield than 'on' years, depending on the rootstock. Similarly for New Zealand, with yield declines in 'off' years capable of reaching 90% or more compared with 'on' years. It is also worthwhile noting that Scholefield *et al.* (1985) reported extreme variation

in the cropping of 'Fuerte' in Southern Australia with 'off' cropping years producing 74% and 98% less fruit than the preceding 'on' cropping year.

A considerable part of the effect in avocado trees appears to be the high crop load suppressing flowering for the following crop, thereby reducing yield. Heavy crop loads also reduce return flowering in tree crops such as apple (Fulford, 1966b), citrus (Moss, 1971) and macadamia (Wilkie, 2010). The heavy crop load has been reported to reduce avocado return flowering in a number of ways.

First, heavy avocado crop loads can reduce shoot growth and available flowering sites for the follow-on flowering. The overall effect of heavy crop load reducing vegetative growth over the cropping season has been well demonstrated (Ziv *et al.*, 2014; Hofman, 2018). In California, heavy crop loads have been shown to have little to no effect on the number of terminal shoots (vegetative growth flushes that have an apical bud that can either produce another vegetative shoot or an inflorescence) produced by the spring flush (Salazar-Garcia *et al.*, 1998; Lovatt, 2010). However, these heavy crop loads have been shown to reduce the number of terminal shoots produced by summer and autumn growth flushes, with spring growth flushes arising from indeterminate inflorescences that retained fruit unlikely to produce summer and autumn vegetative growth (Salazar-Garcia *et al.*, 1998; Lovatt, 2010). The reduction in summer terminal shoots can have a significant effect on flowering in the spring because most inflorescences are borne on the summer grown terminals in the Californian environment (Lovat, 2010). In some locations, heavy 'on' crop flowering has also been reported to have high proportions of determinate inflorescences (Dixon, 2007), a situation likely to contribute to low regeneration of flowering sites for the following crop.

Second, heavy crop loads can reduce the proportion of terminal shoots that produce inflorescences. In a trial in California, 13% of terminal shoots produced inflorescences and 72% of terminal shoots produced vegetative shoots following an 'on' crop, compared with 46% of terminal shoots producing inflorescences and 38% of terminal shoots producing vegetative shoots following an 'off' crop (Salazar-Garcia *et al.*, 1998). In Israel, 25% to 100% of buds along terminal shoots produced inflorescences in trees that were de-fruited early in the summer before flowering, compared with 0% of the buds on assessed terminal shoots producing inflorescences in heavily cropping trees (Ziv *et al.*, 2014).

Third, the timing of harvest, or removal of the crop load, affects return flowering and yield. In warm, subtropical Central Queensland, 'Hass' harvested in late winter/early spring at 35% dry matter developed an alternate bearing pattern across a four-year trial, whereas harvesting in late autumn at 24% dry matter led to more consistent bearing (Whiley *et al.*, 1996). The same trial was repeated at the cool subtropical location of Maleny in southern Queensland where harvesting at 24% dry matter occurred between late-June and mid-July and harvesting at 35% dry matter occurred in November. The trees at the Maleny site exhibited strong alternate bearing across the three years of the trial and the earlier harvesting at 25% dry matter had no effect on the extent of the alternate bearing. In Israel, trees carrying a heavy 'on' crop where fruit were removed monthly between July and November had significantly better flowering in treatments where fruit was removed between July and September compared with October and November or at the commercial harvesting time in the following February (Ziv *et al.*, 2014). Commercial harvesting of 'Hass' can commence in Israel during November (Amnon Haberman, pers. Comm.) and so in Israel, harvesting as soon as fruit reach minimum commercial maturity may not be early enough to prevent inhibition of flowering and alternate bearing, similar to the cooler trial site reported above in Whiley *et al*. (1996).

The effect of the time of harvest on return flowering is related to the presence of fruit on the tree at the time that flowers are initiated (or a period of time before flowers are initiated). Cool temperatures provide the environmental stimulus for floral induction in avocado (Chaikiattiyos *et al.*, 1994; Acosta-

Rangel *et al.*, 2021) with some flowering at 23°C/18°C (day/night temperatures), more flowering at 15°C/10°C and no flowering at 25°C/20°C (Chaikiattiyos *et al.*, 1994). Expression in the leaves and buds of flowering genes has been reported to coincide with the onset of these temperatures during late autumn and winter (Ziv *et al.*, 2014; Ahsan *et al.*, 2023) and Acosta-Rangel *et al.* (2021) reported that flowering genes were only expressed in the experimental treatments where potted trees were placed in cool temperature conditions. The presence of a heavy 'on' crop over late autumn and early winter inhibited the expression of these key flowering genes in the leaves and buds compared with trees in which fruit had been removed (Ziv *et al.*, 2014). Thus, explaining the results of Whiley *et al.* (1996) where harvesting at 24 % dry matter in early May in Central Queensland did not lead to alternation of bearing, whereas harvesting at 35% dry matter in late winter/early spring in Central Queensland and from late June onwards in Maleny did lead to alternate bearing.

Ziv *et al*. (2014) speculated that this inhibition of flowering gene expression in the presence of high fruit loads may have been due to reduced availability of carbohydrates or the export of hormone signals from the fruit. The authors noted that sugar signalling has been implicated in the regulation of floral initiation and flowering time in Arabidopsis (King *et al.*, 2008; Wahl *et al*., 2013) and that avocado fruit are a strong sink for carbohydrates. For example, Scholefield *et al.*, (1985) noted that heavy 'on' crops in 'Fuerte' were correlated with very low trunk starch levels and subsequent severe 'off' crops in southern Australia. Additionally, trunk starch concentrations in 'Hass' in July in Central Queensland and Maleny were positively correlated with avocado yield in the following year (Whiley et al., 1996). In terms of the potential effect of hormone signals exported from the fruit inhibiting flowering, it has been demonstrated that applications of the hormone gibberellin can inhibit floral initiation in avocado (Salazar-Garcia and Lovatt, 1998). It has been postulated, but never demonstrated, that export of gibberellin from avocado seeds may inhibit floral initiation in avocado under heavy fruit loads. However, in 'Irwin' mango, heavy fruit loads and gibberellin applications reduced flowering gene expression and affected the expression of gibberellin metabolism genes, providing strong evidence for the involvement of gibberellin in the inhibition of flowering with heavy fruit loads (Nakagawa *et al.*, 2012). In Arabidopsis, Goetz *et al*. (2021) demonstrated that fruit load led to the termination of flowering due to high transport of auxin from the fruit inhibiting auxin transport from the terminal bud and changes in sugar signalling and metabolism. The work of Goetz *et al*. (2021) illustrates the possibility that carbohydrates and hormones may act together in the high fruit load inhibition of flowering.

Recent work in Western Australia modified crop load by thinning 'Hass' avocado to one, two or three fruit per inflorescence after fruit set (McCauley, 2024) and repeated this over the four years of the trial. Fruit of each crop were harvested in December or January (approx. 14 months after flowering), well after the time when the fruit load would have inhibited flowering (see above). Thinning to one fruit per inflorescence reduced alternation in crop load between years compared with thinning to two or three fruit per inflorescence or the un-thinned control. This indicates that the size of the crop load as well as the time that it is removed can affect return flowering and cropping in avocado.

Therefore, in terms of return cropping, heavy crop loads can reduce return flowering by reducing the number of terminal shoots available for flowering or reduce the percentage of shoots that produce inflorescences. The time when the crop load is removed from the tree also affects the return flowering, with earlier removal reducing inhibitory effects on flowering. There is minimal understanding of the size of the crop load required to inhibit flowering or sustainable levels of crop loading that allow regular bearing. This contrasts with apple where considerable effort has been made to understand crop loads in terms of fruit/cm^2 of trunk cross sectional area or fruit/cm^2 of branch cross-sectional area that lead to regular cropping of desirable sized fruit. Most of the literature on

avocado alternate bearing has referred to crop load qualitatively, i.e. the effect of an 'on' or an 'off' crop on the return crop. Avocado experimentation and literature moving to quantitative descriptions of crop load would be useful in developing these rules of thumb for sustainable cropping levels.

Resource allocation within the tree

What is allocation?

For any given orchard, fruit yield is a function of the energy available within the tree across the cropping season and the proportion of that energy that is partitioned to the fruit. To increase fruit yield we can attempt to increase energy availability (current or stored energy) or we can increase the proportion of the energy that is partitioned to fruit. For the purposes of understanding irregular and alternate bearing, we will focus our discussion on the factors affecting the proportion of energy that is partitioned to fruit.

Carbohydrates move from plant organs called 'sources', that are net producers of photosynthates, to organs called 'sinks' that are using carbohydrates for growth, storage or respiration. Avocado leaves can be either sinks or sources, depending on their stage of development. During the early stages of growth, avocado leaves are sinks because they are importing carbohydrates for growth, but are net exporters of carbohydrates (sources) by the time they reach approximately 35% of their final length (Finazzo *et al.*, 1994).

As an evergreen, avocado trees do not undergo winter dormancy, they grow and develop through all months of the year. Throughout the winter, the supply of carbohydrates is generally greater than the demand from growing sinks and the tree is usually able to re-build carbohydrate reserves, at least to some extent, prior to flowering and fruit set (Liu *et al.*, 1999). Several authors have reported that carbohydrate reserves peak during early spring and then begin to decline with the demands from spring shoot growth, flowering and fruit development of the new crop (Liu *et al.*, 1999; Scholefield *et al.*, 1985; Davie *et al.*, 1995). During such periods, it is possible that the demand for carbohydrates by the growing flowers, fruit and shoots (sinks) may be greater than the supply of carbohydrates from current photosynthesis and from reserves. Without sufficient resources for the maximum growth of all of the growing organs, the organs compete for the resources that are available.

The concept of 'sink strength' has been used to describe the competitive ability of an organ to gain carbon assimilates (Marcelis, 1996). There is a significant body of work that points to 'sink strength' being related to the potential growth rate of the organ (Marcelis, 1996). That is, the growth rate of that organ at that stage of development in a situation where carbohydrates are unlimited. So, in situations where carbon assimilates are limited, each competing organ will receive a share of the available assimilates relative to their potential growth rate. The growth rate of fruit and shoots in many species, including avocado is sigmoidal (Garner and Lovatt, 2008; Wang *et al.*, 2018); meaning a slow growth rate early in development, followed by rapid growth and then a slow growth rate toward the end of the organs growth phase. For avocado, the practical outcome of this theory of sink strength is that an avocado fruit that has entered its rapid growth phase should be more likely to gain more assimilates than a recently set fruit that is still in its early slow growth rate phase. Or shoots in their rapid growth rate phase should out compete recently set fruit for assimilates (discussed further below). As far as we can tell, these concepts of 'sink strength' have not been properly tested for avocado.

These 'sink strength' hypotheses have been well tested in macadamia. Vegetative re-growth has been shown to out compete setting macadamia fruit following tip-pruning at anthesis and lead to very high

rates of fruit abscission compared with unpruned control trees or trees that were tip-pruned but the re-growth was removed frequently (McFadyen *et al.*, 2011). Subsequent work then tested the effect of the timing of fruit and shoot growth relative to each other to determine if the organs growth rate affected its ability to compete for resources (i.e. affected its sink strength). The work demonstrated that if trees were pruned at a time that led to the rapid shoot growth phase to coincide with early fruit set (low fruit growth rate), the shoots out competed the fruit, leading to high rates of fruit abscission. However, if the trees were pruned at a time that led to the rapid fruit growth phase to coincide with the early shoot growth phase (low fruit growth rate), then the fruit out competed the shoots, leading to fruit retention similar to unpruned control trees and short shoots (Toegel *et al.*, 2021). This demonstrates that, depending on the relative timing of growth, fruit have the potential to out compete shoots or shoots have the ability to out compete fruit. The work above has led to mechanical hedging being recommended to be undertaken in November or December, when fruit are growing rapidly.

Fruit set and the path to abscission

The development and maintenance of fruit load has a significant influence on the allocation of resources within the tree. The transition of an ovary to a fruit and the commencement of fruit growth, termed fruit set, relies on successful pollination and fertilisation leading to cell division and expansion (Ezura *et al.*, 2023).

Initial fruit set and growth of small fruitlets can be affected by a range of factors. The availability of carbohydrate assimilates appears to be an important factor in early fruit set, given that accumulation of starch in the pistil of the avocado flower is variable and correlated with fruit set (Alcaraz *et al.*, 2013). Additionally, it is quite clear that competition between fruit and shoots affects fruit set (discussed below). Successful pollination and fertilisation is also a strong driver of early fruit set (Garner and Lovatt, 2016) with environmental factors such as temperature and humidity at times having a strong influence (reviewed by Whiley, 2013).

A model for avocado fruit abscission has recently been developed (Haberman *et al.*, unpublished-*a*; Haberman *et al.*, unpublished-*b*; Smith, 2024). A range of previous work identified avocado fruit that abscise, tend to be smaller than fruit that are retained on the tree (Garner and Lovatt, 2016; Hofman *et al*., 2021; Dixon *et al*., 2006). The recent work demonstrated that the growth rate of fruit that are on the path to abscising declines and then fruit growth totally ceases. The authors demonstrated that the reduced fruit growth rate was correlated with limited supply of assimilates. This cessation of growth leads to the death of the seed coat, which is an important component of the fruit as it facilitates uptake of assimilates and nutrients. The death of the seed coat then allows the fruit to progress to its programmed maturation phase of development, a prerequisite for the fruit to be competent to abscise (from Habermann *et al.*, unpublished-*b*: Kumar *et al.*, 2014; Fenn and Giovanni, 2021). The authors of the new model for avocado fruit abscission found that the seed coats of avocado fruit that were growing at a normal rate had significantly greater auxin levels than fruit at the same developmental stage that had ceased growth, indicating that the seed coat is a major source of auxin biosynthesis and that the death of the seed coat reduces auxin production and potential export from the seed. It thus appears that avocado fruitlet abscission is regulated by an interplay between carbohydrate availability and auxin production and transport.

It is worth noting that seed coat browning is not necessarily observed in abscised avocado fruitlets that fall during the initial and early fruit set periods (Garner and Lovatt, 2016). This may indicate that

there are different pathways to abscission during early fruit set and later on in the avocado development phase (Harley Smith pers. Comm.).

Competition between fruit and other organs within the avocado tree

There is ample evidence that avocado fruit compete for resources for growth within the tree, with two of the most important sources of competition being other fruit and shoots.

The effect of competition between fruit presents itself in two main ways. First, as described above, under high inflorescence density and initial fruit load, the fruit will be smaller at maturity (Hofman *et al.*, 2018). Second, the percentage of flowers set and retained as fruit is lower under high crop load conditions, as described above (Hofman *et al*., 2018; Garner and Lovatt, 2008). Given smaller fruit at maturity and a similar period of development, the growth rate of the fruit is presumably lower under high fruit load conditions, although this has not been explicitly demonstrated.

The effects of flower density on fruit set and retention are further complicated when avocados are grown in cooler climates when fruit maturity occurs after the time of flowering of the subsequent crop, thereby leading to a crop of fruit nearing maturity and a crop of setting fruit on the tree at the same time. The setting fruit will be competing between themselves for carbohydrates for growth, as described above. The setting fruit will also be competing with the fruit nearing maturity for carbohydrates. This explanation is consistent with alternate bearing 'Hass' in The Bay of Plenty, New Zealand, where fruit set from an 'off' year flowering resulted in less fruit set per inflorescence than the 'on' year flowering (Dixon et al., 2007). As far as I know, these ideas have not been thoroughly tested.

Understanding of the effects of competition between shoot and fruit growth has been investigated from a range of perspectives. First, the behaviour of indeterminate compared with determinate inflorescences provide some insight. The indeterminate inflorescence shoot consists of a series of lateral inflorescences towards the base of the unit of growth (basipetal end) and leaves at the end (apical) of the growth unit. Determinate inflorescence axes also consist of a series of lateral inflorescences, but have no leafy portion of the unit of growth. Both types of inflorescences commence elongation during late winter or early spring, with the lateral inflorescences emerging first, followed by the leafy portion of the inflorescences (for indeterminate inflorescences only). Determinate inflorescences have been reported to set and retain more fruit per inflorescence than indeterminate inflorescences, presumably due to the lack of local competition for carbohydrates between developing fruit and shoots (Hofman *et al*., 2021; Salazar-Garcia and Lovatt, 1998; Alcaraz and Hormaza, 2014). It is also possible that the different conditions that led to the development of either an indeterminate or determinate inflorescence may also impact other developmental processes such as fruit set and retention.

Second, removing the vegetative spring flush from the indeterminate inflorescence can improve fruit size and fruit set. For example, total or partial removal of spring shoots arising from indeterminate inflorescences improved fruit set compared with unpruned control treatments at the end of spring in trials in subtropical Central Queensland and South Africa (Cutting and Bower, 1990; Hofman *et al.*, 2018). Interestingly, in both trials the increased initial fruit set was negated by greater fruit drop over the summer. In macadamia, tip-pruning the shoots on the canopy periphery at full bloom to induce vegetative re-growth led to significantly reduced fruit set compared with the un-pruned control and a treatment that was also tip-pruned but that had the re-growth removed each week so that competition between fruit and shoot growth was minimised (McFadyen *et al.*, 2011).

Third, reducing the growth rate of the indeterminate spring shoot can improve fruit size and fruit set. Paclobutrazol, a gibberellin biosynthesis inhibiting plant growth regulator, when sprayed on whole trees in Central Queensland was found at a branch level to reduce shoot length and dry weight, increase total fruit weight and had no effect on total branch dry weight at the end of spring (Wolstenholme *et al*., 1990). However, the paclobutrazol applications had no effect on final yield, presumably due to greater fruit drop over the summer.

Fourth, reduced vegetative growth and changes in partitioning of resources has also been reported to be affected by rootstock. A long-term systems trial in Central Queensland reported that 'Hass' had significantly greater yield per hectare and yield efficiency (kg fruit/m^3 canopy volume) when planted on 'Ashdot' rootstock compared with 'Velvick'. The 'Hass' on 'Ashdot also had larger fruit size, smaller canopies, shorter shoots and greater proportions of determinate inflorescences than the 'Hass' on 'Velvick', suggesting that 'Ashdot' is allowing greater partitioning of assimilates to fruiting (Hofman *et al.*, 2021). One of the observed benefits of low vigour apple rootstocks on productivity is the increased partitioning of resources to flowering and fruiting, compared with vegetative growth (Robinson and Lakso, 1991).

Finally, experiments where crop load is modified also affect vegetative growth. In work undertaken in Israel, trees in which fruit was removed from the tree early in the summer had greater shoot growth than trees in which fruit was removed late in the summer (Ziv *et al.*, 2014), indicating that carbohydrates that would have been allocated to fruit were made available for vegetative growth earlier, resulting in greater total growth. Additionally, when inflorescences were removed from 'Hass' to create trees with varying inflorescence densities, shoot length and canopy volume was greater in trees where the inflorescence density and subsequent crop load were significantly reduced than for trees that continued to carry a heavy crop load (Hofman *et al.*, 2018). The effect was so extreme that for trees with a yield efficiency of less than one kg/m^3, canopy volume at harvest was almost 50 m^3/tree compared with 30 m^3/tree for trees with a yield efficiency of 10 kg/m^3.

There are a range of reports on competition between vegetative growth and initial fruit set, as described above. Fruit drop that occurs later, termed 'summer fruit drop' in subtropical locations can also have a significant effect on yield, with 30% to 50% of fruit remaining at the end of spring abscising over summer in Central Queensland (Hofman *et al.*, 2018; Hofman *et al.*, 2021). As far as we are aware, there are no reports that demonstrate the heavy summer fruit drop is induced by competition for resources with vegetative growth, although this remains a strong possibility.

The role of reserve carbohydrates

Non structural carbohydrates, such as starch and sugars, can be stored and remobilised in trees to satisfy demand for assimilates not met by the supply from current photosynthesis. In avocado, non-structural carbohydrates are stored in leaves, branches, trunk, and roots of the tree (Liu *et al.*, 1999). Interestingly, the seven carbon sugars mannoheptulose and perseitol have been reported to be the dominant sugars found in tissues measured for storage carbohydrates (Liu *et al.*, 1999).

The levels of storage carbohydrates in avocado appear to be affected by crop load. For example, in a subtropical southern hemisphere environment in South Africa, starch reserves in 'Hass' and 'Fuerte' after harvest were reported to be lower following a heavy 'on' crop than an 'off' crop (Davie *et al.*, 1995). Additionally, the starch reserves in the trees where the 'off' crop had been removed in late autumn had increased to greater levels by mid-winter than those that had carried an 'on' crop. A similar effect was reported for 'Fuerte in temperate southern Australia (Scholefield *et al*., 1985).

Whiley *et al*. (1996*a*) reported that for 'Hass' in Central Queensland, harvesting at lower dry matter (autumn harvest) led to an earlier increase in shoot starch concentration than when harvesting at higher dry matter (winter harvest) and the peak shoot starch concentration was greater in earlier harvested trees. Therefore, it appears that high crop loads draw down carbohydrate reserves to a greater extent than low crop loads over the fruit development period, and late harvesting delays the recovery in stored carbohydrate levels.

There is also evidence that stored carbohydrate levels during autumn and winter can affect the development of crop load for the subsequent crop. The work of Whiley *et al*. (1996*b*) probably provides the most compelling evidence for this, with yield being linearly correlated with shoot starch concentrations in the previous July for 'Hass' grown in Central Queensland and at Maleny in Southern Queensland (higher altitude subtropical conditions). The authors reported that at least part of the effect on yield was due to differences in flowering intensity, which was visually observed but not recorded. Other evidence for the effect of stored carbohydrate levels during autumn and winter on subsequent crops comes from multi-year data sets of yield and stored carbohydrate levels (Scholefield *et al.*, 1985; Whiley *et al.*, 1996*a*; Whiley *et al.*, 1996*b*). For 'Fuerte' in Southern Australia in a severe alternate bearing cycle, trunk starch concentrations were higher in the winters preceding the 'on' crops than in the winter preceding the 'off' crop (Scholefield *et al*., 1985). It is unclear whether the poor yields reported in the study were due to poor flowering or poor fruit set and retention. The conclusions that can be drawn from these multi-year observational data sets tend to be relatively weak because there is always uncertainty around what additional factors may be leading to the observed differences from year to year. Whiley *et al.* (1996a) noted for 'Fuerte' grown in Southern Australia, starch levels of up to 18% in the trunk were recorded (Scholefied *et al.*, 1985), while in subtropical Southern and Central Queensland the maximum levels recorded for 'Fuerte' were approximately 8%. He also observed that in Southern Australia, leaf area during late winter and early spring can be limited until the spring flush has expanded, due to high levels of leaf loss during winter. He concluded that taken together, these observations may indicate that stored carbohydrates play a greater role in crop load development in temperate compared with subtropical growing regions (Whiley, 2013; Whiley et al., 1996*a*).

There is sufficient evidence above to indicate that storage carbohydrates play a role in the development of crop load in avocado. The extent of this role in different growing regions and for different cultivars is unclear. It is also unclear whether levels of storage carbohydrates affect flowering intensity, fruit set and retention, or both. More detailed studies to quantify the interactions between crop load and stored carbohydrates are warranted.

New work on pollination and fertilisation

The review by Whiley (2013) covered the areas of pollination and fertilisation in detail. However, there have been some relevant recent publications in these areas.

Whiley (2013) speculated that investigating the appropriate use of pollenisor trees in avocado orchards in southern Australia was a significant opportunity to improve pollination, fertilisation and regularity of bearing. This is because the cooler temperatures present through significant portions of the flowering period in southern Australia, minimise the chances for self-pollination. Recent work at Childers in Central QLD, reported that yield of 'Hass' trees located 160 m from the closest 'Shepard' trees were 42 to 44% lower than trees located 20 m to 40 m from the Shepard pollenisers (Trueman *et al.*, 2024). The number of self-pollinated fruit per tree did not differ with distance from the pollenisor trees, but the number of cross-pollinated fruit per tree in trees located 160 m from the

pollenisers declined by 69% compared with the trees 20 m and 40 m from the 'Shepard' pollenisers. A related study, also in Central Queensland, found that cross-pollinated fruit were selectively retained by the tree at the expense of self-pollinated fruit. The cross-pollinated fruit were also larger than the self-pollinated fruit, indicating that the cross-pollinated fruit have greater potential to compete for resources than self-pollinated fruit (Hapuarachchi *et al.*, 2024). These studies indicate the potential for improved yield by planting Type-B polleniser trees close to 'Hass' trees, even in subtropical Central Queensland.

Synthesis

In this review so far, we have focussed on reviewing new information (previous 10 years) and issues that were not dealt with in-depth in the Whiley (2013) review. This has led to a focus on crop load and resource allocation within the tree. Issues such as the effects of extreme temperature or humidity on fruit set, most of the issues related to agronomy and pest and disease issues were reviewed by Whiley (2013) and so that review should be read in conjunction with this one, to gain an appreciation of the wide ranging issues related to avocado irregular and alternate bearing.

One of the challenging issues about irregular and alternate bearing in avocado is that there are a wide range of factors that can affect yield stability, and there are differing opinions about what should be included in the irregular bearing discussion. One method to cut through the confusion is to discuss direct effects on critical components of crop load development, which, this review and discussions with scientists and industry participants have led us to identify as: flowering, fruit set, fruit retention and shoot growth.

Below, we separate out and summarise these issues. We also indicate any confirmed or potential issues around growing region and our current thoughts around research gaps.

Factors affecting flowering

1. High fruit load:
    a. Effect on vegetative growth – heavy fruit load can suppress vegetative growth. In temperate environments, the suppression of the summer flush can be to such an extent that return flowering can be reduced and contribute to reduced return yield.
    b. Effect on percentage of terminals flowering – heavy fruit load in locations where the harvest occurs after the time of floral initiation can lead to inhibition of flowering that is expressed as a reduced percentage of terminal buds producing an inflorescence. There is little to no information on the crop load (yield efficiency or fruit density) that leads to this inhibition of flowering. This high fruit load inhibition of flowering occurs more often in cooler growing regions where fruit development takes longer and harvest is later.

Factors affecting fruit set

2. Pollination:
    a. Insufficient pollinators – In Australia avocado flowers are pollinated by bees and other insect pollinators. Exclusion of insects from inflorescences has been shown to almost entirely inhibit fruit set. A range of studies on pollinators for avocado have been conducted in subtropical Australia but work in this area appears to be more limited in southern Australia.

b. Insufficient pollenisers – The avocado's floral behaviour (protogynous dichogamy) promotes cross-pollination by transfer of pollen between flowering group 'A' and 'B' cultivars. Whiley (2013) reviewed evidence that indicated that the closeness to polliniser trees affected fruit set in cooler production regions while there was questionable benefit in subtropical or tropical growing regions. Whiley (2013) stated that the introduction of polleniser varieties into avocado orchards in southern Australia is likely to be the single most important step in reducing irregular bearing for 'Hass'. Recent studies have shown that there may also be significant benefits of polleniser cultivars in subtropical areas. There is scope for additional research to refine the recommendations for the frequency of pollenisers.
c. Temperature - Low temperatures (10 to 12 ^{o}C) during flowering lead to changes in the pattern of male and female flower openings and can lead to a lack of opportunity for pollination events. These effects appear to be relatively well understood.

3. Fertilisation:
    a. Temperature – Exposure of pollen to high temperatures decreases pollen tube germination and pollen tube growth, reducing fertilisation. The phenomenon explains lack of fertilisation and fruit set in some situations, but it is unclear if additional research in this area would improve productivity.
    b. Boron – The effect of Boron deficiency on fertilisation of avocado has been well documented due to an effect on pollen viability. We are unaware of any work demonstrating an effect of Boron on fertilisation over and above that of maintaining Boron within the adequate range.
4. Competition for resources:
    a. Fruit/shoot competition - Competition between shoot growth and fruit growth can lead to reduced fruit set. This is still an issue of practical importance without satisfactory management tools.
    b. Fruit/fruit competition - Heavy inflorescence densities lead to reduced fruit number per inflorescence by fruit maturity, however, it is unclear if fruit to fruit competition from the same crop leads to fruit drop during the fruit set period or later during development (fruit retention). In growing regions where maturing fruit from the previous crop are still on the tree during flowering and early fruit set, it is unclear if a heavy crop of maturing fruit can compete for resources with a setting crop and reduce fruit set.
    c. Nutrition – See below.
5. Extreme high temperatures and low humidity – As discussed in Whiley (2013), avocado evolved in mesic climates and is poorly adapted to environmental extremes. Extreme heat and low humidity conditions during flowering and fruit set periods can lead to desiccation of flower and loss of early set fruit. The phenomenon explains lack of fertilisation and fruit set in some situations, but it is unclear if additional research in this area would improve productivity.

Factors affecting fruit retention

6. Competition for resources – There is evidence that heavy fruit drop over summer is at least partially due to competition for resources. Some of this evidence indicates that the competition is at least partly fruit to fruit competition. The possibility remains that part of this competition is with vegetative growth. Understanding the effect of competition for resources on summer fruit drop would be useful.
7. Water stress – The rapid fruit growth phase is a critical period for irrigation as lack of water stress reduces fruit drop and increases final fruit size (reviewed by Whiley, 2013).

Factors affecting shoot growth

8. High fruit load – The heaviness of fruit load and the time of removal of fruit load affect the amount and timing of vegetative growth. If the growing region is prone to excessive vegetative growth, then reduced growth due to high fruit load can be beneficial. Quantifying crop loads that lead to high and sustainable yields and balanced vegetative growth would be beneficial.
9. Nutrition – There is limited scientific evidence (reviewed by Whiley, 2013) and strong industry experience that rates of nitrogen application can affect shoot growth and indicates that heavy nitrogen applications in tropical growing regions can exacerbate the competition between vegetative growth and fruiting. Whereas in temperate locations, heavy nitrogen applications can increase shoot growth and increase the supply of flowering terminals in the canopy for return flowering following a heavy crop. Solid scientific data on this issue is lacking.

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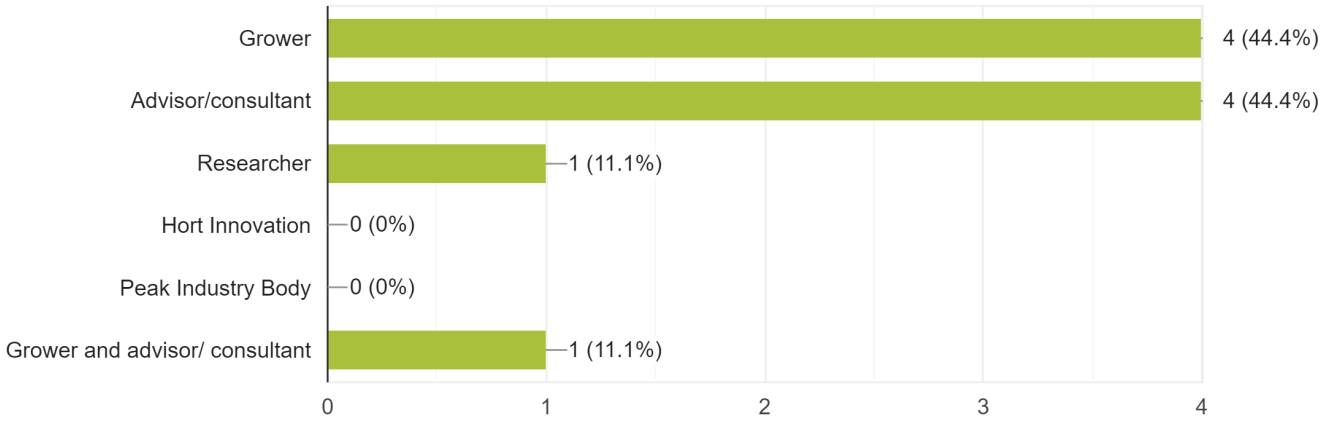
Workshop evaluation summary

Irregular and alternate bearing workshop (AV23014), 7-9 August, State Library of Queensland, Brisbane

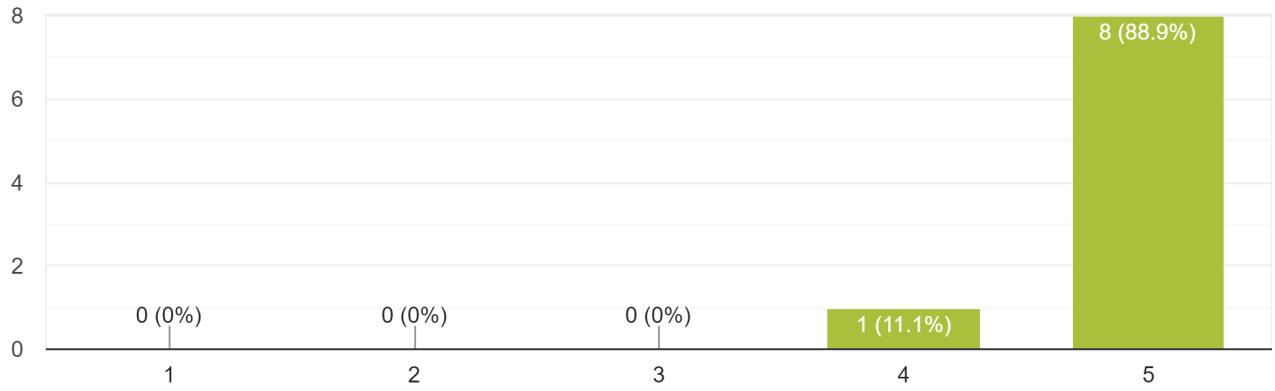
Please select which category you belong to?

9 responses



How useful did you find the technical presentations to support decision making for developing the road map?

9 responses

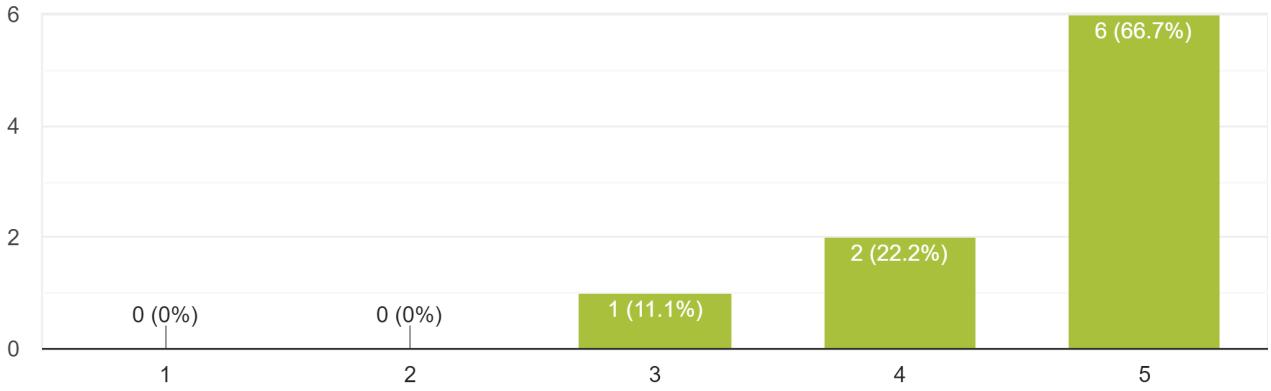


Do you have any comments or feedback on any of these talks?

- Very good selection of topics and speakers (advisor/consultant)
- The presentations provided up to date information with knowledge gaps that helped the road map (researcher)
- I didn't personally find the Apple one useful, the industry has no plan to head in that direction and I think it was a little distracting. The reason they got where they are is because of a dwarfing rootstock, which our Australian avocado industry has no plans of chasing down at all. (grower, advisor/consultant)
- All very helpful and great to hear a range of perspectives and experiences. (grower)
- I think the talks really stimulated discussion and would of interest to many of the more progressive' growers (advisor/consultant)
- Good mix of technical and practical information (grower)

How useful did you find the workshop group activity today?

9 responses



Do you have any comments or feedback on this new activity?

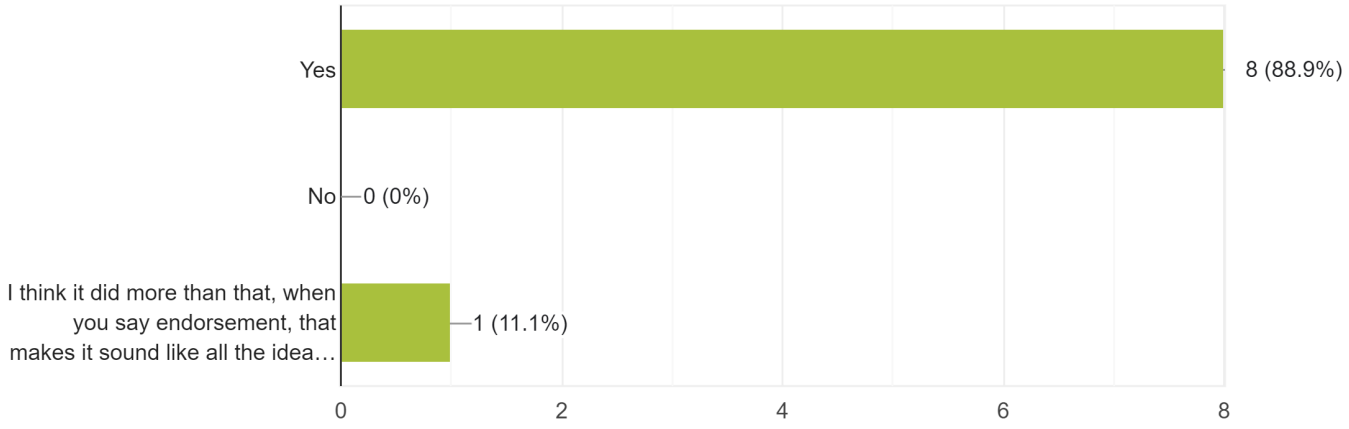
- It was hard but was always going to be. Not sure how the process could be improved. Good call to keep the groups working on the same tables. Theoretically this session needed to be longer. Possibly less time spent on day 1 and 2 by John on getting endorsement from the group on what I felt were semantics could have freed up more time on tackle the 'meaty' issues. (advisor/consultant)
- I really enjoyed the workshop. It's nice to get perspectives of growers, consultants, extension and researchers (researcher)
- When you say workshop activity, you mean the coming together of all ideas? I thought it was absolutely paramount, however everyone did it different- so it could have been improved by some clearer guidelines. I think we got all the ideas down, and from there we had to trust that the ideas and interpretations were

accurate. - but i think by having a good mix of scientists and growers in the room helped achieve that. (grower, advisor/consultant)

- May have been helpful to have a half hour start on this (practice session) the afternoon before. The activity was useful, we just needed to get our game plan together quicker. (grower)
- I think this is a great way to develop project outlines Possibly attendance by a few more Siap members would give a better 'follow through' of the thought process and lead to the development of well thought through evidence based rfps. (advisor/consultant)
- The team did a great job being flexible to get the best outcome. They responded well to how the group activity progressed to get the best outcome rather than sticking with the preplanned structure. It was brought together well so everyone could have input on all aspects of the group activity. (grower)
-

The target outcome of the road map workshop was to seek industry endorsement of approach and framework of the road map (e.g. breakdown by impa... satisfied we have achieved this target outcome?

9 responses



Comment: *I think it did more than that, when you say endorsement, that makes it sound like all the ideas were there and we just had to endorse them. The workshop created the framework, pre filtered all the impact areas and potential R&D and deliverables, so that a road map could be created. (grower, consultant/advisor)*

Do you have any additional feedback or general comments you would like to share with the project team?

- Good selection of participants for what they had to contribute, their representation of industry and how everyone worked positively together. (advisor/consultant)
- It made me wonder if it would be good to have an Australian avocado meetings every two to three years? (researcher)
- This was a complex topic and I felt the organisers tackled it very well (advisor/consultant)
- It was very well organised event, meals, service, rooms were all done well. Great mix of people - could have had some more growers, (grower, advisor/consultant)

- Thank you for planning this workshop well and giving considerable thought about the process beforehand. (grower)
- I thought the workshop was well organised and run Timekeeping was good and the moderators constantly and effectively kept the participants on track to deliver an outcome (advisor/consultant)
- The pre reading was very informative and gave a good background prior to the forum. A difficult topic and I thought it was dealt with well to get an outcome I think everyone was satisfied with. It was good having Philip there from NZ. I think he added great value to a good group. (grower)