Hort Innovation

Final Report

Avocado industry capacity building – Western Australia

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The Department of Primary Industries and Regional Development, Western Australia

Project code:

AV17006

Project:

Avocado industry capacity building – Western Australia (AV17006)

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Funding statement:

This project has been funded by Hort Innovation, using the avocado research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Publishing details:

Published and distributed by: Hort Innovation

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Public summary

Avocados bear fruit inconsistently over time, and Western Australia research capacity for avocados has historically not matched the scale of the WA industry. To resolve those two issues AV17006-Avocado Capacity Building WA was commenced in 2018 to build research capabilities in WA. In addition, the main research goal of the project was to perform fundamental production research into the problem of irregular bearing. Over the five and half years in which the project ran, the western Australia research provider of the project, the Department of Primary Industries and Regional Development (DPIRD), produced extension outputs (articles and posters) and ran regular extension events. More importantly DPIRD participated in multiple fundamental research projects led by other agencies and brought essential research work into WA. Finally, DPIRD ran its own research into the inconsistent bearing typical of Hass avocado and evaluated the potential of early fruit thinning as a management approach for inducing more consistent bearing. As part of the industry development and capability building DPIRD successfully run a series of adoptable discrete experiments including the possibility of harvesting wet fruit, estimation of incidence of fungal inoculum before harvest, an investigation of carbohydrate reserve and distribution after a few years of thinning treatments and improving the usage of the Rubens for the non-destructive determination of fruit dry matter prior to harvest.

Keywords

Irregular bearing, Capacity building, Avocado, Hass, Thinning, Fruit quality, Fungal inoculum, Rubens.

Introduction

The Avocado Capacity Building Western Australia project is a transformational 3-year project by the Department of Primary Industries and Regional Development (DPIRD), with an extension of additional 2 years and 11 months, which aims to build future capacity and contribute to the growth of the avocado industry sector in Western Australia (WA). The Western Australia industry faces unique challenges, including irregular bearing, and post-harvest and production challenges whose representation in other Australian studies has not yet yielded satisfactory WA specific practices.

The project has been implemented to provide the regional avocado industry with a specific local capability to reach a higher or more consistent yield potential and profitability. Achieving more consistent production in the face of irregular or alternate bearing in this project has been done though a trial investigating the use of crop load management. Crop load management was envisaged in the trial as a thinning treatment at fruit set to avoid excess fruit and induce better resource allocation in avocado trees from year to year. In addition to the trial research the project has worked to deliver increased capacity by:

- Communicating to growers all the current research that has been done with regards to best practice avocado production.
- Supporting other avocado research that aims to achieve productivity gains, fruit quality improvements, and better access to future and current export markets.

By achieving a higher and more consistent production, the local industry can grow and take advantage of export opportunities and continue to supply the strong domestic avocado market.

Methodology

AV17006 was developed as a means to build up the capabilities of research work in WA, with the delivery of the capacity building to be done by DPIRD. A major action was the hiring of a junior scientist to specialize in avocado research and to develop them through assisting other national projects with a WA component as well as running specialized research in WA. In addition to assisting to various projects (listed below) DPIRD, through a series of direct interviews and advice from the project reference groups, initiated small trials on compounds to reduce fruit abscission and reduce tree stress as caused by saline irrigation water. Following from this and the disruption caused by Covid-19 the project then focused on a final large trial to investigate the effect of crop load management via deliberate fruit thinning, with an extension of two and a half years to ensure repeatable results. The fruit thinning trial became the largest work of the project overall. In addition to fundamental research DPIRD also developed and updated extension materials for its websites and performed grower directed workshops.

Additional work done by DPIRD exclusively for AV17006 included a fungicide dipping trial to investigate a method for picking wet fruit at harvest, the estimation of incidence of fungal inoculum before harvest, the investigation of carbohydrate reserve and distribution after three years of thinning treatments and work on the finalization of an algorithm for determining dry matter with fluorescence.

Below is the description of the various projects and actions undertaken during the AV17006 project.

Appointment and development of a researcher and increased capabilities of the industry:

DPIRD commenced the project by hiring recent graduate scientist, Declan McCauley, to be based at the Manjimup Horticultural Research Institute in southwest WA, in the heartland of the WA avocado industry. The full time appointment based in Manjimup was considered essential to research in WA, to compete for funding and therefore benefitting WA growers while also being a local contact for other states. In addition, it was considered that assisting with other projects was essential for bringing capability into WA's research and project management abilities of the new scientist as well as better servicing and collecting information for the WA avocado industry.

Below is a list of the project the scientist had direct participation or assisted in, some of which were competitively tendered by DPIRD:

- AV16005-maximising yield and reducing seasonal variation (2018-2020-however project is ongoing)
- AV18000- Avocado supply chain monitoring with work including providing data loggers to packsheds and doing follow ups each season to determine grower and packshed practices (2019-2022).
- AS18000-National Tree Crop Intensification in Horticulture (2020-ongoing).
- APC Funded project: Avocado flowering behaviour related to temperature (2022-2024).
- Participation with the Southwest Catchments Council (Now named South West NRM) eDNA project (Completed 2023).
- AV21005-Avocado Fruit Robustness (2022-ongoing)
- AM21000-Serviced Supply Chain II (2022-ongoing)
- AV22011-Monitoring Avocado Supply Chain Quality 2022-2026

Fruit drop investigations

In January 2019 a trial was run where AVG, Maxcel (a synthetic cytokinin) and glycine betaine (GB-biostimulant or osmolyte) were applied to fruits on defoliated tree to evaluate their possible anti-fruit drop properties. The purpose of the trial was to evaluate products for usefulness with regards to fruit drop and develop skills in managing trials. Glycine betaine was applied at 100mM, AVG at 200 ppm and Maxcel at the label rate to individual fruits in a drenching/'dipping' action in approximately one cup of water. Fruits were then checked for retention at 3-7 day intervals until fruit had stopped abscising. The results of the work were published in WA grower magazine.

Induced Drought

Drought was induced in selected trees for 14 days days in January 2020 and fruit drop was monitored over time. Application of the bio stimulant (or osmolyte) GB and its commercial product were made to selected trees to evaluate effects on reduction of fruit abscission caused by the induced drought.

Stress and saline water investigations

The biostimulant GB was evaluated over 2019/2020 over four sites. The GB trials were performed over two sites in Manjimup with saline irrigation water. GB was being used to evaluate research done in South Africa using GB.

GB was applied in three different treatments; before high temperatures were expected, a standard and a higher rate single applications at fruitset. The applications were made with an electric sprayer to whole trees until run off. Following the applications leaf scorch was evaluated three times and yield was evaluated at harvest. In addition, soil and leaf test were done to measure chloride levels and soil EC meter and tensiometers were used to monitor soil moisture and soil salinity.

Temperatures during the spring flowering period of 2018 and 2019.

After an unexpectedly poor fruit set in Manjimup and Pemberton in 2019 the AV17006 project reference group requested that DPIRD do a desktop study on the prevailing weather conditions in 2018 and 2019 (spring conditions only) to determine if there was a correlation with the poor fruit set.

The analysis was done by counting how many pollination events (a period of three days where temperatures did not go below 10 degrees Celsius) happened in the spring of 2018 and 2019. The number of events was then correlated with minimum, maximum and average temperatures. According to literature the pollination event is considered the best means of identifying good pollination conditions for the avocado.

Fungicide dipping for wet harvesting

The AV17006 project reference group requested DPIRD research the capability of a post-harvest fungicide as a treatment for harvesting wet avocado fruits (after rain or heavy dew). The research was done in late 2021 (September and November) and early 2022 (February). The main question was if a post-harvest fungicide could reduce fruit post-harvest issues caused by wet harvest. The post-harvest fungicide of interest was a product named Graduate A plus and contains Azoxystrobin and Fudioxonil. The post-harvest fungicide was effective at eliminating rots in fruit that were harvested 'wet'.

Research commenced in September 2021 by establishing a repeatable method for wetting fruit (rainfall vs bucket dipping in tap water vs usage of water with plant material in); dipping fruit in a bucket of tap water was identified as replicating a rain event. After this a trial was done in November 2021 (early harvest) with fungicide dipping at different times, 1 hour, 24 hours, and 48 hours of storage at 6 degrees Celsius after 'wet' harvest. Treatments included dry and wet fruit both dipped in fungicide and not dipped in fungicide as control. The trial was replicated with the same conditions later in the season, February 2022 (late harvest), but with fungicide dipping being done after 1 hour, four hours, and six hours of storage at 'room temperature' after the 'wet' harvest. After treatment the fruit were ripened and then assessed once the fruit had ripened to soft ripe stage (below 40 on a Turoni durometer). The fruits were assessed for body rots, bruises, stem end rot and discolouration.

Pre-harvest fungal inoculum evaluation

An experiment was set up to help industry understand the level of inoculum on the fruit prior to harvest to improve fruit quality and consumer satisfaction. The rationale is that if the level of fungal inoculum is known at least 3 weeks prior to harvest, eventual additional fungicide sprays could be delivered to improve fruit quality and robustness.

Fruit were collected in November 2021 (early harvest) and February 2022 (late harvest). They were then ripened at 27 ° Celsius in high humidity level environment (over 90%) to promote the growth of pathogens and then assessed once the fruit had ripened to soft ripe stage (below 40 on a Turoni durometer). The fruits were assessed for body rots, bruises, stem end rot and discolouration.

Finalisation of Algorithm for fluorescence-based determination of avocado dry matter

Rubens technologies Pty Ltd (Melbourne) is an Australian based company which provides and develops sensing technologies for horticulture industries. In 2021 they had a functional fluorescence sensor for measuring sugar and acidity in apples and stone fruit but only an unverified algorithm for measuring avocado harvest parameters (dry matter). From July 2021 to January 2024 DPIRD has worked on verifying the calibration algorithm for the Rubens sensor. The algorithm was verified based on scans with fluorescence devices in research mode compared with oven determined dry matter from the same fruits which were scanned. Calibration scans were deliberately started on fruits with low dry matter and continued until late in the season in order to obtain a large range of comparisons (12% to 42%).

Thinning of fruits for the development of a crop load management methodology for growers.

With AV16005 finding that fruit drop was a necessary part of the avocado fruit growth due to carbohydrate limitation and previous work in AV17006 not showing much benefit from chemicals intended to reduce fruit drop, it was decided that a better approach was to understand overall crop load and the impact of fruit thinning. Irregular bearing is about crop load variability due to large crops in some years and low crops in others, but without a determined pattern. Traditionally fruit thinning has been appropriate for alternate bearing as it skims resources (carbohydrates) off 'on' crops and leaves them available for 'off' crop years. With irregular bearing being associated with ultra large 'on' crops causing years of low 'off' years thinning was still deemed to be beneficial as a control method as it leaves resources for the following year. In addition there is currently no empirically determined target crop load for Hass avocado . Therefore, a thinning trial was implemented to investigate how fruit thinning affects crop load over years and to see if a consistent crop load target could be determined.

A trial was designed and implemented in a Manjimup orchard in November 2020. The trial has run until March 2024 with three complete harvests and three complete thinning applications shortly after fruit set. The thinning treatments applied consisted of three treatments and one control: trees thinned to one fruit per inflorescence, trees thinned to two fruits per inflorescence, and trees thinned to three fruits per inflorescence. Thinning treatments were applied by hand in December 2020, January 2022, and January 2023. Following the treatments tree size, fruit number, fruit diameter and soil and leaf mineral status were monitored until harvest. In addition to the hand measurements electronic monitoring with fruit dendrometers, trunk dendrometers and soil moisture equipment was installed by Supplant.

Carbohydrate analysis of thinning trial trees

In the final year of the thinning trial DPIRD subcontracted the original CSIRO team from AV16005 to analyse samples of stem and inflorescences for carbohydrate (starch and selected sugars) content. Samples were taken before (July) and at flowering (cauliflower stage) and sent in dry ice to Adelaide where the carbohydrates were extracted and analysed. The CSIRO team have prepared a report for AV17006 with full description of methodology and the results (Appendix 46-48).

WA research updates

In 2022 the national Avocado extension project, AV17005, did not plan to have a regional update in WA. Consequently, it was decided to capitalise on the vacuum created and to run a DPIRD led grower update. It was held in June 2022 and was attended by 30 growers, consultants, agronomists and other researchers from as far afield as Queensland.

In 2023 another research update was held but was this time organized by the South West NRM with assistance from DPIRD. This research update was attended by over 70 growers, consultants, agronomist and other researchers.

Results and discussion

Stress, saline water, fruit drop investigations=Appendix 4: Chemicals and Salinity

Fruit drop investigations

Fruit drop could not be stopped or slowed with any of the compounds tested. Either the compounds had little effect or the defoliation treatment was too powerful a driver of fruit abscission. The latter is most likely correct.

Drought

A combination of drought and the osmolyte GB applied to avocado trees showed that GB was probably not able to reduce stress caused by induced drought. Lab grade GB was able to slightly reduce fruit drop but the commercial product was not able to produce the same result, probably due to a lower quantity of active ingredient.

Stress and salinity

Tree stress caused by salinity was too high in both orchards being investigated and was not reduced by the use of GB. Ultimately it was found that the only thing which reduced salinity in the soil, caused by using saline irrigation water, was heavy rainfall. Irrigation flushing did not appear to substantially shift the amount of chloride in the soil either.

Thinning of fruits for the development of a crop load management methodology for growers-Appendix 1 Thinning trial results and Discussion, Appendix 2 Avocado thinning trial detailed methods.

Overall, and despite substantial variability between the trial trees, treatment 1, the thinning treatment which removed the most fruit, caused the most consistent yields from year to year in the trial. The evidence for this is in the average weight of fruit harvested and in the individual fruit weights per tree. Treatment 1 had the fewest trees with an alternate bearing habit and the variability from year to year was one of the lowest amongst the treatments, and much lower than the control. The average weight of harvested fruit was not significantly different from year to year in treatment 1 but was significantly different from year to year in the other treatments and control. While treatment 1 was the most consistent it was still affected by a very large crop in the 2022 season. The removal strategy and targeted fruit load of 1 fruit per inflorescence may have not been enough for that season and left excess fruit on the tree. Alternatively, thinning may have not been required the year previously which would have left more fruit on the tree and reduced the resources available for the 2022 season, resulting in a smaller crop better matched to the productive output of the tree.

While the fruit were thinned to a consistent number per inflorescence the number of inflorescences that bore fruit was highly variable with many not setting any fruit. Therefore, there is no target of how many fruit per defined unit is the number that leads to consistent bearing in avocado orchards. The number of fruit per tree in treatment 1 was an average of 180 fruit per tree, excluding the larger 2022 season which brings the average up to 237 fruit per tree. Assuming a 300 gram fruit and 416 trees per hectare 180 fruit per tree will produce 22 tonnes per hectare. While not reaching the golden and much revered 32 tonnes per hectare suggested for Fuerte by Wolstenholme in 1986, 22 tonnes per hectare still exceeds the national average. The number of fruit per tree has issues in the sense that it does not take into account planting density of the orchard, or the high variability between tree sizes, however it is the easiest definable target number it can reliably identified. The number of fruit per trunk cross sectional area, or canopy volume, or canopy area could be alternatives but they all have issues of inconsistency with tree growth, meaning that the trees keep growing even after having reached full maturity, but the number of fruit per tree should not.

The avocado thinning trial was beset by high variation between trees, most likely due to the use of seedling rootstocks in the trial orchard (a universal practice in WA). A count of fruit numbers on 15 random trees in 2022 revealed a standard deviation of 54.3 on a mean of 125 fruit per tree, or a coefficient of variation (CV) of 43.3%. In the control treatment in particular there was one tree which consistently produced very low numbers of fruit. Likewise in treatment 1 there was another tree which produced less than the other trees. In future the use of clonal rootstocks or a larger replicate number of 15 is essential for future research into fruit thinning.

Carbohydrate analysis of thinning trial trees

There were no differences in carbohydrates as measured on the samples from the thinning trial. The cause of this may be that the differences were too subtle to be detect by the few stem samples collected. Due to the difficulty and time consuming nature of the actual analysis, a compromise needed to be made between the number of stems collected and the representativeness of the whole tree.

Verification of Algorithm for fluorescence-based determination of avocado dry matter

After multiple fruit assessments for oven determined dry matter and associated scans with a prototype fluorescence device Rubens technologies verified the algorithm. The algorithm had an R squared value of 0.9. The latest version of the Rubens it has only recently been tested for its accuracy. So far additional calibration of higher dry matter fruit is required as well as calibration for individual devices.

Fungicide dipping for wet harvesting-Appendix 3: Dipping trial results.

'Wet' harvesting fruit due to rain or heavy dew is acceptable. Our research showed that fruit which are harvested 'wet' can have good post-harvest outcomes assuming they are harvested early in the season (with low fungal inoculum), or are dipped in a post-harvest fungicide less than 24 hours after harvest.

The fruits harvested and trialed in November 2021 (early harvest) were not significantly different between the wet, dry, and fungicide dipped combinations but were different with increasing storage time. The 1 hour treatment had the lowest fruit damage (due to rots) while 24 hours had the next highest followed by the 48 hours treatment. Even cold storage for those later time periods was not able to prevent fungal damage.

The fruit trialed in February (late harvest) were different between wet, dry and fungicide dipped combinations. The fungicide dip reduced rots on dry and wet fruit as compared to the undipped controls. The non-fungicide dipped wet fruits had the worst outcome. There were no differences between fungicide dipping times. Harvesting fruit later in the season caused differences between dipping treatments and worse fruit outcomes in the wet and dry control treatments.

The worse outcome is presumably because more time spent on the tree means that more inoculum can build up.

Our research showed that harvesting wet fruit is possible if fruit are treated with fungicide postharvest and depending on time of harvest in the season. The latest the harvest the shorter the time should be between actual harvest and fungicide treatment.

Pre-harvest fungal inoculum evaluation

Our research proved that the trialed system to speed ripening for the early identification of fungal inoculum in the field was successful. It is suggested that the practice should be adopted regularly by avocado growers. This would allow the grower to identify the level of fungal inoculum at least 3 weeks prior to harvest. Additional fungicide sprays could be delivered to improve fruit quality and robustness if inoculum is too high.

Temperatures during the spring flowering period of 2018 and 2019.

While the temperature study into the 2018 and 2019 spring conditions were started due to low fruit set in 2019, pollination conditions appeared to be better in 2019 than in 2018. There were more pollination events in 2019 than in 2018, over three major avocado growing sites. Possible conclusions from the data are that pollination events are not a good measure of avocado pollination, or that the larger fruit set in 2018 caused a carbohydrate shortage on a regional level in all avocado orchards which resulted in fewer available resources for fruit set in 2019. The crop set in 2018 was 33,239 tonnes, followed by a 13,547 tonne crop set in 2019 Therefore, there is evidence of a bearing habit restricted by a carbohydrate shortage, as opposed to weather conditions causing the low fruit set. An analysis of the weather conditions during 2018 and 2019 was performed and published in the "Talking Avocado" magazine (volume 32, number 3, page 71-74).

Capacity of the Avocado research team in DPIRD's facility in Manjimup.

The research capacity of the Manjimup avocado team has grown with the development of basic extension skills and acquisition of essential research equipment. The team has experience with running growers events, and with reporting articles in industry publications. The team has developed the facilities and equipment at the Manjimup research institute with the addition of a range of tools such as digital calipers, scales, and other measuring tools designed to save time. DPIRD now also has a LI600 machine, a portable -80°C freezer, and a dedicated lab room instead of a shared room. The Manjimup team also has experience with running trials in the field and doing post-harvest evaluations.

Outputs

Table 1. Output summary (All outputs not linked are attached as appendices)

Output	Description	Detail
Industry article x 2	Introduction article on Research Officer – Declan McCauley. Appendix 5.	Published in "WA grower" magazine (Autumn 2019, pages 42-43) and in "Talking Avocados" (Autumn 2019, Volume 30 no 1, April 2019, page 61).
Factsheet	Growing Avocados - The Pegg Wheel	Content for DPIRD website
Factsheet	Avocados in Western Australia – overview	Content for DPIRD website
Factsheet	Avocado industry regulation in Western Australia	Content for DPIRD website
Factsheet	Growing avocados flowering, pollination and fruit set	Content for DPIRD website
Factsheet	Growing avocados - irrigation principles	Content for DPIRD website

Factsheet	Growing Avocados-Fungal Diseases of Fruit	Content for DPIRD website
Factsheet	Plant growth regulators in Avocado -a review	Content for DPIRD website
Factsheet	Avocado maturity testing using dry matter	Content for DPIRD website
Factsheet	Control of Phytophthora root rot in avocado with phosphite – a review	Content for DPIRD website
PowerPoint presentation	"New Fruit Quality project AV18000-Declan McCauley". Appendix 6.	A presentation on the new AV18000 project was delivered at the WA-Pemberton regional Forum in 2019. 9th June 2019.
PowerPoint presentation	"Avocado Quarantine issues and ICAs for WA". Appendix 7.	Presentation of biosecurity issues at 2020 WA Avoskills forum organized by AV17005 team. 11th March 2020.
PowerPoint presentation	"The Avocado Supply chain feedback project" Appendix 8.	Presentation of AV18000 supply chain results at 2020 WA regional forum organized by AV17005 team. 12th March 2020.
Industry Article	"Applied fruit drop investigations in avocado". Appendix 9.	Published in "WA grower" magazine (Winter 2020, pages 24-26).
Seminar/workshop	The "Avocado Phytophthora and phosphite update" was held in November 2020 at DPIRD's offices in Manjimup. It was a hybrid physical and virtual event.	Hosted one extension event for the Murdoch University phytophthora research and DPIRD entomology teams Current link to recording: https://web.microsoftstream.com/video/12e21413-b831-4942-920d-0aa0fe15380a Online event with a maximum of 50 people online.
Industry Article	"Is fruit set related to weather at spring? A retrospective analysis" Appendix 10.	Published in "Talking Avocado" magazine (volume 32, number 3, page 71-74). Spring 2021
Conference Abstract	"Novel Technology for non-destructive measurements of fruit quality in avocado " Appendix 11.	Abstract submitted to IHC2022 Symposium S17: International Symposium on Integrative Approaches to Product Quality in Fruits and Vegetables in December 2021 (Angers, France, 14-20 August 2022).
Completion of fungicide dipping experiment	Completed second repeat trial of post-harvest fungicide application to wet harvested fruits.	
Seminar/workshop	A seminar/workshop was held in Manjimup on 18th June 2022 by DPIRD. A series of talks on avocado production, pollination, pests, latest experimental results and future research plans were presented.	30 growers attended and returned survey on the premises.
PowerPoint presentation	Delivery of preliminary results of thinning trials at 2022 DPIRD Avocado research Update: "DPIRD new projects". Appendix 12.	Update was delivered by Dario Stefanelli on the 18th June 2022.
Poster x 2	"How to Evaluate potential disease on your avocado fruits", and "A perception into the productive picking of wet avocados" Appendix 13 and 14.	Provided as handout at Avo connections 2022

Poster	"Novel technologies for non-destructive measurements of fruit quality in avocado " Appendix 15.	Presented at international conference IHC2022 in Angers, France, in August 2022. See Appendix 2.
Conference Abstract	"Avocado attributes affected by wet harvest are avoided by post-harvest fungicide application." Appendix 16.	Abstract accepted for a poster presentation at the 10th World Avocado Congress in New Zealand. 3-5th April 2023.
Poster	"Avocado attributes affected by wet harvest are avoided by post-harvest fungicide application" Appendix 17.	The poster was presented at the 10th World Avocado Congress in New Zealand (3-5th April 2023) (Appendix 3).
Seminar/work shop	A seminar/workshop was held in Manjimup on May 30th 2023 by the South West catchment council (SWCC) with DPIRD as a co-organizer. A series of talks on avocado production, pollination, pests, latest experimental results and future research plans were presented.	Over 70 growers attended and returned survey on the premises.
PowerPoint presentation	Delivery of preliminary results of thinning trials at 2023 WA Avocado research Update: "Avocado crop load management with manual fruit thinning". Appendix 18.	Update was delivered by Declan McCauley on the 30th May 2023.
Conference Abstract	""Rubens", a non-destructive instrument to measure quality in avocado" Appendix 19.	Abstract accepted at the ISHS International Symposium on Tropical and Subtropical Horticulture in Mediterranean Climate in Palermo, Italy (09 to 12 October 2023). See Appendix 2.
Completion of Avocado thinning trials	Completed the thinning trial activities which ran from 2020-2024.	Completed the application of thinning to 20 trial trees over three years as well as monitoring of fruit load, fruit size, tree size as well as total harvest.

Outcomes

Table 2. Outcome summary

Outcome	**Alignment to fund outcome, strategy and KPI**	**Description**	**Evidence**
Supporting and building capacity for research in Western Australia.	Outcomes 2,3,4 of the Avocado industry strategic plan 2017-2021 (the effective plan for when AV17006 was started)	Research supported in Australia covers a range of topics from production in the field to post-harvest fruit quality, and export supply chains. Productivity research contributes to outcome 4 of the Avocado strategic plan 2017-2021. Post harvest research brought to WA with AV18000, AV22011, and AM21000 contribute to outcome 3 and 2 of the strategic plan 2017-2021.	The initiation of AV18000, AV22011, and AM21000 projects in WA through the signing of their relevant subcontracts.
Identifying factors	Outcome 4 of the Avocado	The work of AV16005	Identification of

influencing irregular bearing and management of irregular bearing in Avocados	industry strategic plan 2017-2021: • Gaining a greater understanding of irregular bearing and minimising the impact it has on tree productivity. • Fundamental production research is undertaken including the technology transfer from international production regions	supported by AV17006 contributed to a better understanding of bearing and crop resource allocation in Avocados. The Avocado thinning trial applied a practical management technique to avocados to induce more consistent bearing over years in avocados. The trial demonstrated that the minor thinning applied was sufficient to improve yield consistency between years.	carbohydrate limitation through research (data). Identification of a benefit to applying thinning to avocado trees in terms of yield consistency over time (data).
Sharing and supporting uptake of good farm practices.	Outcome 4 of the Avocado industry strategic plan 2017-2021. • Uptake of established on farm good practices tailored to variety/region • Fundamental production research is undertaken including the technology transfer from international production regions	Grower workshops run in 20222 and 2023 in the absence of the national Avocado extension project ensured continuity of new WA specific research and information to growers. The post-harvest fungicide treatment research for wet harvesting avocados and the development of fast identification of the level of fungal inoculum in blocks several weeks prior to harvest were completed and extended with posters and presentations, including a poster to the wider international avocado community at the World Avocado Congress. Testing of the Rubens instrument in Avocado to measure dry matter non-destructively	Attendance list and numbers, grower surveys post-workshop. Web analytics for DPIRD webpages. Delivery of posters and presentations on the post-harvest fungicide and fungal inoculum level identification research. Attendance and poster presentation to the world horticulture congress IHC2022 in France.

Monitoring and evaluation

Table 3. Key Evaluation Questions and Answers

Key Evaluation Question	Project performance	Continuous improvement opportunities
Question 1. Has the project achieved	Weather conditions at flowering were initially identified as a cause of	Irregular bearing over the Country has never been truly quantified and

its outcomes? Intermediate outcomes: Identification of factors that contribute to or do not contribute to irregular bearing and reduced yields in avocados.	bearing issues but in a grower identified spring where fruit set failed (2019) weather conditions were found to be good for pollination in the review done by this project. The available data from this project shows that carbohydrate shortages in years following large crops are the most probable cause of irregular bearing habits in avocado trees. Fruit thinning to manage carbohydrates has been identified as a method to substantially improve yield consistency over time.	needs further addressing. A multifactor analysis of crop yield volunteered by growers, weather conditions, and harvest times will be informative in defining what is actually going on with regards to irregular bearing and alternate bearing. Further studies in the identification and implementation of a practical method to perform meaningful fruit thinning in avocado.
Question 1. Has the project achieved its outcomes? Intermediate outcomes: Improved awareness and uptake of best practice information. Avocado industry is informed of developments made by research activities of AV17006.	Delivery of WA industry updates in 2022 and 2023, attendance at regional forums, publication of results and presence of webpages.	During the life of a project as well as when it finishes, information delivered to audience are usually not repeated, therefore there is usually not enough collection of evidence and feedback to prove uptake of best practice information.
Question 1. Has the project achieved its outcomes? End-of-project outcomes: Increased yield through greater best practice management and/or new best practice achieved through research.	Evidence has been collected through the thinning trial that there is a potential to achieve more consistent avocado yields over time.	More research required: • Further define the ideal number of fruit per unit a tree can reliably sustain. • Develop practical means for removing fruit.
Question 2. How relevant was the project to the needs of intended beneficiaries?	Irregular bearing is highly relevant to Western Australian growers; it is a key topic at recent and upcoming WA regional forums, and is incorporated into the strategic plan in Outcome 4.	As for question 1, irregular bearing needs to be quantified better than it has been.
Question 3. How well have intended beneficiaries been engaged in the project?	Key members of the project reference group were kept informed through PRG regular meetings and the industry was kept aware through the WA industry updates in 2022 and 2023.	Suggestion is for AAL to send surveys to growers sometime after the delivery of the information to check if it had an impact. It can be also use as a reminder to look at the info again by growers.
Question 4. To what extent were engagement processes appropriate to the target audience/s of the project?	Publications in industry papers, grower directed workshops are a common method of extending research results and best practice information.	It became apparent over time that what growers prefer in any extension outputs are practical outputs they can implement straightaway, not just research outputs.
Question 5. What efforts did the project make to improve efficiency?	Improvement in research technologies available within DPIRD; acquiring time saving equipment. The thinning trial, the largest in the	

	project, also had the clearest defined scope and process of documentation.	

Recommendations

- More research is needed in the practical applications of crop load management in avocado since our research demonstrated that by thinning it is possible to obtain more yield consistency.
- If thinning is performed, suggestion is to not leave more than one fruit per inflorescence and to perform it no later than 3 weeks after fruit setting.
- The number of fruit an avocado tree can carry per unit of canopy or cross sectional trunk area needs to be further evaluated due to high variability between trees.
- Seedling rootstocks are highly variable and result in some trees in orchards that are consistently non-productive, therefore clonal rootstocks are suggested.
- Pollination events are not suggested as a reliable method to determine pollination, and therefore fruit setting.
- Fluorescence spectroscopy can be used to non-destructively determine dry matter content in avocado fruit.
- Continuous digital monitoring implemented during the trial was partially successful due to some random measurement failure. However, during the experiment the accuracy of the recommendation toward more efficient irrigation was not used, which is the main service of the company.
- Harvesting wet fruit is possible if fruit are treated with fungicide postharvest and depending on time of harvest in the season. The latest the harvest the shorter the time should be between actual harvest and fungicide treatment.
- Speed ripening for the early identification of fungal inoculum in the field is suggested as an adopted practice by avocado growers. This would allow the grower to identify the level of fungal inoculum at least 3 weeks prior to harvest. Additional fungicide sprays could be delivered to improve fruit quality and robustness if inoculum is too high.
- Irrigation flushing did not appear to substantially shift the amount of chloride in the soil and therefore total salinity.
- The experience of the scientists in the DPIRD avocado team is that most of the problems (bearing issues, fruit quality, variability between trees and disease) the avocado has could be resolved with better varieties bred in Australia for Australian conditions.

References

Wolstenholme, B.N., 1986, Energy Costs of Fruiting as a Yield-Limiting factor with special reference to Avocado, Physiology of tree fruits, *Acta Horticulturae,* 175, pp. 121-126.

Acknowledgements

DPIRD gratefully acknowledges the various farms who participated in the project, the guidance and time given by members of the project reference group and CSIRO. DPIRD also acknowledges every avocado grower contributing to the Avocado research and development fund administered by Hort Innovation.

Appendices

Appendix 1 is included below.

Introduction

Avocado trees are known to be afflicted by alternate bearing and in Australia are beset by a phenomenon known as irregular bearing. The definition of irregular bearing is crop loads which vary from year to year without a pattern or cycle. A defining feature of irregular bearing is a very large crop which then causes a small 'off' crop the following year and then an entrenched alternate bearing habit. The very large crop is itself usually preceded by a small crop (Newett, 2013, Whiley, 2013). Irregular bearing is itself very poorly understood with the blame being directed at climatic factors by some and carbohydrates by others (Whiley 2013). Other complicating factors are:

One key feature of both irregular and alternate bearing is that in 'off' crop years very little can be done to resolve the situation. However, in 'on' crop years removing excess fruit can be used to preserve resources for the next year. In apples fruit thinning is the first resort for managing bearing. While thinning was originally invented for alternate bearing it has potential for irregular bearing by virtue of removing excess fruit in times when too many are set.

Therefore we hypothesised:

The removal of some fruits from avocado trees shortly after fruit set will result in more consistent yields year on year than avocado trees with fruits left unremoved.

The consistent yield an avocado can produce is not known. A theoretical value of 32.5 tonnes per hectare has been suggested by Wolstenholme (1986) but this was for Fuerte, not Hass, and assumes a relatively low dry matter at harvest. Also, it assumes a productive orchard equivalent of a high intensity apple orchard, The average apple yield in Australia is only 60 tonnes per hectare, not the 100 tonnes per hectare used by Wolstenholme so the expected yield would only be 19.5 tonnes per hectare. Conversely, some apple orchard achieve higher yields than 100 tonnes per hectare so the theoretical yield could be even higher. Unfortunately, a desktop analysis could go on and on in an attempt to resolve what the avocado yield should be. Instead, the following trial used a quantified fruit thinning target—that is the number of fruits per inflorescence, to develop a consistent yield target for Hass avocado orchards in Western Australia.

Method: Please see other appendix-'Avocado thinning trial detailed methods'.

Results:

The results from three years of thinning trials show an effect in the harvests from thinning applied in treatment 1 and negligible effect in treatments 2, 3. Treatment 1 does appear to show some irregular or alternate bearing when analysing the fruit counts from harvest (Figure 1) however the weight of fruit harvested did not vary from year to year as much (Figure 2). The average fruit size varied considerably between years with the fruit being smallest in the 2022 season (Figure 3). The 2022 season was also when a large number of fruit were counted (Figure 1). The 2023 set was not included in the statistical analysis as three replicates had been pruned considerably, leaving only two trees left with unaffected fruit set. However, the 2023 season is roughly consistent with the years of 2020 and 2021 and 2022 is an outlier 'on' year.

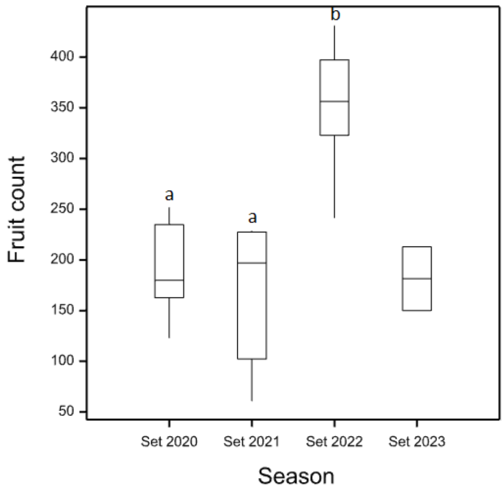


Figure 1. Fruit count of avocado trees over four seasons of Treatment 1-inflorescences thinned to 1 fruit. The name of the season, for example 'Set 2021' refers to the start of the season, or when the flowers opened which was in the spring of 2021. Significance is shown with a lower case 'a' or 'b' with different letters indicating significant differences. Significance for 'Set 2023' is not shown as the count is not the final count at harvest and may change as the harvest is still over 6 months away. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

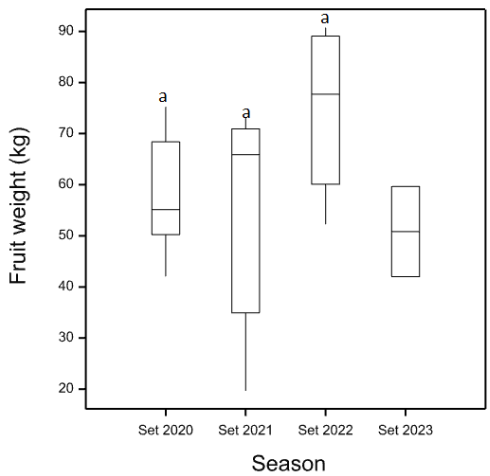


Figure 2. Fruit weight of avocado trees over four seasons of Treatment 1-inflorescences thinned to 1 fruit. The name of the season, for example 'Set 2021' refers to the start of the season, or when the flowers opened which was in the spring of 2021. Significance is shown with a lower case 'a' or 'b' with different letters indicating significant differences. Significance for 'Set 2023' is not shown as the estimated weight is not the final weight at harvest and may change as the harvest is still over 6 months away. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

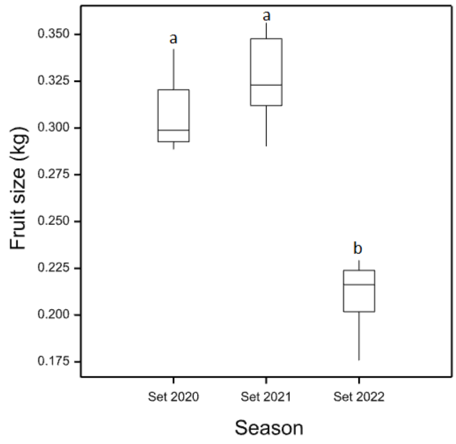


Figure 3. Fruit size of avocado trees over three seasons of Treatment 1-inflorescences thinned to 1 fruit. The name of the season, for example 'Set 2021' refers to the start of the season, or when the flowers opened which was in the spring of 2021. Significance is shown with a lower case 'a' or 'b' with different letters indicating significant differences. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

The harvested fruit weight from treatment 2 was variable from year to year in 2020, 2021, and 2022 with an 'on' season in 2020 and 2022 and 'off' seasons in 2021 and 2023 (Figure 4). The fruit counts showed less statistical variability, but the variability in trends are much greater than the harvested weight (Figure 5). As for treatment 1 2022 was an extreme year with a huge number of very small fruit (Figure 6). The largest fruit size was in 2021 which was also when the trees had fewer fruit, and a lower total harvest weight. The 2023 season is most similar to the 2021 season for both fruit counts and fruit weight, if a little lower.

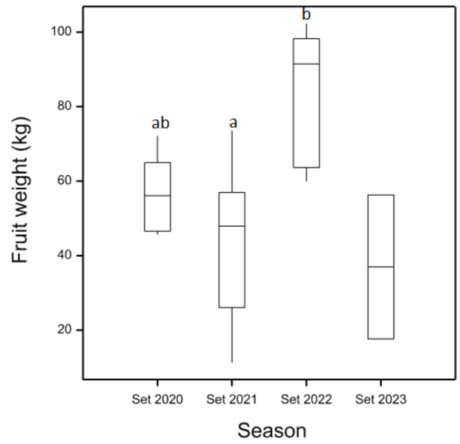


Figure 4. Fruit weight of avocado trees over four seasons of Treatment 2-inflorescences thinned to 2 fruit. The name of the season, for example 'Set 2021' refers to the start of the season, or when the flowers opened which was in the spring of 2021. Significance is shown with a lower case 'a' or 'b' with different letters indicating significant differences. Significance for 'Set 2023' is not shown as the estimated weight is not the final weight at harvest and may change as the harvest is still over 6 months away. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

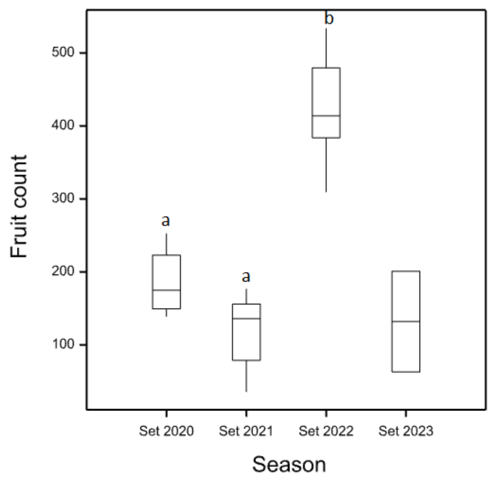


Figure 5. Fruit count of avocado trees over four seasons of Treatment 2-inflorescences thinned to 2 fruit. The name of the season, for example 'Set 2021' refers to the start of the season, or when the flowers opened which was in the spring of 2021. Significance is shown with a lower case 'a' or 'b' with different letters indicating significant differences. Significance for 'Set 2023' is not shown as the count is not the final count at harvest and may change as the harvest is still over 6 months away. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

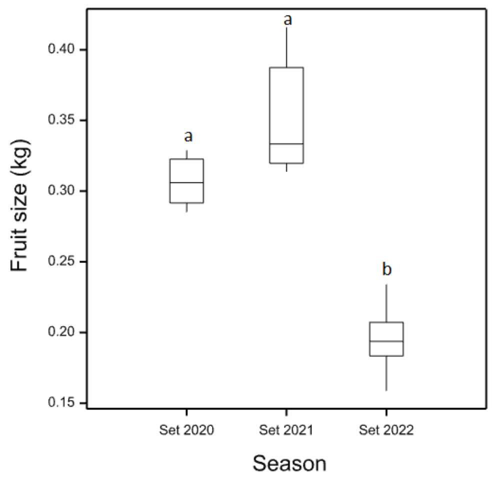


Figure 6. Fruit size of avocado trees over three seasons of Treatment 2-inflorescences thinned to 2 fruit. The name of the season, for example 'Set 2021' refers to the start of the season, or when the flowers opened which was in the spring of 2021. Significance is shown with a lower case 'a' or 'b' with different letters indicating significant differences. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

Avocado fruit weight harvested in treatment 3 was consistent for the first two years but increased dramatically in 2022, and then decreased to very low yields in 2023 (Figure 7). While 2020 and 2021 were not statistically different 2021 was a lower yield. The fruit counts were similar to the fruit weight with a lower but not significantly different yield in 2021 as compared to 2020, followed by a very high number of fruits in 2022. 2023 had a very low fruit count. The average fruit size, like the previous two treatments, was lowest in 2022, highest in 2021 and in-between in 2020.

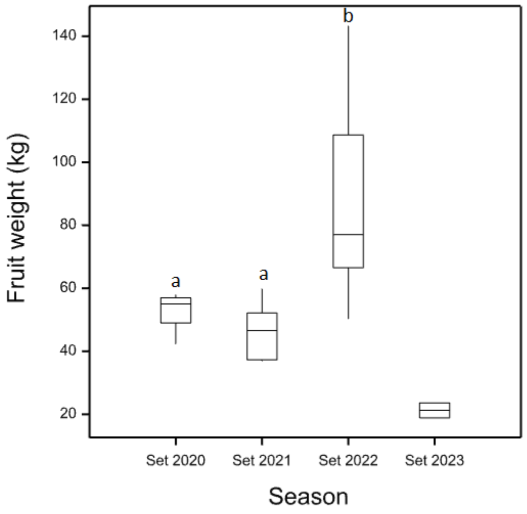


Figure 7. Fruit weight of avocado trees over four seasons of Treatment 3-inflorescences thinned to 3 fruit. The name of the season, for example 'Set 2021' refers to the start of the season, or when the flowers opened which was in the spring of 2021. Significance is shown with a lower case 'a' or 'b' with different letters indicating significant differences. Significance for 'Set 2023' is not shown as the estimated weight is not the final weight at harvest and may change as the harvest is still over 6 months away. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

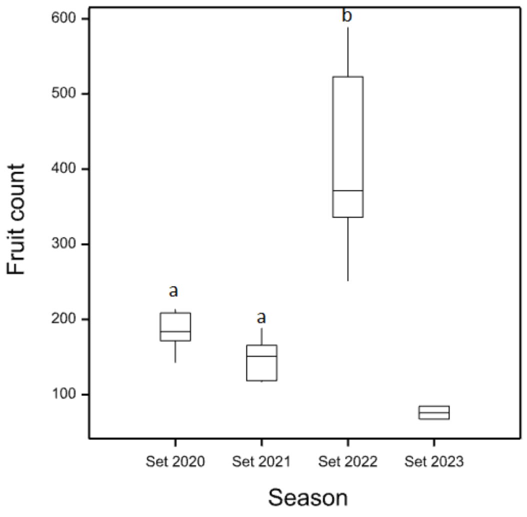


Figure 8. Fruit count of avocado trees over four seasons of Treatment 3-inflorescences thinned to 3 fruit. The name of the season, for example 'Set 2021' refers to the start of the season, or when the flowers opened which was in the spring of 2021. Significance is shown with a lower case 'a' or 'b' with different letters indicating significant differences. Significance for 'Set 2023' is not shown as the count is not the final count at harvest and may change as the harvest is still over 6 months away. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

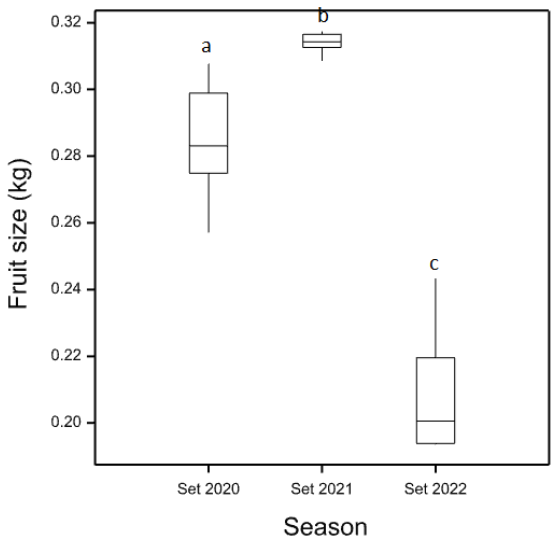
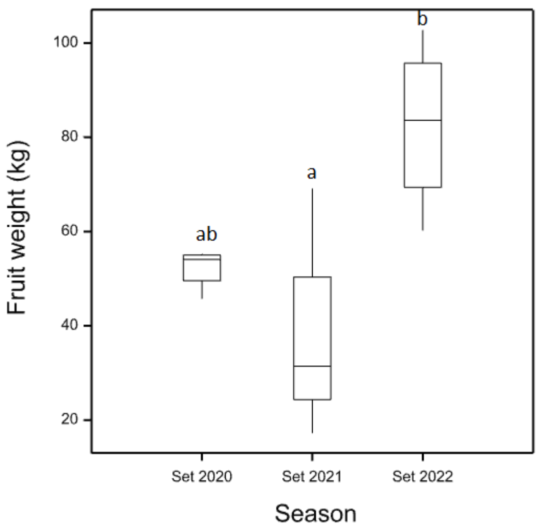


Figure 9. Fruit size of avocado trees over three seasons of Treatment3-inflorescences thinned to 3 fruit. The name of the season, for example 'Set 2021' refers to the start of the season, or when the flowers opened which was in the spring of 2021. Significance is shown with a lower case 'a' or 'b' with different letters indicating significant differences. The boxplot shows the median (even though the graph is named 'average'), the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

The fruit count of the control trees over time showed an alternate bearing pattern with an 'on' year in 2020 and 2022 and an 'off' year in 2021 (Figure 10). The harvested fruit weight showed the same trend as the fruit count (Figure 11) but with additional statistical differences between 2020 and 2021, on top of the differences between 2020, and 2021 with 2022 in the fruit counts (Figure 11). The fruit size differences between years were not as pronounced in the control as in the other treatments with no significant differences (Figure 12). However the fruit were still smallest in 2022 than the other two years with the largest fruit being from 2021, as per the other treatments.



100
80
60
40
20
Fruit weight (kg)
ab
a
b
Set 2020
Set 2021
Set 2022
Season

Figure 10. Fruit weight of avocado trees over three seasons of the control-inflorescences left unthinned. The name of the season, for example 'Set 2021' refers to the start of the season, or when the flowers opened which was in the spring of 2021. Significance is shown with a lower case 'a' or 'b' with different letters indicating significant differences. The 'set 2023' season is not shown as only one replicate could be counted. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

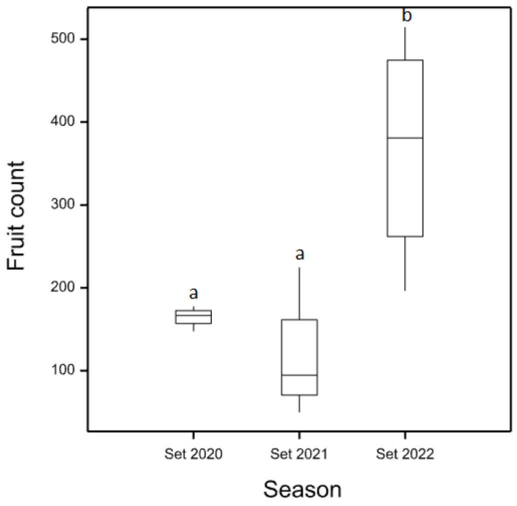


Figure 11. Fruit count of avocado trees over four seasons of control-inflorescences left unthinned. The name of the season, for example 'Set 2021' refers to the start of the season, or when the flowers opened which was in the spring of 2021. Significance is shown with a lower case 'a' or 'b' with different letters indicating significant differences. The 'set 2023' season is not shown as only one replicate could be counted. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

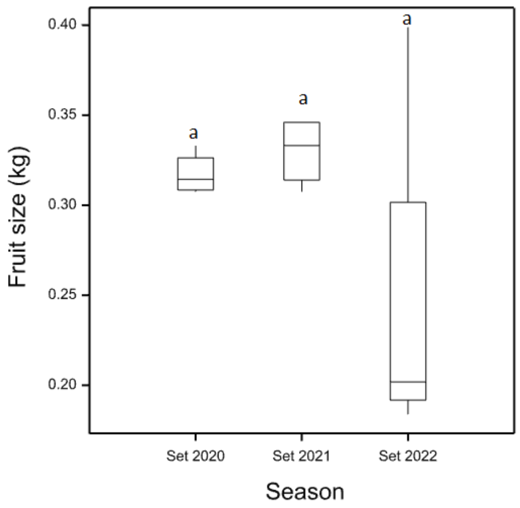


Figure 12. Fruit size of avocado trees over three seasons of control-inflorescences left unthinned. The name of the season, for example 'Set 2021' refers to the start of the season, or when the flowers opened which was in the spring of 2021. Significance is shown with a lower case 'a' or 'b' with different letters indicating significant differences. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

Avocado tree growth did not vary noticeably between treatments for estimated canopy volume (m^3) and trunk cross sectional area (TCSA) over the three years of data collection (Figures 14, 15). TCSA increased over time more consistently than the canopy volume. The canopy volume increased mostly during the summers and did not increase at all during the winter (Figure 15). The rate of increase of the TCSA did not increase or decrease over time. The canopy volume of any of the treatments did not appear to consistently deviate higher or lower than any other treatments.

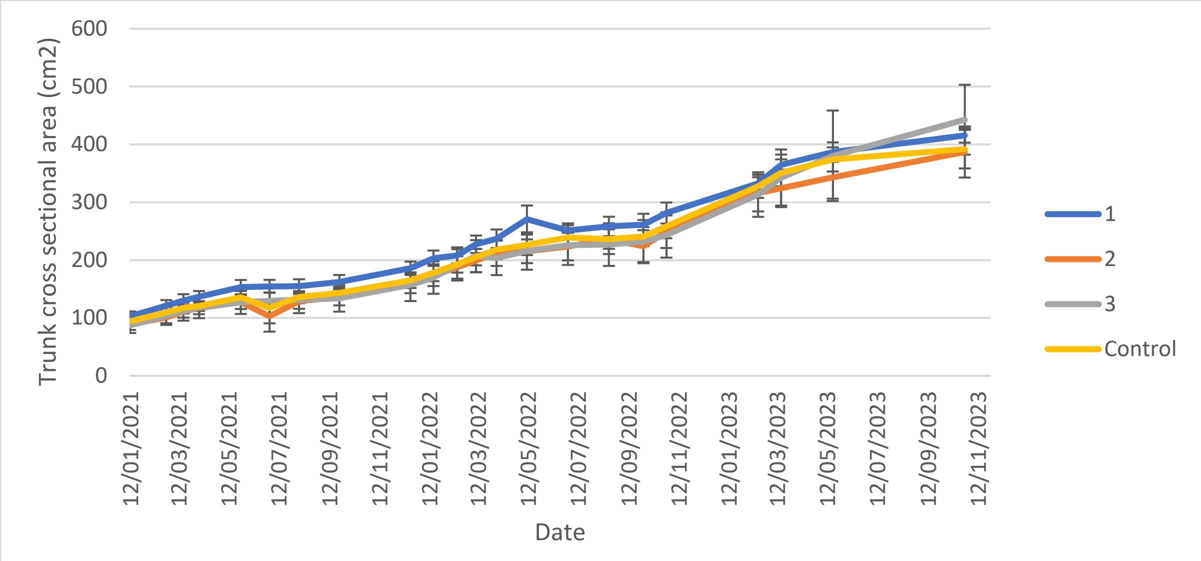


Figure 13. Avocado trunk cross sectional area (cm^2) over three years for all four treatments; treatment 1, 2, 3 and control. Standard errors are shown with updown bars.

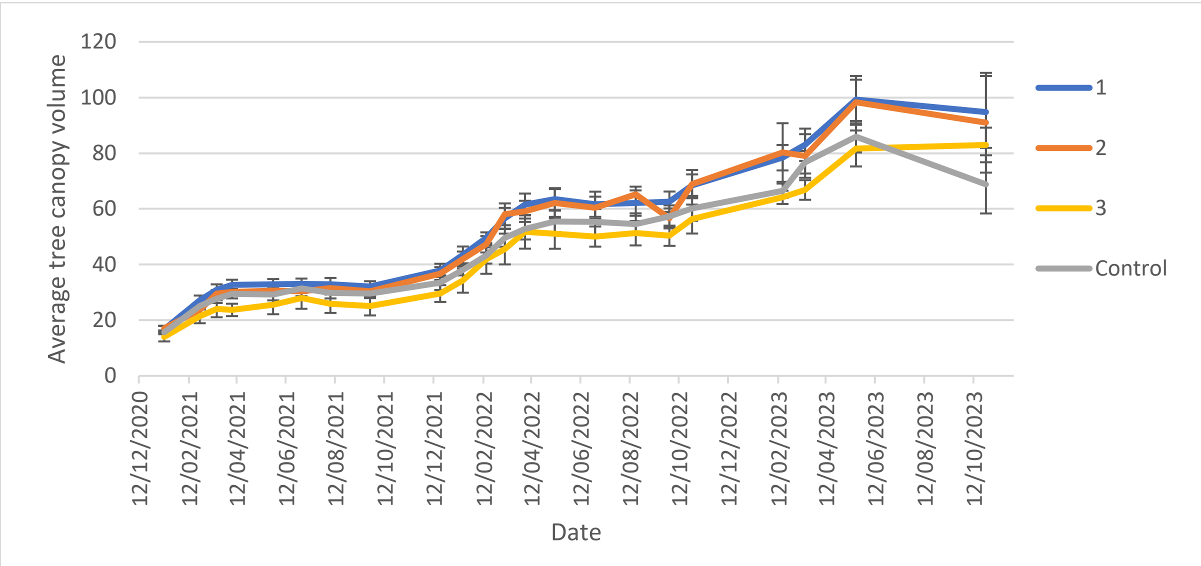


Figure 14. Avocado tree canopy volume (m^3) over three years for all four treatments; treatment 1, 2, 3 and control. Standard errors are shown with updown bars.

The number of fruit harvested from an avocado tree and the number of inflorescences responsible for producing that harvest were not well related (Figure 16). Higher numbers of inflorescences did not cause more fruit and smaller numbers of inflorescences did not cause fewer fruit. In fact the greatest number of fruit at harvest was associated with a tree with fewer inflorescences. Trendlines added to describe the relationship had very low R^2 values that were virtually no different to 0.

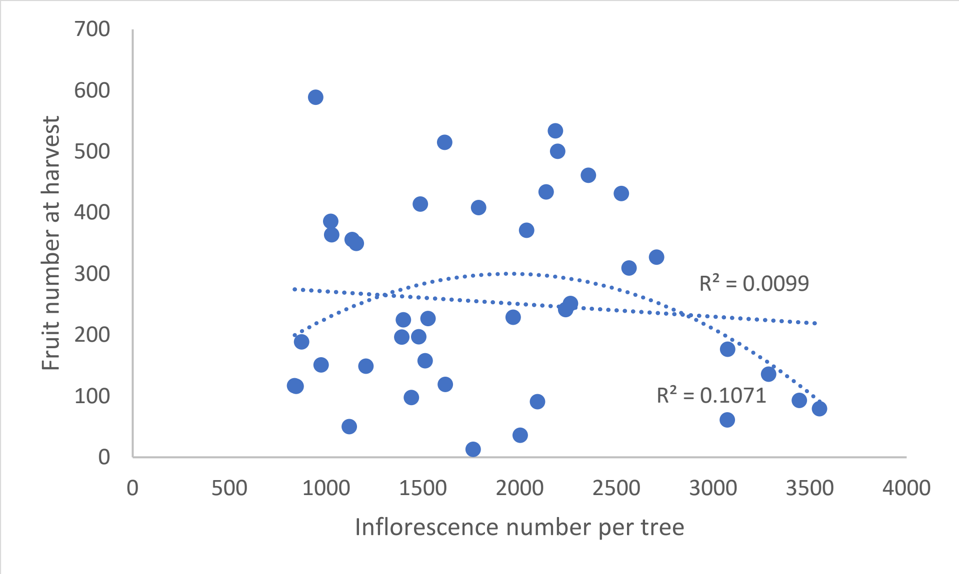


Figure 15. A plot of average inflorescence number of avocado trees and eventual fruit at harvest with the relationship shown with a linear and polynomial trendline. R^2 values are indicated for each relationship.

There was high variability between trees in the thinning tree so individual tree yields over time have been reported in Table 1. The highest individual tree yields all occurred in 2022 and the lowest in 2021. A bearing index (BI) has been created and applied to the individual trees. The BI indicates variable yield from year to year with the 3 year BI having a perfect score of 3 with anything higher indicating variable bearing from year to year. The 4 year BI is the same but a perfect score is 4. Treatment 1 and 3 are the only treatments with a 3 year BI below 4, while treatment 2 and control have trees with a 3 year BI above 5. In the 4 year BI treatment 1 stays below 5, the rest are all well above 5.

Individual trees show different bearing habitats; one tree in treatment 1 has alternate bearing with yields of 66.2, 19.7 and 52.27 kg harvested and a 3 year BI of 3.91. Due to the shortage of replicates the rest of this paragraph concerns only the three years of complete data. All other trees in treatment 1 had less variation from year to year with the next highest 3 year BI being 3.32. Variation was either from alternation or from a gradual increase over time. In treatment 1 two trees alternated while 3 increased over time. Treatment 2 had one notable tree with harvested yields of 62.57, 11.3, and 60 kg and a 3 year BI of 5.41. Other trees in treatment 2 had less pronounced alternate bearing but had extremely high yields in 2022. In treatment 2 three trees had alternate yields and two trees had increasing yield. In treatment three two trees increased over time, however most of the increase happened with an unchecked abundance of fruit in 2022. Three trees had alternate bearing tendencies. In the control treatment four treatments had alternate bearing while only one increased over time.

Including the fourth year estimated weights shows alternate bearing in all treatments, however, it is less severe in treatment 1 as in other treatments as described earlier with the 4 year BI. The fourth year estimated average was highest in treatment 1 as well at 50.82 kg, higher than the 36.96 kg in treatment 2, 24.71 kg in treatment 3, and 21.28 kg in the control.

Table 1. Individual tree data for the thinning trial showing harvested fruit weight per tree for each season. The 'Set 2023' season fruit weight is estimated from a fruit count done in march 2024, several months before harvest (fruit weight was estimated as 280 grams: the rounded average of all fruit size over the previous three years). The 'Set 2023' fruit count did not include all replicates as many of the trees had experienced heavy pruning. The three year Bearing Index (BI) was calculated by dividing the sum of all three years by each year and summing the quotient produced for each of the three years. The number produced will be 3 if each year is perfectly consistent and larger than 3 if variable. For the four year BI the equation was the same but a perfect consistent yield is shown with a score of 4, not 3.

	Harvest (kg)									
Treatment	Set 2020	Set 2021	Set 2022	Set 2023	Three year BI	Four year BI	3 year BI Min	3 year BI Max	4 year BI Min	4 year BI Max
1	52.93	40	77.72		3.23					
1	75.29	73.1	88.55		3.02					
1	55.12	65.9	62.69		3.02					
1	66.12	19.7	52.27	42	3.91	4.90				
1	42.11	70.2	90.77	59.64	3.32	4.32	3.02	3.91	4.32	4.90
2	45.73	73.64	102.31		3.34					
2	56.09	31	96.91		3.70					
2	72.18	47.93	64.89		3.09					
2	46.82	51.4	91.46	56.28	3.27	4.27				
2	62.57	11.3	60.00	17.64	5.41	6.74	3.09	5.41	4.27	6.74
3	56.63	60	143.37		3.58					
3	55.04	37.4	77.03		3.27					
3	51.24	37	71.92		3.23					
3	58.12	46.6	97.11	15.4	3.29	6.19				
3	42.32	49.6	50.41	34.02	3.02	4.10	3.02	3.58	4.10	6.19
Control	55.31	17.3	102.81		5.01					
Control	54.77	69.2	78.47		3.07					
Control	53.36	31.5	88.71		3.57					
Control	23.14	5.3	21.64	18.9	4.64	5.71				
Control	45.77	31.4	60.26	23.66	3.22	4.53	3.07	5.01	4.53	5.71

Fruits per cubic metre of tree canopy was highest in the first year of the trial and then remained low in the next two years (Figures 17, 18). Between treatments there was some variation, mostly due to treatment 1 having a higher number of fruit per cubic metre for all three years (Figure 17).

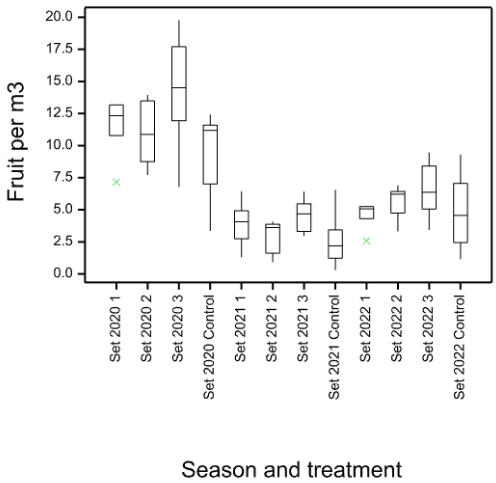


Figure 16. Fruit number per cubic metre of canopy volume for each treatment and season. 'Set 2020 1' is interpreted as the data for the season starting with the flowering in the spring of 2020, and only for treatment 1-which had inflorescences thinned to one fruit. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

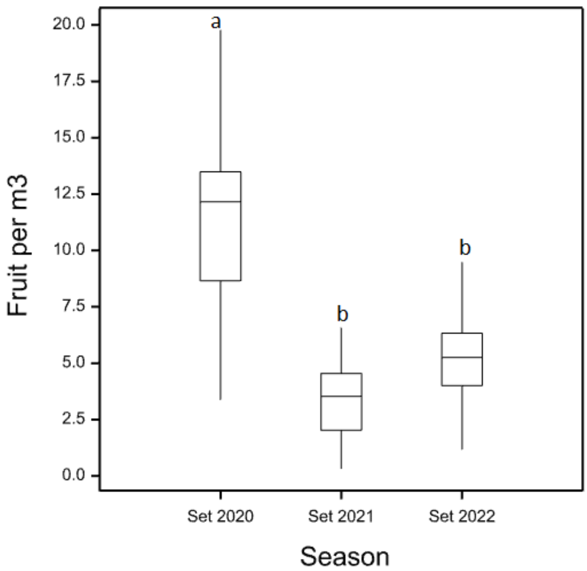


Figure 17. Fruit per cubic metre over three seasons averaged across treatments. Significance between treatments is shown with a lowercase 'a' or 'b' with different letters indicating significant differences. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

Plant photosynthesis fluorometry and porometer measurements were taken over three years but did not show statistical differences between treatments. However, three measurements taken over one day showed differences between different sides of the tree as the day progressed. At 9:00 am the quantum yield of photosystem II was highest on the east side of the tree (Figure 18) while at 3:00 pm it was highest on the west side of the tree (Figure 22). At 12 noon there were no difference between sides. The maximum yield of chlorophyll a fluorescence under ambient light was highest on the west side tree at 9:00 am (Figure 19) and highest on the east side at 3 pm (Figure 23). At 9:00 am the steady state chlorophyll fluorescence was highest on the east side (Figure 20) before reverting to the west side at 3:00 pm (Figure 24).Finally, stomatal conductance to water was highest on the east side of the tree at 9:00 am (Figure 21) and highest on the west side at 3:00 pm (Figure 25).

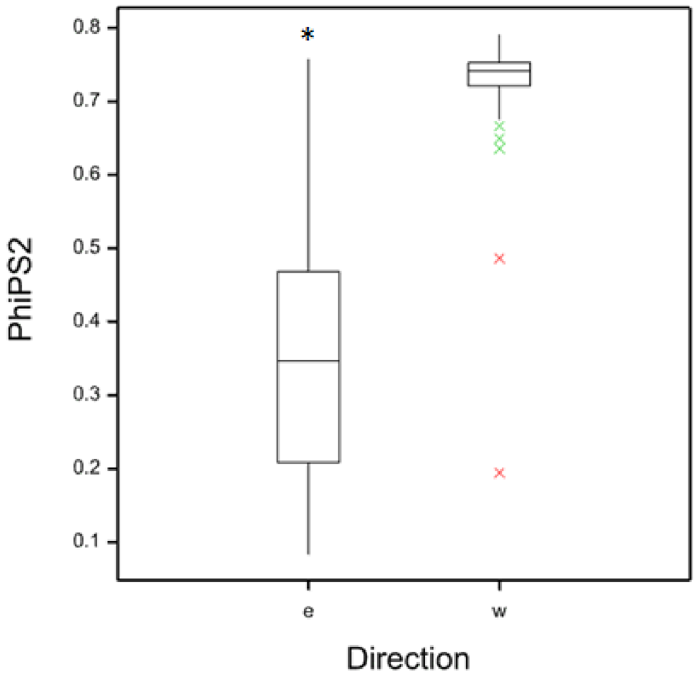


Figure 18. The quantum yield of PSII (PhiPS2) of all trees in the thinning trial at 9:00 am on the 9th of March for the east (e) and west (w) side of the trees. '*' indicates a treatment with significant differences (p=<0.001).

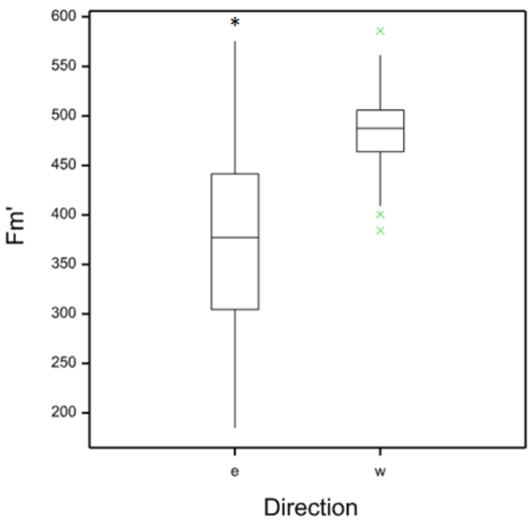


Figure 19. The maximum yield of chlorophyll a fluorescence under ambient light (Fm') of all trees in the thinning trial at 9:00 am on the 9th of March for the east (e) and west (w) side of the trees. '*' indicates a treatment with significant differences (p=<0.001).

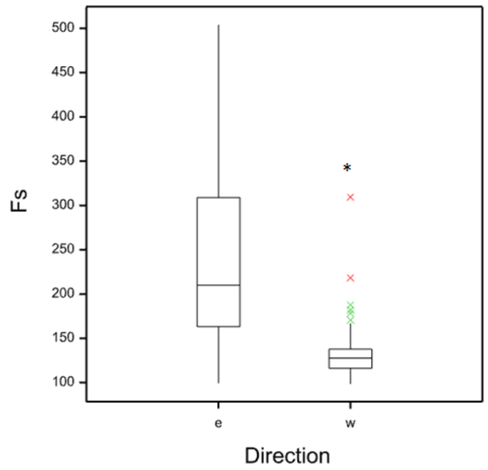


Figure 20. The steady state of chlorophyll fluorescence (Fs) of all trees in the thinning trial at 9:00 am on the 9th of March for the east (e) and west (w) side of the trees. '*' indicates a treatment with significant differences (p=<0.001).

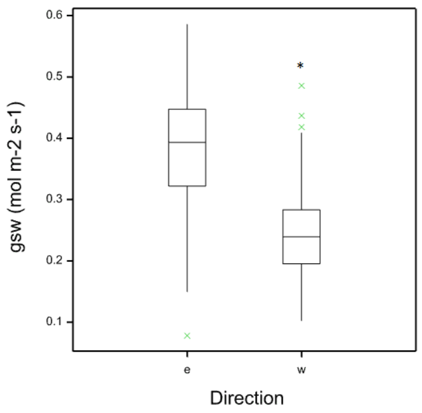


Figure 21.. Stomatal conductance to water of all trees in the thinning trial at 9:00 am on the 9th of March for the east (e) and west (w) side of the trees. '*' indicates a treatment with significant differences (p=<0.001). The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

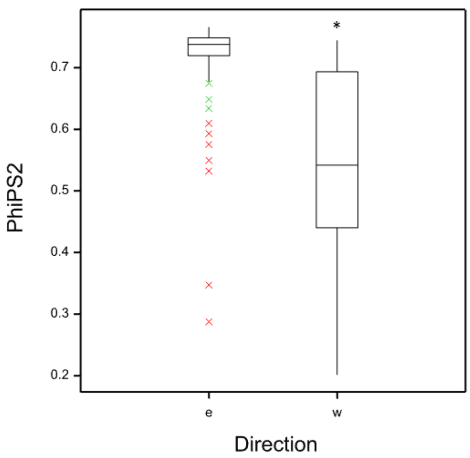


Figure 22. The quantum yield of PSII (PhiPS2) of all trees in the thinning trial at 3:00 pm on the 9th of March for the east (e) and west (w) side of the trees. '*' indicates a treatment with significant differences. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

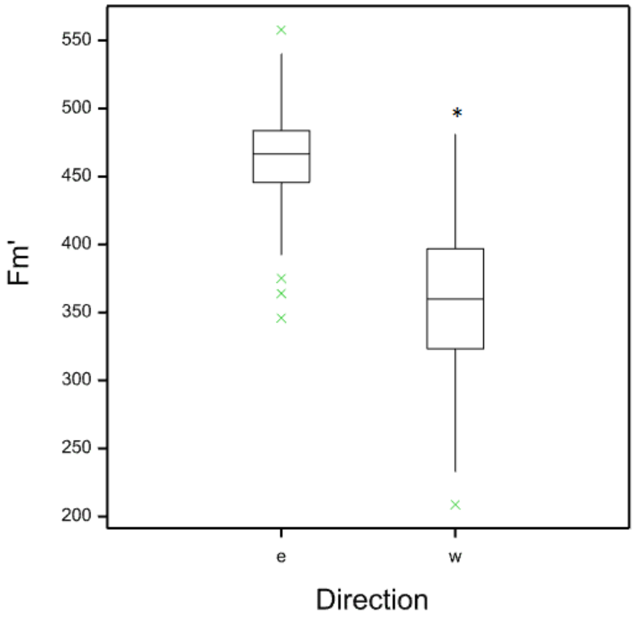


Figure 23. The maximum yield of chlorophyll a fluorescence under ambient light (Fm') of all trees in the thinning trial at 9:00 pm on the 9th of March for the east (e) and west (w) side of the trees. '*' indicates a treatment with significant differences (p=<0.001). The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

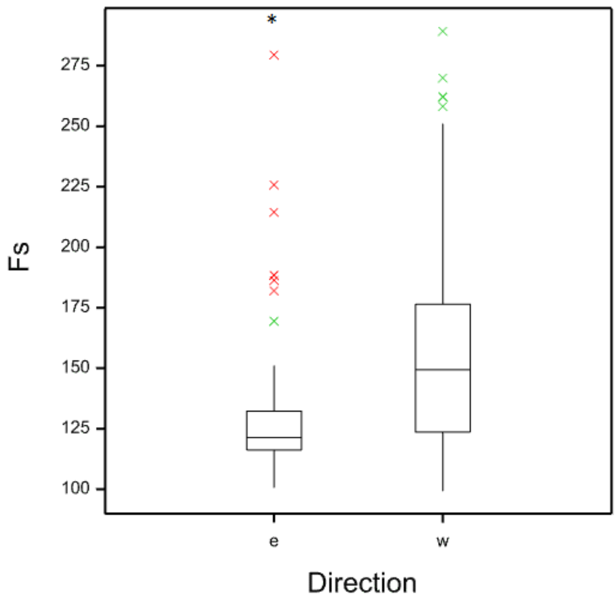


Figure 24. The steady state of chlorophyll fluorescence (Fs) of all trees in the thinning trial at 3:00 pm on the 9th of March for the east (e) and west (w) side of the trees. '*' indicates a treatment with significant differences (p=<0.001). The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range

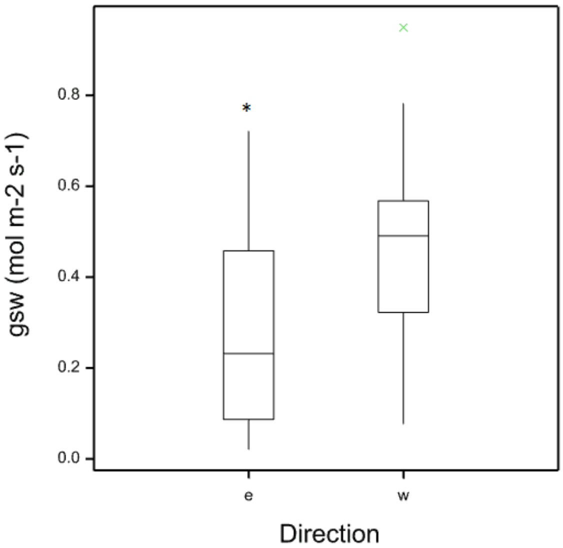


Figure 25. Stomatal conductance to water of all trees in the thinning trial at 9:00 pm on the 9th of March for the east (e) and west (w) side of the trees. '*' indicates a treatment with significant differences (p=<0.001). The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

Fruit mineral analyses were similar from year to year with the only differences being between treatment for nitrogen in 2020 (Figure 26) and potassium in 2021 (Figure 27). Calcium was not different between treatments in any year. Treatment 1 and 2 had the highest fruit nitrogen in 2020 (Figure 26) but only treatment 1 had the highest potassium of all treatments in 2021 (Figure 27).

Between years the fruit minerals were always different with the difference from the years being larger than the difference from the treatments (Table 2). The general trend for calcium across the years was the same in all treatments and was to gradually increase. All treatments had an average calcium of 0.02% in 2020 and in 2022 this had grown to 0.07% (Table 2). Potassium was lowest in 2020, highest in 2021, and midway in 2022. Nitrogen had similar behaviour to potassium (Table 2).

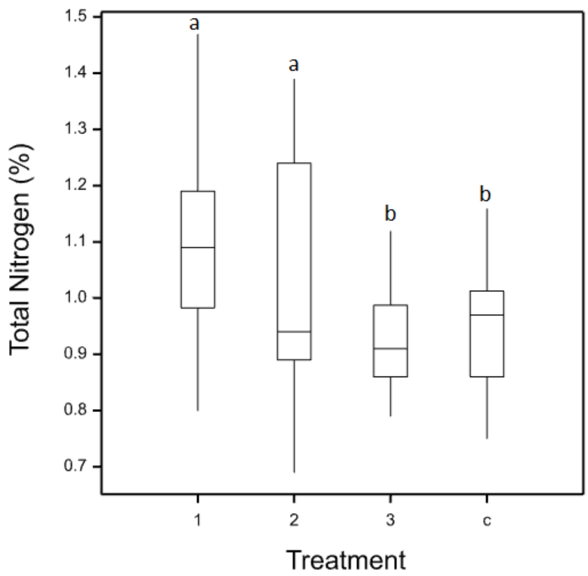


Figure 26. Total nitrogen of fruit flesh from fruit harvested from the 'Set 2020' season over all four treatments: Treatment 1, 2, 3 and control; Treatment 1 trees were thinned to 1 fruit per inflorescence, treatment 2 to two fruits per inflorescence, treatment 3 to three fruits per inflorescence, and the control was left unthinned. Significance between treatments is shown with a lowercase 'a' or 'b' with different letters indicating significant differences. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

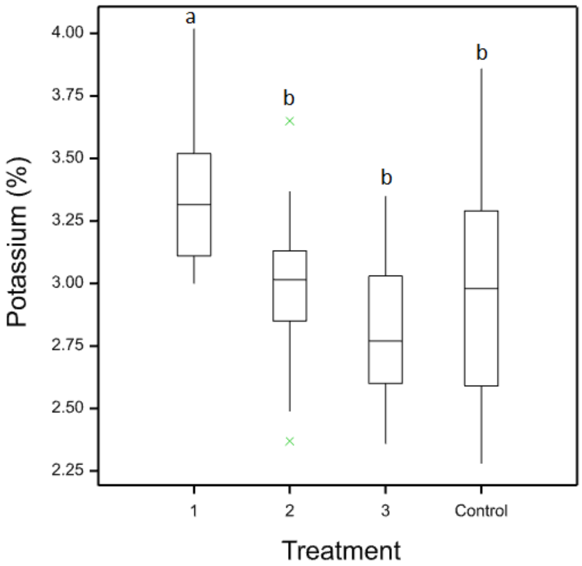


Figure 27. Total potassium of fruit flesh from fruit harvested from the 'Set 2021' season over all four treatments: Treatment 1, 2, 3 and control; Treatment 1 trees were thinned to 1 fruit per inflorescence, treatment 2 to two fruits per inflorescence, treatment 3 to three fruits per inflorescence, and the control was left unthinned. Significance between treatments is shown with a lowercase 'a' or 'b' with different letters indicating significant differences. The boxplot shows the median, the upper and lower quartiles encompass the 25% of values either side of the median. The whiskers indicate values 1.5 times the interquartile range.

Table 2. Calcium, Potassium and Nitrogen of fruit flesh in four treatments and three seasons with significance shown (p<0.05 = significant differences exist). Treatment 1 trees were thinned to 1 fruit per inflorescence, treatment 2 to two fruits per inflorescence, treatment 3 to three fruits per inflorescence, and the control was left unthinned.

Treatment	Season	Element Calcium (%)	 Potassium (%)	 Nitrogen (%)
1	2020	0.02	1.73	1.10
1	2021	0.04	3.35	1.51
1	2022	0.07	2.37	1.38
	p-value	<0.001	<0.001	<0.001
2	2020	0.03	1.79	1.03
2	2021	0.04	2.96	1.47
2	2022	0.07	2.08	1.25
	p-value	<0.001	<0.001	<0.001
3	2020	0.02	1.56	0.92
3	2021	0.04	2.80	1.44
3	2022	0.07	1.94	1.23
	p-value	<0.001	<0.001	<0.001
Control	2020	0.02	1.64	0.95
Control	2021	0.04	2.99	1.39
Control	2022	0.07	2.23	1.32
	p-value	<0.001	<0.001	<0.001

Post harvest assessment of avocado fruits for 2022, the only season where this was done, showed the greatest damage in treatment 1, but was not significantly different to the other treatments (Table 3). Dry matter was also not significantly different between treatments (Table 3). The Turoni durometer measurements were also not different between treatments; this only shows all fruits were assessed at a uniform level of ripeness.

The number of fruit removed per treatment and per year was much greater in 2020 than the following years (Table 4). Treatment 1 had the most fruit removed on average in 2020 with roughly nine times as many fruit removed (900.6) as the other two treatments (124 treatment 2, 121.8 treatment 3). In 2021 the number of fruit removed from treatment 1 was roughly 18 times lower (59.5) but was 30 times larger than the amount of fruit removed from treatment 3, which had only 2 fruit removed on average. In 2022 fewer fruit were removed from treatment 1 (32.8), more were removed from treatment 2 (15.6) and roughly the same amount was removed from treatment 3 (1.6).

Table 3. results from a post harvest assessment of fruit from the 2022 season. Treatment 1 trees were thinned to 1 fruit per inflorescence, treatment 2 to two fruits per inflorescence, treatment 3 to three fruits per inflorescence, and the control was left unthinned. Total damage indicates the proportion of fruit affected by body rots, bruises, stem end rots, vascular strands, and diffuse discolouration after ripening post harvest. The Turoni values indicated the average Turoni readings when fruit were dissected. The dry matter is the oven dry weight of a sample of fruit flesh divided by the fresh of the same sample of flesh (then multiplied by 100). Significance is shown ($p<0.05$ = significant differences exist).

Treatment	Total damage (%)	Turoni	Dry matter (%)
1	4.26	34.64	28.66
2	3.015	32.05	28.87
3	3.646	33.46	27.57
Control	2.646	34.04	29.01
P-value	0.805	0.066	0.482

Table 4. The average number of fruit removed from trees for each treatment over three years of trial. Treatment 1 trees were thinned to 1 fruit per inflorescence, treatment 2 to two fruits per inflorescence, and treatment 3 to three fruits per inflorescence.

Treatment	2020	2021	2022
1	900.6	59.5	32.8
2	124.2	6.7	15.6
3	121.8	2	1.6

Due to variability within the trial trees a count of an additional 15 trees was done in the season of 2021 (Figure 28). The 15 trees show a very large amount of variation in the trees with a coefficient of variation of 43.29 on a mean of 125.33. The standard error was 54.26. The number of fruits ranged from a maximum of 201 and a minimum of 17 fruits per tree.

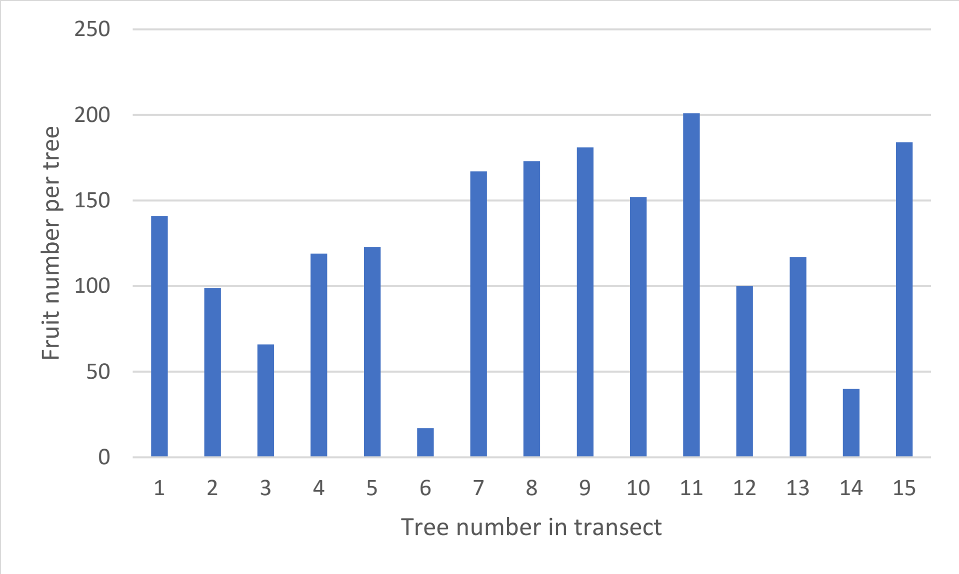


Figure 28. The number of fruit per tree of 15 trees counted along a transect through the same orchard as the thinning trial. The transect was along a compass reading of 315°.

Discussion

All treatments had signs of variable bearing over the years of the trial but it was found the least in treatment 1. There were no significant variation in weight between years in treatment 1 while there were differences in other treatments and the control. Treatment 1 also had the fewest trees in an alternate bearing habit as compared to the other treatment and control (Table 1). Fruit size and total count showed more variation in bearing over the years in all treatments, including treatment 1. However, much of variation is due to the mega crop produced in the 2022 season, and treatment 1 still had a low average for 2022 of 74.4kg as compared to the 83.11 kg for treatment 2, 87.97 kg for treatment 3 and 70.38 kg for the control (or 82.5 kg if excluding the ultra low-performing tree). While many trees were in alternate bearing patterns some trees consistently increased yield over time. The increase in yield over time is due to the growth of the trees as they mature and produce a larger canopy to carry fruit. As treatment 1 had more consistent yields over time and had a smaller yield in 2022, the thinning appears to have somewhat reduced bearing variability over time in the treated trees, if only by small amount and enough to slightly 'smooth' the tops off very high yield years.

Bearing variability extends not just to the yield data, but also to the sizes of the fruit. Fruits were much smaller in 2022 than in 2021 and slightly smaller in 2020 than in 2021. The smaller sized fruit correspond to the purported 'on' years when too many fruits are set. The tree has responded by allocating fewer resources to each fruit, resulting in smaller fruit. In addition nitrogen was lowest in the fruit in 2020 and 2022 presumably for the same reason; the tree restricted how much nitrogen was provided to each fruit as supply was probably not meeting demand. Potassium had the same pattern over the years but calcium didn't have such a clear pattern. Calcium was lowest in 2020 then increased in 2021 and 2022 with the maximum in 2022. The high value in 2022 may be because the large number of fruit were able to compete with the leaves for calcium, a reported phenomenon in avocado (Witney et al., 1990). It is unclear why this didn't also happen in 2020.

The treatments involved the application of a set number of fruit per inflorescence. One problem with this approach is that the number of inflorescences varies per year, and is not itself associated with how much fruit the tree brings to harvest either. However, as is shown in Figures 16 and 17 picking a number based off a consistent unit may not be that easy. The number of fruit per canopy has varied between years with the tree being most 'efficient' in 2020 and then becoming less efficient. The number of fruit per tree in treatment 1 was an average of 180 fruit per tree, excluding the larger 2022 season which brings the average up to 237 fruit per tree. Assuming a 300 gram fruit and 416 trees per hectare 180 fruit per tree will produce 22 tonnes per hectare. While not reaching the 32 tonnes per hectare suggested for Fuerte by Wolstenholme in 1986, 22 tonnes per hectare still exceeds the national average. The number of fruit per tree has issues in the sense that it does not take into account planting density of the orchard, or the high variability between tree sizes, however it is the easiest definable target number that can be reliably identified. The number of fruit per trunk cross sectional area, or canopy volume, or canopy area could be alternatives but they all have issues of inconsistency with tree growth.

The fruit removed per year was highest in 2020 and then dropped with the smallest fruit removal being in the 2022 season. After 2020 the fruit removed in treatment 2 and 3 was virtually negligible and equivalent to natural fruit drop. In 2022 the fruit removed from treatment 1 was also very low. It may have been that having more fruit removed from treatment 1 will have prevented such a large fruit set, maximised fruit size, and preserved resources for the next year.

There is also the question of doing thinning every year. It may have been more appropriate to skip the thinning application in 2021 in treatment 1. Consequently, the crop set may have been larger and left fewer resources for the 2022 season resulting in a smaller and more consistent yield.

Tree variability

The individual avocado trees had highly variable yields. In a transect of 15 trees the number of fruit varied from 17 to 201 fruits. In the main trial itself one tree in the control was a consistently low bearer having yields of 23.14 kg, 5.3 kg, and 21.64 kg over the three years. By comparison other trees in the control were bearing over 50 kg per tree. The tree itself was healthy, flowered well, and was vigorous. The cause of the large variability and the occasional non-performing tree is probably due to the use of seedling rootstocks. Seedling trees are the product of sexual reproduction and the genetic recombination that results from it produces randomness. Therefore, while seedling rootstocks are usually 'named' as Zutano or Reed for example each individual rootstocks is a unique variety with its own attributes. The use of these seedling rootstocks has made it difficult to reduce variability in the trial design and may have masked the results. While undesirable from a scientific standpoint from a grower perspective the ups and down of each seedling rootstock tend to average out and be less noticeable. Consequently, they are in common use. Thus, due to the common use of these rootstocks future research absolutely requires the very large replicate number of 15 recommended by Schaffer and Baranowski (1986). Ideally, clonal rootstocks would be used in rochards.

Photosynthesis and stomatal conductance measurements

With the small increase in yield consistency caused by treatment 1 it is unsurprising that photosynthetic measurements did not identify differences between treatments. there were simply not enough measurements done over time to catch any kind of trend which represented an up or downregulation of photosynthesis as caused by an excess or deficiency of resources. The multiple measurements done in single day showed that avocado photosynthesis is impacted by direct sunlight; it becomes less efficient and transpiration is reduced when sunlight is directly on the leaf surface. However overall quantum yield and maximum fluorescence is higher under direct sunlight, due to the larger amount of light available.

Conclusion

Thinning avocado trees of some fruits shortly after fruit set appears to have induced more consistent bearing in avocado trees. A question still remains as to what tis the best target for a number of fruit per tree or other quantifiable unit to achieve the most consistent yield. This author suggests 180 fruit per tree, at the trial spacing used here: 3.5 metres by 8 metres. Larger or smaller trees will require different numbers of fruit. Follow up research using more replicates and a range of fruit numbers per tree may be able to further define a consistent yield which can be carried year after year by Hass avocado trees. Finally, there remains the issue of how to apply thinning as the manual thinning used in this trial is not practical on a commercial scale. Thinning chemicals and mechanical thinning devices used in other fruit crops may provide a solution.

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