

Final Report

National Tree Crop Intensification in Horticulture (Avocado, Mango and Macadamia)

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National Tree Crop Intensification in Horticulture (Avocado, Mango and Macadamia) (AS18000)

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Public summary

Many tree crop systems have seen significant gains in productivity and profitability through intensification over the past 50 years. These advances were driven by improvements in tree physiology, development of better cultivars, and the use of vigour-controlling rootstocks. However, tropical and subtropical crops such as avocado, macadamia, and mango remain less developed compared to others, mainly due to limited research investment in their genetics and production systems. To address this, the AS18000 Program was launched to improve efficiency, productivity, and profitability of five key Australian tree crops: almond, avocado, citrus, macadamia, and mango. This summary relates to research and development progress made in avocado, macadamia, and mango orchard systems.

Building on the earlier AI13004 project, AS18000 aimed to deepen understanding of orchard physiology, tree architecture, crop load, light environment, canopy microclimate, and vigour management. Recognising the long maturation times of tree crops, the program adopted a long-term Research, Development, and Extension strategy, combining foundational science with practical orchard considerations. Industry stakeholders participated through Crop Reference Groups (CRGs) to ensure relevance and effective communication. Outcomes of this research effort varied: mango showed the highest adaptability to intensification, macadamia made moderate advances, while avocado faced challenges due to rapid vegetative growth and limited genetic tools for vigour control.

Avocado intensification is constrained by the lack of suitable low-vigour cultivars and effective canopy management. Future research should prioritise developing these cultivars, refining canopy practices, and evaluating soil-applied growth regulators. The 'Ashdot 17' rootstock shows promise but requires further testing in diverse conditions. A deeper understanding of avocado physiology and fruit set dynamics could improve input management and reduce irregular bearing. Shade netting may improve productivity in hot, dry areas by improving orchard microclimates but requires careful pollination and pest control.

Mango has strong potential for high-density planting and intensification. Research should continue exploring multi-leader canopy systems, trellising and rootstock-scion combinations across climates and varieties. Further study of tree vigour, fruit quality, and resource optimisation; including water, fertiliser, growth regulators, labour and canopy management, is needed to maximise efficiency and profitability. Understanding carbohydrate dynamics may also help stabilise yields. Long-term productivity and economic viability must be validated through mature orchard studies and updated economic models with real-world data.

Macadamia offers intensification potential if higher per-hectare productivity offsets increased costs. Canopy management is crucial, and soil drench applications of growth retardants need more research. Selecting low-vigour, high-yielding varieties suited to local soils is important. The 'Beaumont' rootstock performs well in poorly drained soils, with rootstock choice significantly affecting productivity. Broader testing across environments will support adoption of intensive systems and sustainable growth.

The AS18000 Program (avocado, macadamia, mango) supported and produced 32 scientific publications, 48 conference presentations, 52 industry presentations, 46 magazine articles, 25 field days, seven educational videos with nearly one million views, and nine manuals/fact sheets. These outputs, shared via conferences and online platforms, enhanced knowledge transfer among growers, researchers, and policymakers, positioning the avocado, macadamia, and mango industries for sustainable intensification and growth.

Keywords

Mango; avocado; macadamia; tree crop; intensification; rootstock; density; architecture; light efficiency; crop load; modelling.

Introduction

Improving profitability is increasingly critical for Australian tree crop producers as rising input costs and growing competition for quality horticultural land and water put pressure on conventional production systems (ABARES, 2025). Intensifying tree crop production systems tackles inefficiencies in resource use, especially land, by increasing output per hectare. However, challenges such as labour costs, labour availability, and integrating new technologies limit many enterprises ability to expand. Building knowledge and understanding of physiology, agronomic, genetic, economic and management practices and the implications of increased orchard intensification will allow breeders, orchard owners and managers to make informed decisions on future orchard design and management. The synergistic optimisation of genetic and production system constraints should lead to increased production per hectare, particularly early in orchard life, leading to increased profitability.

Apple is a landmark example of intensification, with yield per hectare increasing three-fold over a 30-40 year period (Scalisi *et al.*, 2024). These gains in apple, and in similar temperate tree fruit industries, have been based on an understanding of the relationship between orchard design, canopy management, light, crop load, and genetic and management tools for vigour control. Avocado, macadamia and mango have not experienced the same productivity leaps as industries such as apple, so continue to have relatively low production per hectare. Many of the principles of intensification identified in apple production systems, such as the need to increase light interception, are thought to apply universally. However, other components such as the interaction of vigour and productivity must be tested for applicability in individual crops with differing genetic regulation of vigour.

Avocado, macadamia and mango have been selected for inclusion in this program due to their strong potential for improved productivity through intensification and their current substantial contributions to the Australian economy, despite extensive orchard systems. Together, the three crops have a farm gate value of \$1.012B produced from 77,441 hectares of orchards (Hort Innovation, 2025). This project forms a component of the larger 'National Tree Crop Intensification in Horticulture Program' (AS18000), which was a continuation of the larger body of work initiated under the previous 'Transforming sub-tropical and tropical tree crop productivity (A113004)'. While this report relates only to avocado, macadamia and mango, parallel collaborative research in AS18000 was undertaken in citrus and almond.

Due to the lengthy maturation of tree crop orchards, this program has taken a long-term approach to the transition to intensive tree crop production systems, to assess mature experimental orchards while accumulating the knowledge and understanding needed to underpin the sustainable transition of these industries. The three crops are at differing stages in their transition to intensified production systems. These differences are broadly determined by the availability of management tools and genetic resources to control vegetative vigour. Mango has been most successful in implementing intensive production systems due to relative scion dwarfing, macadamia has been intermediate, and avocado has been the most challenged due to rapid tree growth and limited genetic options for vigour control.

Vigour management in the three crops has historically been determined primarily by scion selection. However, rootstock choice and the use of plant growth regulators, such as paclobutrazol, also have a significant role in the management of vigour in modern intensively managed orchard systems. In A113004 rootstock selection was demonstrated to influence scion vigour in all of the focus crops for this proposed research program however selection was at an early stage requiring further validation to provide confidence for commercialisation and industry adoption.

Emerging production systems must increase production per hectare while also responding to immediate industry challenges such as labour shortages and climate variability to minimise crop losses and input costs. This project has provided the basis for testing heat and drought adaptation strategies on commercial properties such as semi-protected cropping in avocados and labour-saving solutions such as robotic harvesting in mangoes.

Functional-structural plant models simulate plant environmental and physiological processes within a virtual growing tree structure or orchard simulation. These computational models can integrate several factors and contribute to interpreting field experiments or formulating new research hypotheses. Models are also a helpful tool for extension, where walk-throughs of virtual planting systems can improve grower's understanding of selected project research

findings.

Building on the the promising results of the AI13004 program, the three industries have commenced transitioning to intensified production systems, though there is variation across and within these industries. Early adopters have required support from the AS18000 research teams in understanding intensified production systems and have in turn provided feedback on their experience, through participation in Crop Reference Groups (CRG) and program organised events such as field days. Within the AS18000 program researchers worked closely with, and across, the five tree crop industries (almond, avocado, citrus, macadamia, mango) with an integrated overarching governance structure, inter-project working groups, and a series of team webinars and annual team meetings. AS18000 researchers also collaborated with research teams in other national and international horticulture programs ensuring that the avocado, macadamia and mango industries have been quick to capitalise on genetic and genomic advances (AS17000 and AS23003) and orchard and physiological advances in other tree fruit and nut crops (AS22002).

Methodology

The AS18000 Program, multi-crop research initiative aimed to enhance scientific capacity and knowledge, and achieve improved industry impact through knowledge sharing and improved evaluation. Partners included Queensland's Department of Primary Industries (DPI), the Queensland Alliance for Agriculture and Food Innovation (QAAFI), the New South Wales Department of Primary Industries and Regional Development, Plant and Food Research Australia, the South Australian Research and Development Institute, and the Western Australia Department of Primary Industries and Regional Development (WADPIRD). With crops at different intensification stages, the program fostered valuable cross-crop collaboration.

The program operated under a logic model with two key areas: developing new research knowledge and communication to achieve industry impact. Its progress and impact were monitored through a comprehensive evaluation plan. Governance was provided by a Project Reference Group (PLG) of senior project researchers, offering strategic guidance and promoting collaboration. The PLG met biannually and was managed by the AS18000 Program Coordinator, an independent role engaged to facilitate integration and collaboration across the crop projects of AS18000. Each crop had a dedicated Crop Reference Group (CRG) of industry stakeholders who ensured relevance, provided feedback, communicated benefits, and championed the research within their networks. CRG meetings were conducted bi-annually online or using a hybrid approach for those located close to the research.

Using a Farmer Participatory Research approach (Dickinson et al., 2025), farmers were integrated into the research process as active participants and champions contributing via the CRGs, action learning events, trial design, hosting of activities and communications. Annual forums involving research teams from Australia and New Zealand promoted collaboration through presentations, planning, and field visits. During COVID-19, virtual field days replaced in-person events, supporting continued progress and feedback. The program hosted twelve webinars to showcase external scientists and technologies.

Avocado

Planting systems trials

The primary purpose of the Avocado Planting Systems Trial was to investigate the impact of orchard planting density on productivity and to enhance our understanding of the factors that influence productivity. The main hypotheses tested were that increased tree density, and the corresponding dimensions of the orchard canopy would result in higher early yields and greater yield per hectare as the orchard matures. It was anticipated that this increased production would stem from improved light interception and enhanced canopy yield efficiency. Furthermore, it was hypothesised that the 'Ashdot' rootstock would be better suited to high-density planting compared to 'Velvick' due to its lower vigour and greater yield efficiency.

The trial was established in July 2014 at the DPI Bundaberg Research Facility, examining 'Hass' avocados at three different tree densities: conventional or low density (9 m x 5 m, totalling 222 trees per hectare); medium density (6 m x 3 m, totalling 556 trees per hectare); and high density (4.5 m x 2 m, totalling 1111 trees per hectare). At each density, two rootstocks were compared: the vigorous industry-standard 'Velvick' and the reportedly less vigorous 'Ashdot'. The results from the first four years of the trial were comprehensively reported in the AI13004 project report. The current project has gathered data for an additional three years and presents findings on how planting density affects crop production in a mature orchard, as well as discusses the factors influencing production levels (see Appendix 29 for more information).

Plant and environmental monitoring were conducted by WADPIRD at Avowest, Carabooda, WA, to evaluate 'Hass' avocado growth, yield, and quality under shade netting. In 2020, approximately 3.5 ha of shade netting was installed, with the roof and walls providing 12% and 50% shade, respectively. The orchard's Mediterranean climate features hot, dry summers and wet, mild winters, with an average annual rainfall of 701 mm. The soil is grey phase Karrakatta sand, low in clay (5%) and organic matter (1.4%). Avocado trees were planted at a low density of 408 trees per hectare using vase-shaped pruning in both open and netted areas. A high-density treatment under netting featured 1108 trees per hectare with central leader pruning. Irrigation used a dual drip-sprinkler system, primarily relying on drip irrigation to optimise water use efficiency. Plant measurements included canopy volume, trunk cross-sectional area, leaf chlorophyll index, total inflorescences and flowers per tree, fruit set percentage, fruit drop numbers, fruit diameter, total fruit count, yield, weight, and quality. Four weather stations were installed across netted and open areas to record daily evapotranspiration, air temperature, wind speed, solar radiation, vapour pressure deficit, and relative humidity. Soil moisture sensors, pan lysimeters, and sap flow sensors supported irrigation scheduling. Sap flow sensors also monitored daily transpiration rates in avocado trees under both netted and open conditions.

Genetic resources

A major factor limiting the intensification of subtropical tree crops is their high vegetative vigour, which can lead to early orchard crowding and necessitate a more intensive canopy management regimen. The most effective method for managing vegetative vigour is through grafting onto a vigour-reducing rootstock. A rootstock assessment trial was included in the project to evaluate the impact of various rootstock cultivars on the potential performance of an intensive avocado orchard system. This work was different from the components involving macadamia and mango rootstocks because of the limited access to a local germplasm collection or a breeding program that could help in selecting new rootstocks. As a result, the focus was on utilising commercially available cultivars. Although extensive research has been conducted on avocado rootstock evaluation in Australia, none has specifically aimed to identify rootstocks that excel in an intensive orchard environment.

The rootstock assessment trial was established at the DPI Bundaberg Research Facility in two phases due to varying delivery times from different nurseries. The trial was configured with a row spacing of 4.5 metres and a tree spacing of 2 metres, resulting in 1,111 trees per hectare, and implemented a vertical trellis system. Phase 1 was planted in May 2016, featuring 'Hass' avocados on nine different rootstocks. Phase 2 followed in January 2018, planting 'Hass' on six different rootstocks, as well as the scion varieties 'Gem' and 'Maluma,' each on a single rootstock. The results from the early years of the trials' Phase 1 were reported in the AI13004 project report. The current project has collected data up to year 7 for Phase 1 and year 6 for Phase 2. The report focuses on the long-term productivity trends and discusses the sustainability of the different cultivars to an intensive orchard system (see Appendix 26 for more information).

Vigour management using plant growth regulators

Findings from the Avocado Planting System and rootstock assessment trials indicated that avocados' extremely high vegetative vigour is a central factor limiting the opportunity for avocado intensification. The growth and development of trees are often controlled in commercial cultivation through the use of plant growth regulators (PGRs). Trials were conducted to investigate the potential use of plant growth regulators (PGRs) from the triazole family, which act as growth retardants. This research aims to enhance our understanding of how these PGRs affect vegetative growth in

subtropical environments. The findings will support the further development of PGR applications as part of a canopy management strategy for intensive orchards. The trials focused on evaluating the effect of a paclobutrazol and uniconazole spray application timing, as well as the longer-term impact of paclobutrazol soil drench applications on vegetative growth and canopy yield efficiency (see Appendix 30 for more information).

To maximise the potential short-term impact, a new experimental orchard was established at the DPI Bundaberg Research Facility to explore the use of growth retardants for canopy management. The orchard was planted in August 2023 at a density of 556 trees per hectare (6 m x 3 m). It mainly consists of 'Hass' trees grafted onto the 'Ashdot' rootstock, which has shown superior performance in prior trials. Additionally, it includes 'Hass' on 'BW2' and the 'Maluma' scion grafted on 'Ashdot', which may be better suited to the higher planting density. The treatments focus on the concentration, frequency, and initiation timing of a paclobutrazol soil drench while also utilising Uniconazole and spray application. This trial is in its early stages, and results will be reported in future projects.

Productivity

Findings from other Hort Innovation-funded research projects on avocados, such as Maximising Yield and Reducing Seasonal Variation (AV16005), have previously identified carbohydrate allocation as a key physiological factor affecting avocado productivity. A new study was established towards the end of the project to investigate the potential role of carbohydrate reserves in supporting fruit development. Trials were set up in a commercial intensive growing system in collaboration with Costa Group. The trial work began in February 2024 and is intended to extend over two seasons, with the second season currently ongoing. The treatments aim to influence carbohydrate partitioning by manipulating carbon assimilation, fruit load, and vegetative growth. The effects on carbohydrate reserve levels are being evaluated through the analysis of over 600 tissue samples collected during the trials, which is still in progress. This work will be continued and reported as part of the new research project, Carbohydrate Management in Avocado Production Systems (AV24008).

Root growth

Optimising the timing and rate of nitrogen (N) fertilisation is critical for effective avocado orchard management. To enhance our understanding of nitrogen uptake and root distribution during the winter and spring growth periods. Two field trials were initiated using mature 'Hass' avocado trees in Bundaberg, Queensland, to investigate root growth and nitrogen dynamics. Continuous rhizotron measurements and stable nitrogen isotope (¹⁵N) applications were employed to assess root growth and determine nitrogen uptake and allocation, respectively (see Appendix 28 for more information). This research was carried out by Michelle Miedecke and submitted as her Honours thesis to Central Queensland University.

Intensive demonstration trial

An intensive avocado system demonstration trial was established in partnership with the Peirson Memorial Trust (PMT) at Goodwood near Bundaberg in May 2022. A fully irrigated one-hectare block comprising 540 trees of the 'Hass' variety was planted at a spacing of 6m x 3m. Half of those trees were grafted onto 'Velvick' rootstock, the other half onto 'Ashdot 17'. Each rootstock comprised nine rows, each with 30 trees. The purpose of the trial was to demonstrate the performance of an intensive avocado system in a commercial environment, serving as a case study for extending the results to the industry. Data on establishment costs and early productivity from the first harvest were to be recorded by PMT staff and provided to the project team, with the aim of assessing early cash flows associated with high-density planting.

Multiple agronomic and systemic challenges limited the viability of this trial, as well as the reliability and accessibility of the data. Numerous dead or sick 'Ashdot' trees were replaced in the 12 months after planting. However, many of the replanted trees struggled and did not develop. The high frequency of changes in farm and project staff throughout the project impacted the continuity in caring for the orchard, implementing specific management approaches for the special system design, as well as data collection and access. PMT staff were ultimately unable to provide the cost and

yield data required to conduct a cash flow analysis prior to the project's completion.

Information on tree performance was, however, provided by PMT in 2024, following the first harvest at age 2 years. The 'Velvick' trees yield was estimated at 8 tonnes/hectare. Fruit quality was best in the 'Velvick' rootstock trees and poorer in the 'Ashdot' rootstock trees, where a lack of good leaf coverage resulted in high sunburn frequency. PMT staff estimated that picking costs for the high-density block would be lower than those for conventionally spaced plantings, due to the relatively lower tree height and associated savings in the use and maintenance of dedicated picking machinery (e.g., cherry pickers). In the absence of reliable yield and cost data, it was not feasible to model cash flows or to confidently forecast the long-term viability of this production system.

Macadamia

Planting systems trials

The strategy for assessing the potential performance of intensive macadamia orchard systems involved establishing long-term planting systems trials. The Macadamia Planting Systems Trial Phase 1 aimed to study the effect of the orchard planting density and its interaction with cultivar attributes on orchard productivity. Understanding these factors can enhance our knowledge of the key orchard system components that drive productivity. Two main hypotheses were tested in this trial. The first hypothesis suggested that increased tree density would lead to higher early yields and greater production potential as the orchard matures. The second hypothesis proposed that greater tree density would result in improved light interception during the orchard's early years, as well as at maturity, which would contribute to the higher productivity potential.

The trial was planted in January 2014 at the Bundaberg Research Facility and included three plant densities: conventional low tree density (8 m x 4 m; 312.5 trees/ha), a medium density (6 m x 3 m; 556.5 trees/ha), and a high density (5 m x 2 m; 1000 trees/ha). The tree density treatments were evaluated across two commercially planted scion cultivars: 'A203' and '741'. The results from the first five years of the trial were comprehensively reported in the AI13004 project report. The current project has collected data for an additional five years and reports on the long-term effect of the orchard planting density on orchard productivity. The report focuses on the performance of the high-density treatment, which reached orchard maturity and discusses the impact of light interception on the orchard system's production potential (see Appendix 12 for more information).

The Macadamia Planting Systems Trial Phase 2 was planted in August 2020 on private property in the Bundaberg area. The trial was set up in collaboration with Macadamia Farm Management (MFM), a leading company in macadamia cultivation, which also manages the agronomy of the experimental orchard. The goal of this trial is to apply the key insights gained from Phase 1 in order to further optimise the intensive orchard system. The orchard was planted at a density of 5 m x 3 m, resulting in 667 trees/ha. This trial evaluates the performance of three commercial cultivars selected for their potential suitability for this higher density. Additionally, two different tree training strategies were implemented, along with the application of a growth retardant soil drench. At the conclusion of this project, the trees in the trial were still young, so only preliminary results regarding the performance of the system are available (see Appendix 16 for more information).

Genetic resources

Macadamia trees naturally grow a vast canopy. This characteristic is antagonistic to the principles of orchard intensification, which aim to develop orchards with a higher density of smaller trees with a higher yield efficiency. Breeding scion and rootstock varieties that generate a smaller, more efficient canopy has been a key milestone in the intensification of other tree crops. To explore this opportunity for macadamia, a rootstock screening field trial was established in April 2017 at the DPI Maroochy Research Facility at Nambour during the AI13004 project.

A total of 24 seedling and cutting rootstock accessions were used in this trial. Accessions consisted of 2 standard rootstocks; 6 commercial cultivars; 3 elite selections with high breeding values for a selection index which combined 8 traits (Hardner et al., 2019); 5 elites with high yield efficiency (nut-in-shell yield/m³) and 4 potential dwarf selections from the National breeding program (Topp, 2015); 3 wild germplasm accessions including 1 *M. jansanii* and 2 *M. tetraphylla*; and 1 thin-shelled cultivar. Rootstocks were propagated at the Maroochy Research Facility, Queensland, from April to October 2014. Propagated seedlings and cuttings were grown in a misting house and transferred to a shade house (Alam et al., 2018). Scions of 'HAES 741' were grafted onto seedling and cutting rootstocks on 20th June 2016. Details of the trial can be found in Appendices 18 and 19.

To gather more information to help the Australian macadamia industry select the most suitable rootstock cultivar, a rootstock assessment trial was conducted in the Bundaberg area. This trial compared two rootstocks, 'H2', the commonly cultivated variety used in Australia, and South Africa's most common rootstock cultivar, 'Beaumont', grafted with three different scion varieties, growing across two different soil types. The growth and yield of these trees were monitored for eight years, starting from their planting in 2014 (see Appendix 13 for more information).

Vigour management using plant growth regulators

Results from Phase 1 of the Macadamia Planting System Trial revealed that effective canopy management is a crucial factor influencing productivity in mature, intensive orchards. Incorporating plant growth regulators (PGRs) into canopy management practices may help reduce the need for pruning and influence resource allocation. Trials were conducted to investigate the effect of plant growth regulators (PGRs) from the triazole family, which function as growth retardants, on vegetative growth. The results will highlight the potential for further developing growth retardant applications as a tool for canopy management. The trials focused on evaluating the effect of paclobutrazol application on vegetative growth, with the aim of establishing that these chemicals are also effective in macadamia (see Appendix 14 for more information).

After validating the potential for using growth retardants to influence vegetative growth in macadamia, a new trial was established in August 2023. The trial commenced in partnership with Macadamia Farm Management (MFM) at a five-year-old commercial orchard located in the Bundaberg area. The treatments focus on the concentration and frequency of a paclobutrazol soil drench, covering two cultivars: 'A16' and 'A203'. The self-organising tree model for macadamia that was developed during the AI13004 project (White and Hanan 2016) was used as the basis for a model incorporating the effect of growth retardant applications on canopy growth. The model was used to create virtual predictions of different application strategies that were used to inform the design of the long-term field trial treatment (see Appendix 35 for more information). The experimental work is scheduled to continue for five years, including assessments of canopy growth using a LiDAR system, analysis of chemical accumulation in leaves and kernels, and evaluation of the impact on productivity and kernel recovery. This work is still in its early stages and will continue as part of the new MC23004 project.

Productivity

To investigate the effects of trunk girdling on the productivity of macadamia trees, trials were conducted in February 2021 at private grower sites near Yamba and Woodburn, NSW. The girdling treatments were applied to 3-year-old trees on 'H2' seedling rootstocks. At the Yamba site, the cultivars tested were 'MCT1', 'MIV1-G', and 'HAES 344', while at the Woodburn site, the cultivars were 'HAES 741' and 'HAES 344'. The impact of the girdling treatments on tree productivity was evaluated by counting the number of inflorescences and the yield per tree.

To investigate the impact of branch girdling on flowering and return crop yield, a small trial was conducted over two years (2021–2022) at a commercial macadamia orchard in Opotiki, located on the east coast of New Zealand's North Island. The trial included six different macadamia varieties: A4, A29, A38, A104, A203, and A268. The study also examined how the timing of the girdle affected flowering and nut yield. Branches were girdled at one of four time points throughout the year: June, September, December 2021, or March 2022. The girdled branches were compared with non-girdled branches to assess the effect on productivity (see Appendix 15 for more information).

Economic analysis

Cash flows for high-density plantings were modelled and compared with standard-density plantings in collaboration with MFM staff. MFM has extensive experience in establishing and managing farms of various ages and planting densities and is currently developing a large-scale high-density macadamia planting south of Bundaberg. Two 100-hectare farm scenarios were developed for this study, which included analysis of financial inputs, outputs and net cash flows from initial investment to year 20. Parameters and assumptions for these scenarios were developed in collaboration with MFM staff. Annual yield potential estimates were validated against research results from the AS18000 Planting Systems Trials. Mature productivity and operating costs were validated using regional data from the macadamia benchmark sample (MC22000).

Cash flows were analysed to estimate annual revenue and costs and subsequently net and cumulative cash flows over a 20-year period. Sensitivity analyses were conducted to assess the relative impact of changes in underlying model assumptions, including reductions in expected yield (10-40%) and combined reductions in both yield and operating costs (20-40%). Discounted cash flows were analysed to derive net present values (NPV) and internal rates of return (IRR). Findings were published in the report *Cash flow analysis of high-density macadamia plantings* (Appendix 17) and presented to stakeholders at the final macadamia industry field day in May 2025.

Mango

Vigour / Rootstock

Rootstock evaluation was the primary method of vigour control investigated during the AS18000 program and was a continuation of evaluation from project AI13004. Two major trials were managed during this program, a preliminary screening trial of 97 rootstock varieties with two scions, continued from AI13004, and a more intensive hub and spoke style evaluation of promising rootstocks with commercial scions, commenced in this program.

In both cases, scion size (canopy volume and trunk cross-sectional area), and yield efficiency (yield / canopy area) were used to assess the suitability of rootstocks for future high-density systems. Trial 1 (screening) was undertaken on Walkamin Research Facility from 2014 to 2022 to enable comparison of rootstocks under identical management and environmental conditions. Trial 2 (hub and spoke evaluation) was undertaken primarily at the DPI Walkamin Research Facility with a sub-trial (spoke) located on a commercial mango farm in Dimbulah to assess the suitability of rootstocks in an alternate environment and soil type. These methodologies were pursued over alternatives to guarantee site access over >10 years, ensure protection of genetic resources, and with some consideration of the importance of environment on rootstock-scion performance. Full details on the methodology used to assess these trials are available in Appendix 8.

Planting systems trial

A replicated field trial was undertaken on the DPI Walkamin Research Facility from 2013 and is ongoing to assess the influence of variety ('Yess!', 'Calypso' and 'Keitt'), planting density (208, 416 and 1250 trees / ha) and canopy system (single leader/ espalier vs conventional open-vase). The trial was designed as a split-split-plot with 6 full replicate blocks. Guard rows were used at the perimeter of each planting density block and the end of each canopy system subplot to minimize light and canopy interactions between treatment blocks. Detailed methodology for this trial is available in Appendix 9.

The system was previously assessed for growth, productivity, fruit quality, and light interception in project AI13004 in the immature trial. In this project the assessment of growth, productivity, and fruit quality continued as the high and medium density plantings reached maturity. This orchard has also served as the primary location for experiments in how intensified production systems influence light distribution, fruit quality, spray optimization, pest management, suitability for robotics and agri-technology, and responses to crop load and plant growth regulators.

Crop load

A series of complementary field experiments were conducted between 2023 and 2025 to investigate how non-structural carbohydrate (NSC) dynamics relate to fruit productivity. Three trials as follows were undertaken to provide a physiological framework for improving productivity and orchard management in mango systems:

- 1) Cultivar × planting density productivity trial (Appendix 10.1) - Two cultivars ('Keitt' and 'Yess!') were assessed under low and high planting densities. The trial evaluated fruit yield, yield efficiency, leaf functionality, and NSC reserve dynamics (starch and soluble sugars in roots and trunks) across key phenological growth stages over two consecutive seasons;
- 2) Carbon depletion and recovery trial (Appendix 10.2) - Trees were defoliated to simulate carbon stress comparable to extreme crop load. Reproductive performance, NSC mobilisation and replenishment, and canopy regrowth were tracked over two seasons to evaluate depletion effects and recovery dynamics across multiple organs;
- 3) Carbohydrate reserves in ageing, low-yielding trees (Appendix 10.3) - A diagnostic study assessed NSC reserves in 40-year-old, low-yielding 'Kensington Pride' trees. Seasonal reserve patterns and their correlations with flowering and fruit load were analysed to evaluate reserve cycling capacity in an ageing orchard.

Fruit quality

The impact of orchard intensification on fruit quality outcomes was assessed in the Planting Systems Trial allowing direct comparisons of canopy management styles and planting density within a uniform environment. Assessments focused on aspects of fruit quality influenced by light availability, as this had previously been found to change with the orchard treatments being assessed. Fruit quality characteristics assessed were blush (extent and intensity), sunburn (intensity), and insect damage from white mango scale (count of pink spot blemishes caused by *Aulacaspis tubercularis*). A comprehensive description of the assessment methodology is available in Appendix 11.

Economic analysis

An economic analysis of intensified mango production systems was conducted comparing conventional low, medium and high-density canopy systems and a trellis high-density canopy system for 'Calypso' mango production in north Queensland. This analysis was supported via funding from the CRC for Developing Northern Australia. Farm level investment information and early production data were sourced from the AS18000 mango Planting System Trial at the DPI Walkamin Research Facility to an orchard age of 6 years. Calculations of establishment costs/hectare, annual gross margins/hectare and net cash flow per hectare were calculated and then modelled forwards over a 20-year orchard lifespan.

Plant modelling

Functional-Structural Plant Models (FSPMs) have been implemented to simulate incident light and photosynthesis for each leaf, carbohydrate allocation, tree structural growth and individual fruit size (Auzmendi and Hanan, 2020). These models are being compared to data from ongoing planting systems trials and considered for application to new planting densities. Architectural data collected during AI13004 in young tree branches have been analysed to define relationships that help to understand the results of field experiments, as well as providing knowledge to be used in our models. Orchard models have been implemented to simulate and investigate trade-offs between accumulated yield, planting density, fraction of covered land and tree size.

Results and discussion

Avocado

Planting systems trials

Long-term results from the Planting System Trial indicate that increasing the planting density of avocado orchards may not necessarily lead to higher yields. After seven years of crop production, the cumulative yields across the different planting densities in the trial were not substantially different. While the high-density initially performed better in the first production year, both the low and medium density surpassed the high-density orchards in production in subsequent years. In the later years of the trial, the tree canopies in the different densities had significantly different characteristics. Still, no differences were observed in fruit quality parameters among the different densities.

Interestingly, the light interception was consistently higher in the high-density plots compared to the low-density ones; however, this increased light did not result in higher production levels. Additionally, no consistent differences were found in reproductive development factors, such as fruit set and abscission, across the different densities. We suspect the lower productivity in the high-density, despite the higher light interception, may be attributed to the intensive canopy management required to maintain the high-density canopy (for further details, see Appendix 29).

Findings from the shade netting trial in Carabooda, WA, showed that netting increased avocado fruit set, fruit numbers per tree, and fruit yield by more than 2-fold in 2024 compared to the open area by improving orchard microclimate. These improvements included a decrease in daily evapotranspiration (ET) (by 46-53% for days >20°C), maximum air temperature (by 0.6-1.2°C for days >30°C), maximum wind speed (by 32-44%), maximum solar radiation (by 14-19% for days >20°C), and maximum Vapour Pressure Deficit (VPD) (by 6-8% for days >30°C), and an increase in maximum relative humidity (by 2.0-3.6%). Findings suggest that improving fruit setting during light crop years (i.e., 2024) may ease the irregular bearing cycle of avocado trees, but further monitoring should verify this. Water stress during flowering, fruit set, and early fruit development can result in smaller fruit and significant yield loss (Piccone and Banks, 1991; Cárceles Rodríguez et al., 2023), but no effect of netting was observed on fruit diameter or weight. This could suggest that trees were probably not severely impacted by water stress. Daily sap flow and length of daily growing periods during summer were also not impaired under high VPD (i.e., 7 kPa), regardless of netting, though it is generally understood that avocado trees can limit transpiration by closing their stomata in response to increasing VPD (Whiley et al., 1988; Scholefield et al., 1980).

More research, including different shading percentages, is needed to improve our understanding of avocado physiology (e.g., transpiration and sap flow) in hot and dry environments, particularly at high VPD, which could help growers better manage summer water stress and optimise irrigation and fertiliser timings with crop transpiration and nutrition requirements. By contrast, poor productivity was observed in high-density trees compared to low-density trees under netting due to having younger/smaller trees and poor pollination. Studies show that bee pollination can be limited under netting due to reduced mobility (Mditshwa et al., 2019) and altered visual cues that bees use to navigate when foraging (Kendall et al., 2021). Therefore, the west wall of the net was removed by the grower in late 2024 to encourage pollination in the deeper (northern) part of the net. The grower is also testing alternative pollinators, such as hoverflies (*Eristalis tenax*), to boost pollinator populations. Overall, this study demonstrates that shade netting can enhance water use efficiency and improve avocado productivity in Carabooda, which could help growers manage future reductions in groundwater allocation (for further details, see Appendix 27).

Genetic resources

A long-term assessment conducted over seven years of avocado rootstock and scion cultivars planted at ultra-high planting density reveals that the excessive vegetative vigour of 'Hass' avocados poses a significant challenge for avocado orchard intensification. None of the ten rootstock cultivars tested generated enough reduction in vegetative vigour to support sustainable cultivation of 'Hass' avocados at ultra-high planting densities. Lower-vigour scion varieties like 'Maluma', which require less pruning, performed better in the high-density settings, underscoring the

difficulties presented by the high vegetative vigour of 'Hass'. This suggests that alternative scion cultivars, such as 'Maluma', may be advantageous for orchard intensification. However, other factors, including market acceptance, must also be considered. Successful avocado orchard intensification will require the development of suitable scion or rootstock varieties with lower vegetative vigour. Additionally, innovative canopy management strategies tailored for intensive orchards will be essential. (See Appendix 26 for more information).

The yields of 'Hass' grafted on the 'Ashdot 17' rootstock cultivar were significantly higher than those of all other rootstocks. In fact, its cumulative yield was approximately 90% greater than that of the second-best-producing rootstock, 'BW181'. The 'Ashdot' rootstock series was selected in Israel for its high productivity and adaptability to calcareous soils and saline conditions. A previous assessment conducted in Australia reported that 'Hass' on 'Ashdot' trees generated noticeably smaller canopies while exhibiting the highest yield efficiency, which is measured as crop yield per canopy volume. Therefore, the 'Ashdot' rootstock may be better suited for higher planting densities. Additionally, in this assessment, the 'Ashdot' rootstock was among those that produced the smallest canopies and required less pruning. However, its slightly reduced vegetative vigour was not sufficient to explain the increase in productivity.

'Ashdot 17' also outperformed the popular Australian rootstock 'Velvick' in a separate trial that compared different planting densities. Interestingly, 'Ashdot' yielded better across the high, medium, and low planting densities. Thus, 'Ashdot's' superior productivity in the rootstock assessment isn't solely a result of lower vegetative vigour, which is typically better suited for high planting densities; rather, it stems from its overall high productivity. It appears that when a 'Hass' scion is grafted onto 'Ashdot', there is a greater commitment to reproductive development, leading to improved production. However, we cannot identify a specific genetic trait that accounts for 'Ashdot's' superior performance (see Appendix 26 for more information).

Vigour management using plant growth regulators

Applications of growth retardants have been found to effectively reduce the elongation of avocado shoots and control canopy growth, highlighting their potential for optimising canopy management. The timing of foliage spray applications was found crucial for achieving the desired growth effects. Spraying either paclobutrazol or uniconazole before or during the vegetative bud burst significantly inhibits shoot internode elongation, leading to reduced shoot growth. However, if the spray is applied three weeks after bud burst, its effect on shoot elongation is minimal.

Additionally, a soil drench application of paclobutrazol was also successful in reducing shoot elongation. A single application in late winter resulted in reduced shoot growth over three consecutive flushes—spring, early summer, and summer. With a higher concentration, even the fourth flush in autumn showed a reduction. This application led to a considerable decrease in annual canopy growth but did not impact the quantity or quality of yield for that season. Nonetheless, the yield efficiency of the trees was significantly improved as a result of the treatment (see Appendix 30 for more information).

Root growth

Findings from continuous rhizotron measurements indicate that the spring root flush of avocado in Central Queensland may occur approximately one month earlier than current crop cycle calendars suggest. Analysis of stable nitrogen isotope (^{15}N) uptake shows that the immature leaves from the spring shoot flush act as a stronger sink for nutrients than the roots (see Appendix 28 for more information). Additionally, the study revealed that the tree's root system extends well beyond the dimensions of its canopy. Roots seem to infiltrate the space beneath adjacent trees in the row; however, we believe that the root system is primarily confined to the row and does not extend into neighbouring rows. Future research utilising soil-applied treatments should be designed with more than just one tree serving as a buffer between treatments.

Macadamia

Planting systems trials

Long-term results from the Planting System Trail Phase 1 indicate that increasing the orchard planting density can lead to higher yields, especially in the early years of the orchard (see Appendix 12 for more information). This increased production is attributed to the faster establishment of a significant canopy volume and greater light interception. Thus, a higher planting density may be a valuable technique for optimising production, particularly in the early years of the orchard. Nevertheless, a higher planting density requires earlier, more intensive canopy management, which may be counterproductive. Sustainable production in a higher planting density will depend on the development of effective canopy management strategies, as well as suitable, less vigorous cultivars.

The Macadamia Planting Systems Trial Phase 2 was initiated in August 2023, and only preliminary results are available at this stage. However, the 'P' cultivar trees in the trial produced annual yields exceeding seven tons of nuts in shell (at 10% moisture) per hectare within just five years after planting. This yield is significantly higher than the industry benchmark, which is less than half of this amount. While the effect of different cultivars is generally significant, it is still too early to determine which cultivar is best suited for the intensive conditions of the trial system. Additionally, the tree training strategies and the application of growth retardants being tested in the trial have not shown significant effects on productivity, nut quality, and canopy growth at this early point in the study (see Appendix 16 for more information).

Genetic resources

The rootstocks showed significant genetic diversity, clustering into four distinct groups. Wild species, such as *M. jansanii* and *M. tetraphylla*, formed genetically separate groups, representing the untapped genetic resources with the potential for breeding improved rootstocks. The analysis confirmed that rootstocks significantly influence vigour traits, with some rootstocks showing notable increases or decreases in vigour compared to the standard rootstocks 'H2' and 'Beaumont'. Seedling rootstocks such as *M. jansanii* ('Mjan1'), 'A16,' and a dwarf selection ('BDW3') exhibited reduced vigour, as did cutting-propagated rootstocks like 'Mjan1' and 'BHY3.' Compared to 'H2' and 'Beaumont,' the least vigorous rootstocks ('Mjan1' and 'BDW3') reduced tree height by 18–47%, trunk circumference by 54–74%, and canopy volume by 97–210%. These low-vigour rootstocks offer potential for high-density orchards, reducing costs while maintaining performance. While rootstocks are an efficient means of vigour control, Neal et al. (2016) highlighted that scion contributed 72% of the variance in tree height, while rootstocks accounted for only 23%. This suggests that scion breeding will have a more substantial impact on vigour improvement, and therefore, rootstock and scion breeding should progress concurrently.

Heritability estimates revealed moderate genetic control for several key vigour traits. Tree height and canopy area showed sufficient heritability, indicating that these traits can be improved through targeted breeding programs. Trunk circumference correlated strongly with canopy traits, suggesting it as a reliable, easy-to-measure indicator of early vigour. Analysis of correlations showed a positive correlation of canopy traits between grafted trees and ungrafted trees from the same rootstock accession. This suggests a probable trait transmission from rootstock to scion, allowing low-vigour selections to be used as rootstocks for canopy management. In future, these rootstocks should be evaluated for their effects at a mature age, in different environments combined with multiple scions.

Although the rootstock effect on yield was not significant, breeding accession 'BHI3' seedlings tend to increase the precocity and productivity of 'HAES741' (Appendix 18). Further investigation on multiple scions in multilocation replicated trials is required. Gene expression analysis indicates that PIP genes play a role in controlling scion vigour.

Results from the rootstock assessment comparing the 'Beaumont' and 'H2' rootstocks suggest that 'Beaumont' outperforms and could be a better rootstock choice than H2, particularly for planting on a block with potential drainage issues. More importantly, however, the results clearly show that rootstock choice can have a significant

impact on the orchard productivity, with further implications for management due to differences in tree size, health and uniformity. In the case of 'Daddow' on the vertosol soil, the cumulative yield after eight years from planting was 44% better for 'Beaumont' than 'H2'. This is a considerable potential boost to the orchard's profitability (see Appendix 13 for more information).

Nevertheless, it is incorrect to assume that 'Beaumont' will consistently outperform 'H2'. This trial evaluated only two rootstocks across two soil types using three scion cultivars, which does not provide a reliable basis for predicting outcomes under varying conditions. Noting that this work shows a significant rootstock effect on the potential productivity, conducting additional evaluations of different rootstocks in diverse environments would greatly benefit the Australian macadamia industry.

Vigour management using plant growth regulators

Applications of growth retardants were found to be effective in inhibiting macadamia shoot elongation, resulting in reduced vegetative vigour and a smaller tree canopy (see Appendix 14 for more information). Thus, growth retardant applications can be further developed as a tool for macadamia canopy management. Nevertheless, agrochemicals containing triazole chemicals, such as paclobutrazol and uniconazole, are currently not permitted for commercial use in macadamia in Australia and should not be used until registered.

Computational modelling using an updated self-organising tree model for macadamia (White and Hanan, 2016) suggests that timely applications of PGRs may effectively reduce canopy growth and the need for pruning. While the results may not be exact, they provide valuable insights indicating that more frequent applications could be more effective in limiting canopy growth over time. Additionally, the model suggests that for achieving significant effects, it may be more effective if these applications are initiated earlier in the orchard's life rather than delayed until the orchard reaches maturity. The current model cannot be used to examine the impact of PGR applications on resource allocation, as it was originally developed to assess light interception rather than carbohydrate partitioning (see Appendix 35 for more information).

Productivity

The 'MIV1-G' and 'HAES 344' trees at the Yamba site responded positively to the girdling treatment applied in February, showing an increase in inflorescences and higher crop yields compared to the control and April-girdled treatments. The data on fruit set, measured as the weight of fruit produced per inflorescence per tree, were similar across all treatments and cultivars. In contrast, the 'MCT1' cultivar showed no significant effect from the girdling treatments. This may be due to floral initiation occurring earlier in 'MCT1' than in the 'MIV1-G' and 'HAES 344' cultivars, suggesting that a response might have been observed if the girdles were applied in January or earlier in February. At the Woodburn site, a consistent trend was also noted, indicating that the February girdling treatment increased the number of inflorescences on the trees. Additionally, there was no evidence that the girdling treatments reduced tree height at either site (see Appendix 15 for more information).

The results of the branch girdling trial are mixed. The average number of racemes per branch increased with the December girdling treatment for A4, the September girdling for A38, and the June and December girdling for A203. However, this increase in the number of racemes did not result in a corresponding increase in nut count. September girdling led to an increased nut count in A104, whereas June and December girdling reduced the nut count in A4. The trial did not provide a clear conclusion regarding the potential benefits of branch girdling for optimising productivity (see Appendix 15 for more information).

Economic analysis

Cash flow modelling of 100-hectare plantings at both standard and high density showed that the high-density scenario had relatively higher yield, operating costs and revenue, which ultimately led to higher net cash flow than the standard-density scenario over a 20-year period. Net cash flows for the high-density scenario were initially much lower

than the standard-density scenario due to significantly higher establishment costs. Net cash flows were similar and negative for both scenarios from years 2 to 5, due mainly to similar operating costs during this period. From years 6 to 9 the high-density scenario produced 33% higher yield per hectare than the standard-density scenario, primarily due to the significantly higher number of trees (75% more) and high performance per tree prior to canopies touching. From maturity (year 10) onwards yield in the high-density scenario reduces into a long-term average that remains 12% higher than the standard-density scenario.

When compared with the standard-density scenario over the full 20-year period, the high-density scenario achieved 17% higher yield at 11% higher cost, resulting in 19% higher revenue. This resulted in a 43% difference in cumulative cash flow by year 20 (HD \$15.6M vs SD \$10.9M). A discounted cash flow analysis resulted in a Net Present Value (NPV) for the high-density scenario that was almost \$3.5M higher than the standard-density scenario over the 20-year term (NPV/IRR HD \$11.5M / 11.3% vs SD \$8.1M / 9.9%). See *Cash flow analysis of high-density macadamia plantings* in Appendix 17 for more information.

Mango

Vigour / Rootstock

In mango, few rootstocks have been identified that reduce vegetative vigour while maintaining or increasing canopy yield efficiency, and only 'Kensington Pride' or 'Common' are currently used commercially in Australia. Three field experiments have been established between 2014 and 2025 to screen, select, and evaluate 94 potential rootstocks for scion vigour and yield efficiency effects. In the first trial, rootstock performance with two scion cultivars from the Australian National Mango Breeding Program, 'Yess!' (NMBP-1243) and 'Now' (NMBP-4069) was ranked giving equal weighting to vigour reduction and yield efficiency, relative to the industry standard rootstock, 'Kensington Pride'. Yield efficiency and vigour were generally negatively correlated indicating that scions on rootstocks with greater yield efficiency were generally less vigorous, even if per tree yield was lower in smaller trees. Nearly all rootstocks evaluated were smaller with greater yield efficiency than 'Kensington Pride' as a rootstock, demonstrating the potential for industry improvement. Selections for further evaluation were made based on performance, availability of seed, consistency of results, and genetic variability in progeny (true-to-type).

In a second and third trial planted in 2023, best performing selections from the screening trial were planted with five commercial scions and as ungrafted seedlings. Assessments of ungrafted seedlings suggest that seedling vigour is likely not a good indicator of rootstock dwarfing capacity. Early results suggest that the rootstock effects on scions may not be universal but may dwarf some scion cultivars more than others. Findings between trials at two locations suggest that the rootstock-scion combinations may perform similarly on different soil types and under different management. Ongoing assessment of the second and third field trials is required to clarify effects. A thorough examination of study results and discussion is available in Appendix 8.

Planting systems trial

Years six to ten of the Planting Systems Trial (PST) provided valuable insight into the effects of tree spacing, canopy management and trellising on tree growth and productivity and the interaction of these effects with variety. This is a continuation of work in project AI13004, to study mature orchards however none of the varieties have yet fully filled the allocated tree space in the low-density system suggesting that the low-density system is not yet mature. High-density trellised and slim hedge mango orchard systems have demonstrated a 220 – 310% long-term yield increase per hectare, relative to industry standard production systems, across the 11 years, and 9 harvests they have been studied. The increase in production with planting density appears to follow a saturating function indicating that while more trees increase yield per hectare the benefit diminishes with greater planting density, likely due to inter-tree competition.

Yield was highly dependent upon variety, with peak yields per hectare of 80 (Keitt), 57 (Calypso), and 44 (Yess!) tonnes per hectare per year in year 7 or 8. The three varieties also differed in their response to high-density planting with

'Keitt' having the greatest relative increase compared with low density, and 'Yess!' having the least increase. This is likely due to differences in the vegetative vigour of the varieties. 'Keitt' as the least vigorous of the varieties benefitted from less intertree competition in high density systems and the relative increase in high density production was inflated as trees in the low-density system did not fully occupy their allocated orchard space, limiting their yields. Conversely, 'Yess!' as the most vigorous variety occupied more of the orchard space in the low-density planting and likely suffered from some intertree competition in the high-density planting. This may indicate that highly vigorous scion varieties such as 'Kensington Pride' and 'R2E2' will benefit less from high-density planting than dwarfing scion varieties.

The comparison between the high-density hedge and espalier trellis systems provided insight into the potential benefit of trellising and branch-bending, methods that have been beneficial in advanced apple production systems. There was not a significant yield benefit from trellising or branch bending in this study, indicating that the additional infrastructure and establishment costs would not be recouped. A thorough examination of study results and discussion is available in Appendix 9.

Crop load

The series of crop load and carbohydrate physiology trials provided new insights into how NSC reserve dynamics influence fruit productivity, cropping stress responses, and age-related yield decline.

The cultivar × planting density trial (Appendix 10.1) demonstrated that yield-efficient mango trees exhibit strong leaf functionality and a greater capacity to mobilise and replenish starch reserves. These trees also allocate sugars more readily to reproductive development, following a more 'optimistic' usage pattern, drawing down reserves to lower levels during fruiting and replenishing them more effectively post-harvest. In contrast, cultivars that favour vegetative canopy growth adopt a more 'conservative' strategy, maintaining higher reserve levels but allocating fewer resources to fruiting. 'Keitt' displayed higher yield efficiency and more dynamic NSC cycling than 'Yess!', which retained larger reserves but invested less in fruit production. These findings suggest that cultivar selection for strong leaf functionality and dynamic reserve cycling may improve productivity under intensive orchard systems, and offer new physiological indicators to guide breeding.

The carbon stress trial (Appendix 10.2) resulted in significant NSC reserve depletion in specific tissues, leading to yield reduction and multi-season reproductive penalties. During recovery, trees prioritised canopy regrowth and reserve replenishment over reproductive effort, indicating a physiological shift under carbon limitation, one that favours restoring structural capacity before resuming fruit production. The study also identified tissues that respond more distinctly to NSC source–sink imbalances, providing a basis for more streamlined sampling protocols to monitor recovery from stresses such as heavy cropping.

The diagnostic study in ageing 'Kensington Pride' trees (Appendix 10.3) showed that low-yielding trees exhibited limited starch mobilisation, with reproductive success more closely linked to soluble sugar availability than starch reserve status. This suggests that diminished carbohydrate cycling capacity, potentially influenced by both tree age and cultivar-specific traits, may constrain productivity in ageing orchards. These findings may inform management practices for older blocks.

Fruit quality

The fruit quality assessments conducted over multiple seasons provide practical insights for growers evaluating intensified mango production systems (Appendix 11). High-density systems—particularly the single-leader espalier trellis—were shown to improve blush coverage in varieties such as 'Calyпсо[®]' and 'Keitt', a valuable trait for premium and export markets. However, these systems also recorded higher sunburn severity in some seasons, especially on the west-facing side of trees, likely due to increased afternoon sun exposure. Despite these trends, sunburn severity ratings remained low across all systems and seasons at the Walkamin site, indicating that the overall impact on fruit quality was minimal under the climatic conditions experienced.

Canopy aspect consistently influenced blush development, with fruit on the east-facing side exhibiting greater blush coverage and intensity. This suggests that orchard design and canopy management operations should aim to maximise morning sun exposure to enhance visual fruit quality. The low-density open vase system continued to perform well for sunburn mitigation, though it generally produced fruit with lower blush intensity than some high-density systems. Varietal differences also played a role—'Yess!' stood out for its lower sunburn susceptibility and higher proportion of blushed fruit, making it a strong candidate for high-density planting where both fruit appearance and resilience to sun damage are priorities. Importantly, while sunburn was generally mild, blemishes caused by mango white scale—seen as pink spotting on the fruit surface—was often more visually severe and more likely to result in downgrading. These findings highlight the need to balance system design, variety choice, and management strategies to optimise both yield and fruit quality outcomes.

Economic analysis

Three key outcomes were identified for the economic comparison of investment and performance of planting densities and canopy management systems. Outcome 1, establishment costs/hectare for high-density trellis systems are up to six times that of low-density conventional orchards. Outcome 2, higher density orchards achieve much higher annual gross margins/hectare (difference between annual gross revenue and annual variable costs) than lower density orchards. Outcome 3, the cumulative nett cash flow/hectare became positive across all four systems at a relatively young age (4 years for conventional high density, 5 years for conventional low and medium density and 6 years for trellis high density), but then rapidly accelerated in the systems with increased planting density and intensification.

Overall, this case study concludes the adoption of higher density planting densities requires a higher level of investment during establishment and the first 10 years – but these costs are rapidly recouped by the higher revenues achieved by increased yield per hectare. The full report is publicly available on the Australian Mangoes Best Practice Resource and the CRC for Developing Northern Australia websites.

Plant modelling

Field-based tree canopy architecture measurements were used to simulate growth during one season in young macadamia orchards in their 4th and 6th year after planting. Results showed that in simulations using the FSPM, yield increased with increasing planting density before plateauing and decreasing after reaching a maximum. The older the trees the lower the planting density that produced the maximum orchard yield. Based on the hypotheses generated by our simulations, we reinterpreted field measurements at the Planting System Trial in Bundaberg, as well as previously published data for north-east NSW and south-east Queensland (Appendix 31). Planting 556 trees/ha resulted in a higher accumulated yield after 15 years compared to both 667 trees/ha and 417 trees/ha. Orchards planted at 556 trees/ha produced twice as much fruit as those with only 200 trees/ha (Appendix 31).

The calibration of an orchard model allowed us to calculate the most productive planting densities with more accuracy than previously, for example, the highest productivity over 20 years was achieved at 572 trees/ha (Appendix 32). Orchards with the same land coverage and smaller trees were more productive, however there was an optimal size beyond which benefits decreased. Therefore, canopy management techniques to keep tree size small should be further researched. This model also estimated the time at which trees reached their mature size (11 years at 556 trees/ha, and 15 years at 313 trees/ha).

Branch growth parameters and young macadamia tree productivity seem connected through raceme number, fruit and shoot growth, as well as carbohydrate supply, however, the analysis of these interactions is complex (Appendix 33). The differences in yield between cultivars '741' and 'A203' between 2 and 6 years was not due to the number of racemes per node, percentage of lateral branches or number of nodes per shoot. 'A203' had longer shoots than '741', therefore it does not seem that carbohydrate competition between growing shoots and fruit could explain the difference. For the same tree size, 'A203' had greater production than '741'. Therefore, it seems necessary to study other physiological processes in more detail, such as cultivar differences in immature fruit drop.

The analysis of young mango tree architecture revealed differences between ‘Keitt’, ‘Calypso’ and ‘Yess!’ (NMBP 1243) in terms of vegetative and reproductive growth. These cultivars responded differently to training systems at three planting densities (Appendix 34).

The self-organising macadamia tree model developed during AI13004 was used as the basis for simulating the effect of plant growth regulators on growth (Appendix 35). Simulations showed that applying a PGR in macadamia, which halved internode length, every year from year 3 after planting produced a long-term reduction in tree size, while delaying PGR applications consequently reduced the effect, but could still delay the need for mechanical pruning to maintain size.

FSPM simulations also showed the complexity of the effects of tree architecture and carbon distribution on fruit size spatial variability pattern, i.e., when trees were divided in quadrants according to height and exposure: N, E, S and W, we did not find clearly bigger fruits in the top of the trees and northern exposure, neither in simulations nor in field measurements (Appendix 36). Other approaches with a higher spatial detail could be further researched in species such as mango, for which we have now digitized tree architecture and simulated light environment (Appendix 37).

Outputs

Table 1. Output summary

Output	Description	Detail
Scientific publications Audience: Researchers and Policy makers	31 published journal papers and 1 book chapter comprising: Avocado (2 papers): 1 x rootstock/scion 1 x production systems Macadamia (9 papers): 4 x rootstock/scion 2 x production systems 3 x modelling Mango (18 papers + 1 book chapter): 1 x rootstock/scion 13 x production systems 3 x crop load 1 x modelling 1 x extension theory Multi-crop (2 papers): 1 x modelling (avo/mac) 1 x extension/comms theory (almond, avo, citrus, mac, mango)	The 32 publications are detailed in Appendix 1. 19 of these papers were also presented at horticulture conferences to scientific and industry stakeholders. The publicly-available information within each of these publications contains valuable new discoveries that will increase national and international scientific knowledge and understanding of avocado, macadamia and mango intensification practices. The improved scientific understanding from the 32 scientific publications will underpin future growth of these industries, supporting improvements in productivity, innovation and sustainability. Publication also ensures that this knowledge is available to guide future RD&E investment policy and implementation, to ensure efficiency, effectiveness and collaboration while avoiding duplication of effort.
Conference presentations Audience: Researchers, Growers, Policy makers, Industry Stakeholders	48 presentations comprising: Avocado (4 presentations): 1 x rootstock/scion 3 x production systems Macadamia (22 presentations): 14 x rootstock/scion 4 x production systems 4 x modelling Mango (20 presentations): 1 x rootstock/scion 12 x production systems 2 x crop load	The 48 presentations are detailed in Appendix 1. 19 of these presentations were also submitted as published papers, with much of the information also converted into other industry communications outputs including industry presentations, magazine articles, and fact sheets. Conference presentations are a valuable method to present information to very large and diverse audiences. Conferences included a wide range of scientific forums and also significant grower/industry stakeholder conferences including the World Avocado Congress (2023), Australian Macadamia Conferences (2022 and 2024) and the Australian Mango Conference and Scientific Symposium

	<p>3 x modelling 2 x extension/comms theory Multi-crop (2 presentations): 1 x modelling (avo/mac) 1 x extension theory (almond, avo, citrus, mac, mango)</p>	<p>(2024). These outputs have increase knowledge and understanding of avocado, macadamia and mango intensification practices amongst industry stakeholders and the horticulture scientific communities.</p>
<p>Industry presentations Audience: Growers, agronomists, industry stakeholders, researchers</p>	<p>52 presentations to 1364 participants + 1000 virtual views comprising: Avocado (8 presentations to 366 participants): Macadamia (19 = 15 live presentations to 288 participants + 4 virtual with 1000 views): Mango (25 presentations to 710 participants):</p>	<p>The 52 presentations are included in Appendix 1. Industry presentations were almost entirely conducted within industry events, at the major crop growing regions across regional Australia, co-ordinated by the horticulture peak industry bodies; Avocados Australia, Australian Macadamia Society and the Australian Mango Industry Association or with Hort Innovation. While primarily face-to-face events, virtual webinars were also used. These events provided the greatest opportunity for direct communication, feedback and discussion on progress and project results with growers and stakeholders of the avocado, macadamia and mango industries. Facilitated Q&A sessions at these events provided further communication and awareness of project outputs and assisted growers to understand these in the context of their own growing systems and regional conditions. A total of 366 avocado, 288 Macadamia and 710 mango participants were directly engaged within these presentations.</p>
<p>Industry magazine articles Audience: Growers, agronomists, industry stakeholders, researchers</p>	<p>46 magazine articles comprising: Avocado (8 articles): 8 x Talking Avocados Magazine Macadamia (15 articles): 13 x Australian Macadamia Society News Bulletin 2 x Other Mango (23 articles): 21 x Mango Matters Magazine 2 x Other</p>	<p>The 46 Magazine articles are detailed in Appendix 1. Industry Magazines published quarterly in both hard copy and electronic forms are distributed directly to every Australian grower and to many registered stakeholder subscribers. Approximately 2000 hard copies are published and distributed quarterly (1000 avocado, 500 Mango, 500 Macadamia). This represents a direct engagement method for communicating AS18000 activities and information outputs with industry stakeholders. These magazines are also archived on the industry websites/best practice resources providing long-term accessibility to this information. Certain articles were also disseminated using eNewsletters and social media.</p>
<p>Field days Audience: Growers, agronomists, industry stakeholders, researchers</p>	<p>25 Field Days comprising: Avocado: 6 Field Days Macadamia: 11 Field Days Mango: 8 Field Days</p>	<p>The 25 Field Days are detailed in Appendix 1. Field Days are one of the most grower-preferred R&D communication methods as these provide a practical demonstration of intensification R&D activities and outcomes. The majority of these field days were conducted at the major AS18000 trial sites at the DPI Bundaberg and Walkamin Research Facilities. Other field days were conducted on growers collaborative trial sites or growers own innovative orchards where intensification practices could be practically demonstrated.</p> <p>A total of 223 avocado, 218 Macadamia and 329 mango participants attended the field days. Evaluation of these</p>

		<p>events was undertaken using either the AS18000 Program Event evaluation (online & hard copy), or QDPI evaluation. Ratings varied from 3.5-4.9/5 for “today was worthwhile attending”, with similar results for “content was well presented and opportunity to engage” and “increased knowledge was gained”. Refer to Appendices 2 and 3. The Final Stakeholder Impact Reviews also found that respondents found engagement efforts highly valuable with the following results: Avo- 4.3/5, Mac- 4/5 and Mango- 4.3/5. (Appendices 5,6,7).</p>
<p>Videos</p> <p>Audience:</p> <p>Growers, agronomists, industry stakeholders, researchers, general public</p>	<p>7 Videos comprising:</p> <p>Avocado: 1 video</p> <p>Macadamia: 1 video</p> <p>Mango: 5 videos</p>	<p>The 7 videos are detailed in Appendix 1. Videos are a highly effective method to present information and outcomes from the AS18000 project to a very large and diverse audiences. The videos are highly accessible and easily searchable for the public via various Youtube channels. This enables a long-term method for communicating the latest knowledge and understanding of avocado, macadamia and mango intensification practices to a huge audience. The videos were developed utilising information, knowledge and advice sourced directly from the AI13004 and AS18000 Hort Frontiers projects and project personnel. The allied project; CRC Northern Australia (Transforming Orchard Futures), contributed to the production of a number of the mango videos. At this time (30/5/2025) the 7 videos have received nearly one million views.</p>
<p>Industry Manuals/Fact Sheets</p> <p>Audience:</p> <p>Growers, agronomists, industry stakeholders, researchers</p>	<p>9 Industry Resources comprising:</p> <p>Mango:</p> <p>Economic Case study manual</p> <p>Establishment of high-density orchards manual</p> <p>7 High-density Orchard Management Fact Sheets (Australian Mangoes BPR)</p>	<p>The 7 Industry manuals/Fact Sheets are detailed in Appendix 1. The resources were developed utilising information, knowledge and advice sourced directly from the AI13004 and AS18000 Hort Frontiers projects and from AS18000 project personnel. These resources were then completed and distributed under the allied projects: CRC Northern Australia (Transforming Orchard Futures) and Hort Innovation MG1700 (Building Best Management Practice Capacity for the Australian Mango Industry). Partnering with these allied projects to produce these outputs has enabled greater industry engagement and wider industry impact for AS18000 mango intensification investment.</p>

Photos



Program team members and guests (almond, avocado, citrus, macadamia and mango) at the AS18000 Annual Program meeting, Bundaberg, 2023.

Outcomes

Table 2. Outcome summary

Outcome	Alignment to fund outcome, strategy & KPI	Description	Evidence
Avocado			
1. Improved understanding of factors underlying productivity.	Avocado SIP Outcome 2.2: Develop improved orchard management practices to increase productivity, yield consistency and fruit quality based on enhanced knowledge of tree physiology	<p>The gains in understanding factors underlying productivity are:</p> <p>The industry is more aware of the limited benefits of increasing avocado orchard planting density for maximising long-term productivity.</p> <p>The industry has a better understanding of the detrimental effects of excessive pruning on productivity.</p> <p>The industry is better positioned to take advantage of potential production benefits under shade netting, including the</p>	<p>Avocado Final Stakeholder Impact Review report, “There were gains in knowledge and understanding” = 3/5 (Appendix 5)</p> <p>Increasing the orchard planting density did not improve productivity (Appendix 29).</p> <p>Excessive pruning was identified as a central factor limiting productivity in intensive systems (Appendices 26 and 29).</p> <p>The implications of increasing orchard planting were communicated through an intensification field day, two articles in the Talking Avocados magazine, two industry presentations, and two journal articles (Appendix 1).</p> <p>Shade netting increased avocado fruit set, fruit numbers per tree, and fruit yield by</p>

		ability to optimise orchard microclimatic conditions and promote better productivity.	<p>more than 2-fold in 2024 compared to the open area due to improvements in orchard microclimate (Appendix 27).</p> <p>The advantages of production under shade netting were communicated to the industry in a trial field Walk, an article in the Talking Avocados magazine, and an industry presentation (Appendix 1).</p>
2. Industry awareness of management systems, scion and rootstock selections and their suitability for intensive orchard systems.	<p>KRA1: Development of new knowledge and understanding of intense orchard systems and their components</p> <p>Avocado SIP Outcome 2.1: Identify and evaluate high-performing commercial rootstock varieties in major growing regions</p>	<p>The industry has new knowledge to understand better how the 'Hass' cultivars' high vegetative vigour impacts orchard overcrowding and pruning requirements, creating a notable barrier to avocado intensification.</p> <p>The industry has research-based evidence for the limited availability of rootstock cultivars that promote lower vegetative vigour, indicating that selecting new low-vigour cultivars is essential for sustainable production in intensive systems.</p> <p>The industry now has evidence of the high productivity potential of the 'Ashdot 17' rootstock cultivar.</p> <p>The industry is armed with some promising initial results that growth retardant soil applications can be a valuable tool for optimising canopy management and now believes further investment in the development of this tool is needed.</p>	<p>Avocado Final Stakeholder Impact Review report: <i>"The project was seen to have increased discussion and understanding of the whole- system and interconnecting factors that influence tree growth, productive growth, and drivers of yield-whether in the current or systems of the future. Overall, industry science knowledge and understanding had increased, and growers are more open to talking about the underlying science and how this influences their management, and vice versa."</i></p> <p>The 'Ashdot 17' rootstock has outperformed the second-best cultivar in the assessment by 90%, as well as yielded better than 'Velvick' in normal low-density (Appendices 26 and 29).</p> <p>Soil drench application of paclobutrazol improved the canopy yield efficiency by over two-fold (Appendix 30).</p> <p>The performance of rootstock and scion cultivars in intensive systems was communicated through three field days, an article in the Talking Avocados magazine, a poster at Avo Connections, a poster at a scientific symposium, two industry presentations, and a journal article (Appendix 1).</p> <p>The work of on growth retardants was communicated to the industry through an article in the Talking Avocados magazine and two growers' workshops (Appendix 1).</p> <p>Avocado Final Stakeholder Impact Review report: <i>"The plant growth regulator trial late in the project was considered highly relevant, although suggested it did not go far enough (was more 'proof of concept') and needed more time."</i></p>
3. Understanding	KRA2: Industry stakeholders	The industry has a better understanding of the	Results consistently identify a good correlation between excessive canopy

of canopy management and light relations which may be applicable in conventional orchards.	are more aware of the implications of intensification. Avocado SIP Outcome 2.2: Develop improved orchard management practices to increase productivity, yield consistency and fruit quality based on improved knowledge of tree physiology	implications of canopy overcrowding and excessive canopy management on productivity. The industry has more information to understand better the role of light interception and canopy management in determining the productivity potential of mature avocado intensive systems.	management and a decline in avocado productivity (Appendices 26 and 29). Light interception levels appear to be a minor factor in determining the productivity levels in mature avocado orchards (Appendix 29). Six avocado field days and eight industry presentations provided summaries to the industry on the learnings on canopy management and light interception in intensive avocado orchards. Results from the Avocado & macadamia field days/events evaluation (Appendix 2), Question 7: "Today I increased my knowledge to make more informed decisions" scored highly = 4.1/5
4. Understanding of establishment costs and relative economic performance of intensive production systems.	KRA1: Development of new knowledge and understanding of intense orchard systems and their Components.	Analysis of the relative costs and economic performance of intensive avocado production systems was not feasible as a sustainable model for high-density production has not been identified at this stage.	Avocado Final Stakeholder Impact Review report found that there were three main focus areas needing further investigation: "Future drivers to adoption: 1. <i>Genetics to support smaller, efficient and disease-resistant trees.</i> 2. <i>Design that allows for mechanised systems to reduce labour inputs and increase the efficiency and effectiveness of nutrition, irrigation and pest and disease management.</i> 3. <i>Evidenced business case of changing the whole-of-system required to adopt more intensive systems.</i>
Mango			
Outcome	Alignment to fund outcome, strategy & KPI	Description	Evidence
1. Improved understanding of factors underlying productivity, fruit quality and tree growth in intensive orchard systems.	KRA1: Development of new knowledge and understanding of intense orchard systems and their components. Mango SIP outcome 2:	There were demonstrated gains in understanding on factors underlying productivity: Intensive orchard systems have greater light interception and distribution leading to greater orchard efficiency. Intensive orchard systems were identified as improving fruit quality outcomes due to greater	Mango M&E Stakeholder Impact Review report, "There were gains in knowledge and understanding" = 4/5 Development of new mango knowledge is evident from scientific outputs (19 scientific papers and 20 conference presentations) and industry outputs (25 industry presentations, 23 magazine articles, 8 field days, 5 videos and 9 industry manuals/fact sheets (Table 1 and

	<p>Industry supply, productivity and sustainability.</p>	<p>fruit exposure to light including increased fruit blush, reduced pest damage and slightly increased fruit sunburn.</p> <p>Intensive orchards are more efficient, with a greater proportion of tree energy reserves allocated to fruiting, rather than tree growth.</p> <p>Some varieties may be more suitable in intensive orchard systems due to their ability to effectively use carbohydrate reserves.</p> <p>Inter-tree competition for resources such as light appears to reduce tree growth rates in intensive systems.</p> <p>Scientific understanding improved through conference participation, publication of scientific papers, and AS18000 collaborative meetings. Industry understanding improved through grower field days, industry conferences, events and magazine articles. This is relevant at the fund level by enabling growers to increase farm productivity.</p>	<p>Appendix 1).</p> <p>Specific understanding of productivity, light, and tree growth (Appendices 8 and 9), fruit quality (Appendix 11), and the underlying importance of carbohydrates and crop load (Appendix 10) in intensive orchard systems has been improved and communicated to the scientific and industry communities.</p>
<p>2. Industry awareness of fundamental relationships between key orchard components and their effect on productivity in intensive systems with trees aged 6 to 12 years.</p>	<p>KRA2: Industry stakeholders are more aware of implications of intensification.</p> <p>Mango SIP outcome 2: Industry supply, productivity and sustainability.</p> <p>Mango SIP outcome 3: Extension and capability.</p>	<p>Industry awareness in this topic was built through extension activities, in particular field days, due to their hands-on, informal structure. This is relevant at the fund level by supporting skill and knowledge development in the mango industry to increase productivity.</p> <p>Mango M&E Stakeholder Impact Review report summary, <i>“Each component of the research was considered relevant by the respondents to build a whole-of-system appreciation for how, and to what extent, manipulation of the tree and/or orchard environment had physiological and yield</i></p>	<p>Mango field days response, “today I increased understanding of practices for intensified orchard systems” = 4.1/5 (Appendix 3).</p> <p>Mango M&E Stakeholder Impact Review report, <i>“There has been a big improvement [in knowledge], for sure. The light penetration into the tree and the way we need to prune. Carbohydrate influences more production means more carbohydrate. Have definitely been able to transfer knowledge to other varieties too”.</i></p>

		<i>implications.”</i>	
3. Industry awareness of new vigour controlling rootstocks.	KRA2: Industry stakeholders are more aware of implications of intensification. Mango SIP outcome 2: Industry supply, productivity and sustainability.	Industry is aware of the importance of dwarfing rootstocks as a foundational tool for intensification. Three rootstock cultivars of good potential have been identified from AS18000 trials and are being tested with multiple commercial mango scions. Industry are aware of the long time required for rootstock selection and many growers have offered to host rootstock trials on their farms. This is relevant at the fund level as it supports improvements in productivity and sustainability.	Mango M&E Stakeholder Impact Review report, <i>“Regarding rootstocks, that is going to be the real big one. If you're able to get orchards smaller and more efficient to harvest, it's a big winner...but it will be more like 10 years”</i> . Rootstock trial 1 has completed and rootstock trial 2 is underway with industry scions and multiple locations (Mango Matters article on Mango rootstock selections, Appendix 1). Industry request for presentations on rootstock selection at 2024 Australian mango symposium and 2025 Mango industry R&D symposiums in Darwin, Mareeba, Ayr and Carnarvon.
4. Understanding of canopy management and light relations that may be applicable in conventional orchards.	KRA1: Development of new knowledge and understanding of intense orchard systems and their components. Mango SIP outcome 2: Industry supply, productivity and sustainability.	Growers and researchers have built understanding of canopy management such as pruning and light in relation to impacts on fruit quality which has been presented at industry conferences, field days and a webinar video recording on the Australian Mangoes BPR website. In addition, the response to light intensity at the leaf and tree scale has been determined. This information has supported growers in decision making regarding current and future climate risks and management options.	2022 Field day, <i>“Understanding of canopy management and light impacts on fruiting and quality” = 4/5</i> . Mango M&E Stakeholder Impact Review report, <i>“The light intensity work going on is so relevant to WA, and highly relevant to our growers. Fruit quality and understanding light through the canopy and how to manage this better.”</i> Presentation on light distribution and use at Australian Mango Symposium, 2024 and Orchard Systems conference in New Zealand, 2025 (Appendix 1).
5. Understanding of establishment costs and relative economic performance of intensive production systems	KRA2: Industry stakeholders are more aware of implications of intensification. Mango SIP outcome 4: Business insights for informed decision making.	An economic analysis was conducted based on modelling of the the results from the mango Planting System Trial. Key findings were: 1. Establishment costs/hectare for high-density non-trellis and trellis systems were up to three and six times higher than low-density conventional orchards. 2. Higher density orchards however, achieved much higher annual gross margins/hectare (difference between annual gross revenue and annual	Mango M&E Stakeholder Impact Review report, <i>“Understanding HD with trellising & costs in Australia has been important. It can be done elsewhere, but here it's more important.”</i> <i>“HD [High density] has been influenced by understanding the science- and that HD is good enough without the high-cost trellis”</i> . The economic report is available on the Australian Mangoes BPR and CRCNA websites where it has been accessed 52 times in 12 months. A summary Fact Sheet is also included on the Mango BPR website. Economic information was presented at Northern Australia Food Futures

		<p>variable costs) than lower density orchards.</p> <p>3. The cumulative nett cash flow/hectare became positive across all systems at a relatively young age (4 years for conventional high density, 5 years for conventional low and medium density and 6 years for trellis high density). It then rapidly increased in those systems with increased planting density demonstrating the long-term benefits of intensification.</p>	<p>Conference, 2021, during the 2021 Mango Industry Roadshow Series, and within a Mango Matters Magazine article “High-density mangoes – more mangoes, but more profit?”. (Appendix 1).</p> <p>Three large mango growers/cooperations have also requested additional economic data to advance their own cost-benefit analysis.</p>
Macadamia			
Outcome	Alignment to fund outcome, strategy & KPI	Description	Evidence
1. Improved understanding of factors underlying productivity.	Macadamia SIP outcome 2.2: Increase resource use efficiency (water, nutrients) through better understand of physiology requirements for optimum nut set, and abscission in integrated orchard management	<p>The industry has a better understanding of the impact of canopy volume establishment rates and light interception on the productivity potential of young orchards.</p> <p>The industry is now more aware of the extensive canopy management requirements in mature intensive orchard systems and their implications for productivity.</p> <p>Computational simulations have enabled a better understanding of the interplay between yield, planting density, land coverage, and age.</p> <p>Branch growth analyses using data from the Bundaberg PST experimental work have allowed a better understanding of yield efficiency as a function of tree size, as well as characterising the interplays between yield, flowering and vegetative growth for cultivars ‘741’ and ‘A203’.</p>	<p>Macadamia M&E Stakeholder Impact Review report, “There were gains in knowledge and understanding” = 3.5/5 (Appendix 6)</p> <p>Young orchard productivity is highly dependent on canopy growth (Appendix 12).</p> <p>Light interception levels appear to be a secondary factor in determining productivity levels in mature intensive orchards (Appendix 12).</p> <p>The learnings on factors underlying productivity (such as light interception and canopy management) were communicated through four field days, a poster at the AusMac 2024 symposium, two AMS masterclass sessions, and two articles in the AMS New Bulletin (Appendix 1).</p> <p>The findings from the computational simulations and modelling of branch growth were communicated in publications in scientific journals, industry magazines, and growers’ field days (Appendix 1).</p>
2. Industry	KRA1: Development of new knowledge	The industry has research-based evidence to support the benefits of orchard intensification for	Macadamia M&E Stakeholder Impact Review report, “ <i>The knowledge that HD does give you higher early yield, because</i>

<p>awareness of fundamental relationships between key orchard components and their effect on productivity over the life of the orchard.</p>	<p>and understanding of intense orchard systems and their components</p>	<p>optimising productivity and profitability.</p> <p>Computational simulations suggest that maximum productivity over the 20 years of orchard lifetime is achieved at planting densities of around 572 trees/ha, based on published data from SE QLD and NE NSW.</p>	<p><i>beforehand, that was not a given- now there is the evidence. That was a very important concept to demonstrate. There is a greater understanding of the system's nature of Macadamia now, so the variety can be "fit for purpose".</i> (Appendix 6)</p> <p>The cumulative yield 10 years after planting was approximately 30% higher in a high-density system than in a traditional low-density system (Appendix 12).</p> <p>Key findings on the impact of planting density on orchard productivity were presented to the industry at the AusMac2024 symposium, Macadamia Field Days at Bundaberg in July 2024 and May 2025, and in articles in the AMS New Bulletin (Appendix 1).</p>
<p>3. Industry awareness of management systems, scion and rootstock selections and their suitability for intensive orchard systems</p>	<p>KRA1: Development of new knowledge and understanding of intense orchard systems and their components</p> <p>Macadamia SIP outcome 2.2: Develop new genetics & trait improvements via breeding to support the development of elite scion varieties</p> <p>Macadamia SIP outcome 2.3: Develop new systems for orchard intensification, including tree size and architecture</p>	<p>The industry strongly supports further investment in growth retardant applications to optimise canopy management in intensive systems.</p> <p>The industry has research-based evidence showing that the choice of rootstock cultivar in the orchard can significantly affect tree health and productivity.</p> <p>The industry is aware of the benefits of the Beaumont rootstock cultivar, especially when planting in areas with poor drainage.</p> <p>The rootstock trial conducted at Nambour has allowed a better understanding of the effect of a diverse range of rootstocks on vigour, precocity and productivity using the scion 'HAES741'.</p>	<p>Macadamia & avocado event and field days evaluation, Question 7 on “gained increased knowledge to make more informed decisions” = 4.1/5 (Appendix 2).</p> <p>Macadamia Farm Management (MFM) is developing 15,000 hectares of intensive macadamia orchards in the Bundaberg area, demonstrating a high adoption rate of the project's learnings. AMS Bulletin article, p 22-24, Winter 2025 (Appendix 1).</p> <p>The study on growth retardant applications to optimise canopy management is continuing via funding from the new MC23004 project.</p> <p>The cumulative yield after eight years from 'Daddow trees planted on a Vertosol soil was 44% better when grafted on the 'Beaumont' than the 'H2' rootstock (Appendix 13).</p> <p>Key findings on the performance of new cultivars were presented to the industry at the AusMac2024 symposium and the Macadamia Field Day in Bundaberg in May 2025. An article was published in the peer-reviewed journal “Scientia Horticulturae” and also published in the AMS News Bulletin. (Appendix 1).</p>
<p>4. Understanding of canopy</p>	<p>KRA1: Development of new knowledge and understanding</p>	<p>The industry has gained a clearer understanding of how light interception contributes differently to the productivity</p>	<p>Macadamia M&E Stakeholder Impact Review report: <i>“There has been some practical stuff. The most tangible that I can see is confidence for canopy management-</i></p>

<p>management and light relations which may be applicable in conventional orchards.</p>	<p>of intense orchard systems and their components</p>	<p>potential of young versus mature orchards.</p> <p>The industry has a better understanding of the earlier and higher canopy management requirements in intensive orchards, which are directly linked to system management costs.</p> <p>The industry has a better understanding of how girdling can optimise canopy resource allocation to enhance productivity.</p>	<p><i>e.g, PGRs, pruning to control vigour, and I know of people like [name removed] it has given the confidence to people like him. It has just scratched the surface though; it has highlighted what is possible. It has given people another tool in PGRs, and the breeding program” (Appendix 6).</i></p> <p>Light interception is a key factor in the productivity of young orchards. However, it becomes secondary as the orchard matures (Appendix 12).</p> <p>Trunk girdling appears as an effective tool for optimising productivity. At the same time, girdling branches do not show a clear benefit (Appendix 15).</p>
<p>5. Understanding of establishment costs and relative economic performance of intensive production systems.</p>	<p>KRA2: Industry stakeholders are more aware of implications of intensification.</p>	<p>The analysis of cash flows associated with both high and standard-density planting systems has resulted in the availability of detailed data relating to farm establishment and ongoing operating costs for both non-bearing and bearing plantings.</p>	<p>Analysis of cash flows for establishment and operation of a high-density vs conventionally spaced macadamia production system in the Bundaberg region over 20 years showed a 42% gain in net present value (NPV) and 1.4% increase in the internal rate of return (IRR).</p> <ul style="list-style-type: none"> • High-density: NPV \$11.5M IRR 11.3% • Conventional: NPV \$8.1M IRR 9.9%. <p>Reporting and communicating these case study findings to industry has provided stakeholders insight into expected costs, returns and subsequently profitability of a high-density production system:</p> <ul style="list-style-type: none"> • AMS News Bulletin Vol 53 No. 2 and • Macadamia Field Day Bundaberg, May 2025 (Appendix 1) • Macadamia high-density cash flow analysis (Appendix 17)

Monitoring and evaluation

Table 3. 2023 Mid-term Review of AS18000 Program (RMCG, 2023; Appendix 4). Criteria scores were 1 (most negative) to 5 (highly positive).

Key Evaluation Criteria	Avocado	Macadamia	Mango	Almond	Citrus	Average score (5 crops)
C1. Effectiveness	2	4	4	3	4	3.4
C2. Efficiency	2	2	4	3	3	2.8
C3. Relevance	2	2	4	3	4	3.0
C4. Appropriateness	2	4	4	3	4	3.4
Total Score (Max. 20)	8	12	16	12	15	12.6

Table 4. 2025 Final Stakeholder Impact Review of AS18000 Program (ICD Project Services, 2025; Appendices 5,6,7). Criteria scores were 1 (most negative) to 5 (highly positive).

Key Evaluation Criteria	Avocado	Macadamia	Mango	Almond	Citrus	Average score (4 crops)
C1. There were gains in Knowledge & Understanding (Effectiveness)	3.0	3.5	4.0	3.9	Na	3.5
C2. Engagement activities were of value (Efficiency)	4.1	4.0	4.6	4.4	Na	4.2
C3. The R&D was relevant to future needs (Relevance)	3.2	3.9	4.3	3.5	Na	3.8
C4. There are signals of adoption (Appropriateness)	2.6	2.9	3.6	2.3	Na	3.0
Total Score (Max. 20)	12.9	14.3	16.5	14.1	Na	14.5

Table 5. Key Evaluation Questions

PROGRAM LEVEL		
Key Evaluation Question	Project performance	Continuous improvement opportunities
1. To what extent has the program developed a greater understanding of the physiological, genetic, agronomic, and economic factors impacting on intensification in the selected tree crop industries?	The Final Impact Review interviews indicated a high level of confidence that the program delivered improvements in both new science and practical management knowledge to stakeholders with the program receiving a C1. Effectiveness score of 3.5/5.0 and a C3. Relevance score of 3.8/5.0 (Table 4, Appendix 5,6,7).	Improvements could be made in communicating and sharing knowledge between program teams. COVID restrictions in 2021/21 impeded early collaboration, however knowledge sharing improved towards the end of the project. Annual regional meetings, regular virtual meetings and seminars were successful methods utilised.

<p>2. To what extent have the growers and other industry stakeholders demonstrated awareness, interest, and intentions to act on the findings and emerging recommendations – or have already done so?</p>	<p>The Final Impact Review interviews contained positive responses, with the program scoring highest in C2. ‘Engagement activities were of value’ 4.2/5.0, and C3. the ‘R&D was relevant’ 3.0/5.0. However C4. ‘Appropriateness (signals of adoption)’ were lower and varied greatly between crops (eg avocado 2.6/5.0 vs mango 3.6/5.0), indicating a continued need for work in this area. In general there were two main stakeholder views on the adoption of intensified orchard systems. Some foresee there will be a gradual shift to medium density constrained by existing infrastructure, while others believe high-density adoption is already underway, driven by project outputs and outcomes. (Table 4, Appendix 5, 6, 7).</p>	<p>There was good grower and stakeholder awareness and interest in the programs outputs and outcomes, however there is still further need for focused R, D & E to facilitate commercial industry adoption at a larger scale. Activities with shorter adoption timelines (eg canopy management) will have more rapid uptake than others, such as planting density which requires renewal of an entire orchard block.</p>
<p>3. To what extent has the program and its projects effectively engaged their respective industries in providing input into research and extension activities and influenced the outcomes of the project</p>	<p>Crop Reference Groups, (growers and industry stakeholders) met biannually with individual crop teams, and provided significant advice and support to project delivery and outcomes. Many of the CRG members and collaborating or ‘champion’ farmers were included in the project review surveys. These surveys found that industry engagement increased throughout the program, with total stakeholder review feedback for all crops, across the 4 key evaluation criteria improving from 12.6/20 at the Mid-term review to 14.5/20 at the Final review. (Tables 3 and 4). Evaluation results found participants at major project events consistently rated average score of 4.5 out of 5 in response to the statement, “Overall, today was worth attending.” (Appendices 2, 3).</p>	<p>Crop reference groups worked well to engage industries in providing input into research activities. (Some growers felt that greater flexibility in program structure and outcomes was needed to fully enable adaptation to industry input.) Regular engagement of CRG members, collaborative farmers, peak industry bodies and champions of intensification helped adapt and refine R&D activities, and demonstrate the practicality and commercial viability of these practices.</p>
<p>4. What was the reach (to growers and consultants) within the different industries and how effective were the different segments of the industries engaged in activities and/or accessed project information and outputs?</p>	<p>The project achieved broad reach across the mango, avocado, and macadamia industries, with a very large number of communications outputs (Table 1, Appendix 1). Output numbers were larger for crops where the grower readiness for adoption of these intensification technologies was more advanced (e.g. mango and macadamia). More than 500 growers and consultants were engaged through face-to-face field days, workshops, and trial visits. For those unable to attend in-person activities, videos and webinars were widely accessed, achieving over 3,000 views. Industry segments varied in their level of engagement, with the most effective uptake observed where information was supported by demonstration sites and reinforced by early adopters. R&D and case study articles published in industry magazines further extended the project’s reach and enhanced awareness across the broader industry (Appendix</p>	<p>The effectiveness of industry engagement could be improved further by ensuring a greater proportion of industry extension activities are planned towards the conclusion of the project, as it is difficult to present project information or outputs in early stages. Conversely, consultation on project objectives, design and progress should be skewed to the earlier phases of the project to ensure sufficient flexibility and time remains in project activities to adapt to feedback.</p> <p>Outputs including grower case studies, on-farm demonstration trials and grower innovator presentations were particularly</p>

	1). The Final Review rated C2. 'engagement activities' highest of all surveyed criteria with an overall score of 4.2/5.0.	well received by industry and should be continued in future initiatives to facilitate adoption.
<p>5. To what extent did the program and its projects modify activities or outputs based on feedback and input from stakeholders and their own experience and the Crop Reference Groups to improve efficiency and effectiveness of the project?</p> <p>To what extent did collaboration occur between projects/industries to share knowledge and approaches to benefit activities in other industries?</p>	<p>The program was highly responsive to stakeholder and CRG input, with several activities and trial management approaches adapted to better align with industry needs. CRG membership was actively maintained, with new members recruited as required. Event formats, technical content, and communications were refined based on feedback, incorporating flexible delivery methods such as webinars, videos, and hybrid CRG meetings. Cross-industry collaboration, particularly between the mango, avocado, and macadamia, was demonstrated through shared workshops (e.g. the joint macadamia–avocado 2023 Workshop), facilitating knowledge transfer and greater project efficiency. The Final Stakeholder Review ranked C2. efficiency highest at 4.2/5.0, with good responses for relevance 3./5.0 and effectiveness 3.5/5.0. (Table 4, Appendix 5, 6, 7).</p>	<p>Improvements in comparing and sharing knowledge between tree crop industries would be beneficial. COVID restrictions and high project staff turnover also slowed the development of collaboration between crops. Cross-crop annual meetings were highly effective and could be used to address these issues earlier in the program.</p>
Avocado		
Key Evaluation Question	Project performance	Continuous improvement opportunities
<p>To what extent have management practices been developed that combine to result in productive intensive systems despite the lack of genetic vigour control in other rootstocks or scions?</p>	<p>Growth retardants applied via soil drench were found to be an effective management tool for reducing the tree vegetative vigour and increasing canopy yield efficiency.</p> <p>Production under shade netting was found beneficial for optimising the orchard microclimatic conditions that may promote better productivity.</p>	<p>Maximising the adoption of growth retardant applications as a tool for optimising canopy management will require reliable information about the long-term effects on canopy growth and productivity. This should include an examination of how these applications impact pruning requirements, as well as the accumulation of the chemicals in the tree canopy and any residues present in the fruit.</p> <p>More research, including different shading percentages, is needed to better understand avocado physiology in hot and dry environments, particularly at high VPD, to help growers better manage summer water stress and</p>

		optimise irrigation and fertiliser timings with crop transpiration and nutrition requirements. Research should also verify if improving fruit setting during light crop years may ease the irregular bearing cycle. Additional work should assess the benefits of tree intensification under netting, particularly when trees are mature and not impacted by pollination and/or age difference, and how pollination can be improved under netting.
To what extent has greater understanding been gained and shared on scion options, and the need for scion specific management, for intensive systems?	<p>The project findings highlight that the excessive vegetative vigour of the popular 'Hass' scion presents a significant challenge for intensifying avocado orchards. None of the ten rootstock cultivars tested were able to sufficiently reduce vegetative vigour to enable sustainable cultivation of 'Hass' at ultra-high planting densities. In contrast, lower-vigour scion varieties, such as 'Maluma', which require less pruning, performed better in high-density settings. This emphasises the difficulties posed by the high vegetative vigour of 'Hass' avocados.</p> <p>The 'Ashdot 17' rootstock cultivar has been recognized as a highly productive option and could provide considerable benefits to the avocado industry in Australia.</p>	<p>Alternative scion cultivars, such as 'Maluma', may be advantageous for orchard intensification, however other factors, including market acceptance, must also be considered. Successful avocado orchard intensification will require the development of suitable scion or rootstock varieties with lower vegetative vigour.</p> <p>The performance of the 'Ashdot 17' rootstock cultivar should be evaluated further in various growing environments to validate its superior productivity and encourage potential adoption.</p>
To what extent have there been gains in understanding of the factors that affect plant resource allocation and of management practices that can be used to manipulate allocation to increase crop load?	The results of the project enhance our understanding of the antagonistic relationship between reproductive and vegetative development in avocado trees. This relationship is characterised by competition for carbohydrate resources necessary for growth and is a crucial factor influencing the productive potential of the orchard systems.	A better understanding of the different options for canopy management and their impact on the balance between reproductive and vegetative development is critical for improving avocado productivity. This may include exploring the impact of different pruning timings and using PGRs to manipulate resource allocation.
Macadamia		
Key Evaluation Question	Project performance	Continuous improvement opportunities
What new understanding has been gained on physiological and production systems	The results of the project clearly demonstrate that higher planting density can be an effective strategy for increasing production, especially in the early years of an orchard. The production potential of	After outlining the potential benefits of intensifying macadamia orchards, it is essential to focus on further

<p>limitations to orchard productivity and the implications for intensification?</p>	<p>young orchards relies heavily on achieving a significant canopy volume. A larger canopy volume enhances early light interception, leading to increased production potential. However, in mature intensive orchards, light interception does not seem to be the primary factor influencing production levels. Instead, canopy management may play a crucial role in determining productivity in these mature orchards. In high-density orchards, effective canopy management becomes even more important due to the significant pruning requirements involved.</p>	<p>optimising the system. The two main opportunities are identifying the most suitable cultivars for intensive systems and developing effective canopy management strategies to unlock the system's potential.</p>
<p>To what extent have there been gains in understanding about canopy management, tree training and other factors impacting on early fruiting and the productivity/profitability implications?</p>	<p>Applying growth retardants via soil drenching effectively reduces the vegetative vigour of trees and can improve canopy yield efficiency. This evidence suggests that the application of growth retardants could be developed as a canopy management tool for intensive orchards.</p>	<p>To maximise the potential adoption of growth retardants as a tool for canopy management, it is essential to have reliable information about their long-term effects on canopy growth and productivity. This should include an evaluation of how these applications affect pruning requirements, the accumulation of chemicals in the tree canopy, and potential residues in the kernel.</p>
<p>To what extent has greater understanding been gained and shared on rootstock and scion options supporting intensification?</p>	<p>The comparison between the Beaumont and H2 rootstocks has shown that selecting the right rootstock can significantly impact orchard performance. This effect is especially noticeable when growing in challenging soil conditions, where a rootstock that is better adapted to the specific stress can prove to be extremely valuable.</p> <p>Trees of the new scion cultivar P, grown in an intensified orchard system, achieved yields of over seven tons of nuts in shell (at 10% moisture) per hectare within just five years of planting. This yield is significantly higher than the industry benchmark, which is less than half of that amount. This highlights the very high production potential that can be achieved by utilising superior cultivars in intensive orchard systems.</p>	<p>New cultivars should be assessed for their performance and suitability in intensive orchards. Selecting new rootstock varieties that promote lower vegetative vigour can significantly enhance sustainable production in intensive systems.</p>
<p>Mango</p>		
<p>Key Evaluation Question</p>	<p>Project performance</p>	<p>Continuous improvement opportunities</p>
<p>To what extent have promising root stocks been identified for their potential to suit intensification and trials</p>	<p>Promising rootstocks for future mango intensification have been identified. The initial phase of rootstock screening has been completed with promising candidate varieties identified. These candidates were then taken forward to a</p>	<p>Rootstock seed propagation has slowed this activity due to the approximate two-year lag between seed collection and planting. Seed availability has also</p>

<p>commenced to test that suitability?</p>	<p>new trial currently underway incorporating a wide range of commercial scions and two growing environments. Rootstocks were assessed on their capacity to dwarf scions and for high yielding, characteristics necessary for suitability in intensified systems. See Appendix 8.</p>	<p>limited the number of locations trials can be undertaken. Clonal mass propagation methods for mango are currently undeveloped. R&D in mango propagation will be necessary to achieve large-scale clonal rootstock adoption.</p> <p>Additional support for this activity would enable further rootstock trials on commercial farms in mango-growing region, allowing stronger selection, and greater industry confidence in future.</p> <p>Methodological consistency could be improved to ensure data quality given the long periods of time for this activity.</p>
<p>To what extent has new understanding been gained in relation to canopy management and light capture and its impacts on production and fruit quality?</p>	<p>New understanding has been gained and extended on the effect of intensified production on light interception, light distribution, leaf structural, chemical, and functional adaptation, tree canopy response to light, and productivity (Appendix 9).</p> <p>Knowledge has also been generated regarding the effect of canopy management and planting density on light related fruit quality attributes such as fruit blush, sunburn, and pest damage (Appendix 11).</p>	<p>Assessment of a wider range of orchard production systems would provide a greater variety of choice to growers.</p> <p>Assessment in diverse growing regions is needed given differences in light intensity, availability due to differences in latitude, and pest pressures. Fruit quality pressures may differ between regions.</p>
<p>To what extent has there been new understanding gained and shared about fundamental relationships between orchard components and productivity?</p>	<p>New knowledge has been gained and shared regarding the relationship between flowering panicle density and yield, leaf-to-fruit ratios and productivity, fruit quality, carbohydrates, and tree recovery, and between canopy management and tree yield, carbohydrates, and tree performance.</p> <p>New insights were generated on how cultivar traits, carbohydrate reserve dynamics, and crop load stress affect fruit productivity and recovery. Findings highlighted key physiological traits (e.g. NSC mobilisation patterns, leaf functionality) that underpin yield efficiency and age-related decline. These were shared through industry reports, technical appendices, and future journal publications (Appendix 1).</p>	<p>Broader validation across cultivars, orchard regions, and management conditions is needed to strengthen industry relevance. Future work should assess how inputs such as pruning, PGRs, fertilisation, and irrigation influence NSC dynamics and inter-seasonal crop load relationships. Streamlining NSC sampling protocols and linking reserve status to productivity thresholds will support commercial decision-making.</p>

Recommendations

Program level

- The collaborative multi-crop AS18000 Program strategy increased research capacity across the five crops, which facilitated improved R, D & E outcomes, and should be continued as a model for future projects.
- Farmer engagement and integration were critical to the Programs success, offering valuable guidance on project design and management while challenging research teams to ensure new orchard designs and management practices were practical and commercially viable.

Avocado

- High-density avocado planting is currently limited by the lack of suitable cultivars and effective canopy management strategies, highlighting the need for the investigation of new, low-vigour cultivars.
- 'Ashdot 17' shows the most promise as a rootstock for intensive systems, its higher productivity should be further evaluated across diverse growing environments to support broader adoption.
- Soil drench applications of growth retardants show good promise for controlling canopy vigour and enhancing canopy yield efficiency to support orchard intensification.
- Optimising orchard productivity requires canopy management strategies that prioritise yield efficiency over light interception, while also supporting consistent crop loads to reduce irregular bearing.
- Shade netting with a 12% roof shade has shown to enhance avocado water use efficiency and productivity in hot, dry climates. Future research into tree physiology under different shading levels is needed to help growers better manage summer water stress, particularly under high vapour pressure deficit conditions.

Macadamia

- High-density macadamia plantings can boost productivity and generate greater long-term cash flows compared to standard densities; however sustained high productivity is essential to offset higher establishment and operating costs. Long-term analysis of variety and production system interactions and their effects on productivity and profitability is needed to fully assess the economic benefits of intensification.
- Soil drench applications of growth retardants can be used to reduce canopy size, presenting a promising tool for orchard management. Their long-term potential to improve canopy yield efficiency warrants further investigation.
- Maximising future macadamia productivity and orchard efficiency will depend on strategic rootstock and scion selection. Further multi-site trials should prioritise dwarfing rootstocks such as 'BDW3', 'BHI1' and 'M. jan1', evaluate new compact, high-yielding scions and potential dwarfing rootstocks from the Hort Innovation Macadamia Breeding Program, and the use of 'Beaumont' rootstock for poorly drained sites.

Mango

- Increased planting density has increased productivity and profitability in mango, setting the stage for further intensification benefits through multi-leader non-trellis and trellised canopy systems, as achieved in other horticultural industries. To ensure greater applicability, these systems must be rigorously tested across regions, climates, and both current and new varieties for productivity and fruit quality outcomes.
- Ongoing evaluation of the promising, vigour-reducing rootstock selections with commercially relevant scions, is essential as stage two of development begins. Expanding trials across diverse production regions will identify regional influences on rootstock performance and suitability.
- A good basic understanding of carbohydrate dynamics in mango has now been established. Future work should investigate treatment options to manage carbohydrates with a view to increasing productivity and reducing interannual yield variability.
- Long-term assessment of mature high-density orchard systems will be crucial for guiding industry adoption. Real-world data from fully mature plantings, will give growers greater certainty around lifetime performance

and profitability. This evidence is essential for updating economic models with actual productivity figures, costs and returns, enabling confident, informed investment decisions.

Plant modelling

- Future modelling must integrate field data from mature tree trials across diverse regions, adapting orchard and functional-structural plant models (FSPMs) to multiple species, cultivars, and training systems for robust, scalable insights.
- Incorporating additional physiological processes, such as carbohydrate reserves and phytohormones, will enhance model applicability to real-world scenarios including canopy management, fruit drop, climate variability, and yield fluctuations.
- Continued analysis of tree architecture data from planting systems trials is needed to clarify yield efficiency relationships, while exploring alternative, more efficient modelling approaches for whole-tree simulations.

Refereed scientific publications

There were 31 journal articles, and 1 book chapter published or accepted that can be attributed or partly attributed to this project (Attachment 1). This includes two avocado, nine macadamia, nineteen mango and two for multiple crops.

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Intellectual property

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Appendices

Appendix 1 – All crops communications outputs

Appendix 2 – Avocado and Macadamia field day evaluation all years

Appendix 3 – Mango field day evaluation all years

Appendix 4 - All crops midterm review 2023

Appendix 5 – Avocado final stakeholder impact review report 2025

Appendix 6 - Macadamia final stakeholder impact review report 2025

Appendix 7 - Mango final stakeholder impact review report 2025

Appendix 8 - Mango rootstocks

Appendix 9 – Mango planting system trial and light

Appendix 10 – Mango crop load (carbohydrates)

Appendix 11 – Mango fruit quality

Appendix 12 – Macadamia Higher planting density improves macadamia orchard productivity

Appendix 13 – Macadamia rootstock comparison Beaumont vs H2

Appendix 14 – Macadamia Potential use of triazole growth retardants as a tool for canopy management in macadamia

Appendix 15 – Macadamia Trunk and branch girdling effect on macadamia productivity

Appendix 16 – Macadamia Early results from the phase 2 macadamia plant systems trial

Appendix 17 – Macadamia cash flow analysis of high-density plantings

Appendix 18 – Macadamia rootstock trial update

Appendix 19 – Macadamia MRF rootstock trial summary

Appendix 20 – Macadamia QAAFI poster ASHS2024

Appendix 21 – Macadamia QAAFI poster ICTP

Appendix 22 – Macadamia QAAFI poster IECPS2021

Appendix 23 – Macadamia QAAFI poster TropAg2022

Appendix 24 – Macadamia QAAFI poster AusMac24

Appendix 25 – Macadamia QAAFI AMS article 2024

Appendix 26 – Avocado Assessment of avocado rootstock and scion varieties in an ultra-high planting density

Appendix 27 – Avocado production under netting

Appendix 28 – Avocado Quantifying the timing of avocado spring root flush and concurrent nitrogen uptake-allocation through rhizotron imaging and ¹⁵N isotope tracing

Appendix 29 – Avocado planting density impact on long-term productivity

Appendix 30 – Avocado Optimising avocado canopy management using triazole growth retardants

Appendix 31 – Virtual plants for interpreting the effects of planting density in young macadamia orchards

Appendix 32 – Orchard modelling to investigate trade-offs between planting density and lifetime yield

Appendix 33 – Relationship between reproduction and branch composition in young macadamia trees over three years of development

Appendix 34 – Mango tree architecture morphology

Appendix 35 – Macadamia Modelling the effect of plant growth retardant applications on macadamia canopy growth

Appendix 36 – Studying spatial variability of fruit size within the tree canopy with a functional-structural plant model

Appendix 37 – Mango tree architecture and light simulation