Hort Innovation

Final Report

Developing smarter and sustainable pear orchards to maximise fruit quality, yield and labour efficiency

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Delivery partner:

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Developing smarter and sustainable pear orchards to maximise fruit quality, yield and labour efficiency (AP19005)

Disclaimer:

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Public summary

Over the last decade, leading growers in the Australian pear industry have adopted modern tree training systems in higher density plantings and invested in new, predominantly blush or red, pear selections with the aim of improving domestic and export markets. This project aimed to build on knowledge developed in AP12002 ("Profitable Pears: Maximising productivity and quality of new pear varieties") to support optimum production of quality fruit that meets market expectations for fruit size and colour by continuation of planting systems and rootstock experiments, examination of crop load relationships and establishment of new experiments investigating implications for fruit colour of heat and novel netting designs. New technologies to support both premium production and labour efficiency were investigated in crop regulation experiments and by testing the reliability of a mobile sensing platform.

Results from the project showed:

- Semi-dwarfing rootstocks like Quince A and C are preferred mainly due to consistency in yield and better fruit colour.
- Trees planted at high density produced more fruit and higher yields in young trees, but care needs to be taken to avoid biennial bearing.
- The best cumulative yield was on trees with Quince A rootstock, trained to Open Tatura trellis irrespective of tree density.
- The 2D Open Tatura trellis and vertical leader systems are preferred over traditional 3D central leader and spindle training systems because fruit had better colour.
- Thinning to 1 – 2 fruit per cluster increased fruit red colour and the removal of flowering buds by artificial spur extinction early in the season lead to increased fruit size with only a marginal impact on yield.
- Red colour expression in blush pears is determined by exposure to sunlight but can be halted by heat.
- Pre-harvest spatial measures of pear orchard productivity are now available to fruit growers and scientists through ground-based mobile sensing technologies.

Communication to industry occurred via magazine articles, participation in orchard walks, presentations at industry forums, regional roadshow, engagement with a project reference group and service providers, and websites (including APAL's PIPS3 site https://apal.org.au/programs/more-industry-programs/pips3program/).

Communication to scientific peers occurred via six peer-reviewed papers and presentations at scientific conferences. Increased program efficiency was realized by provision of resources and staffing support to other PIPS3 projects and opportunities to provide linkage between projects, service providers and the science community were taken throughout the project.

The following future research for pears is recommended:

- Explore management systems to increase fruit colour (e.g., leaf blowing, reflective mulch, spray-on products, netting and evaporative cooling).
- Evaluate the utility of spatial data to provide orchard-specific crop load management based on tree size to target fruit size.
- Test robotic harvesters in 2D pear orchards and undertake an economic analysis of robotic harvesting compared to platforms and ground-based picking.
- Undertake an economic analysis of spatial management including fruit thinning, pruning and variable rate spraying.
- Determine the period of floral transition and explore the chemical signals that enhance or antagonise floral initiation.
- Determine the effects of hand cluster and bud thinning on return bloom and fruit set, and test mechanical thinning techniques and chemical thinners.

Technical summary

AP19005 aimed to improve pear fruit quality and yield consistency by evaluating orchard design (training system and planting density, cultivar and rootstock selection) in long-term experiments, determining crop load relationships, investigating crop regulation strategies, exploring management options to enhance red colour development in pears and testing sensor technology to estimate flowering, fruit number, fruit size, fruit colour and tree geometry.

This project was undertaken in the experimental pear orchard at the Tatura SmartFarm and in commercial orchards in the Goulburn Valley. The experimental pear orchard was established to meet the objectives of project AP12002 (Profitable

Pears). Large, replicated experiments were planted in a dedicated 4 ha research orchard in 2012 and 2013. The Planting Systems and Rootstock experiments were continued by AP19005. Crop regulation experiments were conducted in the field and laboratory. Field experiments included mechanical, hand and chemical thinning treatments, while the laboratory-based experiments undertook preliminary screening of potential chemical thinning agents. Effects of light and heat on colour development were investigated using novel netting configurations, artificial in-field heating and cooling, and examination of effects of heat events on seasonal patterns of colour development. Calibration, validation and evaluation of a mobile sensing platform equipped with optical cameras, LiDAR and GPS for spatial detection of flowers and fruit and estimates of canopy geometry, fruit and flower number, fruit diameter and fruit colour was conducted using the commercially available Green Atlas *Cartographer* (https://greenatlas.com.au/cartographer/).

Project results and implications:

- Quince A and C are preferred rootstocks with less vegetative vigour, high and consistent yields, and better fruit colour compared to BP1 and D6 rootstocks. Trees planted at high density (0.5 – 1 m spacing) with 1- and 2-leaders produced more fruit in young trees but entered a biennial bearing pattern; whereas trees planted at lower density (2 – 3 m tree spacing) with 6- and 8-leader cordon systems maintained moderate yields with less interseasonal fluctuation.
- Open Tatura trellis and vertical leader systems had similar yields, but higher colour coverage compared to 3D central leader training systems. Vase trained trees had the lowest yield in young trees. Open Tatura had greater ability to size fruit at high crop loads.
- Investigation of crop load relationships indicated that orchard-specific crop load management based on tree size (i.e., light interception) to target fruit size is important to maximise packout yield.
- Crop regulation studies showed positive effects of thinning flower buds on fruit size. Hand thinning to 1 or 2 fruit per cluster increased red colour but yield was reduced. Mechanical thinning (with a Darwin string thinner) showed promising results that warrant further investigation. While chemical thinners used in field trials had no significant effect, laboratory screening identified new options for further testing.
- Red colour expression in blush pears is determined by exposure to light. Red colour expression is dynamic throughout the season, being lost from shading (e.g., through excessive vegetative vigour) and re-established when exposed to sunlight. Heat events can halt colour synthesis although fruit can acclimatize. Heat also causes a loss of background greenness. Late season reflective mulch appeared to have no impact on colour (and may cause bleaching)
- Estimates of flower and fruit number, fruit diameter and yield using the Green Atlas *Cartographer* (a mobile sensing platform equipped with optical cameras and LiDAR) were validated for pears. In addition, relationships were established to provide accurate and precise measures of fruit colour coverage and canopy light interception.
- Pear growers can irrigate more efficiently based on weather conditions and monitoring systems. Seasonal planning tools for irrigation management and instructional videos and guidelines to assist understanding and interpretation of sensor (trunk dendrometer) outputs were provided online.

Project results were communicated to next-users (growers, service providers and the science community) via industry articles (published by APAL in Australian Fruitgrower magazine and online), online videos (produced in collaboration with AP19007 and hosted online by APAL), presentations at industry forums, orchard walks and science conferences, PIPS3 roadshow,publication of peer-reviewed papers and participation at PIPS3 meetings. New technologies that support pear growers to irrigate efficiently and manage fruit quality were described in user guidelines, technical videos and industry articles. The sub-project reference group provided guidance regarding the current and future projects and growers and service providers contributed to a survey examining constraints and incentives driving adoption of modern management options and technology.

Keywords

Rootstock; training system; planting density; crop load relationships; crop regulation; chemical thinning; mechanical thinning; fruit colour; mobile sensing; flower detection; fruit detection

Introduction

The Australian pear industry is slowly revitalising from a combination of attractive and high-quality new cultivars, Asian export demand, more efficient orchard management and better storage technology. Production of pears experienced a slow decline from approximately 190,000 tonnes in 1969/70 to approximately 105,000 tonnes in 2014/15. At the commencement of this project, volumes had recovered to 114,500 tonnes in 2018/19 (valued at ~ $115 million) and now sit at 124,338 tonnes in 2020/21 (valued at ~ $140 million). Historically, production was dominated by supplying the processing market with 'Williams' Bon Chrétien' and the fresh market (both domestic and export) with 'Packham's Triumph'. Nowadays, the domestic fresh, the processing and the export markets account for 51, 43 and 7% of production, respectively. The Goulburn Valley grows 88% of Australia's pears.

Despite the demand from Asia for blush pears, the majority of pears are still produced from old orchards using traditional cultivars, tree densities and tree training systems. There has been some re-planting of pear orchards using new cultivars like 'ANP-0131' (a blush cultivar marketed as Ricó™), higher tree density and trellising systems such as Open Tatura, but investment is slow. In contrast, management of pear orchards is no longer traditional. Most have converted to micro-irrigation with some level of automation combined with a fertigation injection system, and they all use modern orchard pest and disease management. Like apple growers, the industry is looking for advanced production systems and technology that can consistently produce high yields of quality fruit to maximise profitability.

Research and innovation of orchard systems of new pear cultivars to maximise productivity 3 – 4 years after planting was the main objective of the previous project "Profitable Pears: Maximising productivity and quality of new pear varieties" (AP12002). The results from AP12002 were widely communicated to the pear industry (http://www.hin.com.au/networks/blush-pear-research#tab_177783) so that growers could invest with confidence in new high-density pear orchards. The knowledge gained and the information provided to the industry set the foundation for orchard design and management. However, one of the key recommendations from the Hort Innovation, APAL and Industry Advisory Committee's engagement with growers, researchers and advisors was the need to focus on the development of climate-smart pear orchard systems that go beyond the use of conventional orchard management practices and become more technology savvy.

The overall objective of this project was to provide the pear industry with new technology and advanced management systems to maximise fruit quality, yield and labour efficiency under increasing climate variability. The project focussed on:

- Determining the long-term effects of planting systems, rootstocks and training systems on yield, fruit quality, nutrition, soil and pest and diseases.
- Investigating crop load relationships and crop regulation to minimise biennial bearing and maximise fruit quality and yield.
- Delivering a better understanding of colour expression and sun protection in blush pears to reduce the impact of extreme heat events.
- Testing practical sensing technologies to monitor fruit development (e.g., number, size, colour) that will enable growers to confidently adjust management to grow fruit to market specification.
- Communicating the findings to growers and the wider industry.

This project was undertaken in the experimental pear orchard at the Tatura SmartFarm and in commercial orchards in the Goulburn Valley. The previous project established a dedicated experimental pear orchard to investigate planting systems, tree training and irrigation, and to provide a resource for industry and student education and future research projects including the testing of ag tech.

Compared with apples, there are few published studies on crop regulation of pears to maximise fruit quality and reduce biennial bearing in pears and, of the few studies that have been published, most have focused on the effects of PGR's (e.g., Teng et al. 2018; Theron 2011; Theron et al. 2018). Previous studies in Australia using both blossom and post-bloom chemical thinners on Packham's Triumph have shown positive results (Bound 2015) but these need to be tested on new cultivars, particularly those that show a tendency towards biennial bearing. This project investigated fruit thinning methods for 'ANP-0118' and 'ANP-0131' pears, the application of plant bioregulators (PBRs), level and timing of hand-thinning and the potential for mechanical thinning.

Peel red colour intensity and coverage are critical for meeting market standards for red and blushed pears. Recent studies showed the dynamic nature of peel colour expression of several blush pear selections in response to sunlight exposure (Peavey et al. 2020, 2022; Visscher et al. 2021) and defined fruit temperature thresholds for development of sunburn damage in one of these selections (McClymont et al. 2016). While the necessity of light exposure for colour development in 'ANP-0534', 'ANP-0118' and 'ANP-0131' was clearly demonstrated and the detrimental impact of extreme high temperatures was likewise clear, the influence of temperature on colour development or degradation (change in redness or yellowing of peel as opposed to sunburn) in these selections was not described. An artificial cooling experiment aimed to evaluate the ability to increase and reduce individual fruit temperature in the field and measure fruit peel colour responses to elevated or decreased fruit surface temperatures.

Netting has been shown to decrease fruit surface temperature in pear and reduce sun damage (Goodwin et al. 2018) but to the detriment of colour expression. Further studies to measure the effects of different coloured nets on radiation wavelength transmission revealed that clear netting has little impact on radiation transmission whereas black netting showed a high ratio of photosynthetically active to infrared radiation transmission (Goodwin and Perry 2018). This project explored the effects of alternate-side coloured hail netting to maximise fruit colour (i.e., maximise sun exposure in the morning) and minimise sun damage (reduce sun exposure in the afternoon).

Sensing technologies (software and hardware) developed and commercialised by Australian company Green Atlas (https://greenatlas.com.au/cartographer/) have the potential to vastly alter management of perennial horticultural crops by providing growers with detailed crop information in near real-time. For example, spatial mapping of flower cluster number and fruit number can be utilised by growers to support decisions regarding rates for chemical flower thinning and strategies for mechanical and hand thinning of flowers and fruit. This project aimed to support the future use of sensing technology by testing the accuracy, precision, reliability and utility of hardware and software, currently used in apple orchards, for flower and fruit mapping in pear orchards. Additionally, this project explored the use of *Cartographer* to estimate fruit size, fruit skin colour and canopy radiation interception.

Methodology

Planting systems and Rootstock experiments

The experimental pear orchard at Tatura was established to meet the objectives of project AP12002 (Profitable Pears: Maximising productivity and quality of new pear varieties). The effects of training system, rootstock, tree density, root pruning and irrigation method on young tree precocity, fruit quality and yield of blush pear selections 'ANP-0131' (Ricó™), 'ANP-0118' (Lanya™), and 'ANP-0534' were investigated (McClymont et al. 2015; McClymont and Goodwin 2016, 2018; Stott et al. 2018). AP19005 continued to measure and disseminate the effects of cultivar, training system, rootstock and tree density in these experiments. In addition, the impact of these treatments on soil health, pest and disease management, irrigation requirements and tree nutrition were observed.

Briefly, two large, replicated experiments (referred to as the Planting Systems and Rootstock experiments) were planted in a research orchard in 2012 and 2013. The Planting Systems experiment consisted of 'ANP-0131' on three rootstocks (D6, BP1 and Quince A with 'Beurre Hardy' interstem) planted at four tree densities (0.5 to 3 m tree spacing) and trained to three systems (Open Tatura, Vertical Leader, and Traditional with vase or single leader trees) (Table 1). The Rootstock experiment consisted of three blush pear selections ('ANP-0118', 'ANP-0131' and 'ANP-0534') grafted to seven rootstocks (including D6, BP1, Quince A and Quince C). Yield parameters, fruit quality and radiation interception were measured over three seasons. A pest and disease scorecard was used to qualitatively assess selection and rootstock effects on pests, disease and tree health each season. Plot-scale soil (tree line and interrow) and leaf sampling were undertaken to measure soil porosity (i.e., soil structure) and tree nutrient status. Detailed methodology is reported in Appendix A1 and A2.

Table 1. Description of training system and tree density treatments applied to 'ANP-0131' scions on three rootstocks (D6, BP1 and Quince A with 'Beurre Hardy' interstem).

Tree Density	Training system		
	Open Tatura trellis (2-dimensional)	Vertical (2-dimensional)	Traditional (3-dimensional)
Low	8-leader cordon 1111 trees/ha	6-leader cordon 741 trees/ha	Vase 741 trees/ha
Moderate	6-leader cordon 1482 trees/ha	4-leader 1111 trees/ha	Central leader 1111 trees/ha
High	4-leader 2222 trees/ha	2-leader 2222 trees/ha	Spindle 2222 trees/ha
Ultra-high	2-leader 4444 trees/ha	1-leader 4444 trees/ha	Slender spindle 4444 trees/ha

Validation of crop load relationships

Historical and new data from the Planting Systems and Rootstock experiments and commercial pear blocks were used to compare functional yield relationships between fruit number and yield and fruit weight. 'ANP-0131' and 'PremP009' orchard blocks were scanned using the Green Atlas *Cartographer* at harvest in 2022. Detailed methodology is reported in Appendix A1.

Crop regulation experiments

A review of the literature relating to crop load regulation in European pears was undertaken in year one (2020–21) and has been published in an open access journal (Bound 2021, see Refereed scientific publications). A portfolio of available options that could be integrated into a systematic approach for managing crop load was provided. However, further research is required to develop thinning programs that are relatively risk free.

A field experiment was conducted at the Tatura SmartFarm on 'ANP-0118' (Lanya™) pear examining the effect of single or multiple applications of a range of chemicals. Three field and two laboratory-based experiments were undertaken on 'ANP-0131' (marketed as Ricó™) pear at the Tatura SmartFarm and a commercial orchard. Field experiments included mechanical, hand and chemical thinning treatments, while the laboratory-based experiments undertook preliminary screening of potential chemical thinning agents as per Bound (2006) to expediate testing and minimise unnecessary damage to orchard trees. Detailed methodology is reported in Appendix A1.

Fruit colour experiments

A method of artificially heating and cooling blush pears in the field was established in the 2021–22 season. Air was piped from air conditioners and hair dryers to the fruit surface during two periods of five days. Fruit temperature was monitored continuously with fine wire thermocouples and daily measures of fruit peel colour were taken with a colorimeter. Detailed methodology is reported in McClymont et al. (accepted, see Refereed scientific publications).

The alternate netting experiment was installed at a commercial orchard in October 2021 over a row of 'ANP-0131' trees and two buffer rows. Five plots were established: control (open), crystal netting, crystal netting on the east and grey netting on the west, grey netting on the east and crystal netting on the west, and grey netting. Fruit colour and sunburn occurrence were assessed during the 2021–22 season. Data were analysed by ANOVA using trees within plots as pseudo-replicates. The row was scanned with *Cartographer* prior to harvest in 2023 to assess fruit colour and size. Detailed methodology is reported in Appendix A1.

Testing of mobile sensing platform

Optical cameras and a LiDAR sensor (*Cartographer*, Green Atlas, https://greenatlas.com.au/cartographer/) mounted on an electric ATV were used to scan the Planting Systems and Rootstock experiments at the Tatura SmartFarm and in commercial orchard blocks in Ardmona to detect flower clusters and fruit, estimate fruit size and fruit colour, and determine tree geometry characteristics. Predictions of these fruit and tree parameters were compared to traditional measures. The data were used to test the accuracy and precision of *Cartographer* at different phenological stages and to evaluate the utility of *Cartographer* to provide spatial maps of key production parameters in commercial pear orchards.

Grower survey

Grower and consultant interviews informed a review of current pear industry orchard design and management practice, and the constraints and incentives needed to adopt new orchard design and advanced management systems. The grower survey (Appendix B) was designed with advice from Fruit Growers Victoria Ltd (Michael Crisera) and Fruit Help (Nic Finger). Five participants answered questions regarding current pear industry orchard design and management practice, and the constraints and incentives needed to adopt new orchard design and advanced management systems. APAL has commissioned collation of pear industry production data; to avoid duplication of data collection, production areas and volumes were not a focus of this survey.

Project reference group (PRG)

A sub-project reference group was formed with seven growers and service providers to provide advice with respect to the selection of commercial orchard sites, suitable service providers to collect survey data, insights and challenging ideas with respect to the practical application of orchard design and management. Formal meetings were limited (1 per year in the first two years of the project) and one-to-one contact was used for specific advice throughout the project to minimize the time commitment from each participant. Meeting agendas, minutes and presentations are provided in Appendix C.

A separate PIPS3 program reference group was formed by the independent coordinator (project 19007) and met on six occasions during the project. The aim of these meetings was for project leaders to present updates and discuss implications for the industry as well as communication strategies and cross-project linkages.

Grower tools and guidelines

Grower tools and guidelines regarding sensor technology and irrigation management were produced based on previous research publications (Appendix D). Access was provided to the public via APAL's PIPS3 website and Agriculture Victoria's irrigation extension website.

Results and discussion

Planting systems experiment

'ANP-0131' is a vigorous scion and vegetative growth, precocity and yield were influenced by the selected rootstocks. Scions were most vigorous on D6 rootstocks whereas scions on Quince A rootstocks with Beurre Hardy interstems produced more fruit and greater yields per ha. Tree establishment, vigour and, subsequently, bearing patterns were affected by training systems and tree density such that the best performing treatments in terms of cumulative and 'marketable' yield (yield of fruit 150 – 260 g) were trees on Quince A rootstocks trained to Open Tatura trellis (all tree density treatments) or with 6-leaders (Low tree density) trained to a Vertical trellis. Blush coverage and intensity were improved by treatments that decreased vegetative vigour and increased fruit exposure to light. Consequently, 2D multi-leader systems (Vertical and Open Tatura treatments) produced the most desirable fruit colour compared to 3D central leader and spindle training systems. Similarly, BP1 rootstock improved blush colour but is not recommended because of yield penalties.

Precocity (early bearing) was increased by Quince A rootstocks and planting at UltraHigh densities (4444 trees/ha). Yields in the first two bearing seasons (2015–16 and 2016–17) were low (less than 20 t/ha) but reached 74 t/ha (trees grown on Quince A rootstock, trained with two leaders to Open Tatura trellis i.e., 'UltraHigh' densities) in the 2017–18 season (5th growing season). Yields in subsequent seasons (2018–2023) fluctuated. However, trends in response to rootstock remained consistent. Cumulatively, Quince A rootstocks increased overall total yields by 38–49 % and marketable yields by approximately 35 % compared to other rootstocks.

Differences in biennial bearing pattern were evident between tree density treatments. Trees planted at 'High' and 'Ultrahigh' densities produced more fruit initially but then entered a biennial bearing pattern, whereas trees with 6- and 8-leaders (Open Tatura-Moderate and Vertical-Low, and Open Tatura-Low treatments, respectively) maintained moderate yields with less interseasonal fluctuation.

Cumulative marketable yield (yield of fruit within the 150–260 g weight range) showed that a large proportion of crop was over- or under-sized each season. This problem could be addressed by setting appropriate crop loads based on the crop load relationships established in this project and avoiding excessive vegetative vigour. Crop loads were not normalized in this experiment. Furthermore, excessive vegetative vigour was a likely factor compromising yields. Trees were grown without use of plant growth regulators to control vigour or improve fruit set.

Detailed results and crop load relationships are reported in McClymont et al. (2021, see Refereed scientific publications) and Appendix A1.

Rootstock experiment

'ANP-0131' is a late season pear cultivar (harvest late Feb to early March). Fruit can be stored for > 6 months and eaten as a crisp pear straight out of cool storage or softened at room temperature to a melting flesh. Best marketable fruit size is approximately 180 g with 30% blush coverage. Fruit can be very large when there is a low crop. The following dot points summarise the results over a 10-year period:

- Trees on Quince A were most precocious. Following low yields in the 3rd and 4th seasons, trees on D6 and Quince A and C rootstocks produced > 70 t/ha in the 5th leaf and then consistently 60 – 70 t/ha. Lower yields in 10th season were likely due to fruit drop following hail event and poorer fruit growth.
- Trees on D6 set less fruit but compensated for lower fruit numbers with larger fruit size.
- Trees on BP1 had consistently lower yields. Cumulative 10-year yield was 23 % (93 t/ha) less than trees on QA and fruit did not size well until the 9th leaf.
- D6 rootstocks + use of interstems and summer-budding with virus material appeared to induce biennial bearing.
- Blush development had a negative correlation with light interception most likely due to internal canopy shading of the fruit. D6 tended to have poorer blush coverage than trees on Quince attributed to excessive vegetative growth and fruit shading.
- Crop load management is required to target fruit size to avoid under and/or over sizing fruit. Adjustment for light interception gives some improvement to crop load management and fruit size prediction.
- Vigour management (via rootstocks or other management like deficit irrigation and PGRs) is advised to help colour fruit.

'ANP-0118' is an early season pear cultivar (harvest mid to late Jan). Fruit does not store for long periods. Fruit can be eaten as a crisp pear straight off the tree or softened at room temperature. Fruit quality improves with short storage duration (e.g., 6 weeks). Fruit is naturally small (145 g) with approximately 35% blush coverage. At maturity the fruit is bright red with a yellow-green background. The following dot points summarise the results over a 10-year period:

- Trees on Quince A were most precocious. Following low yields in 3rd and 4th seasons, trees on Quince A and C rootstocks produced 40 – 50 t/ha consistently from 5th to 8th leaf before producing > 60 t/ha in 9th leaf, whereas trees on D6 and BP1 produced yields of 20 – 30 t/ha to 9th season when yields ~ 40 t/ha were achieved. The 10th season crop was severely compromised by hail event and stripped early to avoid pest and disease issues.
- D6 and BP1 yields were compromised by low fruit numbers. Fruit weights were greater but this did not compensate for the lower fruit numbers.
- D6 + interstems increased seasonal yield variability but the pattern was not biennial.
- Cumulative 9-year yield of quince treatments were 61 – 141 t/ha > than other treatments; however, mean fruit weight was < 100 g in some seasons, highlighting the need for thinning to ensure adequate fruit size.
- Blush development had a negative correlation with light interception most likely due to internal canopy shading of the fruit. Light interception tended to be greatest and blush coverage lowest for D6-Nij and QC, whereas light interception tended to lowest and blush coverage greatest for BP1 and other variants of D6 rootstock treatments.

'ANP-0534' is a mid-season pear cultivar (harvest mid Feb). Fruit can be stored but fruit continues to ripen with some shrivel. Fruit quality improves with short storage duration. Fruit is naturally small (150 g) with approximately 40% blush coverage. At maturity the fruit is bright orange red with a green background. Trees are spur bearing with some fruit drop near maturity. The following dot points summarise the results over a 10-year period:

- Most rootstock treatments produced a steady 30 – 40 t/ha from 4th season. Increased fruit numbers in 9th season resulted in yields 56 – 72 t/ha; however, mean fruit weight dropped below 130 g.
- Generally little difference in yield between rootstocks although bearing of trees on BP1 initially lagged behind other treatments. Cumulative 10-year yields were significantly lower for trees on D6-BM2000 (210 t/ha compared with 281 t/ha for trees on D6-Nij).
- In contrast to 'ANP-0131' and 'ANP-0118', yields and inter-season variability were not affected by interstems or budded virus material.

Detailed results and crop load relationships are reported in McClymont et al. (2022, see Refereed scientific publications) and Appendix A1.

<u>Crop load relationships</u>

The Green Atlas *Cartographer* can be used to investigate relationships between absolute or relative crop parameters and support investigation of orchard- and cultivar-specific relationships to achieve the best yield and fruit quality and reduce variability within the orchard blocks. This research showed that the trends and correlation directions of crop parameter relationships in 'ANP-0131' and 'PremP009' remained consistent, despite their different fruit quality characteristics and genetics. For example, even in the uniformly red pear 'PremP009', CDI was inversely related with canopy size, like in 'ANP-0131'.

Significantly different relationships between fruit weight and fruit number were obtained in the three 'ANP-0131' orchards. Normalising crop load for radiation interception — i.e., adjusting for tree size — explained some of the difference but other environmental and management factors continued to impact these relationships. This suggests that it is important to develop orchard- (not only cultivar) specific relationships between crop load parameters in order to maximise efficiency and optimise fruit quality and yield. Detailed results are reported in Scalisi et al. (2023) and Appendix A1.

<u>Crop regulation experiments</u>

Crop regulation experiments demonstrated that, with some further work, mechanical thinning has potential for crop load regulation in pears. The Darwin string thinner showed some results at a significance level of $p \leq 0.1$, so effective results should be able to be produced with refinement of spindle rotation and tractor speeds. The drawback with the leaf blower was that it was set at the bottom half of the tree and only one pass was made on each side; however, by making two passes at different heights to cover the entire tree, results should improve. The leaf blower also has the advantage that there is no physical damage to the tree.

The hand-thinning results suggest that fruit quality can be improved. In particular, thinning to 1 – 2 fruit per cluster increased fruit red colour and the removal of flowering buds by artificial spur extinction early in the season lead to increased fruit size without compromising quality and only a marginal impact on yield. Spur extinction is worth further investigation, including a comparison of bud removal prior to bud burst with removal of flowers during flowering as performed in the work reported here.

While the chemical thinning results were disappointing, it is worth pursuing some of these chemicals, particularly ACC and trialing SARsil in the field. Noting that initial work on apples by Bound with ATS recommended the use of a non-ionic surfactant with this chemical, the inclusion of a surfactant with ATS may also improve performance in pears, although the label does not include addition of a surfactant.

There is considerable scope to continue studies on crop load regulation in pears using mechanical, hand and chemical thinning. Detailed results are reported in Appendix A1.

<u>Fruit colour experiments</u>

Artificial cooling appeared to mitigate yellowing of blush pear 'ANP-0534'. Prior testing showed the heating units effectively heated fruit but the lack of temperature control (e.g., a feedback control switch as implemented by Tarara et al. 2000) introduced a risk of cooking fruit, particularly on warm days. Consequently, the heating units were not used during the day in the main experiment. Cooling units effectively lowered fruit surface temperatures but targeting desired temperature ranges was not possible with the methodology utilised in this study. Usefulness of artificial heating and cooling systems to investigate impacts of temperature on colour in the field is likely limited by the interrelationship of light and temperature and difficulties in adequately controlling either light or temperature under field conditions. Detailed results are reported in McClymont et al. (accepted, see Refereed scientific publications).

Under the 2021–22 season conditions, crystal and grey netting reduced sunburn compared to no netting but did not elicit different fruit colour responses. However, fruit colour measurements showed trends for differences in red colour development related to fruit position. Red colour development was better in the upper and middle portions of canopy compared to lower portions of the canopy. Importantly, trends for differences in red colour development between east and west sides of the canopy were observed. Furthermore, sunburn only occurred on the western side of non-netted trees. Likewise, in the 2022–23 season, mobile scanning indicated colour differences between east and west oriented fruit. Grey netting appeared to mitigate differences between east and west oriented fruit. Differences in red colour development associated with fruit height are likely due to differences in fruit exposure to light. Differences in colour development associated with fruit orientation (whether they are positioned on the east or west side of a tree) may be due to high light conditions in the afternoon. These findings support further investigation of novel colour management practices designed to differentially adjust conditions within trees based on row and fruit orientations. Detailed results are reported in Appendix A1.

<u>Testing of mobile sensing platform</u>

Validation of flower and fruit detection by *Cartographer* enabled prediction of flower and fruit numbers with standard errors commonly less than 10 %, across different training systems. To improve the accuracy of these predictions it is recommended to undertake a block-specific calibration. Validation of fruit size measures with *Cartographer* were conducted using stationary scans. Prediction errors for fruit diameter were approximately 4 mm. Later, Scalisi et al. (accepted, see Refereed scientific publications) reported robust association between predictions of fruit diameter by mobile scans with *Cartographer* and measurements with callipers (on commercial orchards) or a commercial fruit grader (at the Tatura SmartFarm), with a RMSE less than 5 mm in both cases. There was a strong positive linear relationship between *Cartographer* pre-harvest measures of fruit colour development index (CDI, Scalisi et al., 2022) and post-harvest fruit grader measures of blush coverage. Later testing in commercial orchards was reported by Scalisi et al. (accepted, see Refereed scientific publications).

Strong relationships existed between tree geometry parameters determined with *Cartographer* and traditional measures of canopy radiation interception. This supports the idea of using *Cartographer*'s tree geometry parameters to fine-tune irrigation management, based on relationships between water use and canopy radiation interception (O'Connell and Goodwin 2004; Goodwin et al. 2006).

Finally, Scalisi et al. (2023, see Refereed scientific publications) demonstrated the use of spatial data collected with *Cartographer* to establish orchard-specific relationships between tree geometry, fruit number, fruit clustering, fruit size and fruit colour in commercial pear orchards. Similarly, as described earlier, use of *Cartographer* to investigate functional yield relationships between fruit number and fruit weight suggested that it is important to develop orchard-specific relationships to optimise fruit quality and yield. Obtaining relationships in the manner shown by Scalisi et al. (2023, see Refereed scientific publications) has potential to drive orchard design and management strategies so that trees can consistently produce high-quality fruit.

Grower survey

Survey results highlighted that the major constraint for the pear industry is low returns, partly driven by an over-supplied domestic market and limited development of potential export markets. Despite this, growers have continued to modernize orchard production systems, adopt new technologies and innovate practices. Growers have attempted to generate market interest with new red and blush pear selections but, without improvements to market conditions, contraction of the current area of plantings is underway and likely to continue. Market development is essential for sustainability of the industry while greater availability of skilled staff is required for continued successful adoption of technology. Growers provided feedback regarding recent incentive programs and suggestions for future programs and strategies to enhance sustainability of the pear industry. The full report is provided in Appendix B.

Project reference group (PRG)

The project PRG met online (4 March 2021) and in-person in conjunction with a 'Rico™ Orchard Walk' (15 February 2022) hosted by Fruit Help (Nic Finger) and APAL (Andrew Mandemaker). Issues raised during PRG meetings and 'Rico™ Orchard Walks (22 November 2021 and 15 February 2022) have informed future project proposals. For example, growers expressed concern regarding ability to develop colour in shaded fruit of blush pears and occurrence of colour degradation late in the season and questioned whether leaf removal early in the season could enhance colour development at harvest. Future projects will trial use of reflective foil and leaf blowing early in the season and use of overhead cooling and spray-on products to reduce sunburn and colour degradation.

Project Leader, Dr Ian Goodwin, attended and presented at the biannual whole of program reference group meetings (23 Sep 2021, 27 Jan 2022, 3 Jun 2022, 29 Sep 2022, 15 Dec 2022, 21 Jun 2023). Meetings were coordinated by the PIPS3 program coordinator (project AP19007). Outcomes of these meeting were relayed to the project team.

Grower tools and guidelines

An irrigation budgeting and seasonal planning tool based on previous studies of pear tree water use (Goodwin et al. 2015) was made available online. The workbook and explanatory video are accessible via the HIN — Blush pear research website (Irrigation budgeting and seasonal planning tool for pear growers - HIN) and 'Irrigating Agriculture' websites (https://extensionaus.com.au/irrigatingag/irrigation-budgeting-tool-for-pear-production/). The workbook enables orchardists in the Goulburn Valley (producers of ~ 85 % of Australia's pear crop) to calculate monthly irrigation requirements for pears and typical irrigation intervals based on historical weather data and orchard specific tree and irrigation system information. Orchardists can then investigate impacts of different scenarios (e.g., high or low rainfall, application of deficit irrigation, conversion from microjet to drip irrigation) on irrigation requirements.

A series of technical guides (Appendix D) were produced to support grower adoption of new technologies, including mobile sensing to map orchard tree and fruit parameters, dendrometers to improve irrigation decisions, and colorimeters to provide objective and non-destructive assessments of fruit colour (https://apal.org.au/programs/more-industry-programs/pips3program/pips3resources/). Validation of the reliability of Green Atlas' mobile sensing tools and software (i.e., *Cartographer*) by this project supports the adoption of such technologies to obtain accurate data of the variability in fruit number and for pre-harvest forecasts of fruit size distribution and yield. The technology has great potential for further integration and automation of spatial management operations such as thinning, pruning, leaf blowing and variable rate spraying. Adoption of trunk and fruit dendrometers to aid irrigation scheduling by commercial orchards commenced in Australia in the last five years. As frequently happens with new technology, a few leading growers have learnt from initial mistakes often related to misconceptions regarding data interpretation. Industry articles and grower guidelines were produced to support growers' understanding and ability to effectively use these decision support tools. Finally, red colour development is a key quality attribute for red and blush pears (and apples) and use of handheld, Bluetooth-enabled colorimeters offers an objective, non-destructive method to consistently assess colour.

PIPS3 Program efficiencies

AP19005 shared resources with AP19002 "Strengthening cultural and biological management of pests and diseases in apple and pear orchards". AP19005 staff managed the experimental pear orchard at the Tatura SmartFarm and this was utilized by AP19002 for the effects of inter-row cropping on insect populations. Furthermore, AP19005 staff acted as links between service providers, Agriculture Victoria extension and compliance staff, and scientists.

Events during AP19005 highlighted the gap in practices between horticultural industries using pollination services — the almond industry has annual auditing systems in place whereas the fruit industry is lagging in attention to potential on-farm risks to pollination services. In response to information from AP19005 staff, Agriculture Victoria's Bee Biosecurity officers worked proactively to improve orchardist knowledge and implemented a local inspection campaign in the Goulburn Valley in September 2021. Bee Biosecurity officer Ally Driessen and Emily Crawford (Agriculture Victoria Services, Aus IDPM) developed extension material (website posts and articles) to further promote awareness of bee management on orchards and bee health.

Subsequent to attending the XIV International Pear Symposium, AP19005 staff provided introductions between Marcel Wenekker (Wagingengen University and Research) and Tonya Wiechel (Agriculture Victoria, Research Scientist – Plant pathology). Tonya has joined Dr Wenekker's working group on pear scab (*Venturia pyrina*).

Communication

Project results were communicated to next-users (growers, service providers and the science community) via industry articles (published by APAL in Australian Fruitgrower magazine and online), online videos (produced in collaboration with AP19007 and hosted online by APAL), presentations at industry forums, orchard walks and science conferences, publication of peer-reviewed papers and participation at PIPS3 meetings. The experimental pear orchard at the Tatura SmartFarm was utilised for student education (University of Melbourne undergraduate student Asha Gould and University of Pisa Master's student Lorenzo Bonzi), additional projects (Ag Victoria's Agrivoltaics project) and grower education (including Agriculture Victoria's irrigation training program). Visits to the Tatura SmartFarm by growers, APAL and ANFIC staff, service providers, ag technology companies, international growers and cooperatives, and scientists (including project concept meetings with the Monash University robotics team and QLD Department of Agriculture and Food and Plant and Food NZ staff), school and university students and the Victorian Minister for Agriculture were hosted at the experimental orchard.

Outputs

Table 2. Output summary

Output	Description	Detail
Industry articles (2 per year)	Project scope and outcomes were communicated to growers via APAL's Fruitgrower magazine. Audience: 960 in print, freely available online.	**Project introduction** Goodwin, I., McClymont, L., 2020. Smarter pear orchards. Australian Fruitgrower, 14(3): 61–62. Smarter pear orchards (apal.org.au)(apal.org.au) **Planting systems and Rootstock experiments** McClymont, L., Goodwin, I., 2021. Growing high-density blush pears on Quince A rootstock. Australian Fruitgrower, 15(3), 56–58. APAL Publications **Crop load relationships** McClymont, L., Goodwin, I., 2021. Optimising 'climate-smart pear' relationships. Australian Fruitgrower, 15(1), 42–43. AFG Autumn 2021 (apal.org.au)) **Crop regulation** Bound, S., 2023. Pear crop load regulation by mechanical, hand and chemical thinning (submitted). **Fruit colour** Singh, R., Peavey, M., McClymont, L., 2023. Effect of high temperatures on red colour development in blush pears. Australian Fruit Grower, 17(1) 35–37. APAL Publications (not direct link). **Mobile sensing platform** Scalisi, A., McClymont, L., Goodwin, I., 2021. *Cartographer* maps path to uniform, high quality pears.

		Australian Fruitgrower 15(4), 46–47. APAL Publications (not direct link). Scalisi, A., McClymont, L., Goodwin, I., 2022. Orchard estimates of blush coverage in pears. Australian Fruitgrower, 16(4), 37–39. Orchard estimates of blush coverage in pears (apal.org.au) **Irrigation technology** Goodwin, I., McClymont, L., Scalisi, A., 2022. Irrigation support: The role of trunk dendrometers. Australian Fruit Grower, 16(3), 33–37. Irrigation support: The role of trunk dendrometers (apal.org.au)
Minutes from annual PRG meeting	The AP19005 project reference group met online (2021) and in-person (2022). The PIPS3 program reference group met on six occasions during the project. Issues raised during PRG meetings have informed future project proposals and communication opportunities. Meeting presentations and minutes were circulated to PRG members and captured in milestone reports.	M103: AP19005 PRG meeting held online 4 March 2021. M105: AP19005 PRG meeting was held in conjunction with the second 'Rico Orchard Walk', 15 February 2022, at Calimna Orchard, Ardmona. M107: PIPS3 PRG meeting was held 15 Dec 2022 and facilitated by Marguerite White (iCd project services). Meeting focused on roadshow including presenting at the Fruit Growers Tasmania conference and the Horticulture Field Day at the Tatura SmartFarm. See Appendix C.
Project updates via APAL publications and website	Research updates were published on the APAL website, and subsequently APAL's PIPS3 page (https://apal.org.au/programs/more-industry-programs/pips3program/), in collaboration with AP19007 (M. White) and APAL staff (A. Barber and T. McGlone). These resources are freely available to the public.	The PIPS3 website provides links to updates on project and 'Resources' pages: https://apal.org.au/programs/more-industry-programs/pips3program/ap19005/ https://apal.org.au/programs/more-industry-programs/pips3program/pips3resources/ (not direct link). **Project introduction** PIPS 3: Developing smarter and sustainable pear orchards (apal.org.au), AP19005-Pear-Systems-Info-Sheet_Final.pdf (apal.org.au). **Project update (2021)** PIPS3 Resources (apal.org.au). **Crop regulation** Chemical and hand thinning experiments at Calimna Orchard, Ardmona. PIPS3 Resources (apal.org.au) (video). Chemical thinning experiments in the laboratory at Tatura SmartFarm. PIPS3 Resources (apal.org.au) (video). **Fruit colour** Heating and cooling tests at Tatura – PIPS3 update: PIPS3 Resources (apal.org.au) (video), Heating and cooling tests at Tatura - PIPS3 update (apal.org.au)date/. Barber, A., 2022. Raising the bar: Light, colour and the role of temperature in blush pears. Australia Fruitgrower 16(1):35-37. Light, colour and the role of temperature in

		blush pears (apal.org.au). **Mobile sensing** McGlone, T., 2020. PIPS3: Green Atlas Cartographer. PIPS 3: Green Atlas Cartographer (apal.org.au).
Scientific journal paper (1 per year)	AP19005 staff have authored four peer reviewed papers reporting results of AP19005 experiments and reviewing current crop regulation options for pears. A further two papers have been accepted for publication [Bound (2021) and McClymont et al. (2021) are open access. Acta Horticulturae papers are available by subscription or request to authors].	**Planting systems and Rootstock experiments** McClymont, L., Goodwin, I., Whitfield, D.M., 2022. Yield and canopy radiation interception of two blush pear selections in Australia. Acta Hortic. 1346, 295-302. https://doi.org/10.17660/ActaHortic.2022.1346.37 McClymont, L., Goodwin, I., Whitfield, D.M., O'Connell, M., Turpin, S., 2021. Effects of rootstock, planting density and training system blush pear cultivar ANP-0131: early growth, yield and fruit quality. HortScience 56 (11):1408–1415. https://doi.org/10.21273/HORTSCI16146-21 **Crop regulation** Bound, S.A., 2021. Managing crop load in European pear (Pyrus communis L.)—A Review. Agriculture 11(7): 637 – 663. https://doi.org/10.3390/agriculture11070637 **Fruit colour** McClymont, L., Scalisi, A., Singh, R., Goodwin, I., 2023. Peel colour responses to in-field artificial cooling of fruit in blush pears. Acta Hortic. (accepted). **Mobile sensing** Scalisi, A., McClymont, L., Morton, P., Scheding, S., Underwood, J., Goodwin, I., 2023. A ground-based platform for estimates of fruit size in pear orchards – accuracy of block average, spatial variability and classification. Acta Hortic. (accepted). Scalisi, A., McClymont, L., Peavey, M., Morton, P., Scheding, S., Underwood, J., Goodwin, I., 2023. Using Green Atlas Cartographer to investigate orchard-specific relationships between tree geometry, fruit number, fruit clustering, fruit size and fruit colour in commercial apples and pears. Acta Hortic. 1360, 203–210. https://doi.org/10.17660/ActaHortic.2023.1360.25 Scalisi, A., McClymont, L., Morton, P., Scheding, S., Underwood, J., Goodwin, I. (2023). Detecting, mapping and digitizing canopy geometry, fruit number and peel colour in pear trees with different architecture. Scientia Horticulturae (submitted).
User guidelines on new technology and advanced management systems.	New technologies that support pear growers to irrigate efficiently, manage fruit quality, and estimate yield and fruit size distribution prior to harvest, map the variation in flower and fruit number, fruit size, fruit skin colour and tree size across an orchard have been described in four user guidelines available via	Ground-based mobile sensing — Orchard mapping of tree geometry, flower clusters, fruit number, fruit size and fruit colour. Irrigation sensors – trunk and fruit dendrometers. Trunk dendrometers – data interpretation. Colorimeter – objective fruit colour measurements. See following link to access above fact sheets:

	APAL's PIPS3 webpage.	https://apal.org.au/programs/more-industry-programs/pips3program/pips3resources/ (not direct link).
Technical videos of new technology and advanced management systems.	Videos were published on the APAL website, and subsequently APAL's PIPS3 webpage (https://apal.org.au/programs/more-industry-programs/pips3program/), in collaboration with AP19003 and AP19007. Videos addressed: mobile sensing of flower clusters, fruit, fruit diameter and skin colour; use of irrigation sensors; outcomes of planting system and rootstock experiments; and data management with SmartPhones.	**Planting systems and Rootstock experiments** Rootstocks and systems: outcomes of pear systems trials PIPS3 Resources (apal.org.au) **Mobile sensing** Green Atlas Cartographer™ Mobile sensing technology calibration and validation for apples and pears https://apal.org.au/pips-3-green-atlas-cartographer/ (not direct link). Sensing technologies to improve predictions and management of crop load (AP19003) PIPS3 Resources (apal.org.au) Technology driven measurement of fruit & flower cluster numbers (AP19003) Using tech and data for apple orchard management and optimal crop load - a PIPS3 update (apal.org.au)ips3-update/ Technology driven fruit diameter and colour measurements (AP19003) Tech-driven fruit diameter and colour measurement - PIPS3 update (apal.org.au) **Irrigation sensors** Technology driven irrigation scheduling (AP19003) hIrrigation scheduling in the Sundial Orchard - PIPS3 update (apal.org.au) **Managing orchard data with smartphone technology** (AP19003): PIPS3 Resources (apal.org.au) PIPS3 Resources (apal.org.au)
Grower and service provider field walks.	AP19005 staff participated in 'Rico™ orchard walks', an APAL grower tour, the Ag Vic Horticulture field day, and the LaunchVic orchard technology event. The 'Rico™ orchard walks' were hosted by Fruit Help consultant Nic Finger. These walks gathered 'ANP-0131' growers to share seasonal information and research and marketing updates. APAL and Ag Vic events were attended by growers, consultants and technology providers.	**'Rico™ orchard walks' (22 Nov 2021 and 15 Feb 2022)** Lexie McClymont presented rootstock and planting system results (22 November 2021). Alessio Scalisi presented a *Cartographer* validation update (15 February 2022). Field walk wraps up successful Ricó season (apal.org.au) **LaunchVic Orchard Technology event (25 Mar 2022)** Alessio Scalisi presented *Cartographer* at the LaunchVic orchard technology event (audience approximately 80). **APAL grower tour (2 Sep 2022)** Alessio Scalisi and Ian Goodwin provided an update on the Green Atlas *Cartographer* system. **Ag Vic Horticulture Field Day (23 Mar 2023)** Ag Vic Tatura SmartFarm hosted the Horticulture Field Day 'Future-proofing horticulture in a changing climate'. Over 80 participants attended the event including 18 different service providers and exhibitors of technology and machinery. http://www.hin.com.au/current-

		initiatives/future-proofing-horticulture-in-a-changing-climate-goulburn-broken-2023
Presentations to industry at various forums.	Lexie McClymont presented rootstock experiment results at the APAL R&D Day (1 September 2022). Ian Goodwin presented on 'How can I prepare my orchard for extreme conditions?' at Horticulture Field Day, 23 March 2023. Ian Goodwin participated and presented at the PIPS3 Roadshow in Lenswood SA and Manjimup WA. Ian Goodwin and Lexie McClymont presented at the Fruit Growers Tasmania conference (15–16 June 2023).	Research insights shared with growers at R&D Day (apal.org.au) http://www.hin.com.au/current-initiatives/future-proofing-horticulture-in-a-changing-climate-goulburn-broken-2023 https://apal.org.au/invaluable-two-way-conversations-at-pips3-roadshow/ Ian Goodwin presented 'Opportunities for management decisions using Cartographer – mobile sensor platform'. Lexie McClymont presented 'Climate impacts and challenges in the orchard' (presentations will be available online at the following FGT site: https://www.fruitgrowerstas.org.au/conference2023/
Presentations at science conferences.	Ian Goodwin presented to the National Tree Crop Intensification in Horticulture Program (TCI Program-AS18000) Team Webinar. Lexie McClymont presented at the XII International Symposium on Integrating Canopy, Rootstock and Environmental Physiology in Orchard Systems and was a panel member for the Workgroup of Orchard and Plantation Systems' round table discussion. Ian Goodwin was invited to present at the International Fruit Tree Association annual conference in the USA. Alessio Scalisi presented at the International Horticulture Congress in France (17 – 19 August 2022). Alessio Scalisi (oral) and Lexie McClymont (poster) presented at the XIV International Pear Symposium in Stellenbosch, South Africa (23 – 27 January 2023).	Goodwin, I., 2021. Development of a rapid apple and pear orchard assessment tool using a ground-based mobile sensing platform Green Atlas *Cartographer*. TCI Program (AS18000) Team Webinar: Indirect measurement in tree crops using advanced technologies. 14 April. McClymont, L., 2021. Yield and canopy radiation interception of blush pear selections. XII International Symposium on Integrating Canopy, Rootstock and Environmental Physiology in Orchard Systems. 26 – 30 July. Goodwin, I., 2022. Profitable pears. IFTA 65th Annual Conference, Pennsylvania, 12–15 February. Scalisi, A., 2022. Using Green Atlas *Cartographer* to investigate orchard-specific relationships between tree geometry, fruit number, fruit clustering, fruit size and fruit colour in commercial apples and pears. International Horticulture Congress – III International Symposium on Mechanization, Precision Horticulture, and Robotics: Precision and Digital Horticulture in Field Environments, 17 – 19 August. Scalisi, A. 2023. A ground-based platform for estimates of fruit size in pear orchards – accuracy of block average, spatial variability and classification.
Presentations at PIPS3 meetings as per AP19007.	Presentations to PIPS3 meeting, 8 and 9 Mar 2022 held at Tatura SmartFarm by Ian Goodwin (project overview), Alessio Scalisi ('*Cartographer'* during orchard walk) and Lexie McClymont (temperature and light experiment; alternate-side netting experiment during orchard walk).	Presentations by Ian Goodwin and Lexie McClymont (see Appendix E).
Presentations to Tatura SmartFarm	During the project, Agriculture Victoria staff hosted many visitors to the pear orchard, strengthening links	Nov 2020 – Apr 2021 visits by APAL, horticulture consultants, sensor companies and internal Ag Vic staff. Tatura SmartFarm staff hosted the Victorian Minister for

visiting groups.	to pear growers and consultants, industry representatives, scientific peers and collaborators. Hosting students, political representatives, international visitors and the general public raises awareness of both the pear industry in Australia and the scientific capacity within Agriculture Victoria.	Agriculture Mary-Anne Thomas in mid-January and assisted Minister Thomas with presenting two of the blush pear cultivars to her parliamentary colleagues. Nov 2021 – Apr 2022 Hosted visitors from ANFIC, Monash University civil engineering, Kubota Australia, Ripe Robotics, Monash University robotics team and high school science students May 2022 – Oct 2022 Hosted visitors from QDAF, Plant and Food Research NZ and Australia, Melbourne University engineering students, Federation University, Ag Vic extension officers. Nov 2022 – Apr 2023 Hosted visitors from Washington State University, AgFirst NZ, APAL, Fruit Help, University of Melbourne, University of Nottingham, CSIRO, high school and university student, Agrivoltaics conference delegates, Ministry Primary Industries NZ, NEC Corporation, University of Horticulture & Forestry, India, and Ag Vic extension officers. Note, Covid restrictions limited site visits during the Jun – Oct 2020 and May – Oct 2021.
Podcast	Ian Goodwin was interviewed by Angie Asimus from Seven Network (Operations) Limited for a podcast on Ricó pear.	National Farmers Federation podcast - Australian Farmers: Telling Our Story: Episode 44 - Pear Shaped Perfection on Apple Podcasts
Grower survey	Pear growers in the Goulburn Valley were surveyed to describe current pear industry orchard design and management practice, and the constraints and incentives to invest in ag-tech and advanced management systems. Growers provided feedback regarding recent incentive programs and suggestions for future programs and strategies to enhance sustainability of the pear industry.	The survey was reported in Milestone 106, and is provided as Appendix B.
Irrigation budgeting tool	An irrigation budgeting tool (MS Excel format) and explanatory video were produced for pear growers and irrigation managers. The tool enables growers to quantify consequences of different irrigation scenarios (e.g., drip vs. microjet irrigation, regulated deficit irrigation vs. irrigating to potential water use) on irrigation inputs, and to generate 'typical' within season irrigation schedules.	The spreadsheet tool and video are accessible via Agriculture Victoria's HIN – Blush pear research website (Irrigation budgeting and seasonal planning tool for pear growers - HIN) and 'Irrigating Agriculture' websites (https://extensionaus.com.au/irrigatingag/irrigation-budgeting-tool-for-pear-production/). Links are provided on the PIPS3 website (https://apal.org.au/programs/more-industry-programs/pips3program/ap19005/).

Outcomes

Table 3. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Short-term: Effects of orchard design on yield and fruit quality of new pear cultivars measured and management implications communicated to growers. **Intermediate:** Decisions to rework orchards informed by knowledge of yield and fruit quality potential of new cultivars and whole systems implications.	**Industry profitability and global competitiveness is improved by reducing the average cost per carton** SIP Strategy 1.1 Drive orchard reworking with emphasis on preparedness for increased mechanisation/automation/scale. SIP Strategy 1.4 Improve labour productivity through greater adoption of technology and leadership training. SIP Strategy 1.5 Research IT and data systems that enable better collection and connectivity of orchard and business data at every level of the supply chain **The value of the average bin has risen, resulting in improved industry profitability** SIP Strategy 3.1 Improve quality consistency and percentage of Class 1 fruit per hectare.	The effects of orchard design on yield and fruit quality have been measured in the Rootstock and Planting Systems experiments for 2020–21, 2021–22 and 2022–23 seasons. A grower survey was undertaken to determine current industry orchard design and management practices and constraints to ag technology adoption.	Results of planting systems and rootstock experiments were communicated to growers, consultants and the science community via industry articles, orchard walks, webinars, on-line videos, science presentations and scientific papers. Growers choosing to develop or rework pear orchards have access to information to support decisions. The grower survey provides current information regarding orchard practices and technology adoption. This information will allow comparison with future practices and provides grower and consultant suggestions for future extension and support programs for the pear industry.
Short-term: 'Proof-of-concept' and/or calibration of sensing technology to provide data to support management decisions in pear orchards. **Intermediate:** Use of sensing technology in pear orchards to assist growers to grow fruit to market specifications.		Completed evaluation of Green Atlas' *Cartographer* via scanning and measurements in the Rootstock and Planting Systems experiments at the Tatura SmartFarm (2020 – 21 and 2021 – 22 seasons). Completed data collection for testing of crop load relationships with Green Atlas's *Cartographer* via scanning of a commercial orchard (2021 – 22 season). Evaluation of Green Atlas' *Cartographer* in a commercial orchard was undertaken with flowering, fruit-set and pre-harvest scans conducted in 2021 – 22. Maps were provided to the grower and consultant	Evaluation of Green Atlas' *Cartographer* system was communicated to growers, consultants and the science community via industry articles, orchard walks, webinars, on-line videos, science presentations and scientific papers. Independent evaluation of the mobile sensing platform provides confidence regarding reliability of the system. Use of the system in commercial orchards has demonstrated potential for generation of orchard-specific relationships of measured yield and fruit quality parameters to inform management. Testing of this concept is required.

		during the season.	
Intermediate: Better crop load management in pears to avoid biennial bearing and maximise fruit quality.		An initial thinning experiment was undertaken on 'ANP-0118' during the 2020 – 21 season. Further experiments were delayed until 2022 – 23 due to COVID restrictions. Dr Sally Bound established four crop regulation experiments at a commercial 'ANP-0131' orchard and the Tatura SmartFarm (2022 – 2023).	Current knowledge was compiled in a review and new information reported to growers via an industry article and online videos. Promising methods of crop regulation of blush pear 'ANP-0131' have been identified for further evaluation.
Short-term: Increased knowledge of drivers of fruit colour development and degradation and effectiveness of novel protection		Fruit temperature and alternate netting experiments were conducted in 2021 – 22. Fruit colour at the alternate netting site ('ANP-0131') was assessed in 2022 – 23 with Green Atlas' *Cartographer*. Additional datasets from Agriculture Victoria projects were examined to identify colour responses to seasonal heat events.	Drivers of fruit colour development and outcomes of experiments were communicated to growers, consultants and the science community via industry articles, on-line videos, presentations at industry forums and scientific papers.

Monitoring and evaluation

Table 4. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
EFFECTIVENESS: To what extent has the sub-project addressed the objectives and achieved the identified outcomes? • To what extent has the project improved knowledge and understanding of orchard design and management to grow new pear cultivars to market specifications within the context of a changing and variable climate? • To what extent has the sub-project advanced sensor technology to enable and/or improve measurement of orchard parameters?	The project has published results regarding relationships between crop load and fruit size, implications of light exposure and heat for colour development, and impacts of rootstock and orchard design on yield and fruit quality of blush pear selections 'ANP-0131', 'ANP-0118' and 'ANP-0534'. The project has published results from independent testing of Green Atlas' Cartographer that support its accuracy, precision and utility for measurement of orchard and fruit parameters. Respondents from the final project evaluation survey were very confident that the project achieved its objectives and activities were	Increasing understanding of conditions influencing fruit colour development are informing future experimental design to investigate efficacy and management (e.g., timing) of current and novel orchard practices. Potential use of Cartographer to develop orchard-specific relationships and inform management decisions to optimize fruit quality and allow targeted within-block management has been conceptualized. Testing is required in the field to support modelling of economic costs and benefits. Future research should attempt to encompass a broader range of pear selections to support resilience of the

	executed as expected. It was identified that Covid had an impact upon the outcome of chemical thinning experiments in the first season. Whilst growers involved were extremely complementary, researchers believed there is always room to adjust and improve. AP19005 effectiveness rating was 4.4 on a scale from 0 – 5 (see Appendix F).	industry to changing market demands and environmental conditions.
RELEVANCE: How relevant was the sub-project to the needs of the identified stakeholders? • To what extent has the project met the needs of growers and front-line advisors to provide information on design and management of pear orchards and use of sensor technology?	Information regarding orchard design and sensor technology has been provided to growers and frontline advisors via industry articles, online resources, industry magazine articles, presentations to industry forums and engagement at orchard walks. The project was considered strongly relevant to both growers and advisors who support them, particularly in relation to light and heat effects on skin colour development and the use of the Green Atlas® Cartographer in pre-harvest spatial measurement. There were no direct comments on thinning or long-term orchard design experiments, and the final development and release of the irrigation budgeting and seasonal planning tool. The researchers are already making plans to convert new knowledge gained in this project into practical management tools for growers and acknowledge the benefits in undertaking their experiments in a commercial setting where growers have input. AP19005 effectiveness rating was 4.4 on a scale from 0 – 5 (see Appendix F).	Provide the industry with the financial advantages of using a mobile sensing platform for spatial management, yield forecasting (including fruit size distribution) and orchard-specific crop load relationships. Explore the concept of narrow row pedestrian orchards that are ag tech ready and maximise fruit quality by better light environment.
APPROPRIATENESS: To what extent was the PIPS3 Program Communications and Extension Plan appropriate and had an impact upon the target audience? • To what extent has the project resulted in greater confidence, intention to adopt, or adoption of new orchard design and management, and improve utilisation of sensor technologies?	Current and previous projects (including AP12002 and AP04009) have demonstrated high density pear production systems to growers and provided yield and fruit quality data to support decisions. While many growers now regard trellised, high density pear production as their preferred orchard system, current market conditions are discouraging investment. Despite this, leading growers maintain a strong level of interest in technology adoption and	Future research projects should increase engagement with leading growers and consultants to facilitate information transfer and target growers currently involved in production of ‘premium pears’. Many growers are not currently in the position to adopt new selections or management systems but will learn from the examples of leading growers if market conditions allow in future.

	research to support improvements in fruit quality. The project was considered extremely strong in engaging with the industry, though more can be done to work directly with what is only a small pool of growers in Australia. Respondents believed the mix of digital, printed and field-based activities on offer was strong, but not necessarily disseminated through the most effective lines to pear growers. Growers indicated they referred to printed materials rather than digital based formats. AP19005 appropriateness rating was 4.6 on a scale from 0 – 5 (see Appendix F).	
EFFICIENCY: What efforts did the PIPS3 Program partners make to improve efficiency? • Did the project efficiently manage shared resources and utilise skills and knowledge within other PIPS3 Program projects?	AP19005 shared project preschedule documents with other projects. AP19005 shared staff and resources where possible with other PIPS3 projects. AP19005 took several opportunities to provide links between service providers, other Hort Innovation projects and international researchers. The AP19005 respondents rated the PIPS3 Program as strong on its performance to deliver an efficient approach to research, and communication and extension of the research. There were obvious indications that the project strongly benefitted from its connectivity to AP19003 and drawing upon the expertise of Sally Bound from TIA. AP19005 efficiency rating was 4.2 on a scale from 0 – 5 (see Appendix F).	Future research will adopt a systems approach where impacts of management to increase colour (e.g., evaporative cooling) will incorporate the effects on pests and diseases.
LEGACY: Are there signs that the PIPS3 Program will influence apple and pear growers in the future? To what extent has the project resulted in greater confidence, intention to adopt, or adoption of new orchard design and the uptake of sensor technologies?	Whilst there has been improved knowledge and understanding gained by all respondents, they are a little less confident about adoption, though the result is still strong. The economic value of changing managements, whether taking rapid measurements in the orchard or applying new management techniques, needs to be clear to growers. Working with leading growers helps to facilitate the process, but more needs to be done to extend the information	For pear growers, communication via printed information and face-to-face presentations where audience (growers) engages with the researchers are needed. Publication in refereed journals must be emphasized as scientific rigor is critical. Such publications enhance international collaboration and promote visiting scientists to Goulburn Valley where most pears are grown in Australia.

	impactfully, more broadly. AP19005 legacy rating was 4.5 on a scale from 0 – 5 (Improved knowledge & understanding of the concepts = 4.4 & Likelihood of adoption < 10 years = 4.1) (see Appendix F).	

Recommendations

The following agronomic recommendation for pear growers can be made because of the research that was undertaken in this project:

- Semi-dwarfing rootstocks like Quince A and C are preferred mainly due to consistency in yield and better fruit colour.
- Trees planted at high density will produce more fruit and higher yields in young trees, but care needs to be taken to avoid biennial bearing.
- Trees on QA rootstock trained to Open Tatura trellis will produce the highest cumulative yield irrespective of tree density.
- 2D Open Tatura trellis and vertical leader systems are preferred over traditional 3D central leader and spindle training systems because fruit has better colour.
- Thinning to 1 – 2 fruit per cluster will increase fruit red colour.
- Pre-harvest spatial measures of pear orchard productivity are now available to fruit growers and scientists through ground-based mobile sensing technologies.

The following future research for pears is recommended:

- Explore management systems to increase fruit colour (e.g., leaf blowing, reflective mulch, spray-on products, netting and evaporative cooling).
- Evaluate the utility of spatial data to provide orchard-specific crop load management based on tree size to target fruit size.
- Test robotic harvesters in 2D pear orchards and undertake an economic analysis of robotic harvesting compared to platforms and ground-based picking.
- Undertake an economic analysis of spatial management including fruit thinning, pruning and variable rate spraying.
- Determine the period of floral transition and explore the chemical signals that enhance or antagonise floral initiation.
- Determine the effects of hand cluster and bud thinning on return bloom and fruit set, and test mechanical thinning techniques and chemical thinners.

Suggested education and extension programs include a grower manual for new pear selections, continued support for online information, utilization of the Tatura SmartFarm, and greater sharing of grower experiences through on-farm trials of planting systems and ag tech. Pear production is concentrated in the Goulburn Valley so extension programs should target leading growers and consultants to directly communicate research outcomes. The grower survey identified several additional education and extension priorities for growers that more broadly apply to whole of industry, for example spray and fertigation management training days.

Refereed scientific publications

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Scalisi, A., McClymont, L., Morton, P., Scheding, S., Underwood, J., Goodwin, I., 2023. A ground-based platform for estimates of fruit size in pear orchards – accuracy of block average, spatial variability and classification. Acta Horticulturae (accepted).

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Intellectual property

No project IP or commercialisation to report.

Response functions from data collected in designed experiments, field testing of sensors to measure crop parameters, and the irrigation scheduling tool for pears were published and made widely available through Agriculture Victoria (DEECA) and APAL. No patent or copyright issues were identified during the project. Sensor testing was undertaken in agreement with the manufacturers. The blush cultivars studied in this project are owned by Agriculture Victoria.

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Appendices

Appendix A1. Methods and Results

Appendix A2. Effects of orchard design on soil porosity and tree nutrient status

Appendix B. Pear grower survey

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Appendix D. Guidelines on new technology

Appendix E. Presentations to PIPS3 meeting

Appendix F. Monitoring and evaluation

Developing smarter and sustainable pear orchards to maximise fruit quality, yield and labour efficiency

Appendix A: AP19005 Methods and Results

July 2023

L. McClymont, A. Scalisi, S. Bound and I. Goodwin

Victoria State Government
Energy, Environment and Climate Action

AGRICULTURE VICTORIA

External Project Code	AP19005
AVR Reference	6402
Project Leader Name	Ian Goodwin

Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

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Contents

Executive Summary

AP19005 aimed to improve pear fruit quality and yield consistency by evaluating orchard design (training system and planting density, cultivar and rootstock selection) in long-term experiments, determining crop load relationships, investigating crop regulation strategies, testing sensor technology to estimate flowering, fruit number and tree geometry, and exploring management options to enhance red colour development in pears. This document describes the primary study site (the experimental pear orchard at the Tatura SmartFarm), experimental designs and results from each experiment. This appendix has been compiled to provide detailed methodology and results for the AP19005 final report to Hort Innovation.

Summarised methodology, key results and subsequent recommendations are provided within the AP19005 final report to Hort Innovation.

Introduction

Background

The intended outcome of AP19005 was to increase the profitability of pear orchards by providing the knowledge and tools to consistently produce better quality pears for domestic consumption and export markets.

AP19005 aimed to improve pear fruit quality and yield consistency by evaluating orchard design (training system and planting density, cultivar and rootstock selection) in long-term experiments, determining crop load relationships, investigating crop regulation strategies, testing sensor technology to estimate flowering, fruit number and tree geometry, and exploring management options to enhance red colour development in pears. This document provides detailed methodology and results of the field experiments undertaken in AP19005.

Project Objectives

Broadly, the objectives of AP19005 were to:

- Demonstrate appropriate training methods, planting density and rootstocks for new pear cultivars.
- Investigate crop load regulation to minimise biennial bearing and maximise fruit quality and yield.
- Determine the long-term effects of planting systems, rootstocks and training systems on yield, fruit quality, nutrition, soil and pest/diseases.
- Deliver a better understanding of colour expression in bi-coloured pears and sun protection to reduce the impact of extreme heat events.
- Demonstrate and validate practical use of sensing technologies to monitor fruit development (e.g., number, size, colour) that will enable growers to confidently adjust management to grow fruit to market specification.

Methodology

The primary study for AP19005 was the experimental pear orchard at the Tatura SmartFarm. Commercial orchards were used for the alternate netting experiment, some crop regulation experiments and advanced evaluation of the Green Atlas mobile sensing platform (*Cartographer*).

The experimental pear orchard was established to meet the objectives of project AP12002 (Profitable Pears: Maximising productivity and quality of new pear varieties). Large, replicated experiments were planted in a dedicated 4 ha research orchard in 2012 and 2013. The Planting Systems and Rootstock experiments were continued by AP19005. The Irrigation experiment was decommissioned in 2019; parts of the block have been used for several fruit colour experiments, the Agriculture Victoria Agrivoltaics project and, for AP19005, a crop regulation experiment.

Tatura SmartFarm

The site of the experimental pear orchard is the Tatura SmartFarm (36.44° S, 145.27° E; 114 m APSL) in the Goulburn Valley region of Victoria, Australia. The soil is a Red Sodosol (Isbell 2002) known locally as a Lemnos loam (Skene and Poutsma 1962). The region has a temperate climate with average annual rainfall of approximately 480 mm. Annual average reference crop evapotranspiration (ETo, Allen et al., 1998) is approximately 1190 mm (22-year mean, http://www.longpaddock.qld.gov.au/silo/).

Planting Systems and Rootstock experiments

Data collection has been ongoing in the Planting Systems and Rootstock experiments since 2014. The effects of training system, rootstock, tree density, root pruning and irrigation method on young tree precocity, fruit quality and yield of blush pear selections 'ANP-0131' (Ricó™), 'ANP-0118' (Lanya™), and 'ANP-0534' were investigated in AP12002 (McClymont et al. 2015; McClymont and Goodwin 2016, 2018; Stott et al. 2018). AP19005 continued to measure and disseminate the effects of cultivar, training system, rootstock and tree density in these experiments. In addition, the impact of these treatments on soil health, pest and disease management, irrigation requirements and tree nutrition were observed.

The Planting Systems experiment consisted of three rootstocks (D6, BP1 and Quince A with 'Beurre Hardy' interstem) planted at four tree densities (0.5 to 3 m tree spacing) and trained to three systems (Open Tatura, Vertical Leader, and 'Traditional' with vase or single leader trees) in a split-plot randomised complete block design with three replicates of each treatment. Training system and tree density treatments are summarized in Table 1. Training systems are allocated to whole rows. Each plot is 14 m in length and consists of a central measurement row with two guard rows. Row spacing is 4.5 m. Row orientation is north-south. Irrigation (drip), nutrition, and pest, disease and weed management were the same for all treatments. Trees were bench grafted and planted in winter 2013.

Table 1. Description of training system and tree density treatments applied to 'ANP-0131' scions on three rootstocks (D6, BP1 and Quince A with 'Beurre Hardy' interstem) in the Planting Systems experiment.

Tree Density	Training system		
	Open Tatura trellis (2-dimensional)	**Vertical (2-dimensional)**	**Traditional (3-dimensional)**
Low	8-leader cordon 1111 trees/ha	6-leader cordon 741 trees/ha	Vase 741 trees/ha
Moderate	6-leader cordon 1482 trees/ha	4-leader 1111 trees/ha	Central leader 1111 trees/ha
High	4-leader 2222 trees/ha	2-leader 2222 trees/ha	Spindle 2222 trees/ha
Ultra-high	2-leader 4444 trees/ha	1-leader 4444 trees/ha	Slender spindle 4444 trees/ha

The objectives of the Planting Systems experiment were to:

- Evaluate the responses of 'ANP-0131' to different rootstocks, training systems and tree densities for canopy radiation interception, fruitfulness, yield and fruit quality.
- Evaluate orchard soil porosity and nutrient status of ANP-0131 in relation to differing orchard designs.

The Rootstock experiment consisted of three blush pears ('ANP-0118', 'ANP-0131' and 'ANP-0534') grafted to seven rootstocks (including D6, BP1, Quince A and Quince C with Beurre Hardy interstems) in a randomised complete block design with four replicates of each treatment. Tree spacing is 1 x 4.5 m and trees are trained to the Open Tatura trellis four-leader system. Each plot is 10 m in length. Row orientation is north-south. Irrigation (drip), nutrition, and pest, disease and weed management are the same for all treatments. Trees were grafted and grown as nursery stock in 2012/13 and planted in winter 2013.

The objectives of the Rootstock experiment were to:

- Evaluate the responses of 'ANP-0131', 'ANP-0118' and 'ANP-0534' to different rootstocks for canopy radiation interception, fruitfulness, yield and fruit quality.
- Evaluate nutrient status of 'ANP-0131' and 'ANP-0118' in relation to differing rootstocks.
- Evaluate pest (mite) and disease (e.g., *Pseudomonas syringae*) susceptibility and tree health (e.g., waterlogging) of 'ANP-0131', 'ANP-0118' and 'ANP-0534' in relation to differing rootstocks.

Yield (fruit number and fruit weight), fruit quality (blush colour intensity and coverage, fruit maturity and sweetness) and radiation interception were measured over three seasons (2020 – 2023) in both experiments as per McClymont et al. (2021, 2022) and Peavey et al. (2020). Use of a commercial fruit grader (Compac InVision 9000, Compac Sorting Equipment Ltd, Australia) at harvest enabled measurement of individual fruit weight and blush coverage. Peel colour was measured with Bluetooth-enabled colorimeters. Radiation interception was estimated from measurements of photosynthetically active radiation (PAR) interception at solar noon and three hours before and after solar noon using a combination of a handheld ceptometer (Sunfleck Ceptometer; Decagon, Pullman, USA) and a light trolley (Tranzflo, New Zealand) to capture the daytime dynamics. The 2022/23 crop was impacted by a major hail event in December 2022. 'ANP-0131' and 'ANP-0534' fruit were maintained until harvest so that yield could be assessed but fruit quality was severely impacted.

<u>Nutrient status and soil porosity</u>

Nutrient, soil and interrow management has been the same across treatments within the Planting Systems and Rootstock experiments since planting. Measurements were undertaken to investigate the effects of tree density, training system, scion and rootstock on leaf nutrient concentrations and soil porosity. Leaf samples for mineral nutrient analysis were collected from replicated plots in the Planting Systems and Rootstock experiments in late-January 2021. Complete analysis (N, P, K, Ca, Mg, S, Na, Cl, B, Cu, Fe, Mn, Mo and Zn) were performed by APAL (Australian Precision Ag Laboratory, Hindmarsh, SA). Nutrient concentrations non-replicated fruit samples collected at harvest were also determined by APAL. Soil cores were collected from replicated plots in the Planting Systems experiment in the 2021 winter to determine bulk density and porosity. Detailed methodology was reported in a technical report for Milestone 106.

Pest and disease susceptibility

A pest and disease scorecard was used to assess selection and rootstock effects on pests, disease and tree health each season. Visual assessments were conducted as appropriate for the pest and diseases present each season. For example, in mid-November 2020, mid-canopy shoots with evidence of light brown apple moth (LBAM, *Epiphyas postvittana*) were counted. Mite damage (assessed based on number of trees with visible damage per plot and severity of damage on a scale from 0 = no damage to 3 = severe damage) was observed in mid-January each season.

Validation of crop load relationships

In 2022, 'ANP-0131' and 'PremP009' orchard blocks (Calimna Orchards, Ardmona) were scanned using the Green Atlas *Cartographer* at harvest. The 'ANP-0131' orchard block at Calimna Orchards covers an area of 4.37 ha, with row and tree spacing of 4 m and 1.50 m, respectively, and hosts a total of ~ 7283 trees. Trees are trained to Tatura trellis and grafted on Quince A. The 'PremP009' orchard at Calimna Orchards block covers an area of 4.40 ha, with row and tree spacing of 4 m and 1.50 m, respectively, and hosting a total of ~ 7333 trees trained to Tatura trellis. Fruit number per tree and fruit size were measured for calibration purposes. Data generated from *Cartographer* were used to determine relationships between crop load, fruit quality and canopy geometry parameters.

To extract crop parameters, data points obtained with *Cartographer* were averaged within pseudo-plots (i.e., rectangles generated from a grid using QGIS v.3.6) that had a subjectively selected area equivalent to 3 x row spacing (i.e., 12 m) and 10 x tree spacing (i.e., 15 m). An example of a grid with pseudo-plots overlaying a spatial map of points generated from *Cartographer* is presented in Figure 1.

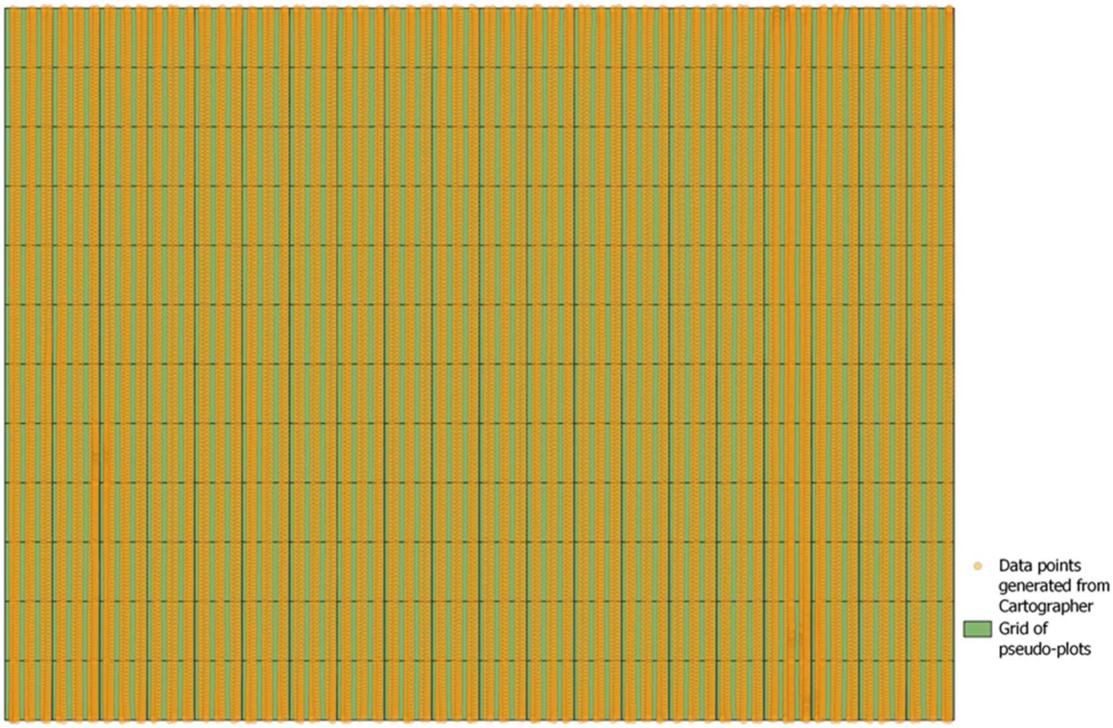

Figure 1. Example of a grid of pseudo-plots (12 x 15 m) overlaid to points generated from *Cartographer* in a pear orchard block.

The relationships of fruit weight against fruit number per hectare and fruit number per hectare normalised per radiation interception (RI) obtained in the 'ANP-0131' orchard block at Calimna Orchards were compared to relationships previously obtained in the Planting Systems and Rootstock experiments at the Tatura SmartFarm.

Crop regulation studies

Review of literature

A review of the literature relating to crop load regulation in European pears was undertaken in year one (2020 – 21) and has been published in an open access journal (Agriculture 2021, 11(7), 637; https://doi.org/10.3390/agriculture11070637).

The review examined current and potential crop load management methods for European pear cultivars, including shading, hand thinning, chemical thinning, and mechanical thinning options and raised the potential of artificial spur extinction to manage crop load. With regard to chemical thinning, the importance of understanding the conditions that influence the carbon balance of the tree and the use of a structured, sequential approach to improve outcomes and manage risks were explained. A portfolio of available options that could potentially be integrated into a systematic approach for managing crop load was provided. However, further research is required to develop thinning programs that are relatively risk free.

Experimental studies

Crop regulation experiments were conducted at the Tatura SmartFarm in 2020/21 and 2022/23 and at a commercial orchard in 2022/23. Experiments included the use of a rapid screening technique and field testing of potential chemical thinners, artificial spur extinction, hand thinning (fruitlet) and mechanical (blossom) thinning options. Effects of field experiments on flower and fruitlet thinning, fruit set, yield and fruit quality were monitored.

Experiment 1 (2020/21): chemical thinning of 'ANP-0118'

Seven thinning treatments were applied to 'ANP-0118' (Lanya™) on BP1 rootstock during September and October 2020 at the Tatura SmartFarm (Table 2). Experimental design was a randomised complete block with single tree plots and six replicates per treatment.

Table 2. Thinning treatments applied to 'ANP-0118' pear.

Treatment	Applications
Control	Untreated control
ATS	1.5 % ammonium thiosulphate (ATS) at 20% and 50% bloom
NAA	10 mg/L NAA @ FB
Ethephon	200 mg/L ethephon @ full bloom (FB)
Brevis	2.2 kg/ha Brevis @ 10 mm fruitlet size
Brevis x2	2.2 kg/ha Brevis @ 10 mm fruitlet size and 7 – 10 days later (2 applications)
Surround	Surround WP® (kaolin clay) @ 28 dAFB (4 wAFB) @ 5.0 kg /100 L water
Surround x2	Surround WP® (kaolin clay) @ 28 dAFB & 35 dAFB (5 wAFB) @ 5.0 kg /100 L water

Experiment 2 (2022/23): Mechanical thinning of 'ANP-0131'

The mechanical thinning experiment was undertaken at the Tatura SmartFarm on one row of 4-leader trees (Figure 2) with a north-south orientation. Experimental design was a randomised complete block with three replicates of four treatments. Each plot consisted of seven trees. Treatments are detailed in Table 3. Figure 3 shows the leaf blower and Darwin string thinner. Treatments were applied at full bloom in September 2022. Fruit set counts were undertaken on two trees per plot at 5 and 20 weeks after treatment. Fruit samples were harvested mid-March 2023 for laboratory assessment of skin colour, size, flesh firmness and soluble solids concentration (SSC).

Figure 2. Row of ‘ANP-0131’ (marketed as Ricó™) pears used for mechanical thinning experiment.

Table 3. Mechanical thinning treatments applied to ‘ANP-0131’ pear.

Treatment	Description
Control	Untreated control
DT gentle	Darwin thinner – gentle (180 rpm)
DT moderate	Darwin thinner – moderate (240 rpm)
LB	Leaf blower (Red Plus Duo) at 6 bar pressure

Figure 3. Leaf blower (left) and Darwin string thinner (right).

Experiment 3 (2022/23): Hand thinning of 'ANP-0131'

The hand thinning experiment was undertaken on a commercial orchard in Ardmona. Trees were on Tatura Trellis with a north-south row orientation; trees had six uprights, three each on the west and east sides of the row (Figure 4). Experimental design was a randomised complete block with six replicates of six treatments with single tree plots. Treatments are shown in Table 4.

The spur extinction treatment (Figures 5 and 6), performed in mid-September 2022, involved removal of approximately 50% of the flower buds. Clusters in this treatment were hand-thinned to single fruit in mid-October.

The aim in the one and two fruit per cluster treatments was to retain approximately 45 fruit per upright. The October treatments were completed in mid-October and the November treatments in mid-November.

Figure 4. 'ANP-0131' (marketed as Ricó™) pear hand thinning experiment on Tatura Trellis.

Table 4. Hand thinning treatments applied to 'ANP-0131' pear.

Treatment	Application rates and timing
Control	Untreated control
Single - Oct	1 fruit/cluster – October
Double - Oct	2 fruit/cluster – October
Single - Nov	1 fruit/cluster – November
Double - Nov	2 fruit/cluster – November
SE	spur extinction – applied September

Figure 5. Hand thinning experiment showing artifical spur extinction treatment (left) and control tree (right).

Figure 6. Artifical spur extinction treatment (left), showing removed flower clusters on ground (right).

Experiment 4 (2022/23): Chemical thinning of 'ANP-0131'

The chemical thinning experiment was undertaken on a commercial orchard in Ardmona. Trees were on Tatura Trellis with a north-south row orientation (Figure 7); trees had six uprights, three each on the west and east sides of the row. Experimental design was a randomised complete block with six replicates of six treatments with single tree plots. A buffer tree was retained between each treatment tree. Treatments are shown in Table 5.

All sprays were applied as a fine mist with a 16 L motorised backpack sprayer to give complete coverage to just before the point of drip. Note that it was difficult to reach tops of limbs on some trees.

There were no bees in the orchard at 20% application timing, bees were brought in before 80% bloom, and were working at the time of spray.

Figure 7. 'ANP-0131' (marketed as Ricó™) pear chemical thinning experiment on Tatura Trellis.

Table 5. Chemical thinning treatments applied to 'ANP-0131' pear.

Treatment	Application rates and timing
Control	Untreated control
ATS x1	1.25% ammonium thiosulphate (ATS) at 20% bloom
ATS x2	1.25% ATS at 20 % and 80% bloom
ACC x1	50 ppm 1-aminocyclopropane-1-carboxylic acid (ACC) at 80% bloom
ACC x2	250 ppm ACC at 80% bloom & 20 mm fruitlet size (~4 wAFB)
Ecocarb x1	Ecocarb Plus at 20% bloom
Ecocarb x2	Ecocarb Plus at 20% and 80% bloom

Figure 8. Blossom desiccation three days after application of ATS (left) and Ecocarb Plus (right) on 'ANP-0131' (marketed as Ricó™) pear trees.

Experiments 5 and 6 (2022/23): Laboratory preliminary screening using 'ANP-0131'

As field assessment for determining the potential of chemicals as thinning agents is laborious and time consuming and can result in significant damage to experimental trees, several chemicals were examined in a preliminary screening test using the method developed by Bound (2006).

Flowering spurs of 'ANP-0131' (marketed as Ricó™) were collected from the Tatura SmartFarm, all spurs had open flowers. Two experiments were set up in the laboratory.

In Experiment 5, individual flowering spurs, containing at least four healthy open flowers, were placed into glass vials filled with tap water. Spurs were assigned to treatments (Table 6) in a completely randomised design. Each treatment was replicated four times. In Experiment 6, two to three spurs were placed into 100 ml plastic beakers containing 50 ml tap water and labelled with the treatment number.

Table 6. Laboratory screening assessments.

	Experiment 5	Experiment 6
1.	Water control	Water control
2.	ATS 1.5%	Eco-flo lime 20%
3.	ATS 1.5% + Kendeen 20 @1.25 ml/L	Eco-flo lime 10%
4.	ATS 1.5% + Synertrol Horti Oil @ 2.5 ml/L	Eco-flo lime 5%
5.	Ecocarb 2%	Eco-flo lime 5% + 2.5 ml/L Synertrol Horti Oil
6.	Ecocarb 2% + Kendeen 20 @1.25 ml/L	SARsil 8%
7.	Ecocarb 2% + Synertrol Horti Oil @ 2.5 ml/L	SARsil 4%
8.	Ecocarb Plus 2%	SARsil 2%
9.	Ecocarb Plus 2% + Kendeen 20 @1.25 ml/L	SARsil 2% + 2.5 ml/L Synertrol Horti Oil
10.	Ecocarb Plus 2% + Synertrol Horti Oil @ 2.5 ml/L	2.5 ml/L Synertrol Horti Oil

The ATS and Kendeen 20 were purchased from a local agricultural supplier. The Ecocarb, Ecocarb plus, Eco-flo lime, SARsil and Synertrol Horti Oil were provided by Organic Crop Protectants.

All vials and beakers were placed on a laboratory bench and kept at ambient conditions (18°C and 41% relative humidity) for the duration of the experiment.

Sprays were mixed in 500ml trigger spray bottles (Figure 9) and applied as a fine mist to the point of runoff. Pistil damage was assessed on all flowers at intervals of 2, 4, 6, 12, 24 h for Experiment 5, and 2, 4, 6, 24 h for Experiment 6.

Figure 9. Spray bottles prepared for treatment application.

Fruit colour: Artificial heating and cooling experiment

A method of artificially heating and cooling blush pears in the field was established in the 2021/2022 season. Air was piped from air conditioners and hair dryers to the fruit surface during two periods of five days. Fruit temperature was monitored continuously with fine wire thermocouples and daily measures of fruit peel colour were taken with a colorimeter. Artificial cooling appeared to mitigate yellowing of ‘ANP-0534’ fruit at harvest. Usefulness of artificial, in-field heating and cooling systems to investigate impacts of temperature on colour is likely limited by the interrelationship of light and temperature. Detailed methodology is reported in McClymont et al. (accepted).

Fruit colour: Alternate netting experiment

The alternate-side netting experiment was installed on a commercial orchard at Shepparton East. Five treatments were imposed over plots of seven – eight trees in a north-south oriented row of ‘ANP-0131’ (Figure 10): control (open), crystal netting, crystal netting on the east and grey netting on the west, grey netting on the east and crystal netting on the west, and grey netting.

Fruit (n=360) were tagged on central trees (n = 4 or 3) in each plot on the east (E) and west (W) sides of the north-south oriented row and at three canopy heights (low 1 – 1.4 m, middle 2 – 2.6 m and high 3.3 – 3.8 m) in November 2021 and measurements of peel color (CIELab colour scale) were taken on the exposed face in November and December 2021 and February 2022. In mid-February, the tagged fruit were picked and blush coverage was assessed by a commercial fruit grader. The following week (1 week prior to expected commercial harvest) peel colour parameters were measured on a larger sample of pears (n= 1274) with > 10% blush coverage on both sides of the trees (E and W) and within three height zones (low 0.6 – 1.2 m, middle 2 – 2.6 m, and high 3.3 – 3.8 m). Sunburn damage was assessed on the central trees in each plot on 22 February 2022. Replication was not possible at the site and data from tagged fruit were analysed by ANOVA using trees within plots as pseudo-replicates.

Figure 10. Alternate netting experiment.

Testing of mobile sensing platform

The sensors, artificial intelligence and visualisation software operated commercially by Green Atlas (https://greenatlas.com.au/cartographer/) were used to scan the Planting Systems and Rootstock experiments at the Tatura SmartFarm to detect flower clusters and fruit and determine tree geometry characteristics, with objectives to:

- Explore commercial flower cluster recognition and mapping technology to estimate flower density.
- Test commercial fruit recognition technology to map pear fruit number, estimate fruit size and assess fruit colour in orchards.
- Evaluate the ability of commercial technology to measure and map pear tree size in orchards.

Green Atlas *Cartographer* is a sensorised system equipped with a customary number of sensors. The system used in this study was equipped with two RGB cameras, four custom-built strobe lights for continuous canopy illumination, a vertical LiDAR (RoboSense, Shenzhen, China), an onboard GPS antenna interfaced with an offboard GNSS (Global Navigation Satellite System) for Real Time Kinematic (RTK) corrections (Emlid Ltd, Hong Kong, China), two Enviro-ThermTM infrared sensors (Everest Interscience, Chino Hills, CA, USA) and a CO_2 sensor (CO2meter.com, Ormond Beach, FL, USA). The reliability of thermal and CO_2 sensing is currently being investigated in a collaboration between Green Atlas and Agriculture Victoria. Green Atlas uses a proprietary convolutional neural network algorithm to train detections of flower clusters and fruit. Tree geometry parameters calculated from LiDAR data include tree height, canopy area, canopy density and cross-sectional leaf area (CSLA). Canopy area (m^2) represents the area of the polygon drawn around the LiDAR-generated points in the scanned transect, excluding the trunk. Canopy density represents the ratio between the number of light beams generated by the LiDAR that bounces back to the light source and the total number of emitted light beams within the canopy area. CSLA is calculated as the product of canopy area and canopy density and is equivalent to the area of the points (comparable to leaves) within the canopy area polygon in the scanned transect (Scalisi et al. 2021). Detailed methodology of the initial validation process was provided for Milestone 105. Further investigations were conducted in commercial orchards.

Key Research Findings

Planting Systems experiment

McClymont et al. (2021) reported that during the first five seasons (2013 – 2018), ‘ANP-0131’ was observed to be a vigorous scion and vegetative growth, precocity and yield were influenced by the selected rootstocks (Table 7). Scions were most vigorous on D6 rootstocks whereas scions on Quince A rootstocks produced more fruit and greater yields per ha. While increasing tree density from ‘Low’ and ‘Moderate’ to ‘High’ improved cumulative yield per ha in the first five seasons, increasing tree density from ‘High’ (2222 trees per ha) to ‘UltraHigh’ (4444 trees per ha) did not significantly improve yield (Table 7). Yields were low in the first two bearing seasons (less than 20 t/ha) but reached 74 t/ha (trees grown on Quince A rootstock, trained with two leaders to Open Tatura trellis, i.e., at ‘UltraHigh’ densities) in the 2017/18 season (5th growing season).

Yields in subsequent seasons (2018 – 2023) fluctuated (Table 7 and Figure 11). However, trends in response to rootstock remained consistent. Trees on Quince A rootstocks have continued to outperform those on other rootstocks, in terms of yield, each season (Table 7). Cumulatively, since planting, Quince A rootstocks increased overall total yields by 38 – 49 % and marketable yields by approximately 35 % compared to other rootstocks (Table 7). Trees on Quince A had better early yields and continued to set more fruit than trees on D6 and BP1 each season. Yields of trees on D6 rootstocks indicate a persistent decline in productivity, although cumulative yield remained slightly greater than that for trees on BP1.

Main effects of training system on yield were usually not statistically significant (Table 7). However, significant interactions occurred with tree density (Table 7). Trees planted at ‘High’ and ‘Ultrahigh’ densities produced more fruit initially than ‘Low’ and ‘Moderate’ density trees but then entered a biennial bearing pattern (Table 7 and Figure 11). By contrast, trees with 6- (Open Tatura-Moderate and Vertical-Low) and 8-leaders (Open Tatura-Low treatments) had low early yields, likely due to slower establishment of the tree structure, then maintained moderate yields with less interseasonal fluctuation than other treatments (shown for Quince A rootstocks, Figure 11). These differences in seasonal yield patterns moderated the overall trend of increasing cumulative yield associated with increasing tree density. For each training system, cumulative yield over the eight bearing seasons was not statistically different between tree densities, except in Traditional (3-dimensional) training systems (Table 7).

Examining the 36 rootstock x training system x planting density treatments showed that the best performing treatments in terms of cumulative total and marketable yield were trees on Quince A rootstocks, trained to Open Tatura trellis or with 6-leaders trained to a Vertical trellis (Table 8). Trees on Quince A rootstock trained as super-spindles (Traditional-UltraHigh density) also performed well. Cumulative marketable yield (yield of fruit within the 150 – 260 g weight range) showed that a large proportion of crop was over- or under-sized each season. This problem could be addressed by setting appropriate crop loads based on crop load relationships established in this project and avoiding excessive vegetative vigour. Crop load was not normalized in this experiment, thus differences in marketable yield reflect treatment effects on fruit set and the ability to size fruit.

Excessive vegetative vigour has been noted previously as a likely factor compromising yields in the Planting System experiment. ‘ANP-0131’ is a vigorous scion and the approach of providing irrigation to meet crop water use for most of the season, excluding the period of regulated deficit irrigation in November, has limited the capacity to control vegetative growth via water stress. This has likely contributed to low crop loads in some treatments, particularly those on D6 rootstocks. Comparable treatments for trees on D6, Quince A and BP1 in the Rootstock experiment had substantially higher cumulative yields (403.7, 410.5, and 317.2 t/ha, respectively) than those in the Planting Systems experiment (183.6, 262.0 and 142.9 t/ha, respectively), emphasising the risk of interseason yield fluctuations for ‘ANP-0131’ (Figure 11).

Table 7. Early yield (2015 – 2018), annual yield (seasons 2018/19 – 2022/23) and cumulative and 'marketable' yields in response to rootstock (D6, BP1 and Quince A on Beurre Hardy interstem), training system (Open Tatura trellis, two dimensional Vertical, and three dimensional Traditional), and tree density (Low, Moderate, High and UltraHigh). Main effects and training system x tree density interactions are shown. LSD = least significant differences of means (P < 0.05). 'Marketable' yield is yield of fruit weighing 150 – 260 g, note marketable yield was not assessed 2015/16 and 2016/17.

Treatment	Early yield (t/ha)	Yield (t/ha)					Cumulative yield (t/ha)	'Marketable' yield (t/ha)
	2015/16 – 2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2015/16 – 2022/23	2017/18 – 2022/23
D6	53.5	26.7	37.1	20.2	18.3	14.2	170.7	86.6
BP1	42.2	23.4	31.2	17.8	26.6	15.0	157.1	85.1
QA	64.8	25.6	53.4	24.1	39.7	26.3	234.8	116.0
F pr.	*<.001*	*0.342*	*<0.001*	*0.002*	*<0.001*	*<0.001*	*<0.001*	*<0.001*
LSD	*5.28*	*4.6*	*4.9*	*3.5*	*3.5*	*3.7*	*12.8*	*8.5*
Open Tatura	52.2	31.7	37.1	22.3	20.5	22.8	186.9	99.9
Vertical	53.6	18.9	45.9	15.7	34.7	15.0	184.9	94.2
Traditional	54.7	25.1	38.7	24.0	29.5	17.7	190.9	93.6
F pr.	*0.924*	*0.116*	*0.204*	*0.014*	*0.04*	*0.603*	*0.94*	*0.662*
LSD	*17.46*	*13.0*	*11.9*	*4.5*	*9.8*	*20.3*	*47.8*	*20.2*
Low	28.3	39.1	26.8	34.4	25.9	27.6	179.7	95.2
Moderate	49.1	25.4	37.7	19.6	29.0	16.3	178.5	88.8
High	66.5	20.1	47.8	13.3	28.4	13.2	193.5	96.1
UltraHigh	70	16.4	50.0	15.5	29.5	16.9	198.4	103.5
F pr.	*<.001*	*<0.001*	*<0.001*	*<0.001*	*0.29*	*<0.001*	*0.018*	*0.039*
LSD	*6.1*	*5.3*	*5.6*	*4.0*	*4.0*	*4.3*	*14.8*	*9.9*
Open Tatura.Low	28.6	36.9	28.9	31.7	21.6	34.4	175.3	88.2
Open Tatura.Moderate	39.7	37.3	31.8	30.3	19.3	22.8	185.8	95.8
Open Tatura.High	65.7	29.4	45.2	11.5	23.7	16.9	196.2	108.7
Open Tatura.UltraHigh	74.7	23.4	42.5	15.8	17.2	16.9	190.4	106.9
Vertical.Low	30	36.5	36.5	33.0	38.4	22.6	197	103.9
Vertical.Moderate	48.7	18.5	43.3	11.7	37.2	12.6	172.1	94.2
Vertical.High	69.8	10.5	53.5	8.9	32.0	10.7	189.6	90.3
Vertical.UltraHigh	66	10.0	50.4	9.1	31.2	14.2	180.8	88.3
Traditional.Low	26.4	43.8	14.9	38.3	17.6	25.9	166.9	93.5
Traditional.Moderate	58.8	20.2	37.8	16.9	30.7	13.3	177.7	76.4
Traditional.High	64.1	20.5	44.7	19.4	29.3	12.0	194.8	89.3
Traditional.UltraHigh	69.4	15.9	57.3	21.5	40.2	19.8	224.2	115.2
F pr.	*0.018*	*0.012*	*0.002*	*<0.001*	*<0.001*	*0.291*	*0.009*	*0.002*
LSD (overall)	*17.54*	*13.4*	*12.8*	*6.9*	*10.2*	*19.8*	*47.3*	*22.1*
LSD (at same level of training system)	*10.56*	*9.2*	*9.8*	*7.0*	*7.0*	*7.5*	*25.6*	*17.1*

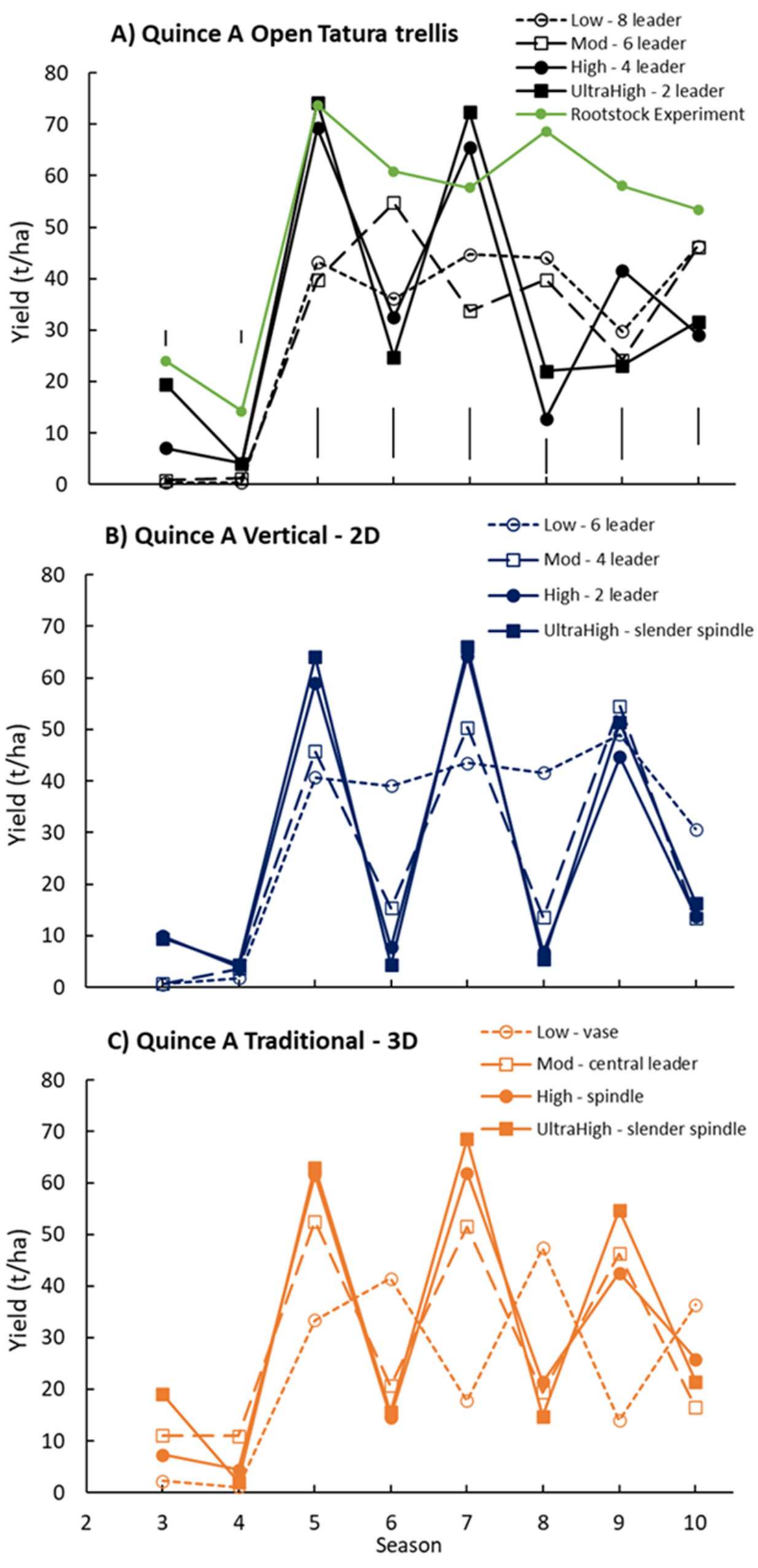

Figure 11. Annual yield of 'ANP-0131' on Quince A rootstocks with 'Beurre Hardy' interstem. Trees were trained on A) Open Tatura trellis, B) two dimensional Vertical, and C) three dimensional Traditional systems, and planted at four tree densities (Low, Moderate, High and UltraHigh). Annual yields of 'ANP-0131' on Quince A rootstocks with 'Beurre Hardy' interstem within the Rootstock experiment shown in A). Rootstock Experiment trees were trained on Open Tatura trellis and planted at 'High' density (2222 trees/ha).

Table 8. Cumulative and 'marketable' yields in response to rootstock (D6, BP1 and Quince A on Beurre Hardy interstem), training system (Open Tatura trellis, two dimensional Vertical, and three dimensional Traditional), and tree density (Low, Moderate, High and UltraHigh). Significance of interactions are shown. 'Marketable' yield is yield of fruit weighing 150 – 260 g, note marketable yield was not assessed 2015/16 and 2016/17.

Treatment	Cumulative yield (t/ha) 2015/16 – 2022/23			Marketable yield (t/ha) 2015/16 – 2022/23		
	D6	BP1	Quince A/ Beurre Hardy	D6	BP1	Quince A/ Beurre Hardy
Open Tatura.Low	147.0	133.8	245.0	68.7	63.3	132.5
Open Tatura.Moderate	186.7	130.3	240.5	89.1	67.6	130.7
Open Tatura.High	183.6	142.9	262.0	108.1	85.5	132.6
Open Tatura.UltraHigh	164.2	135.1	271.9	94.8	89.6	136.4
Vertical.Low	173.6	170.4	247.1	85	94.7	132
Vertical.Moderate	163.6	155.0	197.6	83	91	108.5
Vertical.High	177.6	180.6	210.5	82.2	90.9	97.6
Vertical.UltraHigh	146.1	174.5	221.7	73	92.6	99.3
Traditional.Low	150.4	156.4	193.8	80.9	90.8	108.8
Traditional.Moderate	161.7	142.6	228.9	73.1	59.8	96.4
Traditional.High	185.4	159.4	239.6	92.1	80.5	95.4
Traditional.UltraHigh	208.5	204.5	259.5	109.7	114.6	121.2
F pr						
Training system x Rootstock:		*< 0.001*			*0.001*	
Training system x Density:		*0.009*			*0.002*	
Rootstock x Density:		*0.662*			*0.148*	
Training system x Rootstock x Density:		*0.745*			*0.999*	

Previous work at the Tatura SmartFarm showed that fruit exposure to light is required for development of blush on 'ANP-0131' and other pear selections (Peavey et al. 2020, Visscher et al. 2021). Consistent with the need for good fruit exposure, blush coverage and red colour development were generally improved (coverage increased and hue decreased) by use of BP1 rootstock and, to a lesser extent, Quince A rootstock, and Low and Moderate tree densities (Table 9). With regard to both rootstock and tree density effects, the dominant driver is likely decreased vegetative vigour due to rootstock or increased number of leaders and subsequent better fruit exposure to light. Overall, 2D training systems (Open Tatura and Vertical) improved blush colour development.

Table 9. Blush coverage (seasons 2018/19 – 2022/23) and hue (seasons 2020/21 and 2021/22) in response to rootstock (D6, BP1 and Quince A on Beurre Hardy interstem), training system (Open Tatura trellis, two dimensional Vertical, and three dimensional Traditional), and tree density (Low, Moderate, High and UltraHigh). Main effects and training system x tree density interactions are shown. LSD = least significant differences of means (P < 0.05), sed = standard errors of differences of means. Hue was not measured in 2022/23 due to hail damage.

Treatment	Blush coverage (%)					Hue	
	2018/19	2019/20	2020/21	2021/22	2022/23	2020/21	2021/22
D6	19	30	30	23	22	69.0	70.7
BP1	27	41	37	27	31	50.9	58.8
QA	22	43	32	27	29	56.3	63.6
F pr.	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*
LSD	*2*	*3*	*2*	*2.1*	*3*	*4.9*	*4.7*
Open Tatura	26	38	36	19	28	54.0	70.8
Vertical	22	40	33	30	26	58.7	60.3
Traditional	21	36	30	28	28	63.7	61.9
F pr.	*0.161*	*0.248*	*0.06*	*<0.001*	*0.735*	*0.02*	*0.007*
LSD	*5*	*6*	*2*	*0.8*	*8*	*5.4*	*4.7*
Low	29	38	36	28	33	48.5	61.8
Moderate	23	40	33	28	28	55.7	60.5
High	20	36	32	24	25	65.0	67.5
UltraHigh	20	37	32	22	23	66.0	67.7
F pr.	*<0.001*	*0.13*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*0.012*
LSD	*2*	*4*	*2*	*2.4*	*3*	*5.6*	*5.4*
Open Tatura.Low	31	43	40	24	33	46.4	65.3
Open Tatura.Moderate	28	41	37	22	30	45.1	69.5
Open Tatura.High	22	35	36	18	28	57.4	71.9
Open Tatura.UltraHigh	21	33	32	15	23	67.0	76.5
Vertical.Low	29	41	36	31	32	45.1	58.4
Vertical.Moderate	23	44	34	33	28	56.0	53.1
Vertical.High	18	37	29	27	23	69.3	65.4
Vertical.UltraHigh	19	38	31	27	22	64.3	64.6
Traditional.Low	26	31	33	30	32	53.9	61.7
Traditional.Moderate	19	36	27	29	28	65.9	58.8
Traditional.High	20	36	29	28	23	68.2	65.1
Traditional.UltraHigh	20	39	32	26	22	66.6	62.0
F pr.	*0.026*	*0.011*	*0.027*	*0.428*	*0.532*	*0.043*	*0.509*
LSD (overall; at same level of training system)	*5; 4*	*7; 7*	*4; 4*	*4; 4*	*8; 5*	*9.3; 9.7*	*8.8; 9.3*

Nutrient status and soil porosity

Neither training system (open Tatura trellis versus vertical 2-D) nor tree density (‘low’, ‘moderate’ and ‘high’) were significant sources of variation in leaf nutrient concentrations. Soil bulk density in two plots was affected by historical burn piles located at the south of the Planting Systems experiment. The location of the burn piles was unknown prior to sampling and revealed by presence of charcoal in the samples. These plots’ samples were excluded from analysis due to the presence of fine charcoal material that could not be adjusted for. There was no effect of treatments on bulk density or, consequently, porosity. Bulk density of the interrow (1.59 g/cm3) tended to be higher than in the treeline (1.52 g/cm3). Porosity was calculated to be 40 (interrow) and 43 % (treeline).

Rootstock experiment

'ANP-0131' trees were most precocious on Quince A rootstocks with Beurre Hardy interstems (Figure 12). Following low yields in the 3rd (2015/16) and 4th (2016/17) seasons after planting, trees on D6, Quince A and Quince C rootstocks produced >70 t/ha in 5th season and then consistently produced 60 – 70 t/ha/yr (Figure 12). Lower yields in the 10th season (2022/23) were likely due to fruit drop following a hail event in December and poorer fruit growth. Mean fruit number per leader for trees on D6 rootstock was 32 – 40 fruit, whereas trees on Quince A rootstocks carried 36 – 49 fruit per leader. Trees on D6 compensated for lower fruit numbers with larger fruit size, such that yields were not significantly different. Trees on BP1 had consistently lower yields, with cumulative yield 23 % (93 t/ha) less than trees on Quince A rootstock (Table 10) and did not size fruit well until 9th season. Use of D6 rootstocks with interstems or summer-budding with virus material appeared to induce biennial bearing (Table 10). Blush development had a negative correlation with light interception most likely due to internal canopy shading of the fruit (Figure 13). D6 tended to have poorer blush coverage than trees on Quince attributed to excessive vegetative growth and fruit shading (Table 11). Crop load management is required to target fruit size to avoid under and/or over sizing fruit. Adjustment for light interception gives some improvement to crop load management and fruit size prediction (McClymont et al. 2022, Figure 14). Vigour management (via rootstocks or other management like deficit irrigation and plant growth regulators) is advised to help colour fruit.

'ANP-0118' trees were most precocious on Quince A rootstocks (Figure 12). Following low yields in 3rd and 4th seasons, trees on Quince A and C rootstocks produced 40 – 50 t/ha consistently from 5th to 8th leaf before producing > 60 t/ha in 9th leaf, whereas trees on D6 and BP1 produced yields of 20 – 30 t/ha to 9th season when yields ~ 40 t/ha were achieved (Figure 12). The 10th season crop was severely compromised by hail event and stripped early to avoid pest and disease issues. Yields of D6 and BP1 rootstock treatments were compromised by low fruit numbers. Fruit weights were greater, but this did not compensate for the lower fruit numbers. Use of D6 rootstocks with interstems increased seasonal yield variability but the pattern was not biennial. Cumulative 9-year yield of quince treatments were 61 – 141 t/ha > than other treatments; however, mean fruit weight was < 100 g in some seasons, highlighting the need for thinning to ensure adequate fruit size. Blush development had a negative correlation with light interception most likely due to internal canopy shading of the fruit (Figure 13). Light interception tended to be greatest and blush coverage lowest for D6-Nij and QC, whereas light interception tended to lowest and blush coverage greatest for BP1 and other variants of D6 rootstock treatments.

'ANP-0534' trees produced a steady 30 – 40 t/ha from 4th season (Figure 12). Increased fruit numbers in 9th season resulted in yields 56 – 72 t/ha; however, mean fruit weight dropped below 130 g. Generally, there was little difference in yield between rootstocks although bearing of trees on BP1 initially lagged behind other treatments. Cumulative 10-year yields were significantly lower for trees on D6-BM2000 (210 t/ha compared with 281 t/ha for trees on D6-Nij, Table 10). In contrast to 'ANP-0131' and 'ANP-0118', yields and inter-season variability were not affected by interstems or budded virus material (Table 10).

Canopy radiation interception and yield data from the rootstock experiment (seasons 2015/16 to 2019/20) were analysed and a paper presented to the XII International Symposium on Integrating Canopy, Rootstock and Environmental Physiology in Orchard Systems (McClymont et al. 2022). Functional relationships between yield and fruit number, fruit weight and fruit number and fruit weight and fruit number normalised for canopy radiation interception were reported for 'ANP-0131' and 'ANP-0534' (Figure 14; McClymont et al. 2022). These relationships can be used to manage fruit number and target desired fruit weights.

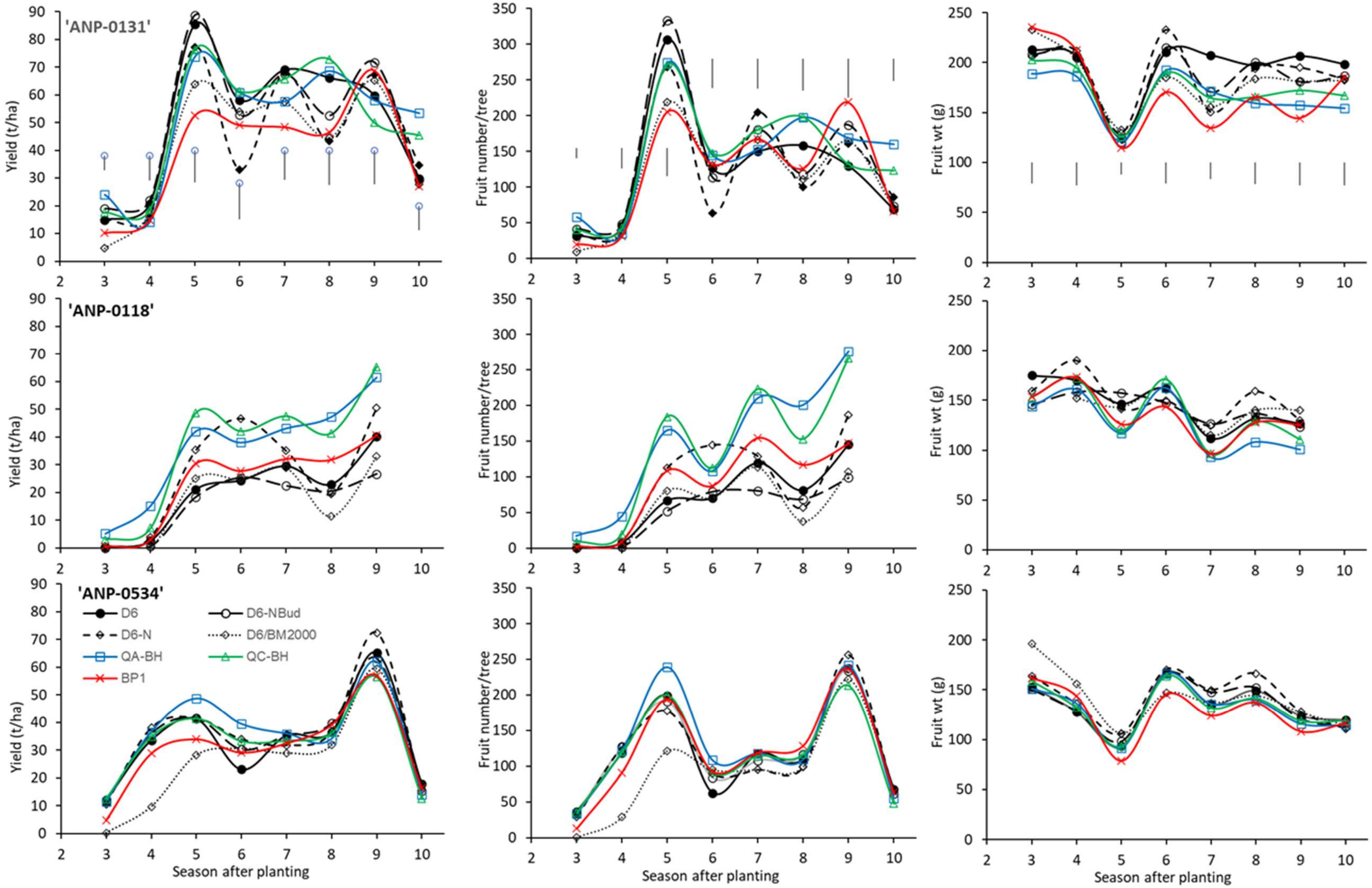

Figure 12. Effect of rootstock and interstem on yield (t/ha), fruit number and fruit weight for scions 'ANP-0131', 'ANP-0118' and 'ANP-0534' in the third to tenth seasons after planting (2015/16 to 2022/23). Errors bars show Fisher's least significant difference (P= 0.05) for Selection*Rootstock.

Table 10. Cumulative yield (2016 – 2023) and biennial bearing index (2018 – 2023) in response to selection and rootstock treatment. LSD = least significant differences of means (P < 0.05).

Treatment	Cumulative yield (t/ha)	Biennial bearing Index
ANP-0131	375.9	0.19
ANP-0118	178.3	0.17
ANP-0534	257.7	0.24
F pr.	*<0.001*	*<0.001*
LSD	*14.6*	*0.03*
D6	270.0	0.21
D6-Nij	275.5	0.28
D6-budNij	263.6	0.23
D6-BM2000	223.5	0.22
QA/BH	312.0	0.15
QC/BH	308.0	0.16
BP1	241.9	0.18
F pr.	*<0.001*	*<0.001*
LSD	*22.4*	*0.05*
ANP-0131 D6	403.7	0.19
ANP-0131 D6-Nij	354.4	0.30
ANP-0131 D6-virus	403.4	0.24
ANP-0131 D6-BM2000	334.6	0.18
ANP-0131 QA/BH	410.5	0.12
ANP-0131 QC/BH	407.7	0.13
ANP-0131 BP1	317.2	0.20
ANP-0118 D6	141.4	0.17
ANP-0118 D6-Nij	191.5	0.26
ANP-0118 D6-virus	114.1	0.18
ANP-0118 D6-BM2000	126.1	0.25
ANP-0118 QA/BH	252.5	0.09
ANP-0118 QC/BH	255.5	0.13
ANP-0118 BP1	166.7	0.13
ANP-0534 D6	264.8	0.28
ANP-0534 D6-Nij	280.6	0.27
ANP-0534 D6-virus	273.2	0.26
ANP-0534 D6-BM2000	209.8	0.23
ANP-0534 QA/BH	273.1	0.26
ANP-0534 QC/BH	260.9	0.21
ANP-0534 BP1	241.7	0.20
F pr.	*<0.001*	*0.09*
LSD	*38.7*	*0.09*

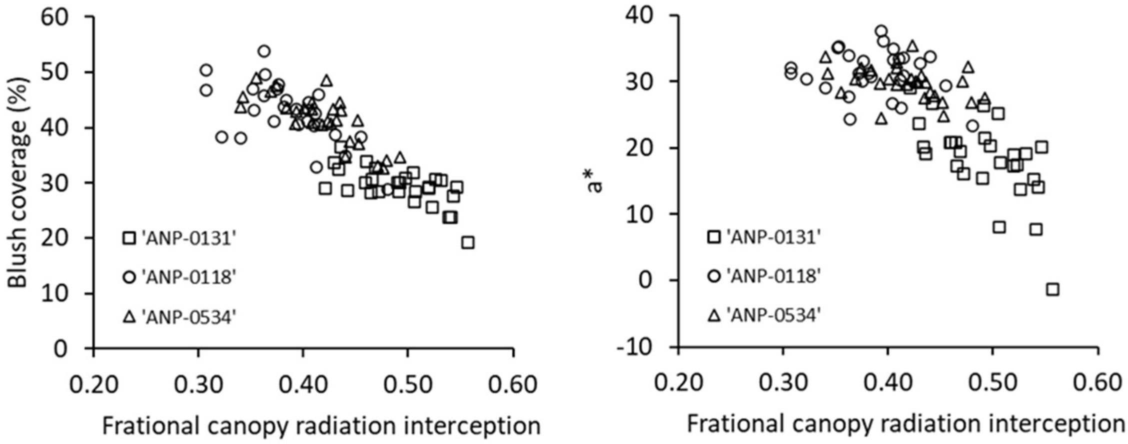

Figure 13. Blush coverage (%) and red intensity (a*) of blush pears ('ANP-0131', 'ANP-0118' and 'ANP-0534') in relation to fractional canopy radiation interception (season 2020/21).

Table 11. Fruit maturity (firmness), soluble solids concentration (SSC) and blush coverage (%) and hue CIELab colour measures) in response to selection and rootstock treatment at harvest (season 2020/21 and 2021/22). LSD = least significant differences of means (P < 0.05). Fruit quality was not assessed in 2022/23 due to hail damage.

	2020/21				2021/22			
Treatment	Firmness (kgf)	SSC (°brix)	Blush (%)	Hue	Firmness (kgf)	SSC (°brix)	Blush (%)	Hue
ANP-0131	5.1	13.7	29	51.3	5.4	13.6	19	62.5
ANP-0118	6.2	13.0	43	39.8	4.6	12.5	30	47.9
ANP-0534	7.6	14.3	41	34.6	6.3	13.9	40	48.4
F pr.	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*
LSD	*0.2*	*0.3*	*1.7*	*3.1*	*0.2*	*0.3*	*2*	*3.6*
D6	6.4	13.1	36	46.8	5.3	13.0	28	55.5
D6-Nij	6.4	13.2	35	41.9	5.5	12.5	27	54.5
D6-budNij	6.5	13.4	36	44.4	5.5	13.5	30	52.1
D6-BM2000	6.2	13.5	40	40.6	5.4	13.0	29	54.3
QA/BH	6.0	14.1	40	36.9	5.5	13.9	31	52.8
QC/BH	6.2	14.2	39	42.2	5.5	13.7	30	52.4
BP1	6.2	14.3	38	40.4	5.4	13.4	33	48.9
F pr.	*0.237*	*<0.001*	*<0.001*	*0.006*	*0.768*	*<0.001*	*0.004*	*0.304*
LSD	*0.4*	*0.5*	*3*	*4.8*	*0.3*	*0.4*	*3*	*5.6*
ANP-0131 D6	5.1	12.9	25	64.2	5.3	13.1	14	70.4
ANP-0131 D6-Nij	5.4	13.2	30	48.3	5.5	13.1	19	61.2
ANP-0131 D6-virus	5.4	13.4	26	59.8	5.5	13.3	18	63.0
ANP-0131 D6-BM2000	5.0	13.5	31	44.9	5.6	13.4	20	59.2
ANP-0131 QA/BH	5.0	14.3	31	48.7	5.3	14.3	19	63.5
ANP-0131 QC/BH	4.9	14.3	31	52.3	5.4	14.2	17	62.3
ANP-0131 BP1	5.0	14.0	31	40.9	5.3	13.4	23	58.2
ANP-0118 D6	6.5	12.4	43	40.7	4.5	12.6	31	47.4
ANP-0118 D6-Nij	6.1	12.5	39	41.6	4.8	11.3	24	52.1
ANP-0118 D6-virus	6.4	12.9	43	39.5	4.6	12.9	32	44.4
ANP-0118 D6-BM2000	6.3	13.0	46	41.5	4.6	12.3	30	54.0
ANP-0118 QA/BH	6.0	13.5	44	42.1	4.7	12.9	31	44.1
ANP-0118 QC/BH	6.1	13.3	39	36.6	4.7	12.6	27	48.0
ANP-0118 BP1	5.7	13.6	46	36.4	4.5	12.9	34	45.5
ANP-0534 D6	7.6	13.9	40	35.4	6.2	13.5	39	48.7
ANP-0534 D6-Nij	7.6	13.8	37	35.7	6.3	13.0	38	50.2
ANP-0534 D6-virus	7.7	13.9	39	33.8	6.3	14.4	39	49.0
ANP-0534 D6-BM2000	7.3	14.0	44	35.5	6.2	13.3	37	49.8
ANP-0534 QA/BH	7.7	14.9	43	35.9	6.5	14.5	42	50.9
ANP-0534 QC/BH	7.5	15.1	45	32.3	6.4	14.4	44	47.0
ANP-0534 BP1	7.4	14.6	42	33.5	6.2	14.0	42	42.9
F pr.	*0.884*	*0.975*	*0.029*	*0.006*	*0.982*	*0.149*	*0.028*	*0.449*
LSD	*0.7*	*0.8*	*5*	*8.3*	*0.5*	*0.8*	*5*	*9.6*

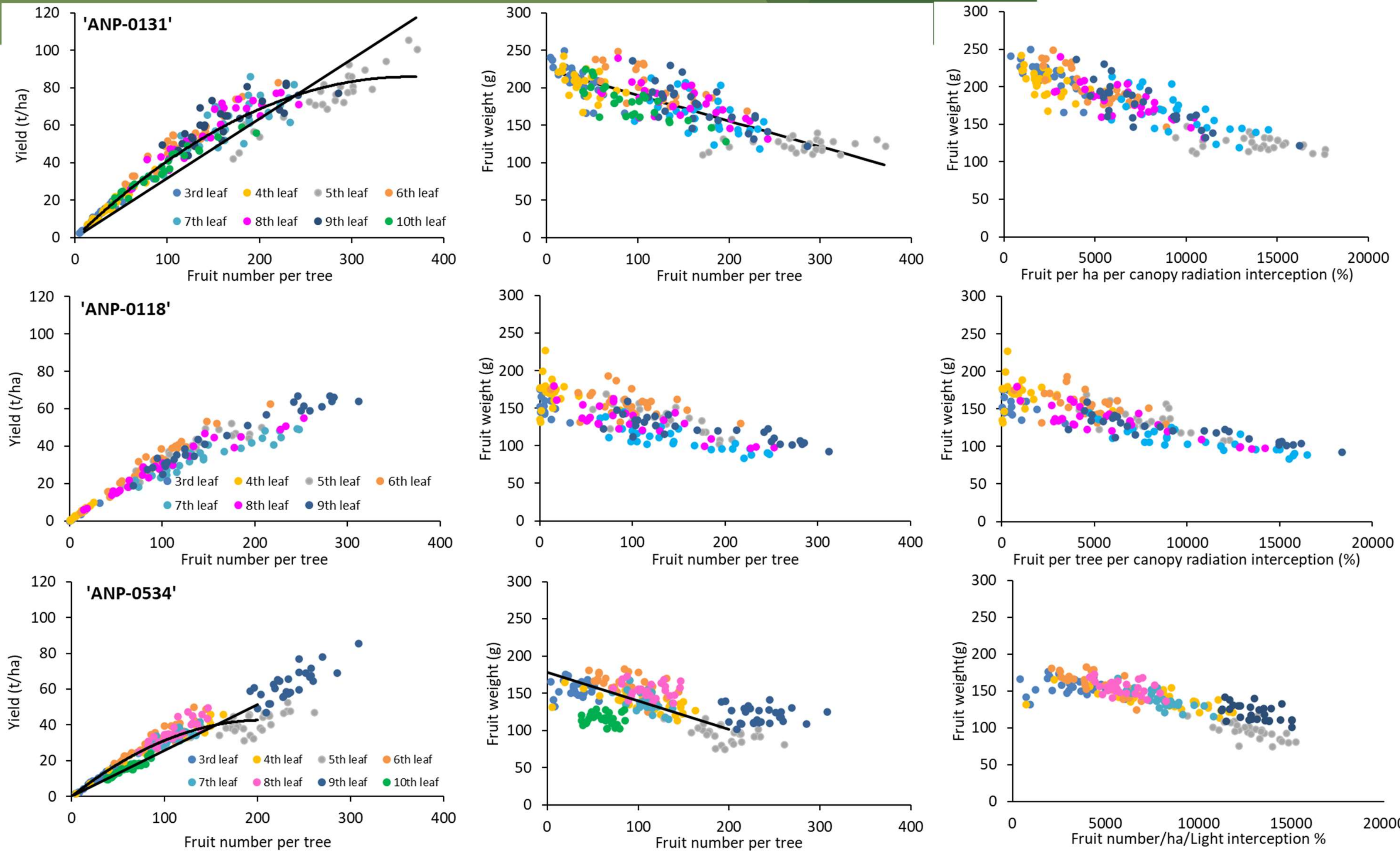

Figure 14. Relationships between fruit number (per tree) and yield (t/ha) and fruit weight (g) and fruit number normalised for canopy radiation interception and fruit weight. Lines indicate relationships described in McClymont et al. (2022) determined from harvest data to 7th leaf (2019/20).

Nutrient status

Scion ('ANP-0131' and 'ANP-0118') and rootstock (D6, D6-'Nijiseikki', Quince A-Beurre Hardy and BP1) significantly affected leaf mineral nutrient concentrations. Differences in leaf nutrient concentration biometrically attributable to scion and rootstock may be due to differences in uptake by roots, transport upwards, allocation between leaves and fruit and re-distribution. It is beyond the scope of this study to determine whether the effects of scion and rootstock are directly limiting or increasing uptake of particular mineral nutrients, or if the effects are indirect via differences in vegetative growth or fruit number. Similarly, it is not within the scope of this study to determine whether rootstocks take up and transport more or less of particular mineral nutrients or whether scions respond differentially to more or less of particular mineral nutrients reaching their leaves in terms of biomass production and reproductive behaviour. However, strong correlations between leaf K and B mineral nutrient concentrations and crop loads, and the obvious structure related to rootstock and less so to scion lend weight to the idea that underlying the relationship between the trees' reproductive behaviour and their mineral nutrient status is modulated more by rootstock than by scion. Detailed results were reported for Milestone 106.

Pest and disease susceptibility

Monitoring of pest and disease occurrences in the Rootstock experiment revealed differences between pear selections but not rootstocks. Clear differences in the presence of light brown apple moth (LBAM) and severity of mite damage existed between selections in the 2020/21 season (Table 12). LBAM were more likely to have laid eggs on 'ANP-0534' than 'ANP-0131' and 'ANP-0118' ($P < 0.001$). Mite damage was most severe on 'ANP-0131' scions and least severe on 'ANP-0118' ($P < 0.001$ for each damage parameter). Differences between rootstocks were not significant for either LBAM or mite damage and there were no significant interactions between selection and cultivar. Likewise, in the 2021/22 season, mites caused mild damage on 'ANP-0131' and 'ANP-0534' but did not affect 'ANP-0118' (Table 13). Damage patterns in 2021/22 suggested that damage on 'ANP-131' (leaf damage in the low-mid canopy) was caused by two-spotted mite, whereas damage on 'ANP-0534' (speckling of undersides of leaves in the upper canopy) was caused by Bryobia or European red mite. Mild damage in the upper canopy was observed in all plots in 2022/23; predator mite were frequently observed in 2022/23 and may have reduced two-spotted mite activity. Observations of mite damage were consistent with casual observations of mite damage in previous seasons, when 'ANP-0131' was observed to suffer mite damage at lower CLIDs (cumulative leaf infestation days) than 'ANP-0118' and 'ANP-0534'. It has been observed previously that 'ANP-0118' is more susceptible to *Pseudomonyis syringae* than either 'ANP-0131' and 'ANP-0534'. 'ANP-0118' is the only cultivar that has had symptoms of *Pseudomonyis syringae* within the Rootstock experiment. One tree each of 'ANP-0131' and 'ANP-0534' on D6 with BM2000 interstem died and one tree of 'ANP-0118' on D6 with BM2000 showed signs of decline, no obvious external causes of death were observed suggesting the problems were related to grafts.

Table 12. Pest presence and severity scores for light brown apple moth (LBAM) and mites within the Rootstock experiment in season 2020/21. LSD = least significant differences of means ($P < 0.05$), sed = standard errors of differences of means.

Cultivar	LBAM	Mite damage - affected trees/plot	Mite damage - severity score
ANP-0131	0.57	5.4	1.4
ANP-0118	0.57	0.8	0.5
ANP-0534	4.64	2.2	0.8
F pr.	<.001	<.001	<.001
lsd	0.75	1.2	0.3
sed	0.37	0.6	0.2

Table 13. Pest presence and severity scores for mites within the Rootstock experiment in season 2021/22. LSD = least significant differences of means ($P < 0.05$), sed = standard errors of differences of means.

Selection	Mite damage - affected trees/plot	Mite damage - severity score
ANP-0131	8.2	0.7
ANP-0118	0	0
ANP-0534	7.7	0.8
F pr.	<0.001	<0.001
lsd	0.8	0.1
sed	0.4	0.1

Validation of crop load relationships

‘ANP-0131’ commercial orchard block

Table 14 shows the crop parameter summary obtained near harvest (22 February 2022) using *Cartographer*. The grid overlaid onto the ‘ANP-0131’ block consisted of 243 pseudo-plots. Scans in the block generated an average of 74 estimates of machine vision-derived parameters (i.e., fruit number, fruit size, cluster size and fruit colour development index (CDI)) per pseudo-plot, and 75 measures of LiDAR-derived parameters (i.e., canopy height, canopy area, canopy density and cross-sectional leaf area (CSLA)).

Table 14. Block summary of crop parameters in the ‘ANP-0131’ orchard block at Calimna Orchards scanned on 22 February 2022.

Average crop parameter	
Fruit number (n / tree)	137
Cluster size (fruit n / cluster)	4.1
Fruit size (mm)	69.7
Colour development index (0 – 1)	0.54
Canopy height (m)	3.50
Canopy area (m^2)	3.24
Canopy Density (0 – 1)	0.66
Cross-sectional leaf area (m^2)	2.20

Crop parameters obtained from *Cartographer* scans were correlated using a correlation matrix and significant relationships were tested with the Spearman’s correlation coefficient and reported in Table 15. Scatterplots and linear fits of the relationships were presented in Figure 15. The most important observations deriving from the correlation analysis (Table 15 and Figure 15) are that:

- Fruit number per tree and cluster size (i.e., average number of fruit per cluster) were significantly negatively affected by increasing canopy height, area, density and CSLA.
- Fruit diameter was inversely related with fruit number and cluster size.
- CDI significantly decreased with increasing canopy height, area, density and CSLA and slightly increased with higher fruit and cluster number.

Table 15. Correlation matrix of the crop parameters extracted from *Cartographer* data obtained in each pseudo-plot of the 'ANP-0131' block. Spearman's correlation coefficients and significance levels are reported.

	Canopy height (m)	Canopy area (m²)	Canopy density (0 - 1)	CSLA[y] (m²)	Cluster size	CDI[z] (0 – 1)	Fruit diameter (mm)
Canopy height (m)	—						
Canopy area (m²)	0.710 ***	—					
Canopy density (0 – 1)	0.636 ***	0.886 ***	—				
Cross-sectional leaf area (m²)	0.709 ***	0.988 ***	0.930 ***	—			
Cluster size	−0.555 ***	−0.77 ***	−0.769 ***	−0.784 ***	—		
Colour Development Index (0 – 1)	−0.643 ***	−0.633 ***	−0.618 ***	−0.639 ***	0.363 ***	—	
Fruit diameter (mm)	0.330 ***	0.355 ***	0.355 ***	0.359 ***	−0.499 ***	−0.183 **	—
Fruit number per tree	−0.541 ***	−0.800 ***	−0.780 ***	−0.808 ***	0.982 ***	0.368 ***	−0.507 ***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; [y]cross-sectional leaf area, [z]colour development index

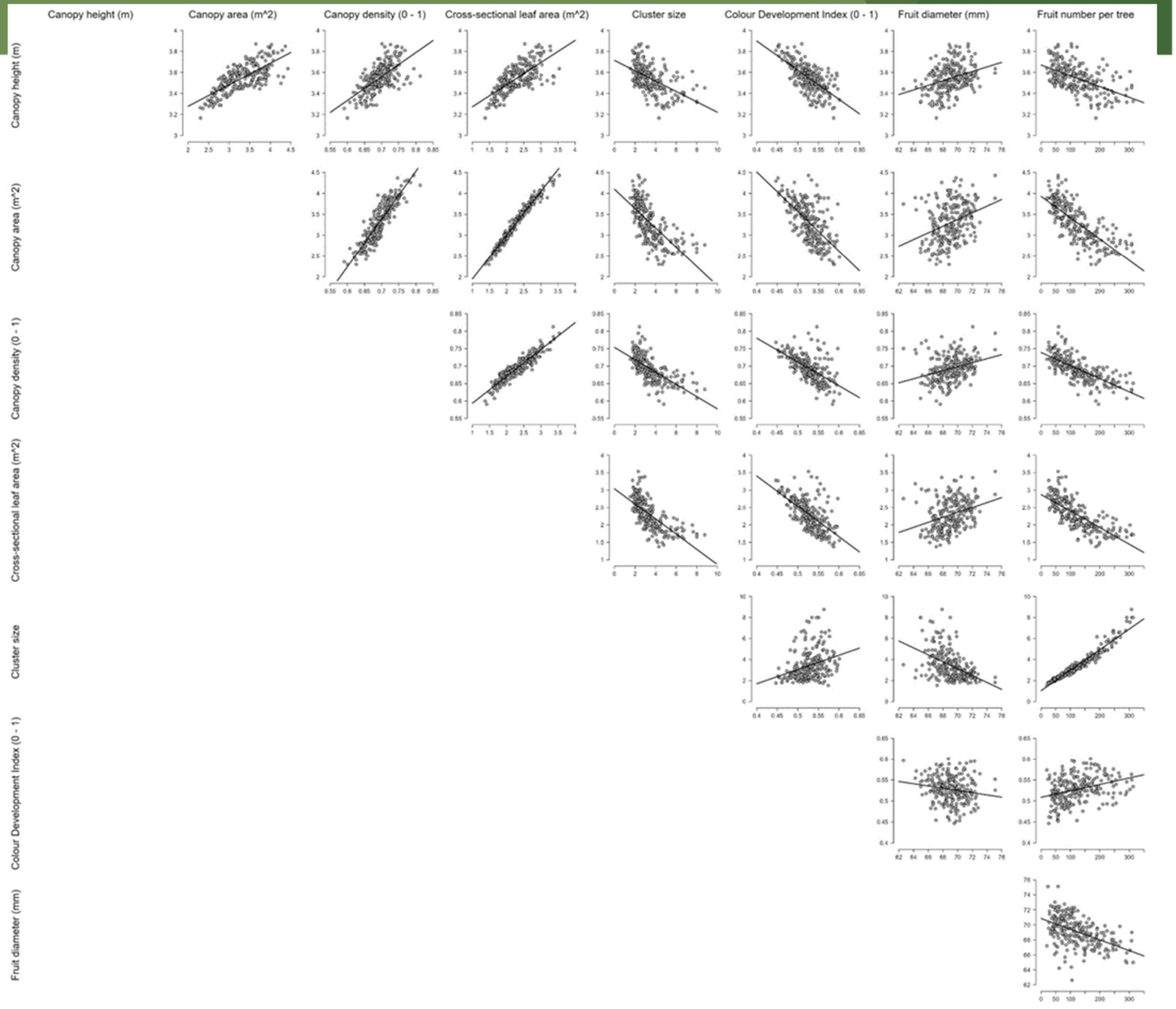

Figure 15. Scatterplots and linear fit matrix of the crop parameters relationships in each pseudo-plot of the 'ANP-0131' block.

In addition, the crop parameters obtained in the pseudo-plots were pooled together and analysed with a Principal Component Analysis (PCA). PCA was used to summarise the relationships among crop parameters using a dimension reduction approach. Table 16 shows that the principal components 1 and 2 explained more than 80 % of the variance of the crop parameters. The loadings plot in Figure 16 used principal component 1 and 2 and highlighted some expected highly significant positive correlations:

- Fruit number against cluster size.
- Between tree geometry parameters (canopy height, canopy area, canopy density, CSLA).

In addition, Figure 16 shows that there are two additional well-defined trends in 'ANP-0131':

1. An inverse relationship between CDI and canopy size and density.
2. An inverse relationship between fruit number and/or cluster size and fruit diameter.

The other relationships are weaker and the first two principal components do not agree in their direction:

- Fruit number and/or cluster size are negatively correlated with tree geometry parameters according to principal component 1 but positively correlated according to principal component 2.
- Fruit diameter is positively correlated with tree geometry parameters according to principal component 1 but negatively correlated according to principal component 2.
- CDI is negatively correlated with fruit diameter according to principal component 1 but positively correlated according to principal component 2.
- CDI is positively correlated with fruit number and cluster size according to principal component 1 but negatively correlated according to principal component 2.

Table 16. Number of principal components, Eigenvalues, and variance obtained from the Principal Component Analysis (PCA) generated from crop parameters obtained in the 'ANP-0131' block.

Principal component	Eigenvalue	Variance (%)	Cumulative variance (%)
1	5.348	66.853	66.853
2	1.138	14.226	81.080
3	0.701	8.767	89.846
4	0.379	4.740	94.587
5	0.286	3.573	98.160
6	0.116	1.444	99.604
7	0.023	0.293	99.897
8	0.008	0.103	100.000

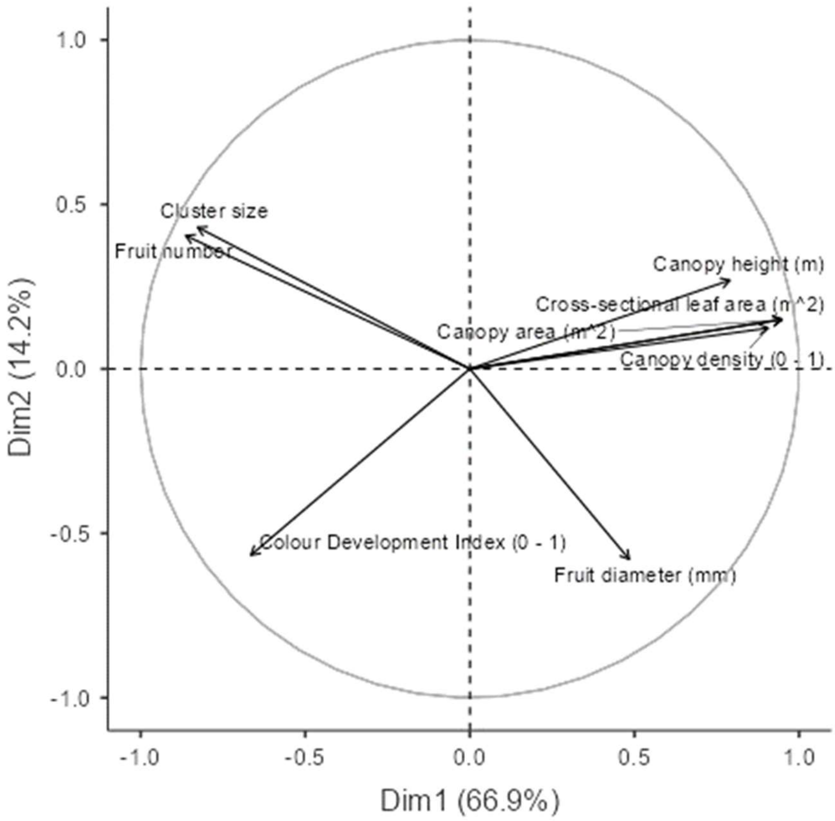

Figure 16. Principal Components Analysis (PCA) loadings plot for principal components 1 (Dim1) and 2 (Dim2) generated from crop parameters obtained in the 'ANP-0131' block. Explained variance (%) for Dim1 and Dim2 is reported in brackets.

'PremP009' orchard block

Table 17 shows the crop parameter summary obtained near harvest (7 February 2022) using *Cartographer*. The grid overlaid onto the 'PremP009' block consisted of 240 pseudo-plots. Scans in the block generated an average of 83 readings of machine vision-derived parameters (i.e., fruit number, fruit size, cluster size and fruit colour development index (CDI)) per pseudo-plot, and 84 readings of LiDAR-derived parameters (i.e., canopy height, canopy area, canopy density and cross-sectional leaf area (CSLA)).

Table 17. Block summary of crop parameters in the 'PremP009' orchard block at Calimna Orchards scanned on 7 February 2022.

Average crop parameter	
Fruit number (n / tree)	47
Cluster size (fruit n / cluster)	2.2
Fruit size (mm)	65.2
Colour Development Index (0 – 1)	0.77
Canopy Height (m)	3.44
Canopy Area (m^2)	2.99
Canopy Density (0 – 1)	0.64
Cross-sectional Leaf Area (m^2)	1.95

Crop parameters obtained from *Cartographer* scans were correlated using a correlation matrix and significant relationships were tested with the Spearman's correlation coefficient and reported in Table 18. Scatterplots and linear fits of the relationships were presented in Figure 17. The most important observations deriving from the correlation analysis (Table 18 and Figure 17) are that:

- Canopy density and CSLA were the tree geometry factors that mostly affected fruit number per tree and cluster size. With increasing canopy size, fruit number and cluster size were reduced.
- Fruit diameter was inversely related with fruit number and cluster size.
- CDI significantly decreased with increasing canopy area, density and CSLA, and was poorly inversely correlated with canopy height.

Table 18. Correlation matrix of the crop parameters extracted from *Cartographer* data obtained in each pseudo-plot of the 'PremP009' block. Spearman's correlation coefficients and significance levels are reported.

	Canopy height (m)	Canopy area (m^2)	Canopy density (0 - 1)	CSLA[y] (m^2)	Cluster size	CDI[z] (0 – 1)	Fruit diameter (mm)
Canopy height (m)	—						
Canopy area (m^2)	0.691 ***	—					
Canopy density (0 – 1)	0.528 ***	0.697 ***	—				
Cross-sectional leaf area (m^2)	0.678 ***	0.943 ***	0.865 ***	—			
Cluster size	−0.437 ***	−0.438 ***	−0.610 ***	−0.543 ***	—		
Colour Development Index (0 – 1)	−0.335 ***	−0.629 ***	−0.611 ***	−0.646 ***	0.192 **	—	
Fruit diameter (mm)	0.331 ***	0.157 *	0.117 n.s.	0.145 *	−0.412 ***	0.129 *	
Fruit number per tree	−0.469 ***	−0.495 ***	−0.617 ***	−0.583 ***	0.963 ***	0.175 **	−0.394 ***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; [y]cross-sectional leaf area, [z]colour development index

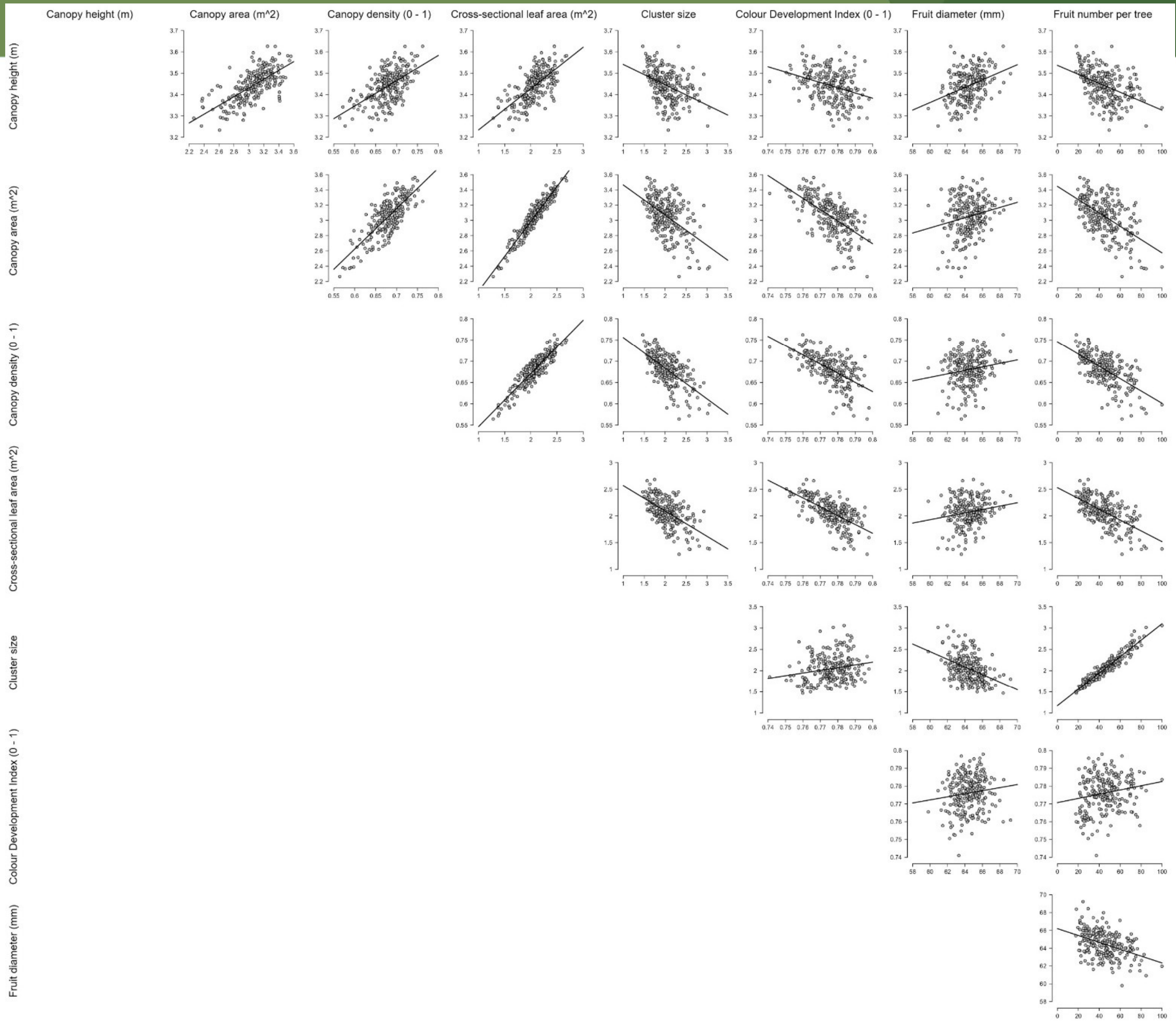

Figure 17. Scatterplots and linear fit matrix of the crop parameters relationships in each pseudo-plot of the ‘PremP009’ block.

Similarly, to the analysis for ‘ANP-0131’, the crop parameters obtained in the ‘PremP009’ pseudo-plots were pooled together and analysed with a PCA. Table 19 shows that the principal components 1 and 2 explained 78 % of the variance of the crop parameters. The loadings plot in Figure 18 used principal component 1 and 2 and highlighted similar trends to those observed in ‘ANP-0131’.

Table 19. Number of principal components, Eigenvalues, and variance obtained from the Principal Component Analysis (PCA) generated from crop parameters obtained in the ‘PremP009’ block.

Principal component	Eigenvalue	Variance (%)	Cumulative variance (%)
1	4.754	59.422	59.422
2	1.490	18.627	78.049
3	0.794	9.919	87.968
4	0.448	5.600	93.567
5	0.266	3.328	96.896
6	0.203	2.534	99.43
7	0.033	0.408	99.837
8	0.013	0.163	100

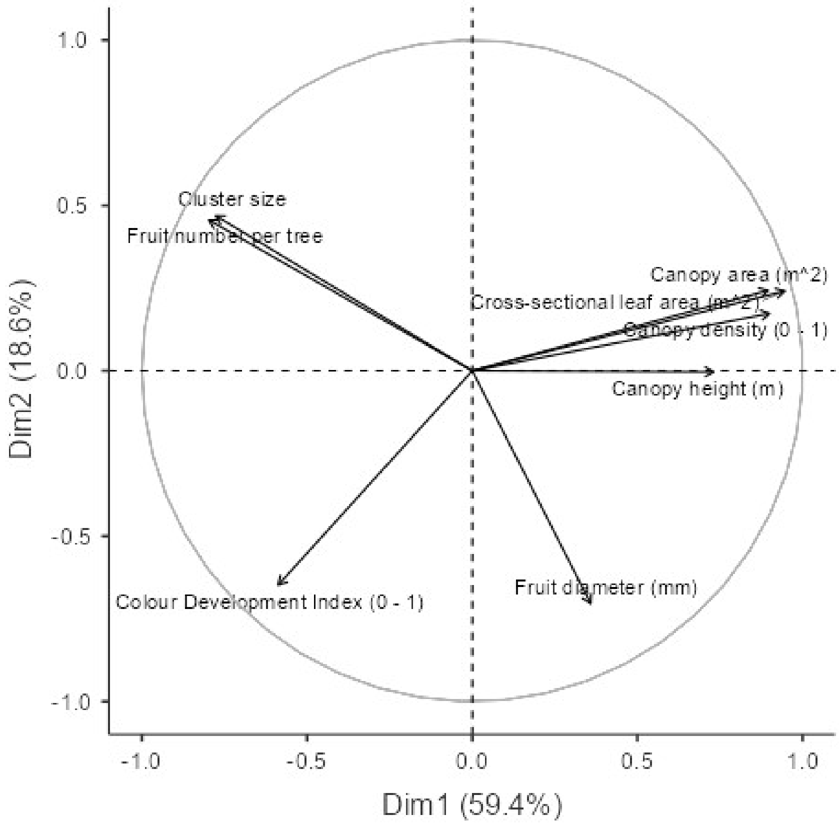

Figure 18. Principal Components Analysis (PCA) loadings plot for principal components 1 (Dim1) and 2 (Dim2) generated from crop parameters obtained in the ‘PremP009’ block. Explained variance for Dim1 and Dim2 is reported in brackets.

Comparisons of crop load relationships in ‘ANP-0131’ obtained in different blocks

The relationships of fruit weight against fruit number per hectare and fruit number per hectare normalised per radiation interception (RI) obtained in the ‘ANP-0131’ orchard block at Calimna Orchards were compared to relationships previously obtained in the Planting Systems and Rootstock experiments at the Tatura SmartFarm.

Scatterplots with side density plots are presented in Figure 19 — A, fruit weight against fruit number per hectare; B, fruit weight against fruit number per hectare normalised by radiation interception (RI). Statistics of the slope and intercept coefficients revealed significant differences (Fisher’s LSD, $p < 0.001$) among the linear models in the three orchards (Figure 19A and B).

The data from the planting system experiment shown in Figure 19 was collected over four seasons (2018 – 2021), data from the rootstock experiment was collected over six seasons (2016 – 2021), whereas data from Calimna Orchards was only obtained in one season. This may justify the lack of fruit weight range in the Calimna Orchard block comparable to the other two sites (i.e., different shapes of the fruit weight distribution shown in blue, Figure 19). The use of RI to normalise fruit number data obtained from *Cartographer* did not cause a significant improvement of the fruit weight vs fruit number model (R^2 = 0.246 and 0.248, for fruit number per hectare and fruit number per hectare normalised using RI, respectively).

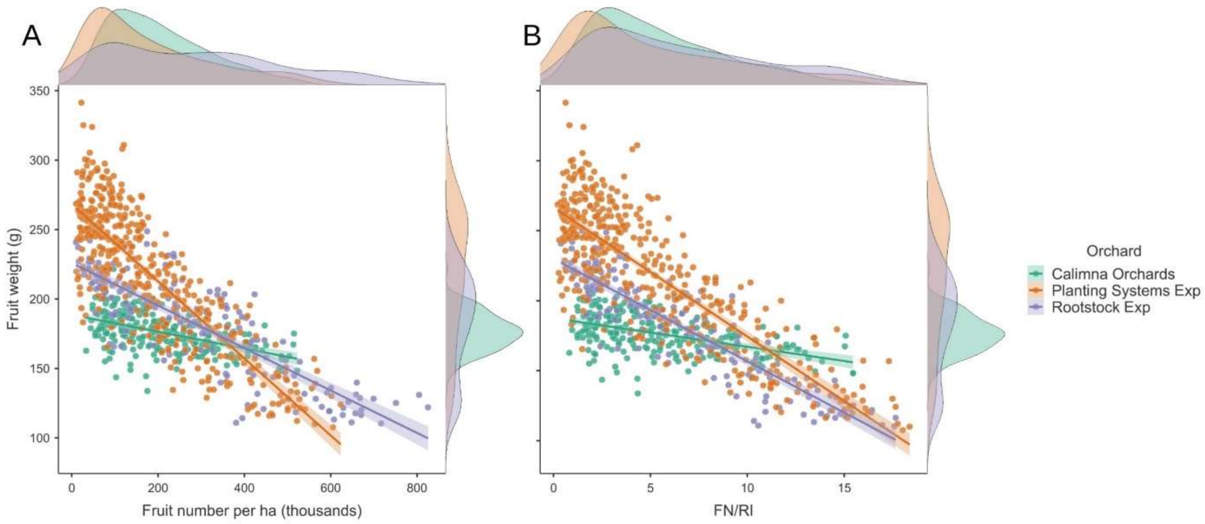

Figure 19. Scatterplots and linear fits with standard error bands of (A) fruit weight against fruit number per hectare, and (B) fruit weight against fruit number per hectare normalised using radiation interception (FN/RI) in different orchards. Density plots of the data distributions are shown along the secondary horizontal and vertical axes.

Possible reasons why the same relationship obtained in the Planting Systems and Rootstock experimental sites was not obtained in ‘ANP-0131’ trees at Calimna Orchards are described below:

- Different methodology utilised, as fruit number and fruit weight were measured using a commercial fruit grader in the Planting Systems and Rootstock experiments, rather than using *Cartographer*.
  - Fruit weight at Calimna orchards was estimated using a consolidated power relationship between fruit weight and fruit diameter (fruit weight (g) = 0.0014 × [fruit diameter (mm)]$^{2.772}$) and not directly measured like in the case of the Planting Systems and Rootstock experiments.
  - Fruit size measures obtained from *Cartographer* are likely to be not representative of the entire fruit population in the orchard as often fruit size distributions are shrunk around the average.

   - *Cartographer* data include fruit size and numbers on the pollinisers present in the orchard block that would cause a weighted effect on the crop parameters obtained. For example, if 5 % of the orchard is planted with pollinisers, we can expect 5% of the fruit size and number measurements to be erroneous.
- Different time range: the Planting Systems and Rootstock experiment data were collected over four and six seasons, respectively, whereas data from Calimna Orchards was obtained over one season.
- Abiotic and biotic stress, because of orchard management or the environment, could be impacting fruit size.

In conclusion, *Cartographer* can be used to investigate relationships between absolute or relative crop parameters and support research to study orchard- and cultivar-specific relationships that could then be used to reduce variability within the orchard, standardizing tree crops to achieve the best yield and fruit quality.

Relationships summarised in this appendix highlighted how, despite their different fruit quality characteristics and genetics, the trends and correlation directions of crop parameter relationships in 'ANP-0131' and 'PremP009' remained consistent (Figures 16 and 18). For example, we demonstrated that even in a uniformly red pear like 'PremP009', CDI was inversely related with canopy size, like in 'ANP-0131'. The linear equations behind the linear fits in Figures 15 and 17 have the potential to be used to manipulate crop load and tree geometry relationships in order to standardise orchard conditions and crops.

The significantly different relationships obtained in the three orchards shown in Figure 19. Normalising crop load for radiation interception, i.e., adjusting for tree size, explained some of the difference but other environmental and management factors continued to impact these relationships. This suggests that it is important to develop orchard- (not only cultivar-) specific relationships between crop load parameters in order to maximise efficiency and optimise fruit quality and yield.

Crop regulation experiments

Experiment 1 (2020/21): chemical thinning of 'ANP-0118'

Fruit set was low with less than 40% of clusters setting in the untreated control (Table 20). There was no treatment effect on fruit set or yield (Table 20), fruit weight, diameter or volume (Table 21), fruit firmness, soluble solids concentration or sunburn (Table 22). Blush coverage was approximately 10% higher in the ATS treatment compared with the untreated control, but there was no difference between other thinning treatments (Table 22). While there were some differences in skin colour measurements between treatments for L* and b*, there were no significant differences in chroma or hue (Table 23).

Table 20. Effect of thinning treatments on fruit set and yield of 'ANP-0118' (Lanya™) pear.

	Clusters set (%)	Fruit per cluster	Yield (kg)
Control	38.6	1.92	11.99
ATS	29.2	1.92	7.90
NAA	44.5	2.01	11.86
Ethephon	35.5	1.83	9.95
Brevis	40.3	1.94	11.00
Brevis x2	45.5	2.08	13.35
Surround	40.7	2.04	10.63
Surround x2	41.8	2.01	11.49
LSD (p=0.05)	*ns*	*ns*	*ns*
F Prob	*0.148*	*0.753*	*0.332*

Table 21. Effect of thinning treatments on fruit size of 'ANP-0118' pear.

	Mean fruit weight (g)	Grader MFW (g)	Diameter (mm)	Grader diameter (mm)	Grader length (mm)	Grader volume (ml)
Control	137	133	59.6	54.8	79.3	119
ATS	154	149	61.4	56.1	83.5	131
NAA	137	134	59.2	53.9	80.7	118
Ethephon	136	132	59.2	54.2	79.8	116
Brevis	136	133	58.8	54.1	81.0	118
Brevis x2	138	135	59.2	54.2	82.5	119
Surround	144	139	60.7	55.7	81.2	124
Surround x2	144	139	60.5	55.5	82.2	124
LSD (P<0.05)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
F Prob	*0.793*	*0.859*	*0.722*	*0.829*	*0.788*	*0.894*

Table 22. Effect of thinning treatments on fruit firmness, soluble solids concentration (SSC), blush coverage and sunburn of 'ANP-0118' pear.

	Fruit firmness (kgf)	SSC (°Brix)	Blush coverage (%)	Blush (grader) (%)	Sunburnt fruit (%)
Control	4.64	14.79	26 a	33	8.1
ATS	4.59	14.89	36 b	39	10.6
NAA	4.66	14.60	26 a	35	8.6
Ethephon	4.60	14.58	30 a	31	7.8
Brevis	4.65	14.54	30 a	32	7.9
Brevis x2	4.57	14.53	27 a	30	7.6
Surround	4.57	14.52	27 a	30	8.0
Surround x2	4.44	14.91	30 a	39	9.0
LSD (P<0.05)	*ns*	*ns*	*5.6*	*ns*	*ns*
F Prob	*0.525*	*0.724*	*0.018*	*0.168*	*0.275*

Table 23. Effect of thinning treatments on skin colour characteristics of 'ANP-0118' pear.

	L	a*	b*	Chroma	Hue
Control	53.38 c	23.52	31.96 bcd	41.38	54.31
ATS	50.11 a	22.30	29.65 ab	38.58	53.57
NAA	53.80 c	22.49	30.49 bcd	40.06	53.80
Ethephon	52.99 bc	21.46	30.72 abcd	40.55	55.38
Brevis	54.30 c	19.89	31.67 bcd	39.94	58.07
Brevis x2	54.92 c	20.36	32.02 cd	40.30	57.87
Surround	55.33 c	18.90	32.70 d	40.63	59.97
Surround x2	50.37 ab	25.63	28.48 a	40.16	48.82
LSD (P<0.05)	*2.87*	*ns*	*2.34*	*ns*	*ns*
F Prob	*0.003*	*0.076*	*0.015*	*0.069*	*0.144*

Table 24. Effect of thinning treatments skin colour characteristics (%) as measured by the fruit grader of 'ANP-0118' pear.

	Light green	Yellow	Dark green	Light blush	Medium blush	Dark blush
Control	2.0 b	2.7	62.4	5.3	1.7 abc	17.6 ab
ATS	0.6 a	1.0	59.1	4.4	0.6 a	23.6 c
NAA	1.8 ab	2.3	60.5	6.0	3.1 c	17.6 ab
Ethephon	1.1 ab	1.1	66.4	4.3	1.6 a	17.7 a
Brevis	2.3 bc	2.3	63.8	5.0	1.5 ab	17.2 abb
Brevis x2	3.4 c	2.6	63.6	4.9	1.5 ab	16.3 ab
Surround	1.5 ab	2.2	66.0	7.1	2.2 bc	13.1 a
Surround x2	2.4 bc	2.2	56.5	6.7	2.7 bc	20.5 bc
LSD (P<0.05)	*1.3*	*ns*	*ns*	*ns*	*1.5*	*5.1*
F Prob	*0.005*	*0.266*	*0.424*	*0.319*	*0.046*	*0.013*

<u>Experiment 2 (2022/23): Mechanical thinning of 'ANP-0131'</u>

There was no significant difference between treatments in the number of fruit per cm^2 limb cross-sectional area (Table 25). However, it is interesting to note that there was a greater fruit drop in the control than in the Darwin thinner (DT) and leaf blower treatments. The slightly higher crop load in the DT-gentle treatment can be put down to errors in counting fruit (note a 5% error is not unusual when counting large trees and is considered acceptable). For the second crop load variable, number of fruit per 100 blossom clusters, there is some thinning effect evident at the earlier assessment time at a significance level of $p \leq 0.1$, but not at the 0.05 level.

While the leaf blower appears to have had a thinning effect, this is not statistically significant. Had two passes been done to cover the whole tree there may have been an effect, so this is worth examining in future work.

Table 25. Effect of treatment on crop load at five and 20 weeks after treatment. wAT = weeks after treatment; DT = Darwin string thinner.

	Fruit cm^{-2} limb cross-sectional area		Fruit/100 blossom clusters	
	5 wAT	20 wAT	5 wAT	20 wAT
Control	3.2	2.4	50.6 ^{a}	35.7
DT-gentle	2.3	2.5	16.4 ^{b}	17.9
DT-moderate	1.8	1.6	22.9 ^{b}	20.6
Leaf blower	2.7	2.7	30.8 ^{ab}	29.5
F probability	*0.367*	*0.350*	*0.087*	*0.110*
LSD	*ns*	*ns*	*27.53*	*ns*

Significant differences were observed at a significance level of $p \leq 0.1$, but not at the 0.05 level, for both the percentage of clusters set and percentage of single clusters (Table 26), with the Darwin thinner having the greatest effect in reducing the number of clusters and thinning the clusters to single fruit. However, there was no difference between the two speeds used for the Darwin thinner. Anecdotally, there were more multiple clusters in the top section of the trees than the middle or lower sections.

Table 26. Effect of treatment on percentage clusters set and single clusters at five and 20 weeks after treatment. wAT = weeks after treatment; DT = Darwin string thinner.

	% clusters set		% single clusters	
	5 wAT	20 wAT	5 wAT	20 wAT
Control	30.9 [a]	26.0 [a]	87 [a]	63 [ab]
DT-gentle	13.3 [b]	14.9 [b]	39 [b]	43 [b]
DT-moderate	16.7 [b]	14.8 [b]	41 [ab]	36 [b]
Leaf blower	22.3 [ab]	22.6 [ab]	77 [ab]	74 [a]
F probability	*0.063*	*0.095*	*0.095*	*0.067*
LSD	*13.39*	*10.65*	*46.0*	*30.5*

The different mechanical thinning treatments had no effect on mean fruit weight compared to the control (Table 27), but fruit diameter was larger in both the DT-moderate and leaf blower treatments. Fruit soluble solids concentration was higher in both Darwin thinner treatments compared to the control. Fruit firmness was increased in the DT-moderate treatment, and while firmness in the DT-gentle treatment was the same as in the moderate treatment, there was no significant difference between this treatment and the control.

Table 27. Effect of treatment on fruit size, soluble solids concentration (SSC) and flesh firmness.

	Mean fruit weight (g)	Fruit diameter (mm)	SSC (°Brix)	Flesh firmness (kg/cm^2)
Control	248.3	77.8 [b]	13.8 [b]	5.2 [b]
DT-gentle	239.3	76.6 [b]	14.4 [a]	5.3 [ab]
DT-moderate	273.3	80.2 [a]	14.3 [a]	5.4 [a]
Leaf blower	270.7	80.3 [a]	13.9 [b]	5.2 [b]
F probability	*0.175*	*<0.001*	*<0.001*	*0.003*
LSD	*ns*	*1.46*	*0.22*	*0.14*

Although all colour parameters on the sun exposed side of the fruit were statistically significant, in practical terms there was little difference between treatments (Table 28). On the shaded side of the fruit, only a* and hue angle showed significant differences between treatments, but no red colour was observed ($a^* \leq 0$ indicate no red colour: hue angles 90° correspond to yellow and 180° to green).

Table 28. Effect of treatment on fruit skin colour at harvest.

	L*	a*	b*	Chroma	Hue angle
(a) sun exposed side of the fruit					
Control	42.71 ^{ab}	13.89 ^{ab}	22.60 ^{b}	28.62 ^{b}	56.8 ^{b}
DT-gentle	44.24 ^{a}	11.57 ^{b}	24.91 ^{a}	30.22 ^{a}	62.5 ^{a}
DT-moderate	44.41 ^{a}	11.16 ^{b}	24.77 ^{a}	30.21 ^{a}	62.4 ^{ab}
Leaf blower	40.82 ^{b}	15.44 ^{a}	21.40 ^{b}	28.27 ^{b}	52.9 ^{b}
F probability	*0.001*	*0.003*	*<0.001*	*0.001*	*0.001*
LSD	*2.00*	*2.56*	*1.91*	*1.22*	*5.64*
(b) shade side of the fruit					
Control	64.47	−13.98 ^{a}	39.86	42.26	109.33 ^{a}
DT - gentle	62.05	−13.54 ^{b}	40.10	42.35	108.64 ^{b}
DT - moderate	62.13	−13.84 ^{ab}	40.23	42.57	108.99 ^{ab}
Leaf blower	62.26	−14.04 ^{a}	40.11	42.51	109.27 ^{a}
F probability	*0.626*	*0.052*	*0.566*	*0.661*	*0.018*
LSD	*ns*	*0.38*	*ns*	*ns*	*0.47*

Experiment 3 (2022/23): Hand thinning of 'ANP-0131'

Compared to the untreated control, crop load was reduced by all treatments (Table 29). The ASE and 1-fruit per cluster treatments had the highest number of single clusters and corresponding lowest number of double clusters.

Table 29. Effect of treatment on crop load, percentage clusters set and single clusters.

	Fruit cm^2 LCSA	Fruit /100 blossom clusters	Total fruit #	% clusters set	% single clusters	% double clusters
Control	7.0 ^{a}	60.0 ^{a}	66 ^{a}	45.9 ^{a}	74.8 ^{b}	21.7 ^{b}
1 fr/cl - Oct	5.2 ^{b}	39.9 ^{b}	48 b	36.8 ^{bc}	92.1 ^{a}	7.6 ^{c}
2 fr/cl – Oct	5.1 ^{b}	40.8 ^{b}	50 ^{b}	39.8 ^{b}	69.0 ^{b}	30.8 ^{b}
1 fr/cl – Nov	4.3 ^{bc}	33.8 ^{bc}	45 ^{b}	33.3 ^{c}	98.7 ^{a}	1.3 ^{c}
2 fr/cl – Nov	3.7 ^{c}	30.3 ^{c}	41 ^{b}	20.5 ^{d}	48.0 ^{c}	52.0 ^{a}
ASE	4.1 ^{bc}	36.1 ^{bc}	45 ^{b}	33.4 ^{c}	92.7 ^{a}	6.0 ^{c}
F probability	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*
LSD	*1.31*	*9.00*	*10.3*	*5.71*	*10.85*	*10.26*

Mean fruit weight was 32% higher in the ASE treatment than in the control (Table 30); all other treatments showed similar fruit size to the control. Fruit length was greatest in the ASE treatment, followed by the 2-fruit per cluster treatments. The November treatments both showed reduced fruit length/diameter ratio, meaning that the fruit was squatter than in other treatments.

Table 30. Effect of treatment on fruit size and shape.

	Mean fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Fruit L/D ratio
Control	121.0 [b]	60.9 [c]	70.6 [d]	1.2 [a]
1 fr/cl – Oct	126.3 [b]	61.8 [c]	71.5 [cd]	1.2 [a]
2 fr/cl – Oct	125.5 [b]	61.5 [c]	72.0 [bc]	1.2 [a]
1 fr/cl – Nov	132.3 [b]	63.2 [b]	70.9 [cd]	1.1 [b]
2 fr/cl – Nov	126.3 b	64.0 [b]	73.0 [b]	1.1 [b]
ASE	160.2 [a]	66.9 [a]	77.2 [a]	1.2 [a]
F probability	*<0.001*	*<0.001*	*<0.001*	*<0.001*
LSD	*16.74*	*0.90*	*1.22*	*0.02*

Fruit in the control treatment had the lowest soluble solids concentration, with the 1 fruit per cluster treatments measuring the highest soluble solids concentration (Table 31). The double October, single November and the ASE treatments showed similar flesh chlorophyll concentration (measured with a DA meter) to the control, while the single October treatment had the most chlorophyll concentration and the double November treatment the least. There was no difference in fruit firmness between treatments.

Table 31. Effect of treatment on fruit soluble solids concentration (SSC), flesh chlorophyll concentration (I_{AD})and flesh firmness on the sun-exposed (red) and shaded (green) sides of the fruit.

	SSC (°Brix)	Flesh chlorophyll (I_{AD})	Flesh firmness (red) (kg/cm^2)	Flesh firmness (green) (kg/cm^2)
Control	13.22 [c]	1.95 [b]	6.2	5.6
1 fr/cl – Oct	14.52 [a]	2.01 [a]	6.5	5.8
2 fr/cl – Oct	13.87 [b]	1.95 [b]	6.4	5.6
1 fr/cl – Nov	14.41 [a]	1.98 [ab]	6.5	5.7
2 fr/cl – Nov	14.09 [ab]	1.88 [c]	6.3	5.6
ASE	13.86 [b]	1.97 [b]	6.4	5.6
F probability	*<0.001*	*<0.001*	*0.054*	*0.056*
LSD	*0.252*	*0.030*	*ns*	*ns*

While there were significant differences between treatments for most of the colour parameters, differences between treatments were not large, and no discernible pattern emerged (Table 32).

Table 32. Effect of hand thinning treatment on fruit skin colour parameters at harvest.

	L*	a*	b*	Chroma	Hue angle
(a) sun exposed side of the fruit					
Control	50.63 [a]	5.06 [e]	29.36 [a]	31.28	78.66 [a]
1 fr/cl – Oct	46.24 [c]	10.87 [ab]	26.66 [bc]	30.20	66.49 [cd]
2 fr/cl – Oct	47.76 [b]	8.39 [cd]	27.71 [b]	31.21	71.04 [bc]
1 fr/cl – Nov	46.07 [c]	9.86 [bc]	26.64 [b]	30.06	67.91 [c]
2 fr/cl – Nov	45.12 [d]	13.07 [a]	25.70 [c]	30.81	61.99 [d]
ASE	47.66 [b]	6.87 [de]	27.85 [ab]	31.11	73.17 [b]
F probability	*<0.001*	*<0.001*	*<0.001*	*0.086*	*<0.001*
LSD	*0.816*	*2.337*	*1.567*	*ns*	*4.933*
(b) shade side of the fruit					
Control	61.21 [a]	−11.89	37.01 [b]	39.06	107.58
1 fr/cl – Oct	60.07 [bc]	−11.69	38.13 [a]	40.06	106.75
2 fr/cl – Oct	60.90 [ab]	−11.72	38.05 [a]	40.00	106.86
1 fr/cl – Nov	58.79 [d]	−10.76	37.79 [a]	39.70	10528
2 fr/cl – Nov	60.49 [ab]	−12.10	37.98 [a]	40.08	107.31
ASE	59.34 [cd]	−11.91	37.64 [ab]	39.72	107.28
F probability	*<0.001*	*0.225*	*0.036*	*0.112*	*0.107*
LSD	*0.846*	*ns*	*0.738*	*ns*	*ns*

Experiment 4 (2022/23): Chemical thinning of 'ANP-0131'

There was no treatment effect on crop load, percentage of clusters set or percentage of single or double clusters (Table 33).

Table 33. Effect of chemical thinning treatments on crop load and clusters set.

	Fruit cm^{-2} LCSA	Fruit /100 blossom clusters	Total fruit	% clusters set	% single clusters	% double clusters
Control	5.6	62.5	89	43.1	66.6	25.7
ATS x1	5.4	56.1	75	39.8	70.9	22.1
ATS x2	5.9	56.4	82	38.6	65.7	25.8
ACC x1	5.6	62.8	75	43.6	66.6	25.4
ACC x2	5.7	60.8	79	39.0	61.9	26.6
Ecocarb Plus x1	5.4	52.5	73	38.1	67.9	27.3
Ecocarb Plus x2	6.1	47.5	72	35.4	70.4	26.1
F probability	*0.885*	*0.195*	*0.263*	*0.266*	*0.118*	*0.525*
LSD	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

Field assessments of fruit russet, length and diameter were undertaken (Table 34). There was a high level of russet in all experimental trees, with no difference between the control and chemically treated trees. Compared to the control, fruit diameter was increased in both ATS treatments and the double ACC treatment, while fruit length was increased in the double ACC treatment. Fruit L/D ratio (shape) was reduced by both ATS treatments, but other treatments had no significant effect compared to the control.

Table 34. Effect of chemical thinning treatments on crop load and clusters set.

	Russeted fruit (sample size of 25)	Fruit diameter (mm)	Fruit length (mm)	Fruit L/D ratio
Control	23.5	60.07 [c]	72.48 [bc]	1.21 [ab]
ATS x1	23.5	61.65 [ab]	72.49 [bc]	1.18 [c]
ATS x2	23.7	62.17 [a]	73.34 [ab]	1.18 [c]
ACC x1	23.5	59.75 [c]	72.29 [bc]	1.21 [ab]
ACC x2	22.5	61.23 [ab]	74.94 [a]	1.23 [a]
Ecocarb Plus x1	23.2	60.88 [bc]	72.45 [bc]	1.19 [bc]
Ecocarb Plus x2	24.8	59.91 [c]	70.91 [c]	1.19 [bc]
F probability	*0.193*	*<0.001*	*<0.001*	*0.006*
LSD	*ns*	*1.152*	*1.741*	*0.029*

Experiments 5 and 6 (2022/23): Laboratory preliminary screening using ‘ANP-0131’

In Experiment 5, petal wilting and discolouring was obvious in the Ecocarb and Ecocarb Plus treatments 2 h after application (Figure 20). There was no stigma damage in the water treated control over the 24 h of observation (Figure 21). Stigma damage in the ATS treatments was lower than in the Ecocarb and Ecocarb Plus treatments. The addition of either Kendeen 20 or Synertrol Horti Oil as a surfactant increased the level of stigma damage. Ecocarb Plus appears to have a slightly milder desiccating effect than the Ecocarb formulation.

Figure 20. Flowering spurs in Experiment 5 – 2 h after treatment. Treatments from left to right: water control, 1.5% ATS, 1.5% ATS + Kendeen 20, 1.5% ATS + Synertrol Horti Oil, 2% Ecocarb, 2% Ecocarb + Kendeen 20, 2% Ecocarb + Synertrol Horti Oil, 2% Ecocarb Plus, 2% Ecocarb Plus + Kendeen 20, 2% Ecocarb Plus + Synertrol Horti Oil.

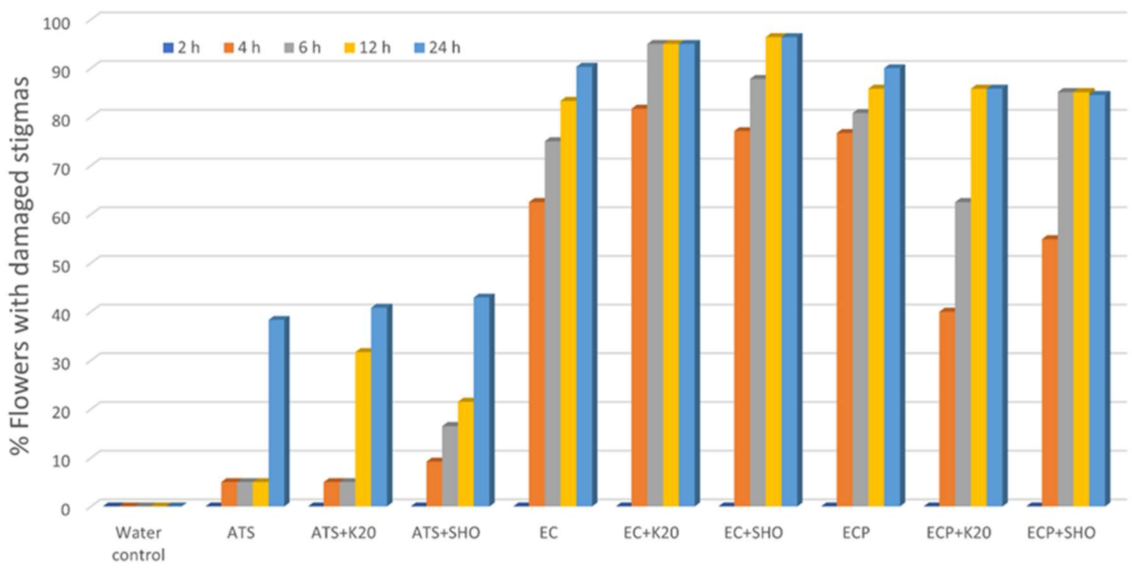

Figure 21. Degree of stigma damage in Experiment 5. ATS = ammonium thiosulphate, K20 = Kendeen 20; SHO = Synertrol Horti Oil; EC = Ecocarb; ECP = Ecocarb Plus.

In Experiment 6, Eco-flo lime had no desiccating effect, even at 20% (Figures 22 and 23), however the addition of Synertrol Horti Oil resulted in a slight increase in desiccation at 6 h after treatment. The 4% and 8% SARsil treatments resulted in almost 100% desiccation of stigmas by 24 h after application. There was no difference between the 4% and *% rates of SARsil from 4 h after treatment. Although slower to show damage, the 2% SARsil treatment resulted in 70% desiccation within 24 h. Addition of Synertrol Horti Oil increased the speed of desiccation of SARsil but reduced the overall level of damage. Synertrol Horti Oil had no desiccating effect. The level of damage to flowers was extreme in the higher rates of SARsil (Figures 22 and 23).

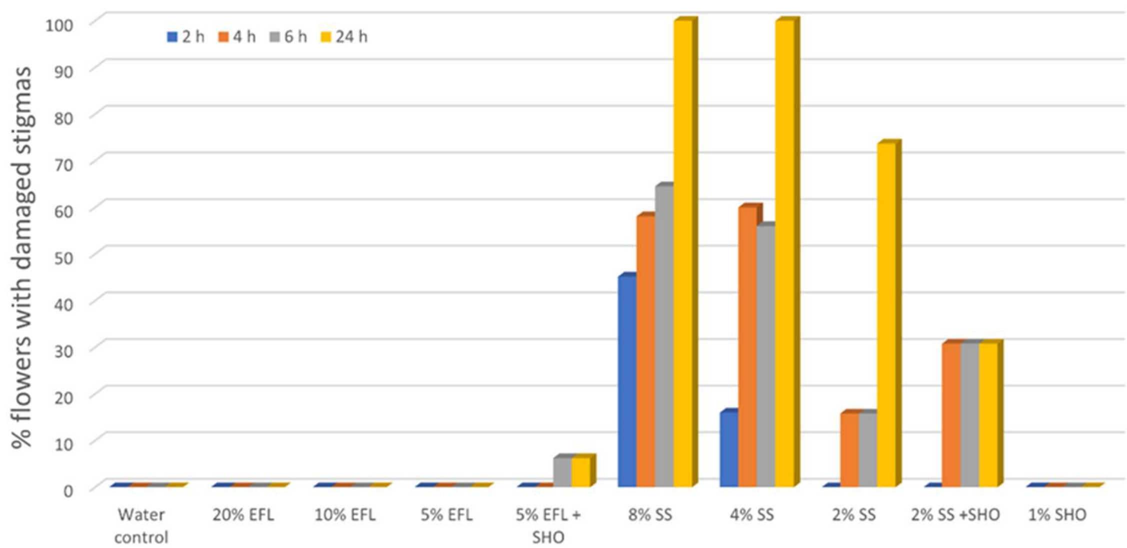

Figure 22. Degree of stigma damage in Experiment 6. EFL = Eco-flo lime, SS = SARsil; SHO = Synertrol Horti Oil.

Water control | 20% EFL | 10% EFL | 5% EFL | 5% EFL + SHO

8% SARsil | 4% SARsil | 2% SARsil | 2% SARsil + SHO | 1% SHO

Figure 23. Experiment 6 - flowering spurs 24 h after treatment. EFL = Eco-flo lime; SHO = Synertrol Horti Oil.

These experiments have demonstrated that with some further work, mechanical thinning has potential for crop load regulation in pears. The Darwin string thinner showed some results at a significance level of $p \leq 0.1$, so effective results should be able to be produced with refinement of spindle rotation and tractor speeds. The drawback with the leaf blower was that it was set at the bottom half of the tree and only one pass was made on each side; however, by making two passes at different heights to cover the entire tree, results should improve. The leaf blower also has the advantage that there is no physical damage to the tree.

The hand thinning results suggest that fruit quality can be improved by earlier thinning. In particular the removal of flowering spurs by artificial spur extinction early in the season can lead to increased fruit size without compromising quality, giving potential to carry heavier crop loads. Spur extinction is worth further investigation, including a comparison of bud removal prior to bud burst with removal of flowers during flowering as performed in the work reported here.

While the chemical thinning results were disappointing, it is worth pursuing some of these chemicals, particularly ACC and trialling SARsil in the field. Noting that initial work on apples by Bound with ATS recommended the use of a non-ionic surfactant with this chemical, the inclusion of a surfactant with ATS may also improve performance in pears, although the label does not include addition of a surfactant.

There is considerable scope to continue studies on crop load regulation in pears using mechanical, hand and chemical thinning.

Fruit colour: Artificial heating and cooling experiment

Artificial cooling appeared to mitigate yellowing of blush pear 'ANP-0534'. Prior testing showed the heating units effectively heated fruit but the lack of temperature control (e.g., a feedback control switch as implemented by Tarara et al. 2000) introduced a risk of cooking fruit, particularly on warm days. Consequently, the heating units were not used during the day in main experiment. Cooling units effectively lowered fruit surface temperatures but targeting desired temperature ranges was not possible with the methodology utilised in this study. Usefulness of artificial heating and cooling systems to investigate impacts of temperature on colour in the field is likely limited by the interrelationship of light and temperature and difficulties in adequately controlling either light or temperature under field conditions. Detailed results are reported in McClymont et al. (accepted).

Fruit colour: Alternate netting experiment

In the fortnight prior to expected commercial harvest, there was generally no indication of effects of netting on colour parameters of tagged fruit (Table 35) or interactions with orientation or height (with the exception of chroma, data not presented). However, trends associated with fruit position (height) and orientation of the blushed surface (E, exposed to morning sun, or W, exposed to afternoon sun) were evident for some parameters (Figure 24, data not shown for tagged fruit). Trends observed in relation to fruit position are likely associated with light exposure, whereas trends observed in relation to orientation may indicate an effect of temperature on colour development. At middle and high canopy heights, L* tended to be lower ($p < 0.001$; darker colour), a* tended to be greater ($p < 0.001$; increased 'red' component), b* tended to be lower ($p < 0.001$; decreased yellow component), hue angle tended to be lower ($p < 0.001$, closer to 'true red') and blush coverage greater ($p < 0.001$) than at the low canopy height. Chroma ($p < 0.001$, saturation) tended to be greater for fruit on the west side than the east, due to a combination of greater a* ($p = 0.049$) and b* ($p < 0.001$) whereas L* tended to be lower ($p < 0.001$; lighter colour). Similar trends for colour parameters were observed in the larger sample of fruit with blush coverage > 10 % (Figures 25 and 26). Sunburn damage was only observed on the west side of the 'open' plot. On the four measurement trees, mild sunburn was observed on 6 fruit, moderate sunburn damage on 14 fruit and severe sunburn damage on 1 fruit (Figure 27).

Table 35. Colour parameters and blush coverage of 'ANP-0131' pears grown in the open (unnetted control) and under netting, 17 February 2022.

Plot	L	a*	b*	Chroma	Hue	Blush coverage %
Open	35.6	23.8	24.0	35.0	44.9	40
Crystal	35.8	23.2	23.7	34.6	45.1	37
E-crystal W-grey	35.5	21.9	24.2	33.6	47.6	36
E-grey W-crystal	35.7	22.6	24.3	34.2	46.5	38
Grey	35.4	23.1	23.1	33.4	44.9	39
F pr.	*0.98*	*0.86*	*0.49*	*0.58*	*0.76*	*0.20*
LSD	*1.3*	*3.9*	*1.5*	*2.4*	*5.5*	*4*

Figure 24. Tagged fruit from A open, B crystal netting, C grey netting, D E-crystal W-grey netting, and E E-grey W-crystal. Trays on the left are fruit sampled from the east side of the canopy and trays on the right are fruit sampled from the west side of the canopy. ‘Low’ fruit are at the top of each photo and ‘high’ fruit are at the bottom.

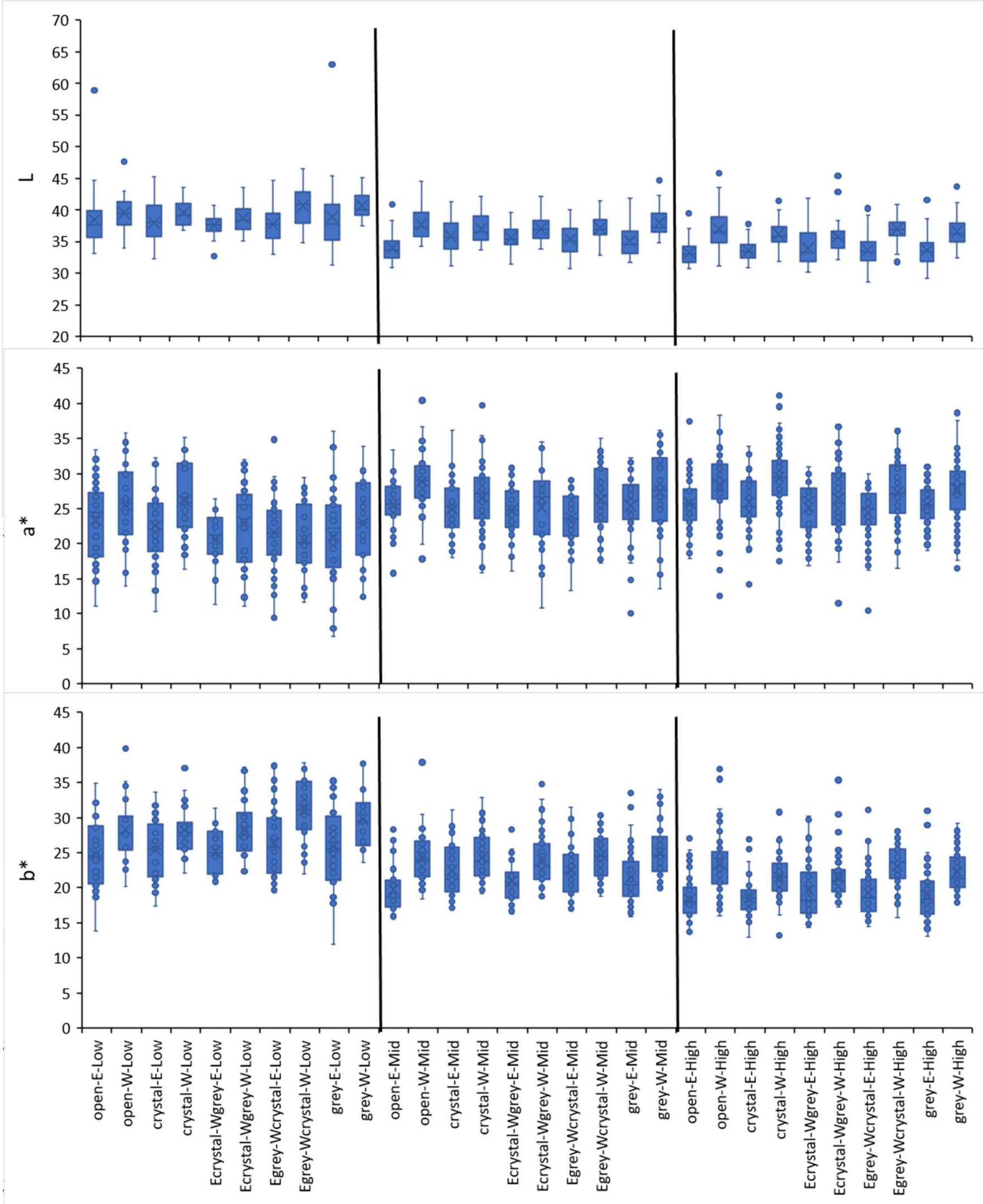

Figure 25. Box plots of blushed peel colour parameters L, a* and b* (CIELab) in the 'alternate netting' experiment.

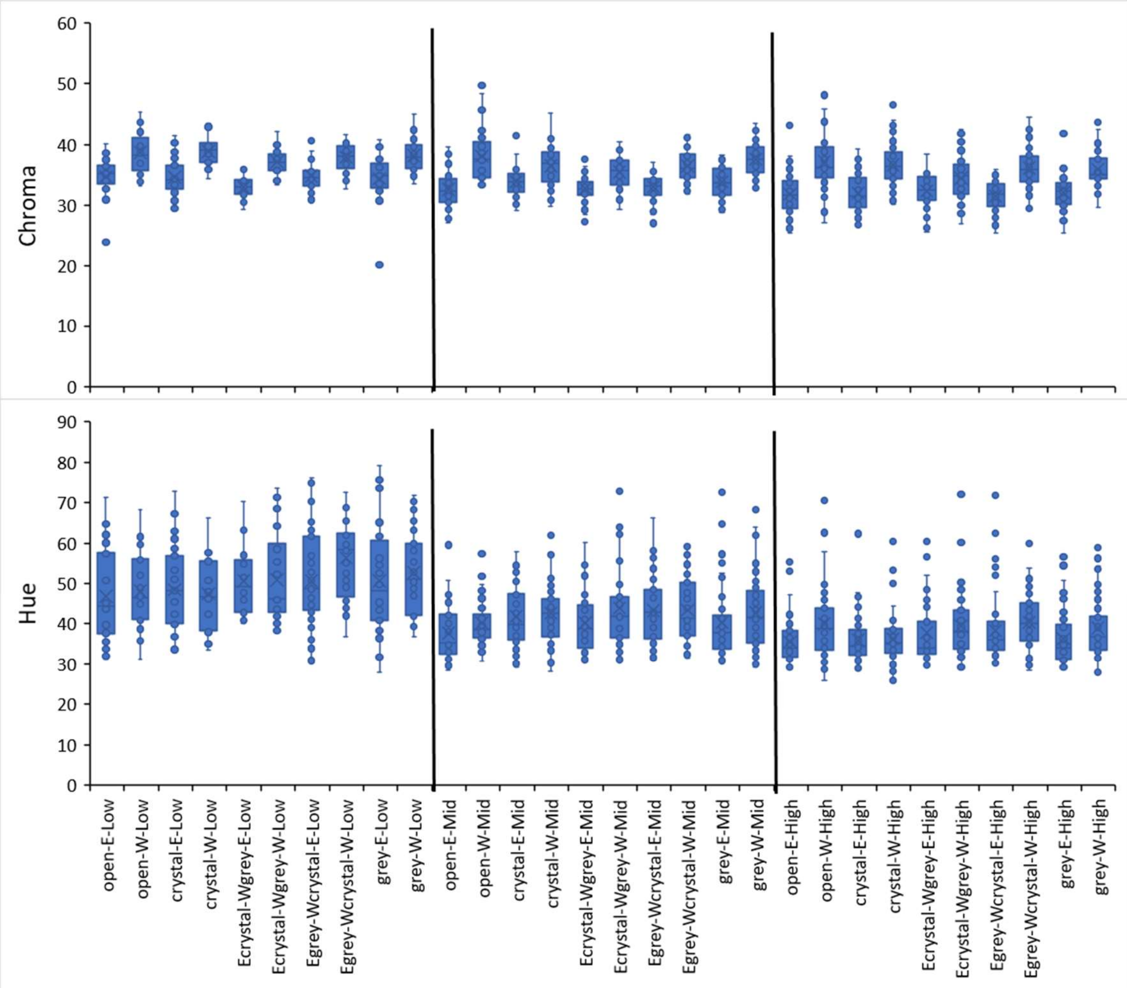

Figure 26. Box plots of blushed peel colour parameters chroma and hue (CIELab) in the 'alternate netting' experiment.

Figure 27. Examples of fruit with mild, moderate and severe sunburn damage.

Testing of mobile sensing platform

Results of validation conducted at the Tatura SmartFarm and evaluations conducted at commercial orchards were reported in three peer-reviewed papers:

- Scalisi, A., McClymont, L., Morton, P., Scheding, S., Underwood, J., Goodwin, I., 2023. A ground-based platform for estimates of fruit size in pear orchards—accuracy of block average, spatial variability and classification. Acta Horticulturae (accepted).
- Scalisi, A., McClymont, L., Morton, P., Scheding, S., Underwood, J., Goodwin, I., 2023. Detecting, mapping and digitising canopy geometry, fruit number and peel colour in pear trees with different architecture. Scientia Horticulturae (submitted).
- Scalisi, A., McClymont, L., Peavey, M., Morton, P., Scheding, S., Underwood, J., Goodwin, I., 2023. Using Green Atlas Cartographer to investigate orchard-specific relationships between tree geometry, fruit number, fruit clustering, fruit size and fruit colour in commercial apples and pears. Acta Horticulturae 1360, 203 – 210. https://doi.org/10.17660/ActaHortic.2023.1360.25

Validation of flower and fruit detection by *Cartographer* enabled prediction of flower and fruit numbers with standard errors commonly less than 10 %, across different training systems. To improve the accuracy of these predictions it is recommended to undertake a block-specific calibration. Validation of fruit size measures with *Cartographer* were conducted using stationary scans. Prediction errors for fruit diameter were approximately 4 mm. Later, Scalisi et al. (accepted) reported robust association between predictions of fruit diameter by mobile scans with *Cartographer* and measurements with callipers (on commercial orchards) or a commercial fruit grader (at the Tatura SmartFarm), with a RMSE less than 5 mm in both cases. There was a strong positive linear relationship between *Cartographer* pre-harvest measures of fruit colour development index (CDI, Scalisi et al., 2022) and post-harvest fruit grader measures of blush coverage. Later testing in commercial orchards was reported by Scalisi et al. (accepted).

Strong relationships existed between tree geometry parameters determined with *Cartographer* and traditional measures of canopy radiation interception. This supports the idea of using *Cartographer's* tree geometry parameters to fine-tune irrigation management, based on relationships between water use and canopy radiation interception (O'Connell and Goodwin 2004; Goodwin et al. 2006).

Finally, Scalisi et al. (2023) demonstrated the use of spatial data collected with *Cartographer* to establish orchard-specific relationships between tree geometry, fruit number, fruit clustering, fruit size and fruit colour in commercial pear orchards. Similarly, as described earlier, use of *Cartographer* to investigate functional yield relationships between fruit number and fruit weight suggested that it is important to develop orchard-specific relationships to optimise fruit quality and yield. Obtaining relationships in the manner shown by Scalisi et al. (2023) has potential to drive orchard design and management strategies so that trees can consistently produce high-quality fruit.

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Developing smarter and sustainable pear orchards

Technical Report: Effects of orchard design on soil porosity and tree nutrient status

Agriculture Victoria Research

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EXECUTIVE SUMMARY

Two main experiments comparing tree density, training systems, rootstocks and cultivar were established in the pear orchard at the Tatura SmartFarm in spring 2013. Throughout the experiments, nutrient, soil and interrow management has been the same across treatments within the 'Planting Systems' (compares tree density, training systems and scion) and 'Rootstock' (compares rootstocks and cultivars) experiments since planting. Measurements were undertaken in 2021 to investigate the effects of tree density, training system, scion and rootstock on leaf nutrient concentrations and soil porosity.

Leaf samples for mineral nutrient analysis were collected from replicated plots in the 'Planting Systems' and 'Rootstock' experiments in late-January 2021. Complete analysis (N, P, K, Ca, Mg, S, Na, Cl, B, Cu, Fe, Mn, Mo and Zn) were performed by APAL (Australian Precision Ag Laboratory, Hindmarsh, SA). Nutrient concentrations in non-replicated fruit samples collected at harvest were also determined by APAL.

Soil cores were collected from replicated plots in the 'Planting Systems' experiment in the 2021 winter to determine bulk density and porosity. Treatment differences were determined by ANOVA.

Neither training system (Open Tatura trellis versus vertical 2-D) nor tree density ('low', 'moderate' and 'high') were significant sources of variation in leaf nutrient concentrations. Scion ('ANP-0131' and 'ANP-0118') and rootstock (D6, D6-'Nijiseikki', Quince A-Beurre Hardy and BP1) significantly affected leaf mineral nutrient concentrations. Differences in leaf nutrient concentration biometrically attributable to scion and rootstock may be due to differences in uptake by roots, transport upwards, allocation between leaves and fruit and re-distribution. However, for certain nutrients, strong correlations existed between leaf mineral nutrient concentrations and crop loads with structure related to rootstock and less so to scion, suggesting that the underlying relationship between reproductive behaviour and mineral nutrient status is modulated more by rootstock than by scion.

Soil bulk density in two plots was affected by historical burn piles located at the south of the 'Planting Systems' experiment. The location of the burn piles was unknown prior to sampling and revealed by presence of charcoal in the samples. These plots' samples were excluded from analysis due to the presence of fine charcoal material that could not be adjusted for. There was no effect of treatments on bulk density or, consequently, porosity. Bulk density of the interrow (1.59 g/cm^3) tended to be higher than in the treeline (1.52 g/cm^3). Porosity was calculated to be 40 (interrow) and 43 % (treeline).

METHODOLOGY

Soil and mineral nutrient supply management

Soils were prepared by ripping the treeline, hilling rows and pre-planting applications of gypsum. The 'Planting System' and 'Rootstock' experiments are irrigated by drip irrigation, and emitter rates are low (1.7 L/h with drippers at 0.5 m spacing) to aid infiltration and minimise runoff.

Nutrient management has been the same across treatments since planting. Most fertiliser is applied as dissolved salts in the irrigation water (i.e., fertigation). In the first two seasons (2013/14 and 2014/15), > 50 kg N/ha/year was applied to encourage vegetative growth and establish tree structure. Applications to boost P soil reserves were 30 and 60 kg/ha in the first and second years, respectively. Applications of K were kept low (11 and 20 kg/ha in the first and second years) due to lack of fruit on the trees. Calcium applications reflected the use of calcium nitrate fertiliser (48 and 28 kg Ca/ha/year). Precautionary applications of magnesium sulphate (Mg 2.3 kg/ha/year and S 3.0 kg/ha/year) were applied due to occurrence of leaf symptoms associated with relatively low Mg concentrations in young pears in a neighbouring block in 2012/13. In the third and subsequent seasons, N applications were decreased to avoid excessive vegetative growth; an average of 34 and 28 kg/ha/year applied to 'Rootstock' and 'Planting Systems' experiments, respectively. Potassium applications were increased too to meet the demand of an increasing crop load (average of 56 and 51 kg/ha/year applied to 'Rootstock' and 'Planting Systems' experiments, respectively). Phosphorus and Ca inputs continued at an average 20 kg/ha/year. Magnesium inputs were discontinued in the last two seasons (2019/20 and 2020/21) in response to 'high' concentrations in leaf samples while S applications increased to >7 kg/ha/year. Boron was applied each season, largely as foliar sprays. Prior to 2021, leaf mineral concentrations were determined from non-replicated samples of selected treatments each season.

Leaf nutrient concentrations

Leaf samples were collected from a subset of plots in the 'Planting Systems' (described in Table 1) and 'Rootstock' (scions 'ANP-0131' and 'ANP-0118'; rootstock: D6, D6-'Nijiseikki', Quince A-Beurre Hardy, and BP1) experiments in late-January 2021 for nutrient analysis of nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, sodium, chloride, boron, copper, iron, manganese, molybdenum and zinc (N, P, K, Ca, Mg, S, Na, Cl, B, Cu, Fe, Mn, Mo and Zn, respectively). Twenty leaves from the middle of shoots were taken from each plot. Cotton gloves were worn and paper bags used for sample storage during transport. Leaves were washed in a series of three distilled water rinses, oven-dried at 60 °C for 24 h and analysed by Australian Precision Ag Laboratory (APAL), Hindmarsh, SA.

Bulked (non-replicated) fruit samples were collected from selected treatments at harvest for nutrient analysis in 2021. A wedge was removed from ten, randomly selected fruit per plot, oven dried at 60 °C for 48 h and analysed for N, P, K, Ca, Mg, S, Na, Cl, B, Cu, Fe, Mn, Mo and Zn by APAL. Fruit samples were collected from selected treatments in the 'Planting Systems' experiment and bulked in 2018 and 2019.

Leaf nutrient concentrations were interpreted according to Weir and Cresswell (1993). Similar interpretations are provided in Robinson and Reuter (1997).

Table 1. Treatments sampled within the 'Planting Systems' experiment for leaf nutrient concentration (January 2021) and soil bulk density (winter 2021). Trees are 'ANP-0131' scions on D6 rootstock.

Tree density	**2-dimensional training system**	
	Open Tatura trellis	Vertical
Low	8-leader cordon, 1111 trees/ha	6-leader cordon, 741 trees/ha
Moderate	6-leader cordon, 1482 trees/ha	4-leader, 1111 trees/ha
High	4-leader, 2222 trees/ha	2-leader, 2222 trees/ha

Bulk density and porosity

Undisturbed soil cores were sampled from plots within the Planting Systems experiment (subset of treatments as described in Table 1). Four cores were taken from the A horizon at approximately 2.5 – 10 cm depth within the treeline (2 cores) and within the inter-row (2 cores). Cores were taken with steel rings with dimensions of approximately 72.5 mm diameter and 63.0 mm height (volume 260.18 cm^3). Samples were trimmed and oven dried for 48 h at 105 °C. Bulk density (mass of sample/volume of core) was calculated following oven drying. Particle density of the soil fraction was set to 2.65 g/cm^3.

Total porosity was calculated from measured bulk density and soil particle density:

total porosity = 1 – (bulk density/particle density).

The soil cores were teased apart and placed in a plastic container filled with water and soaked overnight. The soil was then washed through a 2 mm sieve and the roots, charcoal and gravel collected and oven dried at 105 °C for 24 h and weighed. The mass and volume of roots, charcoal and gravel in the core were calculated (dependent on mass of non-soil material) and removed from the above calculations. The mass of non-soil material was subtracted from the total mass of oven dried soil for each core. The volume of the non-soil material was estimated by placing in volumetric flasks, weighing, adding water to fill the flask, and weighing to determine the mass of water; the difference between the volume of the flask and the mass of water being the approximate volume of non-soil material.

Following adjustment of bulk density for non-soil material, two plots remained obvious outliers. These were evidently located over historical burn piles and it is believed the fine charcoal material (< 2 mm) resulted in lower estimates of the soil bulk density in those plots. The bulk density and porosity estimates from these two plots were excluded from statistical analyses.

Statistical analysis

Leaf nutrient concentrations and soil bulk density and porosity data from the 'Planting Systems' experiment were subjected to analyses of variance using Genstat 18th edition (VSN International Ltd) based on a split-plot design with the main plot being the training system and tree density as a sub-plot. Analyses of variance were conducted on the leaf nutrient concentrations from the 'Rootstock' experiment using cultivar and rootstock as the fixed factors.

KEY RESEARCH FINDINGS

Leaf nutrient concentrations – 'Planting system' experiment

Neither training system nor tree density were significant sources of variation in leaf nutrient concentrations (Table 2). Leaf nutrient concentrations fell within the 'adequate' or 'high' ranges as advised by Weir and Cresswell (1993). Cl concentrations in all samples were less than the lower limit of detection (0.02%). It was noted that crop loads were low in 2021 (mean yields in the sampled treatments ranged from 7.66 to 32.58 t/ha); higher crop loads would likely remove more mineral nutrients in the fruit which may result in lower concentrations of some mineral nutrients in the leaves.

Leaf nutrient concentrations – 'Rootstock' experiment

Scion and rootstock significantly affected leaf nutrient concentrations (Table 3).

Scion-related trends differed between nutrients. For example, 'ANP-0131' leaves had higher Ca concentrations, whereas 'ANP-0118' leaves had higher Mg concentrations. Likewise, rootstock-related trends differed between nutrients; generally, the lowest leaf N, P, K, B and Cu concentrations were found in trees on BP1 or Quince A rootstocks. Leaves on trees on Quince A rootstock had the highest concentrations of Mg, Mn, Mo and Na, though that effect was scion dependent in the case of Mo and Na. Leaf nutrient concentrations were considered 'low' or 'normal' for N, 'normal' or 'high' for P, Ca and Mg, and 'low' to 'high' for K (according to Weir and Cresswell 1993). Most micronutrients were within 'normal' ranges, with the exception of high concentrations of Zn (86 – 160 mg/kg) that were likely due to spray contamination; further consideration of the Zn data were therefore unjustified and those data are not presented. Chloride concentrations in all samples were less than the lower limit of detection (0.02%). Interpretative standards for Mo are not available (Weir and Cresswell 1993, Robinson et al. 1997). Overall correlations between nutrient concentrations and fruit number per tree and crop load (fruit number per tree adjusted for effective area of shade as an index of tree size) are shown in Table 4. Relationships of K and B concentrations with crop load are presented in Figure 1.

Fruit nutrient concentrations

Nutrient concentrations within non-replicated samples of fruit from scion and rootstock combinations ('ANP-0131' on D6, 'ANP-0131' on Quince A with Beurre Hardy interstem and 'ANP-0118' on BP1) in 2021 are presented in Table 5. Data collected in 2018 and 2019 for selected 'Planting systems' treatments are presented in Table 6. Concentrations of K in the fruit were consistently higher than any other nutrient; typically 2-fold higher than N concentrations in fruit.

Table 2. Training system and tree density main effects on blush pear tree leaf mineral nutrient concentrations and main effects' and interaction terms' AoV F-probabilities in the 'Planting Systems' experiment at the Tatura SmartFarm in January 2021. Nutrient concentrations in green text are classed as 'high' according to Weir and Cresswell (1993), italics indicates possible spray contamination, all other nutrient concentrations are considered 'normal'.

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Na (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
'Normal' conc (Weir and Cresswell, 1993)	1.8–2.2	1.5–2.0	1.1–1.5	1.1–2.0	0.21–0.40	<.02	0.2–0.4	21–60	6–20		25–100		16–50
Grand mean	2.43	**0.23**	**1.98**	**2.41**	0.34	0.2	0.004	47	9.3	91	47	0.12	*167*
Training system													
Vertical	2.35	**0.23**	**2.07**	**2.31**	0.33	0.2	0.004	48	9.1	88	47	0.15	
Open Tatura	2.51	**0.23**	**1.88**	**2.52**	0.34	0.2	0.004	46	9.5	94	47	0.10	
Density													
Low	2.4	**0.22**	**1.83**	**2.42**	0.35	0.2	0.004	43	8.7	90	49	0.13	
Moderate	2.39	**0.22**	**2.03**	**2.38**	0.34	0.2	0.004	49	9.3	89	46	0.14	
High	2.51	**0.24**	**2.07**	**2.45**	0.32	0.2	0.004	50	9.8	95	46	0.10	
F pr.													
Training system	0.49	0.92	0.23	0.19	0.74	0.62	0.499	0.8	0.56	0.6	0.98	0.21	
Density	0.29	0.7	0.13	0.94	0.8	0.65	0.78	0.07	0.08	0.74	0.15	0.32	
Training ′ density	0.13	0.84	0.64	0.73	0.9	0.56	0.47	0.56	0.35	0.96	0.16	0.12	

Table 3. Scion and rootstock main effects on blush pear tree leaf mineral nutrient concentrations and main effects' and interaction terms' AoV F-probabilities in the 'Rootstock' experiment at the Tatura SmartFarm in January 2021. Nutrient concentrations in green and red text are classed as 'high' and 'low', respectively, according to Weir and Cresswell (1993), italics indicates possible spray contamination, all other nutrient concentrations are considered 'normal'.

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Na (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
'Normal' conc (Weir and Cresswell, 1993)	1.8–2.2	1.5–2.0	1.1–1.5	1.1–2.0	0.21–0.40	<.02	0.2–0.4	21–60	6–20		25–100		16–50
Grand mean	2.24	0.21	1.24	2.28	0.54	0.007	0.18	35	8.6	63	57	0.11	*127*
Scion													
'ANP-0131'	2.22	0.22	1.23	2.42	0.51	0.005	0.19	36	7.8	69	46	0.12	
'ANP-0118'	2.27	0.20	1.26	2.14	0.58	0.008	0.17	33	9.3	58	68	0.09	
Rootstock													
D6	2.37	0.21	1.43	2.24	0.48	0.006	0.19	37	9.8	63	49	0.11	
D6-Nij	2.26	0.21	1.64	2.38	0.46	0.006	0.18	44	10.1	62	44	0.10	
BP1	2.16	0.23	1.01	2.10	0.53	0.006	0.18	31	6.8	66	51	0.08	
QA/BH	2.18	0.19	0.89	2.40	0.70	0.009	0.18	27	7.5	62	85	0.14	
Scion / rootstock													
'ANP-0131' / D6	2.37	0.21	1.36	2.65	0.47	0.007	0.19	40	8.8	68	38	0.09	
'ANP-0131' / D6/Nij	2.19	0.21	1.57	2.50	0.40	0.005	0.19	42	8.3	68	31	0.11	
'ANP-0131' / BP1	2.13	0.25	1.06	2.10	0.49	0.005	0.19	33	6.5	73	43	0.10	
'ANP-0131' / QA/BH	2.20	0.21	0.91	2.41	0.66	0.006	0.18	29	7.5	66	73	0.18	
'ANP-0118' / D6	2.37	0.21	1.50	1.83	0.49	0.006	0.18	34	10.7	58	61	0.12	
'ANP-0118' / D6 Nij	2.34	0.21	1.70	2.26	0.52	0.007	0.16	45	12.0	56	57	0.09	
'ANP-0118' / BP1	2.19	0.21	0.96	2.10	0.57	0.007	0.17	30	7.1	59	58	0.06	
'ANP-0118' / QA/BH	2.16	0.17	0.87	2.38	0.74	0.012	0.17	25	7.5	59	97	0.11	
F probabilities													
Scion	0.177	**0.006**	0.598	**<0.001**	**0.005**	**<0.001**	**<0.001**	0.055	**<0.001**	**<0.001**	**<0.001**	**0.001**	
Rootstock	**0.002**	**0.013**	**<0.001**	**0.015**	**<0.001**	**0.004**	0.256	**<0.001**	**<0.001**	0.215	**<0.001**	**<0.001**	
Scion´rootstock	0.266	**0.046**	0.402	**0.001**	0.409	**0.008**	0.219	0.13		0.327	0.106	**<0.001**	
LSD													
Scion	0.07	0.02	0.13	0.13	0.05	0.001	0.01	3	0.5	3	3	0.01	
Rootstock	0.10	0.02	0.18	**0.19**	0.07	**0.002**	0.01	4	0.7	4	5	**0.02**	
Scion´rootstock	0.14	0.03	0.25	0.27	0.09	0.002	0.02	6	0.9	6	6	0.03	

Table 4. Pearson's product moment correlations relating the 2021 leaf nutrient concentrations with fruit number or crop load (fruit number per tree adjusted for tree size measured as effective area of shade) on blush pear trees in the 'Rootstock' experiment.

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Na (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)
Fruit number/tree	-0.28	-0.20	-0.69	0.45	0.67	0.03	0.35	-0.64	-0.47	0.12	0.47	0.43
Crop load	-0.30	-0.29	-0.76	0.22	0.75	-0.11	0.49	-0.78	-0.46	-0.04	0.60	0.25

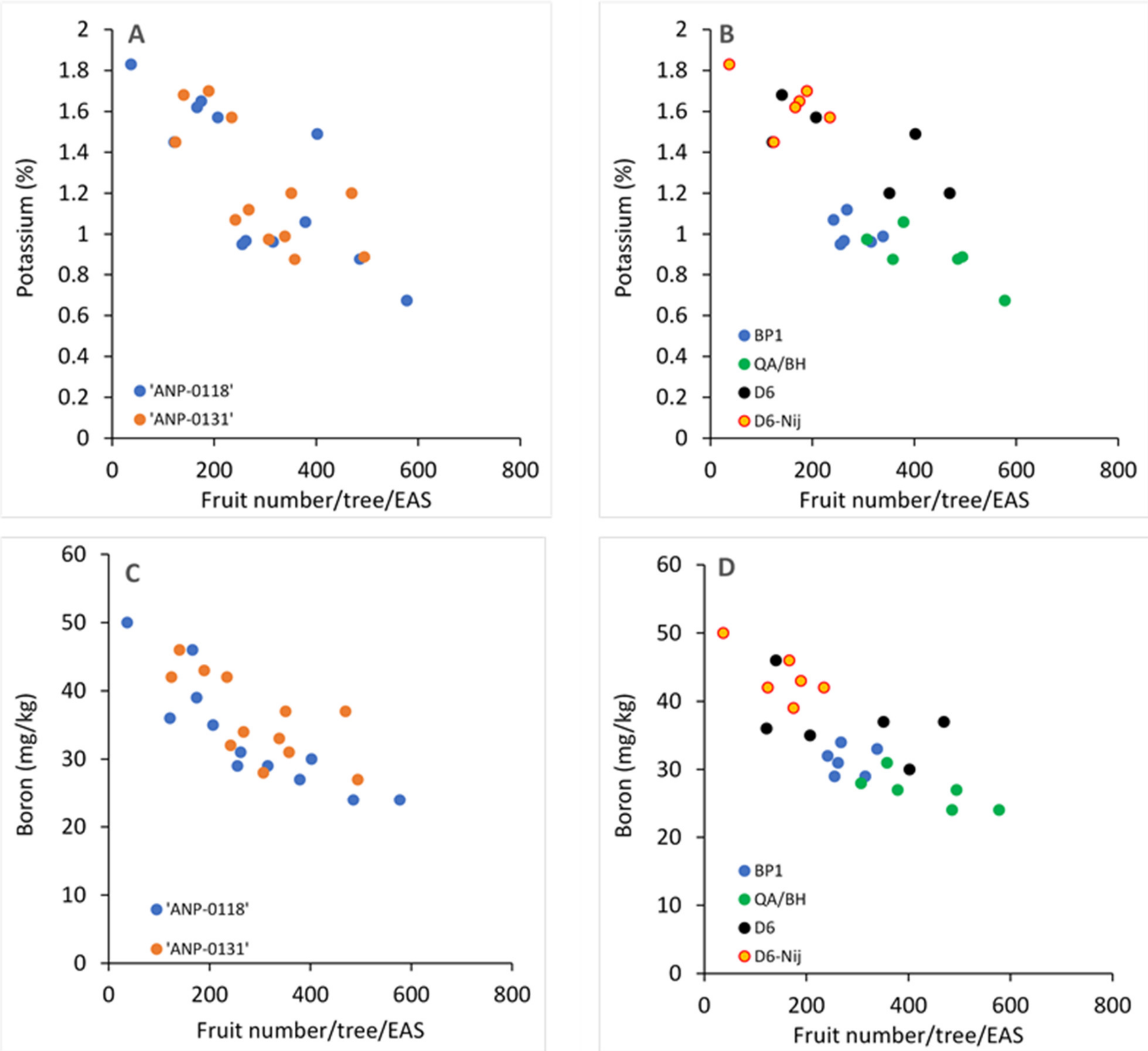

Figure 1. Scatterplots of 2021 leaf potassium (A, B) and boron (C, D) concentrations versus crop load at harvest in 2021 (fruit number tree adjusted for effective area of shade as an index of tree size) showing the main factors: scion (A, C) and rootstock (B, D) in the 'Rootstock' experiment.

Table 5. Pear fruit mineral nutrient interpretative standards and selected blush pear scion/rootstock combination effects on mineral nutrient concentrations of fruit collected at harvest in 2021 from replicated plots and bulked.

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Na (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
‘Adequate’ conc (Little & Holmes, 2000, p. 100)	0.41–0.51	0.06–0.07	0.71–0.95	0.051–0.06	0.046–0.055	>0.02		15	5		4		7
Scion / rootstock													
‘ANP-0131’ / D6	0.32	0.10	0.88	0.04	0.05	<0.06	0.003	25	6.4	7.1	2.4	0.047	8.3
‘ANP-0131’ / QA-BH	<0.25	0.08	0.74	0.04	0.05	<0.06	0.007	11	5.4	8.7	2.5	0.057	7.2
‘ANP-0118’ / BP1	0.28	0.07	0.61	0.02	0.03	<0.06	0.003	12	2.7	9.7	2.2	0.022	8.6

Table 6. Fruit nutrient concentrations of samples from vertically trained trees in selected rootstock (D6, BP1 and Quince A on Beurre Hardy interstem), tree spacing (0.5, 1, 2 m) and treatments in the 'Planting Systems' experiment in 2018 and 2019. Samples were collected at harvest from replicated plots and bulked. Note, prior to 2021 the lower limit of detection of Mo was 0.4 mg/kg.

Rootstock	Density (m)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Na (%)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Zn (mg/kg)
'Adequate' conc (Little & Holmes, 2000, p. 100)		0.41–0.51	0.06–0.07	0.71–0.95	0.051–0.06	0.046–0.055	>0.02		15	5		4		7
2018														
D6	0.5	0.32	0.08	0.7	0.06	0.04	0.03	0.003	15	4.4	10	4.1	<0.4	7.2
	1	<0.25	0.08	0.67	0.05	0.04	0.02	<0.002	16	4.1	<10	4	<0.4	6.1
	2	0.25	0.07	0.66	0.04	0.04	0.02	0.002	13	3.4	<10	4	<0.4	6.3
BP1	0.5	0.27	0.07	0.46	0.04	0.03	0.03	<0.002	12	2.3	<10	3.7	<0.4	5.2
	1	0.25	0.07	0.54	0.04	0.04	0.03	<0.002	13	2.3	<10	3.4	<0.4	5.5
	2	<0.25	0.06	0.53	0.04	0.03	0.02	<0.002	14	<2	<10	2.6	0.46	3.6
QA 1	0.5	0.31	0.07	0.6	0.04	0.04	0.03	0.002	8	3.2	<10	4.2	<0.4	6.1
	1	0.38	0.08	0.63	0.05	0.04	0.03	<0.002	6.9	3.4	<10	4.5	<0.4	7.4
	2	0.28	0.07	0.56	0.04	0.04	0.03	0.003	7.6	3.7	11	4.7	<0.4	7.3
2019														
D6	0.5	0.41	0.09	0.83	0.03	0.04	0.02	<0.002	16	4.7	<10	2.4	<0.4	5
	1	0.41	0.1	0.88	0.03	0.04	0.03	<0.002	26	5.2	11	2.5	<0.4	5.4
	2	0.36	0.09	0.8	0.04	0.04	0.02	<0.002	18	4.9	<10	2.7	<0.4	5
BP1	0.5	0.34	0.08	0.68	0.03	0.04	0.02	0.003	16	2.3	12	2.4	<0.4	3.6
	1	0.36	0.09	0.77	0.04	0.04	0.02	0.003	18	2.3	11	2.7	<0.4	4.1
	2	0.39	0.09	0.69	0.04	0.04	0.02	0.002	16	2.6	10	2.3	<0.4	3.8
QA 1	0.5	0.39	0.09	0.69	0.03	0.04	0.02	0.018	6.8	2.9	<10	2	<0.4	5
	1	0.41	0.09	0.81	0.04	0.04	0.03	0.005	6.6	3.2	<10	2.7	<0.4	5.9
	2	0.34	0.08	0.68	0.03	0.04	0.02	0.008	7	3.5	<10	2.1	<0.4	5

Soil bulk density and porosity

Soil bulk density in two plots was likely affected by historical burn piles located at the south of the 'Planting Systems' experiment. The location of the burn piles was unknown prior to sampling and revealed by presence of charcoal in the samples. The two plots were excluded from analysis due to the effect of fine charcoal material (that was unable to be adjusted for) on bulk density. Neither tree training nor tree density nor the interaction term were significant sources of variation on bulk density or, consequently, porosity. Bulk density of the interrow (1.59 g/cm^3) tended to be higher than in the treeline (1.52 g/cm^3), as expected due to traffic. Porosity was calculated to be 40% in the inter-row area and 43% along the treeline.

Table 7. Soil bulk density and porosity within low, moderate and high tree density x Vertical and Open Tatura training system plots of 'ANP-0131' on D6 rootstocks in the 'Planting Systems' experiment at the Tatura SmartFarm.

	Bulk density (g/cm^3)		Porosity (%)	
	treeline	**inter-row**	**treeline**	**inter-row**
	1.52	1.59	43	40
	F probability			
Training system	*0.50*	*0.15*		
Tree density	*0.82*	*0.87*		
Training × density	*0.16*	*0.61*		

DISCUSSION

Soil N was very low (~ 1 mg/kg nitrate-N) at the study site. Early applications of 50 kg N/ha/year were adequate for tree establishment and leaf N concentrations were 'normal' or 'high' (non-replicated samples collected in 2013 and 2014). Subsequently, N applications were reduced to approximately 30 kg/ha/year to avoid excessive vegetative growth and possible negative impacts on red colour development. As a result, leaf N concentrations declined into the 'normal' and 'low' ranges (non-replicated samples collected in 2015 – 2020 and replicated samples collected in 2021). Moderate applications will be maintained in future seasons.

High P reserves are common in orchard soils in the Goulburn Valley (pers. comm. Melly Pander). However, soil sampling at the study site prior to planting indicated that P reserves (Colwell P 37 mg/kg in the A horizon and 11 mg/kg in the B horizon) were below the 40 mg/kg minimum recommended for apple orchards (Thomas 2008). P applications were planned to initially increase soil P reserves to maintain P availability. In 2019, soil Colwell P averaged 82 mg/kg within the 'Planting Systems' experiment, and, combined with 'high' concentrations of P in leaves in the 2021 season, suggested that lower or less frequent applications of P could be made. Leaf testing in previous seasons indicated P levels ranged from 'low' to 'high' depending on treatments and seasons, with most results being in the 'normal' range. Annual leaf monitoring will continue so P applications can be modulated as necessary.

Potassium concentrations in pear fruit were higher than any other nutrient (Table 4; Fallahi and Lenton 1984). The amount of K export in fruit and soil available K need to be considered when planning K applications. Soil K reserves prior to planting were substantially higher (365 mg/kg Colwell K and 303 mg/kg of exchangeable K) than the minimum 100 mg/kg (Colwell K) recommended by Thomas (2008) for apple orchards. Later testing in the 'Planting Systems' experiment indicated soil K reserves remain high (415 mg Colwell K/kg and 331 mg exchangeable K/kg), suggesting a lower rate could be applied in future. High K levels can induce imbalances in other nutrients and growers should maintain awareness of K soil availability, leaf and fruit status.

In addition to indicating 'low', 'adequate' and 'high' concentrations of nutrients in pears, Little and Holmes (2000) provide recommendations regarding Ca:N (1:7), Ca:P (1:1.5), Ca:K (1:15) and Ca:Mg: (1:0.9) ratios. These are likely based on Packham's Triumph and Williams' Bon Chrétien pears; however, they provide a basis for examining fruit nutrient concentration in other scions. The fruit sampled here indicate low Ca and this may contribute to post-harvest disorders. Industry practice regarding Ca fertilisation varies from only soil applied Ca to multiple foliar sprays per season. Some disagreement in the literature remains as to the effectiveness of Ca application methods and evaluation of options (including timing of applications) in Australia's major production region may be timely.

Low leaf concentrations of Mg in individual trees in a neighbouring trial block were determined from leaf analyses of symptomatic and non-symptomatic trees in 2012 – 13. Hence applications of Mg were made in the initial seasons after planting in the 'Planting Systems' and 'Rootstock' blocks. Low concentrations of Mg in a number of crops have been associated with impaired photosynthetic activity, greater reactive oxygen species concentrations and less biomass production (particularly of root systems) (Cakmak and Kirkby 2008, Hauer-Jákli and Tränkner 2019). Interestingly, experienced agronomists likened the leaf symptoms, observed in the adjacent trial block referred to earlier, to heat damage. It may be that, as a consequence of Mg deficiency, pear leaves are more photosensitive, and this is accentuated during high air temperatures. If this is true, the underlying cause of the leaf damage sometimes seen following a heat event may be Mg deficiency in the leaves.

Mo concentrations were lowest in 'ANP-0118'-BP1 and 'ANP-0118'-D6-'Nijiseikki' treatments. Low molybdenum concentrations are known to adversely affect fruit set in Merlot grapes and susceptibility is influenced by rootstocks (Longbottom 2007, Williams 2007). Application of Mo foliar sprays improved set within Merlot grape bunches at some sites and, consequently, increased yield (Longbottom 2007, Williams 2007). Investigation of the role of Mo in fruit set of 'ANP-0118' pears may be warranted because poor set of 'ANP-0118' has been observed, particularly in association with BP1 rootstocks.

It is not within the scope of this study to determine whether rootstocks take up and transport more or less of particular mineral nutrients or whether scions respond differentially to more or less of particular mineral nutrients reaching their leaves in terms of biomass production and reproductive behaviour. However, strong correlations between leaf K and B mineral nutrient concentrations and crop loads, and the obvious structure related to rootstock and less so to scion lend weight to the idea that underlying the relationship between the trees' reproductive behaviour and their mineral nutrient status is modulated more by rootstock than by scion.

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Developing smarter and sustainable pear orchards

Technical Report: Constraints and incentives for pear growers to invest in ag tech and advanced management systems

Agriculture Victoria Research

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EXECUTIVE SUMMARY

This document has been compiled for AP19005 (Developing smarter and sustainable pear orchards to maximise fruit quality, yield and labour efficiency) to report on "current pear industry orchard design and management practice, and the constraints and incentives needed to adopt new orchard design and advanced management systems." Two main sources of information have been used: formal grower and consultant interviews; and informal conversations with growers.

The pear industry is currently in a state of transition and review, both in terms of individual businesses and industry bodies (AAE 2021, APAL 2022). Growers have adopted modern production systems (high tree density with multi-leaders trained to Tatura trellis or vertical trellis) and introduced new pear selections (predominantly blush or red pears, both interspecific and European) in the last decade, and continue to trial new growing techniques and technologies. However, a range of older production systems (low tree density, trained as vases or central leaders) remain, and pear production is dominated by traditional green pears. The domestic market is over-supplied and exports account for less than 10% of production (Hort Innovation 2021). Subsequently, growers are evaluating their ability to continue growing pears given low prices and difficulty meeting market expectations for fruit quality.

The **current market conditions** are the main constraint to continued modernisation of orchard design and adoption of new selections with limited new plantings planned along with some reworking of old blocks. An overall decline in production area is expected as old blocks are removed and some growers leave the industry. Despite the lack of planned growth in production area, growers remain highly committed to improving practices and adopting technologies to increase fruit production and quality. All growers interviewed were conducting on-farm trials to support management decisions and/or adopting new technology in the form of sensors, machinery and software. However, the enthusiasm for new practices is tempered by:

- Costs
- Availability of skilled staff
- Uncertainty regarding effectiveness

New equipment and technology that prove useful in apple production are likely to be transferred to, or trialed in, pear blocks. While growers are altering orchards to enable mechanization and efficient use of low-skilled labour, highly skilled staff are essential to the adoption of ag technology. Improved training opportunities for the local workforce and better pathways to permanent residency for international staff would enhance the ability of the industry to meet current and future staffing challenges.

Discussions with growers provided feedback regarding recent incentive programs and suggestions for future programs and strategies to enhance sustainability of the pear industry. While support for technology adoption is greatly appreciated, growers were unanimous in feedback regarding the recent IoT program — greater flexibility in choice of products and suppliers was needed so that growers could purchase equipment of greatest benefit with assurance of good provider support. Suggestions for future incentive programs included support for adoption of:

- Variable rate spray technology
- Farm safety equipment

Suggested education and extension programs included:

- A grower manual for new pear selections
- A spray and fertigation management training day
- Greater sharing of grower experiences and support of on-farm trials

SCOPE AND METHOD

This document has been compiled for AP19005 (Developing smarter and sustainable pear orchards to maximise fruit quality, yield and labour efficiency) to report on "current pear industry orchard design and management practice, and the constraints and incentives needed to adopt new orchard design and advanced management systems." Two main sources of information have been used:

- formal grower and consultant interviews (5, accounting for 690 ha of the production area), and
- informal conversations with growers.

The interviewed growers produce pears in the Goulburn Valley; the region produces 80 % of Australia's pears.

Topics discussed included: production systems, mechanisation, software, precision agriculture, and extension and incentive programs (the survey template is included in Appendix A).

APAL is currently conducting surveys of apple and pear growers to compile data of cultivar, rootstock, tree age, area planted, tree density, training system, netting and practise (conventional, organic or conversion). Given the small cohort interviewed for this report and to avoid duplication, the aforementioned factors were not discussed in quantitative terms for this report.

CURRENT ORCHARD DESIGN AND MANAGEMENT PRACTICE

Growers have adopted modern production systems (high tree density with multi-leaders trained to Tatura trellis or vertical trellis) and introduced new pear selections (predominantly red or blush pears, both interspecific and European) in the last decade, and continue to trial new growing techniques and technologies. However, a range of older production systems (low tree density, trained as vases or central leaders) remain and pear production is dominated by traditional green pears. Adoption of new selections is currently restricted by a lack of confidence in market opportunities, while difficulties with production (biennial bearing or overall low yields) and fruit quality (peel finish or storage life) negatively impact willingness to keep certain selections. Options for dwarfing rootstocks are not as effective as those available for apples and have had limited to no testing under local conditions or with new selections as scions. Blocks contracted to the cannery have minimal management and inputs, therefore the information contained in this report primarily reflects practices in fresh-market orchards.

Selections and rootstocks

The processing industry utilizes 40 % of pears produced in Australia (Hort Innovation 2021). Fresh market production (~ 72,069 t in 2020) is dominated by Packham's Triumph (63 %) and Williams' Bon Chrétien (20 %), followed by Beurre Bosc (10 %), Corella (< 1 %) and other selections (Hort Innovation 2021). In the past, older or unsuccessful (due to lack of market or poor yield performance) pear blocks have been reworked to alternative selections and this continues to a limited extent along with some new plantings. At present, growers are choosing to remove (particularly Packham's and Williams) rather than rework plantings and, in some cases, are ceasing to grow any pears. Over the last decade, a number of growers have planted new red or blush pear selections; most recently, there have been minor plantings of coloured European [e.g., Belle de Jumet (HoneyBelle®), Lowry 1 (Red Angel®), Sienna Pride®, Celina (QTee®), and high coloured Corella], interspecific [e.g., 'Prem009' (Piqaboo®) and 'Prem109' (Papple)] and Asian (various nashi) pear selections. A number of growers planted (or reworked trees to) 'ANP-0131' (Rico™), 'ANP-0118' (Lanya™) and/or 'ANP-0534' (none remaining in production) in the last 5 – 10 years. 'ANP-0534' was planted on a very small scale and quickly fell out of favour due to storage problems. 'ANP-0118' has not achieved reliable, high yields in the Goulburn Valley and production area is likely to decrease in future seasons, although there is growing interest in the USA. A risk of biennial bearing has been identified for 'ANP-0131', possibly associated with high early yields. Market development for 'ANP-0131' has been pursued by APAL in the last two seasons with reportedly good prices for class 1 fruit achieved. Despite this, packout limitations due to fruit quality issues in those seasons (poor blush development and post-harvest quality) have meant limited return on investment. It is noted that packout challenges (particularly achieving fruit size and colour requirements and downgrading due to blemish or scuffing) for pears are not unique to any one selection. The main constraint to maintaining or increasing production area of pears is the combination of low prices and difficulty achieving market specifications for fruit quality. Repeated failure of new selections to perform in terms of production and quality, and slow realisation of market potential will further impact willingness of growers to invest.

Growers are interested in the use of quince rootstocks as a mechanism to control vigour in higher density plantings of coloured pears. Adoption of new rootstocks is limited by:

- Availability of rootstocks other than D6.
- Reworking of old blocks in preference to new plantings.

Diversity of rootstock options is unlikely to expand while the interest in new plantings remains low and there is limited evaluation to identify reliable, devigorating options for local conditions. In the absence of an ongoing rootstock evaluation program, collation and sharing of information from growers who have accessed new rootstocks would provide at least an initial assessment of options. At present, Quince A is the most commonly used quince rootstock.

Orchard design - Training system and tree density

While low density, vase-trained trees are still common, growers have no interest in continuing with this style of production. The continued presence of these systems is a reflection of the longevity of pear trees, some having reached their centenary. Limited greenfield sites are in development; where they exist, a high degree of planning is undertaken with consideration of the scion, rootstock and current and future management options. Similarly, growers are not averse to altering tree training when reworking blocks. Grower advice for reworking included:

- September – October is ideal timing, growth is delayed by reworking in summer.
- Grafting into cordons (if present) rather than the stump.

Grafting into cordons to create new leaders increases the cost but apparently improved cropping compared to stump grafts (note, the authors have concerns regarding effectively introducing interstems that will have unknown consequences, this is a risk with both stump and cordon grafts; data to date indicates that negative effects of interstems differ between scion-rootstock combinations).

Traditionally, pears were grown as vases at low densities. Young trees are commonly trained to either Tatura trellis or vertical trellis at medium to high densities. Growers expressed a preference for trellised systems with multi-leaders, cordons or central leaders with branches trained to wires — all essentially 2-D systems. In younger (planted or reworked) blocks, growers have adopted systems designed to allow use of platforms or work primarily from the ground. Multi-leader systems are used to help distribute tree vigour. Leader spacing should be adjusted dependent on the vigour and fruiting habit of the scion with wider spacing (up to 500 mm) for more vigorous scions and closer spacing for less vigorous and spur-bearing scions. Dependent on the level of vigour control achieved, some multi-leader systems will require systematic removal and replacement of overly strong leaders. One grower reported trialling replacement of every second leader to off-set leader age to try to overcome biennial bearing. Two growers mentioned reducing the angle of Tatura trellis systems, one to better accommodate machinery and the other to allow greater access of root pruning implements. Trellising was viewed as beneficial to fruit quality (skin finish) while considerations of yield (greater potential from Tatura trellis), fruit colour (good light exposure for coloured pears on vertical trellis), and individual orchard logistics and workforce further influenced design decisions (e.g., organic systems using vertical rather than Tatura trellis to accommodate weed control, existing machinery determines ability to reduce row spacing, and preferences for platforms, cherry pickers or groundwork determines the height of trees).

The lack of analyses of financial benefits of intensive pear production was pointed out with the comment that "*things are going that way because it has worked well in apples and plums*".

Vigour control and crop load management

Control of vegetative vigour is regarded as essential, particularly when the rootstock is D6. Growers are more inclined to manage crop load when fruit size is of importance or fruit set has been problematic. Options for vigour control and crop load management can be classed as 'chemical' (usually foliar spray applications) or 'agronomic' (via physical manipulation of trees or limitation of resources). A mix of agronomic options are used by all growers. Chemical options were of interest to growers and used by some for control of vigour, encouragement of set and/or fruit thinning and delay of maturity. Although it is legal to use chemicals 'off-label' in Victoria, the provisos around this (that: the maximum label rate is not exceeded, the label frequency of application is not exceeded, the maximum residue limit is not exceeded, and any specific label statements prohibiting the use are complied with) and the lack of inclusion of pears on labels is a concern for growers. Moreover, the lack of inclusion of pears on labels affects confidence regarding appropriate application times and rates and possible negative impacts. Availability of particular chemicals traditionally used for vigour control and encouragement of flowering may become problematic in future as overseas governments increasingly place bans on their use and production.

Use of chemicals to encourage fruit set varies between growers; some growers are reluctant to use them due to negative effects such as fruit deformity (e.g., of Packham's) or poor return bloom while other growers are comfortable with using them on particular selections where greater benefit and no negative effects have been observed (e.g., Corella and Prem109). Overall, growers were hesitant to use chemicals for thinning, particularly at bloom, preferring to '*make sure we have fruit first*'. This reflects a lack of confidence in chemical thinning rather than a lack of need for thinning tools. There is even greater uncertainty regarding the effectiveness and possible negative outcomes of options to delay maturity. The efficacy of products to delay maturity and/or prevent late season drop for particular selections was questioned — again, lack of inclusion of pears on labels and limited research leaves growers uncertain regarding both positive and negative effects of such options.

Agronomic options for vigour control include withholding of water during stages when fruit growth is not affected (regulated deficit irrigation), root pruning, and chainsaw cuts or girdling. Growers tend to favour either withholding irrigation or root pruning. Current use of root pruning tends to be periodic (i.e., not every season and/or not every row) rather than a standard seasonal practice. Those using water restrictions to control vigour might use root pruning periodically, but it tends to be 'less aggressive' (not cutting close to the trunk or only cutting alternate rows); and those using 'aggressive' root pruning don't attempt it in conjunction with deficit irrigation because of concerns for fruit size. As previously discussed, tree training decisions often take vigour control into consideration (i.e., use of multi-leaders to distribute growth).

Agronomic options for crop load management are primarily pruning and hand thinning. Pruning is advocated by a number of growers as a way to avoid excessive need for hand thinning and to improve fruit set. Bud counts are used to determine potential flowering strength prior to bloom and pruning rules aim to leave sufficient buds to target fruit number. Commonly, growers leave a 'buffer' to account for failure of some flower clusters to set fruit. Not all growers have sufficient confidence in either their pruners or the likelihood of a 'good set' to take this approach. Mechanical methods of thinning (e.g., Darwin thinner) were not used for pear thinning by the growers surveyed but had been trialled in apples with 'good' results. Timing of hand thinning is often influenced by concurrent needs to thin higher value apple blocks. The effectiveness of hand thinning in improving fruit size and return bloom is therefore unlikely to be maximised. More broadly, good vigour control helps to maintain flower number; in turn, good fruit set helps to control vegetative vigour.

Management of red colour development

Given the trend towards adoption of red and blush selections, consideration of current practices and technology to enhance red colour development is pertinent. Seasonal patterns of red colour development differ between selections and are influenced by genetic and environmental factors. 'Best practice' management could therefore differ between selections. Light exposure is known to be a critical factor for colour development for a number of pear selections, although at least one new selection grown in the Goulburn Valley was suggested to colour well regardless of shading. Experience in apples has led some growers to trial leaf blowing to improve colour development, they are generally undecided regarding the effectiveness in pears and will continue to trial. On-farm trials of reflective mats are planned on one orchard in the coming season. Regardless of method, growers have questions regarding the best time to undertake practices to increase light exposure and enhance colour development. Growers did not report using biostimulant products designed to enhance colour or altering approaches to nutrition management.

Irrigation

Irrigation management is a highly skilled role dedicated to an experienced employee or the orchard manager. Microjet and, to a lesser extent, drip irrigation systems are common in pear blocks. In the interviewed group, irrigation systems ranged from a mix of drip and microjets to exclusively microjets. Some growers were open to conversion to drip irrigation while others believed the larger wetting pattern provided by microjets was needed for pear production. One grower is currently assessing his ability to control vigour with drip and, dependent on outcomes, will consider conversion from microjet to drip, and another will implement drip in certain blocks to aid weed management. Most growers have programmable irrigation controllers; control systems that can be accessed remotely (via radio systems and PC or the internet) are preferred but not installed on all orchards. Likewise, decision support tools utilising soil or plant-based sensors are popular but not installed on all orchards. Amongst the growers interviewed there was good understanding of sensors as 'decision support' not 'decision making' tools. Despite that understanding, the consequences of overreliance on these aids had been experienced by all interviewees using them. There was often a 'learning phase' where growers initially followed suggestions provided by the software, recognised patterns of under- or over-irrigation and subsequently adjusted irrigation or software parameters; in some cases, this recognition occurred prior to crop damage and in others it did not. Monitoring of field conditions and questioning the logic of sensor data and recommendations helps growers to recognise limitations of both sensors and software and then make best use of the decision support to finetune scheduling.

Soil moisture monitoring to assist in irrigation decision making has been used by various orchards for many years. By contrast, plant-based sensors have only recently moved to the commercial orchard setting following decades of use by researchers. Grower interest in certain plant-based sensors is based partially on current practices. Regular measurements of fruit growth as a feedback indicator for irrigation are seen as desirable, where staffing allows. However, grower experience showed that fruit measurement by dendrometers in irrigation support systems was not a sufficient replacement for field monitoring. Growers are not accustomed to using trunk dendrometers and overall have a low level of understanding of parameters derived from them. Furthermore, statements at recent field walks suggest that some orchard employees have erroneous understanding of how sensor data can be interpreted.

Nutrition and biostimulants

Growers were questioned regarding application practices and approaches to nutrient management rather than nutrient application volumes — nutrient needs vary depending on historical fertiliser use, soil nutrient status, tree nutrient status and crop loads and, while the range of volumes applied may be of interest, 'best practice' should take these factors into account rather than rely on industry means. Nutrient application methods include broad casting, fertigation and foliar sprays and most often growers utilise all three methods. Timing of applications varied somewhat between growers but was more determined by the nutrient e.g., calcium nitrate applications in late winter and spring, selected micronutrients in spring or summer (e.g., Mg, Mn, B and S) and further applications of macro- and micronutrients postharvest. Approaches to determining nutrient requirements vary widely between growers, ranging from 'standard' applications based on experience, thru' occasional soil or leaf analysis to annual leaf analysis. Fruit nutrient status had not been tested. With regard to the nutrients applied: applications of N, K, P, and Ca are common, while applications of other nutrients (e.g., B) vary between growers. Studies have shown that boron applications can improve fruit set and post-harvest quality of some pear cultivars, including in reduction of 'brown heart' in some seasons (Xuan et al. 2003, Wojcik and Wojcik 2003, Lee et al. 2009). Internal decay of 'ANP-0131' fruit was an issue following the 2020/21 season and the cause was unknown but attributed to 'seasonal conditions' as the issue was widespread. Similarly, Ca has been shown to be beneficial for fruit quality (including associated with colour development, Liu et al. 2021) of pears in other regions but growers remain uncertain as to 'best practice' locally. Some growers express concerns about foliar sprays of Ca due to risks of russetting of certain selections while others apply it routinely but are uncertain as to the best timing and application rates of foliar sprays and differences in effectiveness between soil and foliar applications.

Overall, growers expressed interest but cynicism regarding the effectiveness of the chemicals broadly described as 'biostimulants'. Of these, kelp products are the most commonly reported to have been used by growers. Reasons given for use included improvement of set and alleviation of plant stress, e.g., during heat events.

Soil health and groundcover

Individual growers reported concerns regarding soil structure and interest in improving soil microbial health.

One grower had used compost to attempt to improve soil structure but was uncertain of the effectiveness. Slashing and mulching of weeds and prunings is common practice. Cover cropping was not reported to be used in pears, with dry conditions in the post-harvest period cited as one barrier to successful seeding. Specialised equipment (seeders that fit within orchard rows) would need to be bought or hired by growers wishing to alter their current interrow mix and, as yet, there is no local evidence of benefits. In the coming seasons, FGV will investigate spring planting and species options that may cope with mowing and other orchard practices and improve soil health. The PIPS3 project 'Strengthening cultural and biological management of pests and diseases in apple and pear orchards' (AP19002) is investigating effects of increasing native species in the interrow on beneficial insect populations.

Crop protection – netting and pest and disease management

Netting infrastructure is increasingly installed in new blocks as they are planted or reconfigured as a matter of course, to allow for later installation of netting if required. Until very recently, pear blocks were not netted. A few growers now either have netting or plan to install netting, with the aims of protecting their investment from hail, improving skin finish by reducing wind and consequently rub, and reducing sunburn. Similarly, submains are often installed during irrigation works so that growers have the option of using overhead irrigation for sunburn protection in future, but there is no use of this practice in pears.

Monitoring of pests by trapping is standard practice to guide decisions about need for action and timing. In larger operations, monitoring may be conducted by dedicated employees but is more often contracted to suppliers or independent consultants. Growers vary in their level of knowledge of IPDM practices but there is some consensus that use of fewer sprays helps to avoid development of secondary problems (e.g., mealy bug presence being exacerbated by use of certain sprays) and that 'soft' options should be used as much as possible to avoid disrupting non-target organisms. Application of winter oil and copper prior to bud burst are standard practice to help minimise pest and disease problems. Codling moth and Queensland fruit fly are the main pests requiring action each season whereas as pressure from other pests (e.g., plague thrips, mealy bugs and mites) fluctuate dependent on season and block. The PIPS3 project 'Strengthening cultural and biological management of pests and diseases in apple and pear orchards' (AP19002) is investigating use of *Mastrus ridens* for control of codling moth. Release of sterile fruit flies in the Cobram area was viewed to be a particularly successful program and its extension into more regions was encouraged. Growers have previously reported good outcomes for mealy bug and mite control from targeted introduction of predators such as *Cryptolaemus* or lacewings (for mealy bug control), switching to 'softer' pesticide options and reductions in pesticide applications (https://apal.org.au/pear-masterclass-session-1-ipm-for-pears/). Of the interviewed growers, two were involved in trials of remote monitoring of QFF with Rapidaim (https://rapidaim.io/). One grower was positive about the system although he noted some loss of function under hot conditions and that '*it would be great if it can extend to cover more pests*'. The other considered the cost too high and noted the continued need for monitoring of other pests. Growers spoken to had not used the Semios pest monitoring system (https://semios.com/crops/pears/).

Mechanisation

Growers are actively adopting mechanisation options that decrease labour requirements. In some cases, growers are investing in equipment themselves and for other equipment they are hiring from neighbours. The hire option is particularly attractive for equipment that is not multi-use and needed for short periods with flexibility in timing of operations. For example, a mechanical pruner used for pruning tops of trees might be hired from a neighbour, whereas dedicated platforms have been built or purchased and used for pruning, thinning and harvesting. Comments regarding a range of options include:

- **Self-loading bin trailers** – Growers are beginning to purchase self-loading bin trailers. Level of adoption will be influenced by bock layout and harvest logistics. Bins collected by these machines are reportedly taking mud and other material into packing sheds and lines are needing to be closed for cleaning after they are put through. The extent of this issue and how it can be mitigated is unclear. The use of robotic platforms carrying bins to pickers and then returning them to the end of the row for collection was raised as a future possibility.

- **Harvest and work platforms** – A few growers have operated self-built work platforms for many years, some have invested in manufactured platforms for the first time in the last few years while others are evaluating the options. The pros, cons and 'things to think about before you buy' have been discussed at APAL and FGV events over the last year. Essential to the feasibility of investing in a manufactured platform is its use for multiple tasks (e.g., pruning, thinning, and harvesting). Ability of staff to operate them and either a staff member or good local support for repairs and supply of parts were also considered important considerations. Talking to growers already using the equipment, so that expectations of staff training requirements and work rates are realistic, is recommended. Adoption by individual growers will depend somewhat on training systems — some growers report difficulty using platforms in Tatura trellis and growers aiming for 'groundwork only' are not interested in purchasing platforms. Longer-term, growers are hopeful that robotic harvesters will eventuate — a high degree of picking efficiency (percentage pick and rate of picking) will be needed to enable adoption.

- **Variable rate sprayers** – Spray equipment currently in use includes large airblast sprayers that are somewhat ill-suited to higher density orchards with trellis and netting infrastructure but enable good coverage in larger canopies and smaller PTO-drive units. Some growers own both options and use them in different training systems (the airblast in vase-trained blocks and smaller PTO-drive units in trellis systems). Options for greater spray control at present range from 'add-on' controllers (~ $5000 each) that enable the tractor driver to manually increase or decrease spray volume on the go, to integrated units with vision sensors and the ability to turn individual spray nozzles on and off dependent on canopy. The cheaper, manual option may be attractive to growers and orchard managers who either spray themselves or who have skilled and trusted staff capable of 'reading' the canopy. Adoption of either option is currently limited (we are not aware of anyone adopting the latter yet). One grower expressed that he was happy with the uniformity of younger blocks and that spray management that varied applications between blocks and as canopies developed during the season provided a satisfactory outcome. A cost-benefit analysis of likely reductions in spray volumes, given different levels of canopy uniformity, would allow growers to evaluate the potential benefits from within-block variable rate spraying in comparison to managing to an average canopy volume. Growers recognise that attention to spray equipment (e.g., calibration and checking of nozzles) and efficiency (e.g., adjusting spray volumes with consideration of canopy volume) is not as strong as it could be. Growers are interested in improving spray management and spray-related education or incentive programs are likely to generate good engagement. Looking further into the future, there was interest in the use of robotic (driverless) spray units.

- **Mechanical pruners** – These are being purchased for use in other crops. They are used by some growers for 'topping' in pears. Growers who own them may try 'walling' in trellised pear blocks but there is some hesitancy due to concerns regarding reaction growth. Adoption will likely depend on training systems and detailed 'follow up' pruning will be needed.

Precision agriculture

Here we considered primarily the mapping aspect of 'precision agriculture'. Soil mapping is a popular tool when developing greenfield sites. Farm mapping systems provided by farm management software, or local irrigation design and precision agriculture consultants (e.g., Onley's, http://www.onleys.com.au/) are used to aid whole farm planning. One grower had used a subscription-based aerial mapping tool (Nearmap, https://www.nearmap.com/au/en) that enabled comparison of historical images and aided the identification of issues and likely causes in particular blocks. He would like to use drones for the same purpose but identified that he needs to have '*the right person*' on staff to enable this. Mapping of flowers, fruit (number and size) and tree parameters was seen as advantageous, but some growers remain uncertain if the cost and benefit will see them utilise it. Uses envisaged by growers for mapped tree and fruit parameters included:

- Yield forecasting (including fruit size profiles).
- Prioritisation of fruit thinning activities.
- Variable rate application of high-cost inputs such as fertiliser.
- Assessment of new developments (using tree size data to identify problem areas).

Green Atlas's *Cartographer* system for mapping fruit and tree attributes has had limited use in Goulburn Valley orchards. Currently, data is supplied to growers via maps and summaries for individual scan dates. 2022 AgAID Institute (https://agaid.org/about-agaid/) interns, Mia Hargrave (University of Washington) and Joshua Bailey (Purdue University), developed an interactive dashboard interface for management of data from *Cartographer*, and potentially other orchard sensors, to allow growers better access to current and historical data and to support data-driven decision making (Mia Hargrave and Joshua Bailey - YouTube). Further modelling was conducted to help growers correlate fruit size data with packout, understand the impact of within-block variability on profitability and, ultimately, understand the financial value of scans. While theoretical benefits of reducing within-block variability can be modelled, the ability to decrease variability of orchard production parameters by targeted or variable rate management has had little investigation.

Farm management software

Most software systems have some inadequacy and strengths differ between programs (e.g., one program is good for documenting spray management while others are more user-friendly or have good farm mapping). Lack of integration is a major problem; growers would understandably like to access all data from a single software program. Farm management software are largely designed to receive and process data input by users, while data from on-farm sensors (soil moisture sensors, trunk dendrometers, temperature and humidity sensors etc.) transmit data to separate software systems. Cost is another deterrent to using certain systems. Once a grower has invested (time and money) in a system they are reluctant to change, so the choice of system is a major decision and not all growers have made it.

Organic production

Organic production systems face unique challenges, particularly regarding pest, disease and weed management. Good prices are currently offered by processors for organic produce and this has encouraged some consideration of transition from conventional production. One grower interviewed is developing a greenfield site and considerable thought and effort has gone into the site design, equipment and management practices that will support organic production. The cost of investment is high and, in this case, supported by external funding. Other growers will be watching with interest and are unlikely to follow suit unless it is shown that organic production in the Goulburn Valley is a financially attractive opportunity. Regardless of the number of growers electing to transition, sharing of grower learnings may lead to practice change. For example, in relation to weed control, the grower is importing equipment designed to mechanically remove weeds; this equipment could be attractive to growers wishing to reduce herbicide usage.

Staff

Survey questions for discussions with growers focused on orchard management practices and did not include questions directly regarding staff. It is outside the scope of this document to address staff shortages or programs such as the Seasonal Workers Program and Pacific Labour Scheme. Inevitably though, the importance of skilled staff was raised by the growers and the impact of staff availability, reliability and skill on management decisions is obvious. Gowers are seeking to simplify tasks such as pruning (common questions at field walks being 'what are your rules?', 'how many rules?'), and to move away from the use of ladders and cherry pickers, to better enable use of low skilled staff. At the same time, one grower described problems with pruning that had led to a reluctance to adopt modern training systems. The problem was addressed by recruiting a skilled pruner and entrusting them with the role of 'pruning supervisor'. Subsequently, several unsatisfactory pruners were let go as the supervisor was able to train staff and monitor work. The grower was then confident in his staff's ability to manage trellised pears. Similarly, the adoption technology, such as drones or work platforms, is reliant on having a staff member who can be trusted to operate the equipment and, in some cases, manage the data or train and supervise other staff. While shifts to tree training systems that are simpler for inexperienced staff to prune and pick will relieve some pressure regarding workforce, the need for a portion of highly skilled, reliable workers will remain.

Growers identified two main constraints to recruiting suitable staff:

- A lack of horticultural training options for local students either at schools or through vocational training.
- The difficulty and cost of attaining permanent residency for foreign staff.

Local training options are limited and growers identified a need for '*passionate and experienced*' instructors capable of providing good '*hands-on*' instruction. Growers have invested substantial time in training foreign employees, particularly in the last three years. During that time a number of these employees have risen to the level of 2IC and growers are keen to retain them. Employer sponsorship of visas is costly and there is no guarantee employees will stay with the sponsoring company once the process is completed. Besides that, the pathways to permanent residency are difficult to navigate and slow. It is a concern to some growers that people who took the risk of remaining in Australia during COVID, worked hard and became integral to their business, may now be lost due to a belief that extensions allowed during COVID 'must end' without due consideration of the skilled roles they are now filling.

CONSTRAINTS AND INCENTIVES TO FURTHER MODERNISATION

The domestic market is over-supplied and there has been limited growth in export markets. Subsequently, growers are evaluating their ability to continue growing pears given low prices and difficulty meeting market expectations for fruit quality. The current market conditions are the main constraint to continued modernisation of orchard design and adoption of new selections with limited new plantings planned along with some reworking of old blocks. An overall decline in production area is expected as some growers leave the industry. Despite the lack of planned growth in production area, growers remain highly committed to improving practices and adopting technologies to increase fruit production and quality. The enthusiasm for new practices is tempered by:

- Costs
- Availability of skilled staff
- Uncertainty regarding effectiveness

In some cases, uncertainty regarding effectiveness could be addressed by communication of existing information and sharing of grower experiences; in other cases, experimental trials supported or conducted by industry stakeholders or independent researchers are needed.

Incentive programs

Discussions with growers provided feedback regarding incentive and extension programs and produced a broad range of suggestions for future programs and strategies to enhance sustainability of the pear industry. While programs providing investment assistance are appreciated, improvements could be made regarding:

- Communication. Growers reported receiving no notification when they are unsuccessful in applications. More specifically, one grower had experienced so many unsuccessful applications (with no notification or feedback) that he was no longer willing to invest time in applying for grants or co-funding.

- Roll-out. Delays in making promised funds available create ordering difficulties and current COVID delays further exacerbate this. This applies particularly to the netting program, the timeframe for delivery of netting may now run past the date funds have to be spent by and variations are required.
- Flexibility. This applies particularly to the IoT program, growers were not impressed with the list of options or the lack of choice of supplier.
- Useability. Again, this particularly applies to the IoT program. Many of the items offered provided data but lacked 'decision support'. Decision support is key to ensuring technology that collects substantial amounts of data continues to be used and is not abandoned when growers become too busy to collate, process or interpret the data.

Extension services from industry bodies are accessed either online or by attending orchard walks or 'end-of-season' meetings and conferences. Growers scan extension material (Industry Juice, AFG etc.) for topics of particular interest and seek out additional information online. A grower expressed being '*bombarded*' by a constant supply of extension materials by APAL, FGV, HIA and the VFF, while he was not suggesting the volume of extension should be reduced the comment highlights the risks of disengagement or 'missing' key information. It was suggested that greater consideration of the target audience is needed for online extension videos. Growers want to keep up to date with what is being done overseas as well as the experiences of their neighbours. There was an interest in more 'local information' from on-farm trials, other growers and the Tatura Smartfarm. Participation in orchard-walks varied between growers, some regarded orchard walks as more beneficial for younger growers and developing managers or cited 'time' as a constraint to attending. 'By invitation' walks were suggested as a method to target key growers with relevant information and support sharing of ideas and practices between leading growers. It was recognized that considerable efforts had been made to re-establish the Young Growers Network and this was seen as a good program for potential managers to be involved in, but momentum has been affected by COVID.

Programs that addressed clear issues and assisted growers to increase rate of adoption (e.g., netting, new and upgraded farm accommodation) and improve efficiency or safety (e.g., fuel tank sensors, energy audits, roll bars for quad bikes, first aid equipment, chemical storage upgrades) were viewed favourably. Suggestions for future incentive programs included support for adoption of:

- Variable rate spray technology
- Farm safety equipment

Suggested education and extension programs included:

- Grower manual for new pear selections.
- Spray and fertigation management (e.g., what chemicals can be mixed, how to calibrate spray nozzles, how to improve spray efficiency, demonstration of new technology).
- Sharing of grower experiences and support of on-farm trials.

More broadly, greater availability of high-quality industry training and improved ability of foreign staff to gain permanent residency were identified as important to being able to attract and retain staff suitable for modern orchards.

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APPENDICES

Appendix A: Grower survey template

The purpose of this questionnaire is to capture:

- Current stage of adoption of production systems and technology in pear orchards
- Medium-term plans or interests in future technology adoption and changes to production systems
- Incentives and constraints influencing decisions regarding adoption of technology and changes to production systems.

The questionnaire addresses aspects of orchard management including precision agriculture, harvest, tree training, irrigation and crop protection. Grower experiences with utilisation of technology or new production systems will be documented, including any difficulties with installation or maintenance of equipment and general benefits. Feedback regarding the role of extension programs in encouraging adoption and the utilisation of past incentive programs, along with grower experiences regarding application processes and subsequent implementation, will be sought. Ultimately, the survey aims to provide an understanding of the drivers of recent adoption and/or practice change decisions, identify future technology and production system priorities of growers, and provide suggestions regarding future incentive and extension programs.

Format and questions

Category	Current/Experience	Future/Reasoning
Sub category	*Questions*	*Questions*
e.g. /prompts	**When** were changes last made? **Why** What led to/enabled the decision. **Challenges** (e.g. difficulties with installation, maintenance, data vs decision support)? **Benefits** (e.g. financial, time saving, improved fruit quality, better use of resources/labour)? Prompts - Alterations to hardware or software (e.g. modifications needed to work platforms to allow different tasks? Is development of decision support needed?).	**When If planned**, Time frame? **Why If no plans**, is there a $ or other threshold/condition that would encourage change? **Challenge**s **Benefits** What are the expected benefits/why is it a priority? Prompts - What has encouraged OR discouraged change (experience of neighbours, extension info, business needs/logistics).

Production Systems	Current/Experience	Future/Reasoning
Cultivars		
Rootstocks		
Planting System		
Netting		
Nutrition		
Irrigation		
Ground cover		
IPDM		
PGR		

Mechanisation	Current/Experience	Future/Reasoning
Root pruner		
Mechanical pruner		
Darwin thinner		
Leaf blower		
Bin collector		
Harvest/work platform		
Sprayer		
Frost control		
Other		

Software	Current/Experience	Future/Reasoning
Orchard management software		

Precision agriculture	Current/Experience	Future/Reasoning
Soil mapping		
Tree mapping Flower, fruit, etc.		
Variable rate applications		
Practices to tailor management at sub-block scale		

Extension and incentive programs
Intensive Pear program *Young Growers Network* *Future Orchards* *APAL communication* *FGV/IDO support* *Research (e.g., AgVic research/FGV trials/other)* *Other sources (e.g., consultant/supplier/travel/online networks)*
Commonwealth water buybacks
Victorian 'IoT' (Internet-of-things)
Victorian Netting
Other incentive programs…?

Appendix D – Guidelines on new technology

GROUND-BASED MOBILE SENSING

Orchard mapping of tree geometry, flower clusters, fruit number, fruit size and fruit colour

Mobile sensorised platforms allow objective measurements of tree and fruit features in the orchard by integrating multi-purpose sensors and artificial intelligence. Colour-coded maps and histograms are generated from the data to support accurate management.

TECHNOLOGY AND ARTIFICIAL INTELLIGENCE IN ORCHARDS

Hardware technologies such as high-resolution optical (often referred to RGB), thermal, multi- and hyper-spectral cameras, and light detection and ranging (LiDAR) are becoming more popular in horticulture. The difficulty in interpreting the data produced by these sensors can nowadays be overcome by applying artificial intelligence (AI) to translate raw data into powerful orchard management tools.

The combination of hardware and software (AI) can be installed into aerial or ground-based platforms, with each having benefits and pitfalls. Ground-based mobile platforms have the advantage of being more user-friendly, but the disadvantage of taking a longer time to scan larger orchards compared to aerial platforms. Aerial platforms are susceptible to weather conditions and there are strict regulations on operating aerial platforms services. Furthermore, since orchards are discontinuous crop arrangements planted in rows, the use of ground lateral-perspective sensors provides the most accurate estimates of canopy and fruit features such as canopy volume, leaf area, canopy density, flower clusters, fruit number, fruit size and fruit colour.

Sensors

High-resolution RGB cameras gather high volumes of images or videos. AI models are trained to detect features such as flowers, fruit and foliage in images or videos. Features can be counted, and their colour and size extracted.

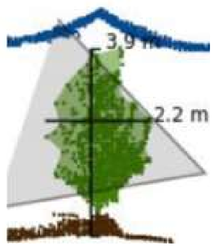
LiDAR sensors are used to digitize tree canopies by generating point cloud imagery. Geometry concepts are applied to the raw data to extract canopy variables such as volume, leaf area, density, height and width.

Agriculture Victoria has undertaken rigorous testing of RGB cameras and a LiDAR sensor attached to a ground-based mobile platform. AI estimates of pear and apple flower and fruit number, fruit size and fruit colour, and LiDAR measures of tree size and canopy leaf density were very accurate and reliable.

Georeferencing and colour-coded maps

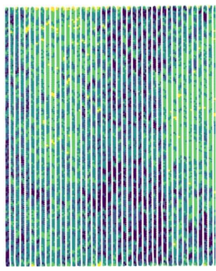
Data logged in mobile platforms is georeferenced with high accuracy by integrating GPS with real-time kinematic positioning (RTK) corrections. Georeferencing data is a necessary step for producing colour-coded orchard maps that support orchard zoning and precision management. The map outputs allow a user to locate their position within the block on smartphones and locate zones that need intervention.

Historical orchard databases



Datasets obtained with sensorised platforms are stored in clouds or servers and visualised using online dashboards. This guarantees future access to objective historical data of the orchard and provides valuable information for temporal trends of productive performance and management efficiency in the long term.

Applications



The use of such technology is a highly scalable option to obtain accurate data of the variability in fruit number and for pre-harvest forecasts of fruit size distribution and yield. The technology has great potential for further integration and automation of spatial management operations such as thinning, pruning, leaf blowing and variable rate spraying.

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Hort Innovation APPLE AND PEAR FUND

This project has been funded by Hort Innovation using the apple and pear research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

AGRICULTURE VICTORIA

UNIVERSITY of TASMANIA TIA Tasmanian Institute of Agriculture

IRRIGATION SENSORS

Trunk and fruit dendrometers

- Improved irrigation decisions can be achieved by assessing the water status of a tree using trunk dendrometers.
- Monitoring micro-variations in trunk diameter — shrinkage during the day and expansion during the night — helps to assess tree water status.
- Fruit dendrometers provide additional monitoring of fruit growth patterns but should not be relied on to measure fruit size.

DENDROMETERS

Contact-type trunk dendrometers monitor micro-variations in trunk shrinkage and expansion with linear variable displacement transformers (LVDTs). LVDTs produce electrical signals in response to sub-millimeter movement of sensor heads in contact with the trunk. The electrical signals are translated to changes in trunk radius. Similar components are used in band-type dendrometers and fruit dendrometers, enabling measurements of trunk circumference and fruit diameter.

Several commercial suppliers provide automated data download systems, software to display the data and varying levels of ongoing support in equipment maintenance and data interpretation.

RATIONALISING SENSORS

Prioritise blocks for instrumentation by considering which blocks can help guide irrigation of others. Factors for grouping blocks include:
- tree size and crop type
- emitter type and soil type (are wetting patterns, infiltration rates and drainage similar?)
- use of irrigation strategies (e.g., regulated deficit irrigation)
- harvest times (early or late season). If irrigation is cutback post-harvest, prioritise instrumenting blocks with late harvest dates.

SITE SELECTION

☐ Distance from the block boundary > 10 m.

☐ Use a 'typical' tree of average size and health.

☐ Record location details (block, row, distance and direction from boundary).

INSTALLATION

Trunk dendrometers

☐ Position sensor head to avoid knots or damaged areas of the trunk.

☐ Remove loose bark under the sensor head or band. Data is likely to become erratic after rainfall if loose bark is present.

☐ Remove weeds that could interfere with the sensor.

☐ Check data – if the sensor body is too close to the trunk, measurements will flat-line. The sensor will need to be adjusted using the thumb screw.

Fruit dendrometers

☐ Feed the cable along the trunk and branches to the fruit position.

☐ Secure the cable to a lateral or wire.

☐ Attach the brackets to the fruit. If possible, stabilise the dendrometer by securing to a lateral or wire but avoid interference with springs and bracket arms.

Note, fruit dendrometers are <u>not</u> an effective substitute for caliper measurements of fruit size.

MAINTENANCE

As trunks and fruit expand, adjustment of sensor positions will be needed.

☐ Point dendrometer: shift the sensor away from the trunk slightly.

☐ Band dendrometer: loosen band.

☐ Fruit dendrometer: adjust the frame and/or bracket positions.

Trunk dendrometer – the LVDT is protected and the sensor head contacts the trunk.

Loose bark removed under the sensor head of a trunk

Fruit dendrometer

For more information

'Trunk dendrometer – data interpretation'

Irrigation scheduling in the Sundial Orchard - PIPS3 update (apal.org.au); Irrigation support: The role of trunk dendrometers (apal.org.au)

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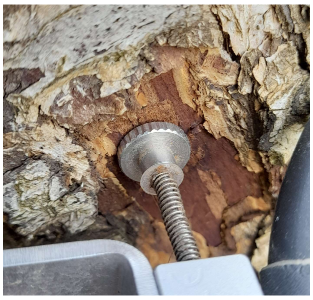
TRUNK DENDROMETERS

Data Interpretation

- Improved irrigation decisions can be achieved by assessing the water status of a tree using trunk dendrometers.
- Dendrometers provide an indication of tree water status by measuring micro-variations in trunk circumference or diameter.
- Real-time monitoring capability provides rapid, accessible feedback on irrigation decisions.

DAILY TRUNK FLUCTUATIONS



Both the **shrinkage** of the trunk during the day and the **daily growth** of the trunk can be examined to assess tree water status. Generally, an increase from day to day in shrinkage indicates a tree is becoming stressed and will need to be irrigated. A decline in daily growth indicates the tree is getting very stressed.

Trunks shrink during the day when the vapour pressure deficit (VPD) of the air (the difference between how much moisture the air *could* hold and how much it *is* holding) drives movement of water through the tree by a gradient in water potential. At night, when VPD falls, the tree 'refills' and the trunk swells.

When soil moisture is low, trees will be slower to 'refill'; trunk growth will slow or cease and shrinkage during the day will increase.

Software systems provide decision support but do not adjust for all factors that influence shrinkage and growth; it is therefore important to know:

- how to interpret daily fluctuations, and
- how various factors affect fluctuations.

It is important to take time in getting to know your system. Continuing with usual observations of soil moisture and tree vigour will help you to understand the general trends and recognise tendencies for software to under- or overestimate plant stress.

SEASONAL PATTERNS

Crop type, tree age and growth stage

Knowing your expected trunk growth pattern will help you quickly identify water stress.

☐ Young trees can show continual daily growth throughout the season.

☐ Older trees may have periods of growth within the season or minimal trunk growth throughout the season, dependent on crop type and irrigation management.

☐ Water stress may be indicated by slowing trunk growth in young trees but absent or limited growth in

ADJUSTING FOR VAPOUR PRESSURE DEFICIT

Higher VPD (drier air) will result in greater shrinkage and slower time to recovery even when trees are well watered.

☐ Shrinkage thresholds for irrigation should be adjusted for VPD. Adjustments are crop, and often cultivar, specific. It is unlikely that software will adequately adjust thresholds for all crops, let alone cultivars. Plant stress may be underestimated OR overestimated (typically the latter, leading to excessive irrigation).

☐ Software systems that determine shrinkage and daily growth at a set time each morning, rather than at the time of maximum trunk diameter, can underestimate recovery. This could result in overestimation of plant stress.

For more information

Irrigation sensors - Trunk and fruit dendrometers

[Irrigation scheduling in the Sundial Orchard - PIPS3 update (apal.org.au)](); [Irrigation support: The role of trunk dendrometers (apal.org.au)]()

Hort Innovation Strategic levy investment | APPLE AND PEAR FUND

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AGRICULTURE VICTORIA

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Apples & Pears

PRODUCTIVITY IRRIGATION PESTS AND SOILS

Data Interpretation

- Soil moisture, VPD, leaf area and root extent influence tree water potential and hence trunk shrinkage and expansion.
- Understand expected patterns of trunk micro-variations and the influence of crop attributes, VPD and soil moisture to accurately interpret data.

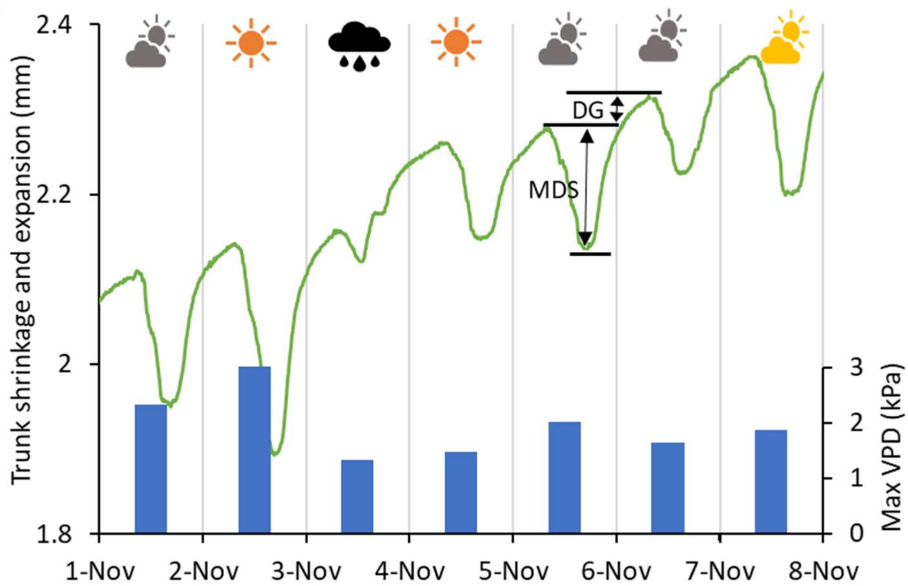
EXAMPLES OF DENDROMETER DAT

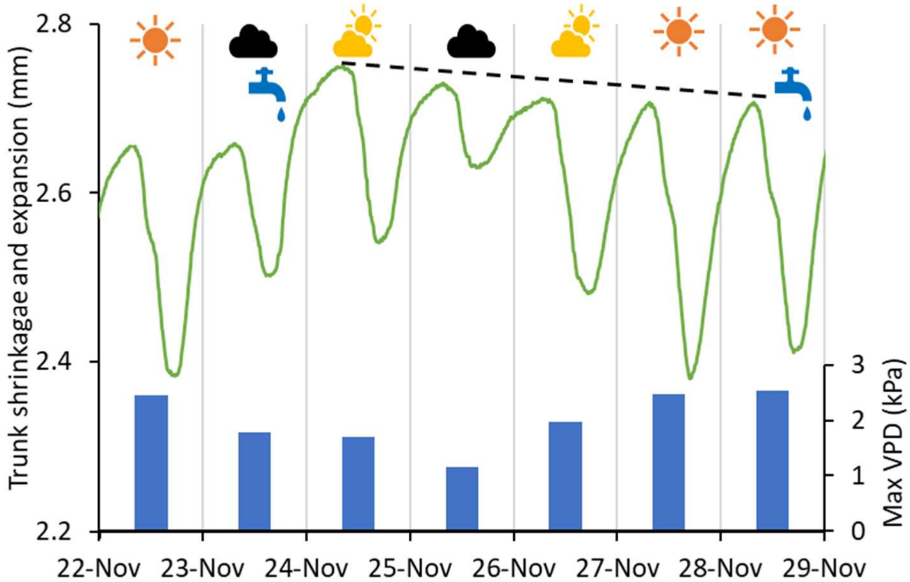
Fluctuations in trunk diameter measured

Maximum daily shrinkage (MDS) of the trunk is calculated from when shrinkage starts in the morning to when shrinkage stops in the late afternoon. Daily growth (DG) of the trunk is calculated from when shrinkage starts in the morning to when shrinkage starts again in the next morning.

Trunk shrinkage and expansion (green line) of a pear tree and the maximum daily VPD (blue bars) from 1 to 8 Nov are shown in the top figure. Indicated is the MDS for the 5 Nov and DG from 5 to 6 Nov. Following a wet winter, trees had not been irrigated and were entering the regulated deficit irrigation period. Recovery of trunk diameter (reaching maximum expansion at approximately 7:30 am each day) and DG on successive days indicated the trees were not yet stressed. Note how a cloudy, wet day (15 mm rainfall, 3 Nov) caused a reduction of MDS.

The bottom figure shows trunk shrinkage and expansion (green line) of the same pear tree and the maximum daily VPD (blue bars) from 22 to 29 Nov, at the end of the regulated deficit irrigation period. Trees were showing evidence of water stress by lack of recovery and negative DG values (i.e., decreasing maximum trunk diameters highlighted by dashed line). Trees were irrigated to supply 15 % of potential water use. Note the recovery of trunk expansion following irrigation (23 Nov) and the influence of atmospheric conditions on shrinkage.





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Hort Innovation Strategic levy investment | APPLE AND PEAR FUND

This project has been funded by Hort Innovation using the apple and pear research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

AGRICULTURE VICTORIA

UNIVERSITY of TASMANIA TIA Tasmanian Institute of Agriculture

COLORIMETER

Objective fruit colour assessments

- Portable, Bluetooth-enabled colorimeters allow accurate, precise and reliable estimates of fruit colour in the field and packhouse.
- By adopting a standard colour scale, consistent and objective assessment is achievable.

COLORIMETERS

Colorimeters provide an objective measure of colour. Handheld colorimeters with Bluetooth capability can be used in the orchard or packhouse to provide reliable assessments of fruit colour. Several models are available commercially and typically cost less than $500.

Colour scale

Most colorimeters provide measures in multiple colour scales. The pear industry should adopt a standard colour scale to aid consistent and objective assessment of colour. Use of the CIELAB colour space (also known as CIE L*a*b*) is recommended because it is based on human perception of colour and is commonly used in horticulture research and other industries.

In the CIELAB colour space, L* represents lightness (0 = black, 100 = white), a* (−60 to 60) represents the green-red axis, and b* (−60 to 60) represents the blue-yellow axis. The angle formed by a* and b* values is the 'hue', where 0°, 90°, 180° and 270° are true red, true yellow, true green and true blue, respectively. 'Chroma' describes the colour saturation, and ranges from 0 (grey) at the centre of the colour space to 60.

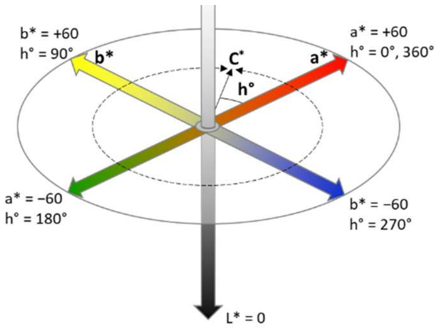
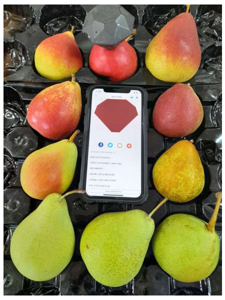


Image:
Alessio Scalisi

Choosing a colorimeter

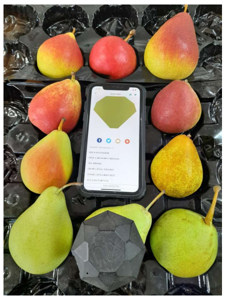
Ideally, a colorimeter should be robust, to withstand field work, and allow transfer of data to a compatible file type, preferably with the ability to identify the assessed samples. Some colorimeters offer the ability to create a 'colour library'.

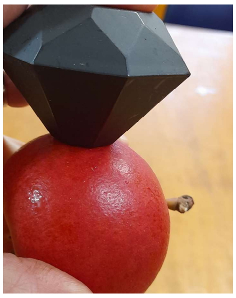
Taking measurements



Colorimeters utilise in-built light sources and are pressed against the fruit. This enables use at any time of day, indoors or outside, but good contact must be made between the fruit surface and the colorimeter to avoid external light affecting measurements. Consequently, measurements taken early in the season when fruit are small may be less reliable. Using a colorimeter with a vibration or sound alert to indicate when a measurement has logged is recommended to avoid moving the colorimeter before a measurement is completed.

Creating a colour library





In the future, a 'colour library' could be created to replace the need for visual (subjective) colour scales. By collecting many fruit samples, classifying the fruit according to visual colour scales, and, finally, taking measurements for each class, a colorimeter can be used to 'classify' fruit. However, both a large dataset and consensus amongst parties involved in the visual classification of fruit is needed to progress this concept. Work has been undertaken by ExperiCo in South Africa to develop a colour library for exported green pears. Similarly, assessments by Agriculture Victoria indicate that values of L* less than 40, hue less than 30° and chroma greater than 35 translate to a desirable, deep red blush of 'ANP-0131'.

References

International Organisation for Standardisation. (1976). CIE 1976 L*a*b* Colour Space. (ISO/CIE 11664-4:2019).

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Appendix E – Monitoring and evaluation

AP19005 Developing smarter and sustainable pear orchards to maximise fruit quality, yield and labour efficiency

The PIPS3 Program Final Evaluation interview process was conducted in June and July 2023.

Overall, forty-three (43) telephone interviews were undertaken by the PIPS3 Program Coordinator, each interview averaging a 20 minute in duration. Eleven questions were asked, seven of these structured with a rating response required between 1 (most negative) and 5 (highly positive), with an opportunity to provide an extended comment to support the rating response. Most often, the respondents were highly motivated to expand upon the ratings provided. Four questions were open-ended to gain feedback and insight in a less formal and structured approach. These responses were particularly important in identifying areas for continuous improvement.

The stakeholder groups represented in the interviews were:

- Research team (n = 8)
- Growers (n = 20)
- Service Providers (n = 15)

The service provider stakeholder group included agency extension, commercial advisors, private advisors, and technical collaborators.

Some interviewees provided a response based upon their involvement across multiple projects of the program. This resulted in fifty-four (54) possible responses when quantifiably analysing results on a project basis. The following is a break-down of possible responses per project:

- Whole-of-program relationship (n = 6)
- AP19002 (n = 10)
- AP19003 (n = 6)
- AP19005 (n = 8; Researcher n = 4, Grower n = 2, Service Provider n = 2)
- AP19006 (n = 24)

Although the spread of project respondents appears to be disproportionate, with AP19006 having 24 respondents, this reflects the large geographic spread of this project. The interviews conducted for this project ensured good representation across the regional areas in which both trial and demonstration activities were being conducted.

The interview process of both quantifiable and qualitative questions was used to evaluate **effectiveness**, **relevance**, **process appropriateness**, **efficiency** and **legacy** of the PIPS3 Program, and the specific program and project questions underpinning these (refer to the table below for questions that were specifically developed by the AP19005 project). The design of the questions enables analysis of responses at both a program and project level so that all users of the evaluation report can apply findings to both program and individual project level questions. A table of the interview questions used to assess performance of the program and projects against the key evaluation questions (KEQ) is provided in the final report for AP19007 (Independent Coordination).

AP19005 achieved a “Strong” performance rating across all KEQ from the final evaluation interview process.

Table 1. Stakeholder interview quantitative response ratings to determine final performance.

Stakeholder interview result	Evaluation criteria
Strong	Rating of between 3.8 to 5
Moderate	Rating of between 2.4 to 3.7
Weak	Rating of between 1 to 2.3

Table 2. AP19005 Key Evaluation Questions and performance results

AP19003 Key Evaluation Questions	Project performance	Example Feedback from respondents.
EFFECTIVENESS: *To what extent has the PIPS3 Program addressed the objectives, research agreement achievement criteria and identified outcomes/ outputs?*		
• To what extent has the project improved knowledge and understanding of orchard design and management to grow new pear cultivars to market specifications within the context of a changing and variable climate? • To what extent has the sub-project advanced sensor technology to enable/improve measurement of orchard parameters?	**AP19005 effectiveness rating achieved:** 4.4 (n = 8) **Overall program effectiveness:** 4.3 (n = 43) Respondents were very confident that the project achieved its objectives and activities were executed as expected. It was identified that Covid had an impact upon the outcome of chemical thinning experiments in the first season. Whilst growers involved were extremely complementary, researchers believed there is always room to adjust and improve.	***Researcher*** *Covid had a major impact on the pear work so the experimental work was delivered a year late. There were also some quality issues in the way the treatments were applied as I couldn't be there in person.* *Accurate (and precise) pre-harvest spatial measures of pear orchard productivity are now available to fruit growers and scientists [Cartographer].* ***Grower*** *For Rico™ we need to get the blush right and we just didn't know what effects the netting was having but this showed us more to consider.* ***Service Provider*** *Validation of technology [Cartographer] was good and examples used in commercial orchards.*
RELEVANCE: *How relevant were the research outcomes/ outputs to the needs of apple and pear growers, advisors, and industry stakeholders?*		
• To what extent has the project met the needs of growers and front-line advisors to provide information on design and management of pear orchards and use of sensor technology?	**AP19005 relevance rating achieved:** 4.4 (n = 8) **Overall program relevance:** 4.4 (n = 43) The project was considered strongly relevant to both growers	***Researcher*** *Some could have been more practical in nature and advanced things further—some planned into the next project. More practical plan for the heat & temperature type work—things they can do rather than the*

<table>
<tr><td></td><td>and advisors who support them, particularly in relation to light and heat effects on skin colour development and the use of the Green Atlas Cartographer in pre-harvest spatial measurement. There were no direct comments on thinning or long-term orchard design experiments, and the final development and release of the irrigation budgeting and seasonal planning tool. The researchers are already making plans to convert new knowledge gained in this project into practical management tools for growers and acknowledge the benefits in undertaking their experiments in a commercial setting where growers have input.</td><td>physiology side of things.

It has been important I think to work on commercial farms.

Grower

What they are trying to address is certainly relevant—all of it. It may not be obvious now, but that is what research is all about.

Service Provider

It's important in AgTech to have that validation. To an extent it has allowed us to point to the work/papers that this technology can be supported with confidence. We now say things like "technology backed by science"—it is a concrete thing.</td></tr>
<tr><td colspan="3">APPROPRIATENESS:

How well have intended audiences been engaged in the project?

To what extent was the PIPS3 Program Communications and Extension Plan appropriate and had an impact upon the target audience?</td></tr>
<tr><td>No specific AP19005 within M&E plan.</td><td>AP19005 appropriateness rating achieved: 4.6 (n = 8)

Overall program appropriateness: 4.6 (n = 43)

The project was considered extremely strong in engaging with the industry, though more can be done to work directly with what is only a small pool of growers in Australia. Respondents believed the mix of digital, printed and field-based activities on offer was strong, but not necessarily disseminated through the most effective lines to pear growers. Growers indicated they referred to printed materials rather than digital based formats.</td><td>Researcher

We need to target the big pear growers for our project, not be so general [More direct integration into the Pear Master classes].

Grower

A mix of everything seems to make sure that everyone is covered.

I get the most out of live presentations where I can engage with the researchers, but they need to be good. I get much more value out of this where we can all engage and have a conversation.

Service Provider

Publications are important as we can point to these.</td></tr>
<tr><td colspan="3">EFFICIENCY: What efforts did the PIPS3 Program partners make to improve efficiency?</td></tr>
<tr><td>• Did the project/s efficiently manage shared resources and utilise skills and knowledge within other PIPS3 Program projects?</td><td>AP19005 efficiency rating achieved: 4.2 (n = 8)

Overall program efficiency: 4.1 (n = 39)</td><td>Researcher

I think across our two teams (AP19003 & AP19005) we have a pretty good idea of the systems in</td></tr>
</table>

	The AP19005 respondents rated the PIPS3 Program as strong on its performance to deliver an efficient approach to research, and communication and extension of the research. There were obvious indications that the project strongly benefitted from its connectivity to AP19003 and drawing upon the expertise of Sally Bound from TIA.	*orchards.* ***Grower (PRG Member)*** *Without doubt. There is good respect and cooperation between everyone. They all know what they're doing for the system.*
LEGACY: *Are there signs that the PIPS3 Program will influence apple and pear growers in the future?*		
• To what extent has the project resulted in greater confidence, intention to adopt, or adoption of new orchard design and management, and improve utilisation of sensor technologies? *PROGRAM* • Is there evidence that outcomes and outputs of the PIPS3 Program will continue to be adopted by growers and front-line advisors? • To what extent do stakeholders believe that outcomes/ outputs of the PIPS3 Program are likely to become "usual grower practice" within the next ten years?	**AP19003 legacy rating achieved:** 4.3 (n = 8) (Improved knowledge & understanding of the concepts = 4.4 & Likelihood of adoption < 10 years = 4.1) **Overall program legacy:** 3.8 (n = 43) (Improved knowledge & understanding of the concepts = 4.0 & Likelihood of adoption < 10 years = 3.6) Whilst there has been improved knowledge and understanding gained by all respondents, they are a little less confident about adoption, though the result is still strong. The economic value of changing managements, whether taking rapid measurements in the orchard or applying new management techniques, needs to be clear to growers. Working with leading growers helps to facilitate the process, but more needs to be done to extend the information impactfully, more broadly.	***Researcher*** *They have had the opportunity but always difficult to gauge. We can get a good sense of this from face to face, that is why the roadshow was terrific. [Knowledge & Understanding}* *I tend to work with the growers who have a good understanding and are leading growers. What we have done in many ways is to answer or confirm some of what they have already noticed/ practiced—so some work has been about confirming what they have taken-on earlier. Now they have new questions.* *It's really only this year that we have been extending that [chemical & mechanical thinning] side of things. PIPS4 will extend this as we will have more time to get this info out.* ***Grower*** *In the varieties where the thinning pays it will be a 5, in those that don't it will be a 2. There are many reasons why people adopt and do not adopt. The economic benefits have to be proven—no increase in fruit price—so has to help me practically and financially.* *People will take notice when the information is relevant to them. We are likely to have hotter summers again soon, then the relevance of temperature and sun damage and netting will be*

		something they look at. ***Service Provider*** *Little was known [on Cartographer application to pears] but now they have much more of an understanding, and we have growers willing to engage consultants on this and use the maps.*

Recommendations for continuous improvement

Comments from interviewees were grouped into the following areas for future research and communication of the results:

- Financial evaluation of thinning, ag tech and spatial management
    - *The economics of different management options will be very important in PIPS4—for all growers. e.g., thinning sprays v other options.*
- Management applications for *Cartographer*
    - *It will grow as more evidence is out there about the practical application and how it can be used to make decisions. [Benefit of Cartographer]*
    - *I take interest if I can see the end result—not just general information. Need the evidence over longer-term.*
- Communication of results
    - *Pick the right growers with extensive networks for our field sites. Get growers to set-up some simple trials themselves and arming them with a few simple measurements.*
    - *More walks. This keeps things social.*