Rural R&D for Profit Program

Multi-scale Monitoring Tools for Managing Australian Tree Crops: Industry meets Innovation

Final Report Summary / 2019

Hort Innovation

Rural Research and Development for Profit
Keeping Australian farmers at the cutting edge

une University of New England

Funding statement

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Project Rationale

The Horticulture Innovation Australia led 'Multi-scale Monitoring Tools for Managing Australian Tree Crops Industry meets Innovation', successfully delivered on the objectives of the Federal Government 'Rural Research and Development for Profit' scheme. The project successfully engaged with a number of industries (avocado, macadamia, mango and banana) to identify a range of applications that were relevant, practical and therefore adoptable.

These priorities included mapping the distribution and extent of all commercial orchards across Australia (avocado, mango and macadamia); improved pre-harvest yield forecasting and yield and quality mapping of each tree crop, and the improved monitoring of abiotic and biotic stresses. To deliver these applications, a diverse collaborative group of industry bodies, universities, research and government agencies, growers and consultants was established (Figure 1).

Together, the project team evaluated a range of commercially available and emerging technologies including satellite, airborne, UAS and ground based remote sensing and robotics, with over 120 field campaigns conducted across four states. Research outcomes are relevant to a range of scales: national, regional, farm and individual tree.

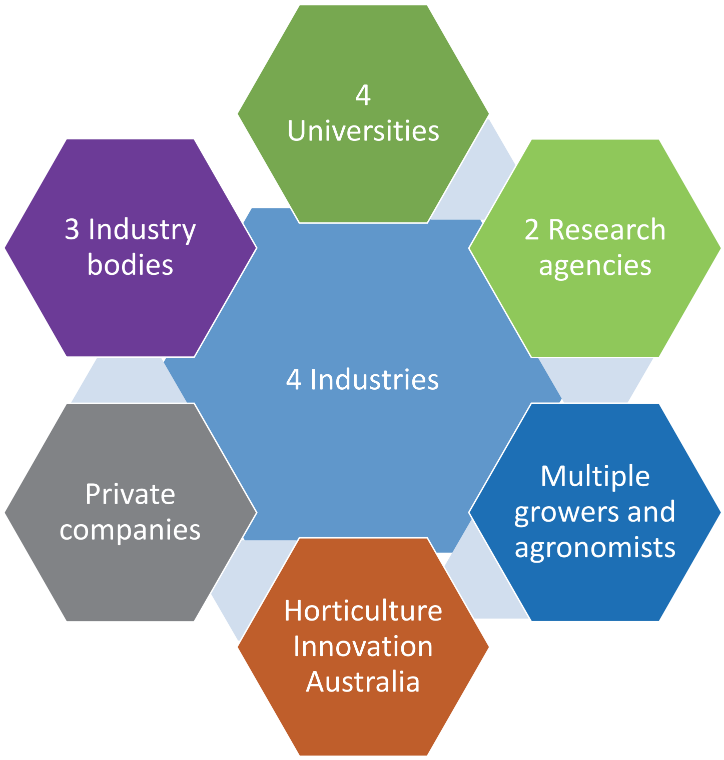


Figure 1. Snap shot of project collaborators

At the National Level

The development of the *'Australian Tree Crop Rapid Response Map'* and the *'Australian Tree Crop Rapid Response App'*, now freely available online (web map web app), not only provides each respective industry with improved knowledge of orchard distribution and area, but serves as an important layer for post- disaster monitoring (Figure 2). Already the map has been used by the respective industries for estimating the impact of cyclones Debbie (Qld) and Marcus (NT). This information is important for revising annual production estimates required for meeting forward selling targets, both domestically and overseas. Also the information may help growers quantify lost production for insurance purposes following a natural disaster. Improved response to plant biosecurity incursions is also a significant benefactor of this project output. Access to a freely available map that identifies the location of specific cropping types can greatly assist with the coordination of on-ground surveys and the establishment of exclusion zones following the confirmation of an incursion. This will ultimately improve response time and reduce potential spread. This project output provides a strong example of how industry, academia and government can work together for mutual benefit.

At the Industry Level

Whilst, making grower information publicly available through the national tree map would not be appropriate, the development of a geographical information systems (GIS) that did house additional attribute information such as tree species, tree age, row spacing, historic yield etc. does offer significant benefit to each respective industry. In its simplest form, an industry level 'GIS' database provides a more refined spatial delineation of orchard boundaries (Figure 3).

With a more exact area of production, more accurate pre- harvest yield forecasts can be made both at the regional and national level. The inclusion of additional attribute information would assist the respective industry bodies to better understand current and historic grower demographics, such as defining areas of new plantings, cultivar distribution, spatial and temporal variability in yield and quality. The information would also support improved decision making around harvest, transport and labour logistics etc. Through this project, a prototype industry level GIS was produced for a small region of the intensive macadamia growing region of New South Wales.

By project completion, macadamia processors servicing 40% of the industry had commenced using the system to

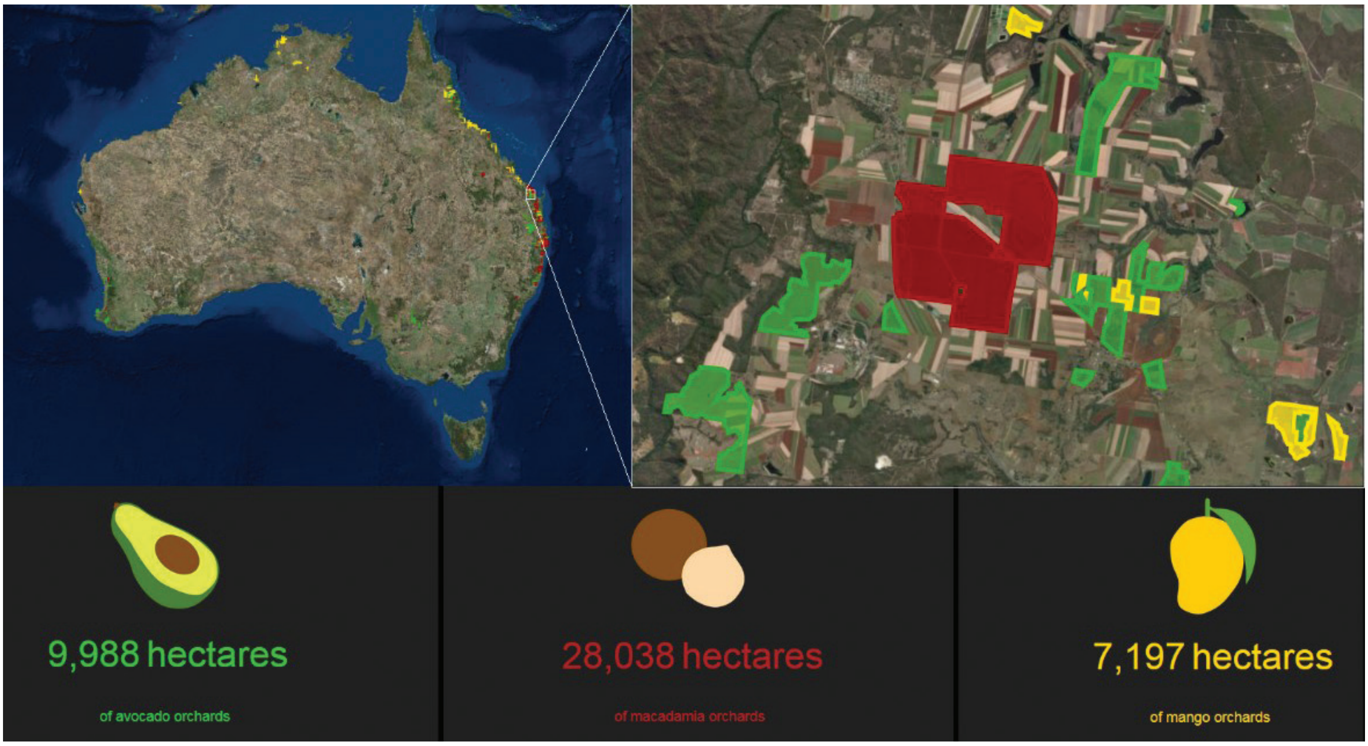


Figure 2. National map of all commercial orchards over 2 ha. This outcome provides important information about industry demographics (extent, spread and area of production), estimates area of impact following a natural disaster and serves as an important biosecurity response tool.

Figure 3. Farm level GIS data layer

capture detailed data. The development of an industry level GIS, can also serve as an interfaces for growers to record farm management operations, crop inputs etc., as well as access and interrogate spatial layers such as tree health, fruit maturity, and productivity data generated from a range of technologies, such as those mentioned below.

At the Farm Level

Improved pre- harvest yield mapping and forecasting was identified as a primary requirement by all industries engaged in this project. In response to this request, a range of commercially available and emerging technologies were investigated. These included satellite, unmanned aerial System (UAS), proximal remote sensing technologies and LiDAR. Ground based sensors included those that were hand held, mounted on utility vehicles and on robotic platforms such as the University of Sydney's 'Shrimp' (Figure 4).

The ground based optical sensors proved to be accurate for counting individual fruit and flowers on mango trees, whilst satellite imagery calibrated by on-ground sampling proved accurate for yield mapping and forecasting for all three tree species (avocado, mango and macadamia) (Figure 5). In the absence a commercial yield monitor, understanding the spatial and temporal variability of yield supports the adoption of improved management practices such as the variable rate application of crop inputs including nutrient, water, insecticide, herbicide etc. Additionally improved forecasting accuracy at the farm level supports more informed decisions around labour requirements, harvesting scheduling, post-harvest processing, storage and transport, and forward selling. Corresponding with the accurate measures of yield, was the ability to measure fruit quality and fruit size of the varying mango and avocado tree crops. A hand held NIR sensor was found to be highly accurate for measuring the dry matter accumulation of Mango.

Figure 4. 'Shrimp'

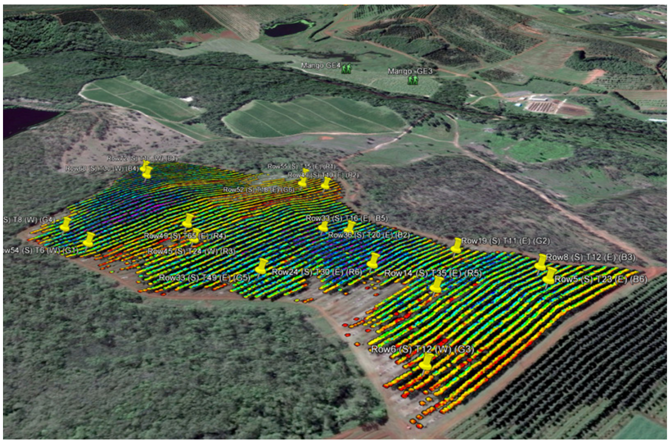


Figure 5. Classified avocado yield map derived from satellite imagery

This information when accompanied with an App (www.fruitmaps.info) developed through this project, provides mango growers with a greatly improved method for optimising harvest timing (Figure 6). Considering the harvest window for mango is only 4- 5 weeks, and a miscalculation can potentially equate to a 30% yield loss, this outcome offers significant benefit. The evaluated technologies also proved to be highly beneficial for mapping tree health including specific diseases such as Phytophthora in avocado, and tree canopy structure. An understanding of the later, measured by LiDAR technologies, allows for the light interception of individual trees to be modelled, thus providing growers with the opportunity to better implement targeted limb removal for optimising fruit quality.

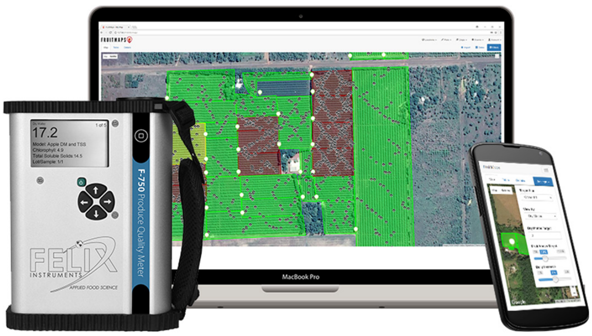


Figure 6. The 'Fruitmaps App' that allows the spatial distribution of mango maturity to be recorded and the optimal harvest date to be derived

Recommendations for future research and development:

The outcomes generated from this project provide a range of direct benefits to the respective industries across varying spatial scales. In some cases these have been well developed, whilst in general further development, commercialisation and extension is required. For The National Tree map, the further refinement of orchard boundaries would greatly assist the national forecasting of yield, whilst the annual maintenance of the layer would allow new plantings to be included. Considering the success and multi-purpose benefit of this output, there is also the opportunity to include additional industries in the future. For the industry level GIS, substantial development and industry engagement is required to incorporate attribute information for all growers as well as to deliver a commercial framework to industry. Satellite imagery wasbe an accurate tool for mapping tree health, disease and a range of yield parameters. However, further development and commercialisation is required to bring this technology to the farm. The development of an App that allows growers to access and calibrate imagery in-field for the purpose of yield mapping is currently being investigated. The success of the various machine vision approaches for counting individual mango fruit presents an opportunity for the development of an autonomous harvester. This outcome would offer significant benefit in addressing current shortages and costs of labour.

Case Study 1.

Mango Production /2019

University of New England

Case Study 1:

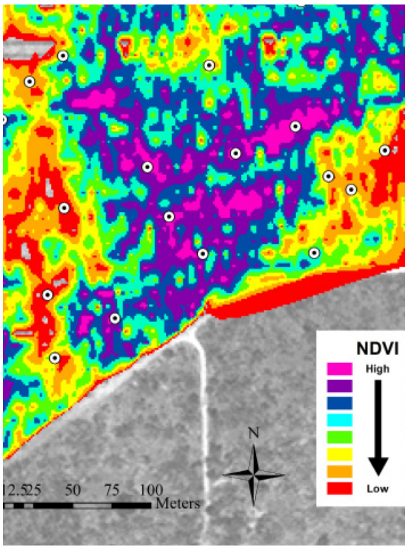
Improved mapping and forecasting of fruit maturity and yield for mango production - a Northern Territory perspective provided by Martina Matzner (Acacia Hills Farms, NT)

In 2017, the GVP of mangos in the Northern Territory has increased by over 11% from an estimated $88 mil in 2015 to around $100 mil. (NT Farmers)

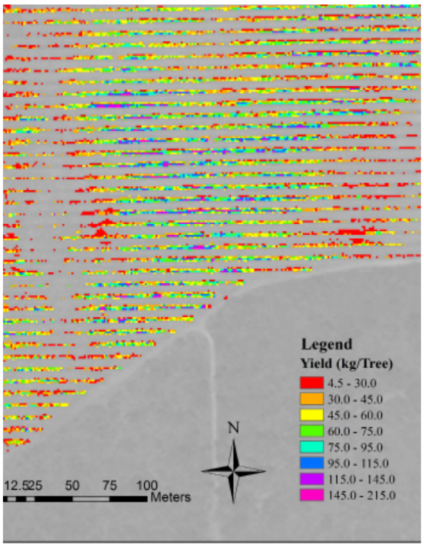
One of the largest limitation to achieving maximum production and price are harvest timing and availability of labour at that time (some farms require in access of 150 staff). Mangoes are a perishable fruit and should be harvested within 3 weeks from maturity as after that quality will deteriorate, shelf live be reduced and fruit drop can occur. Harvesting too early results in fruit of poor eating quality. Correct prediction of the optimal harvest window has significant impact on farm gate price. With the harvest season for Northern Territory mango of any given cultivar lasting an average of 5 to 6 weeks between September and December (weather dependent), harvest timing decisions are required with an accuracy of a week.

Harvest timing forecast is critical for the whole supply chain from organisation of labour to packaging, transport and marketing. For example, premature forecast of optimal harvest time can result in labour recruited for picking having to wait for the harvesting to commence. If they leave the grower loses investment in staff training (i.e. 16 hrs training by ~$30 per hour per person) and, with a limited availability of workers each season, runs the risk of not being able to harvest all fruit within the narrow harvest window. Conversely a late forecast of optimal harvest timing will result in a compressed harvest window, which in worst case scenarios, can result in up to 30- 40% of fruit drop or fruit being left in field due to loss of quality. Given the 2017 mango production for the Northern Territory was $98 mill (production number provided NT Farmers), a potential loss of 30% due to less than optimal harvests timing is a significant concern.

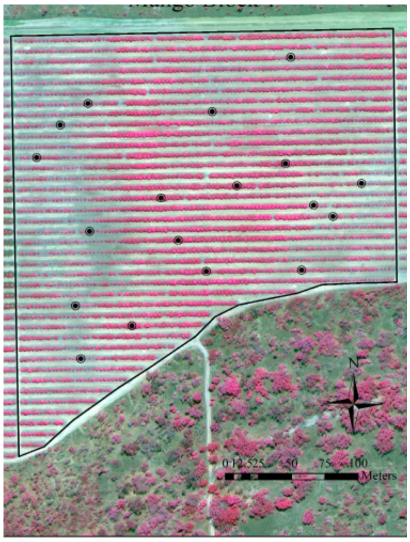
The process for deriving Mango yield maps from satellite imagery.
Predicted yield for this orchard was 76,326 Kg. Actual harvested yield for this orchard 74,243 Kg



NDVI image showing variation in tree vigor across a mango orchard. The higher the NDVI the more healthy the tree

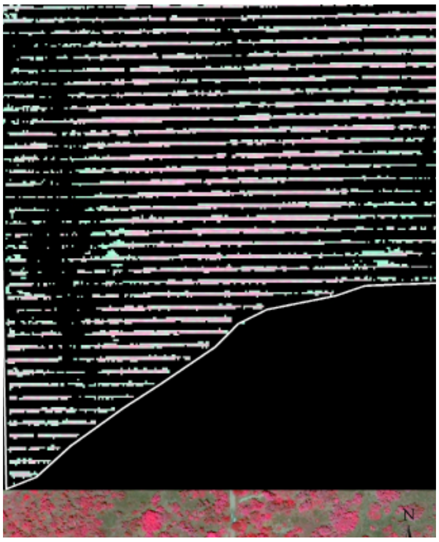


Derived yield map (kg/tree)

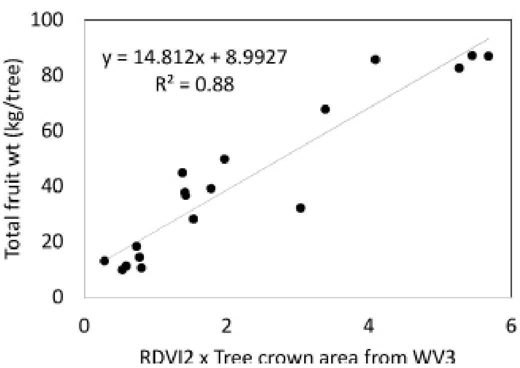


Sample locations of 18 tree overlaid on to a false colour satellite image

Extraction of tree crown area



Extraction of canopy spectral data



Relationship between mango yield per tree versus measured TCA x RDVI2 (a measure of canopy reflectance)

Current methods for estimating fruit maturity, based on heat sums and rate of dry matter (DM) accumulation, can vary by up to 2 weeks, therefore any tool that can assist in the better prediction of fruit maturity will offer significant benefit. Acacia Hills Farm has been heavily involved with the development of the *Felix NIR sensor* with Central Queensland University for the non- invasive measurement of mango dry matter for a number of years, and strongly supports the technology. The recent outcomes from this 'Rural Research and Development for Profit' project 'Multi-scale monitoring tools for managing Australian tree crops - industry meets innovation' have provided a significant step forward in the on farm adoption of this technology through the development of the 'Fruitmaps App' https://fruitmaps.com/

This App has enabled individual fruit DM measures to be collated both temporally (rate of fruit maturation) and spatially (across orchards), and has been combined with a realtimecalculatorofheatsumaccumulationandprediction of optimum sampling date. This information is allowing Acacia Hills Farms to better predict optimal harvesting timing with greater accuracy and at a finer resolution, i.e. harvest segregation based on within orchard variability.

Another welcomed result from this project was the potential for improved pre-harvest yield forecasting. Research undertaken by the University of New England (UNE) identified extremely positive results for predicting orchard yield and mapping yield variability from satellite imagery. As similar to the harvest timing, accurate pre- harvest forecasts of crop yield are essential for establishing labour, transport and marketing requirements. Currently, crop forecasting at the farm level is based on the infield fruit count of selected trees per orchard block. However, this method can be highly inaccurate if the trees selected are not representative of the variation of fruit yield across the orchard.

Martina Matzner (Acacia Hill Farms) and Nicholas Anderson (CQU) measuring the DM of individual mangos with the Felix NIR sensor.

More than 200 growers attending the 11th Australian Mango Industry Conference in Bowen have been told it was no coincidence the retail value of the mango crop increased by 40 per cent in the past three years — more than double the overall fruit category.Australian Mango Industry Association marketing manager Treena Welch said "exceeding consumer expectations hinged on the ability of growers to adopt innovation to improve the eating experience".

Ms Welch said the real game changer had been the rollout of Near Infra-Red (NIR) technology, which enables growers to pinpoint the precise optimum harvest window for their crop, regardless of location or variety. Based on consumer research, the minimum benchmarks for dry matter content of fruit is set at 15 per cent for Kensington Pride (Bowen), Honey Gold and Calypso varieties, while R2E2 required 13 per cent.

"NIR, that's the one that has changed the industry forever more," Ms Welch said.

"They literally shoot the fruit on the tree and instantaneously they get a reading, a near infrared reading, of what the dry matter of that fruit is.

"And then they make the decision to pick or to leave the fruit on the tree a bit longer until it reaches that minimum dry matter level."

Excerpt from an ABC article http://www.abc.net.au/news/rural/2017-05-03/mango-innovation-leads-to-success-growers/8492972

See also http://www.freshplaza.com/article/174953/Aus-growers-attribute-mango-crops-40-procent-rise-in-value-to-innovation)

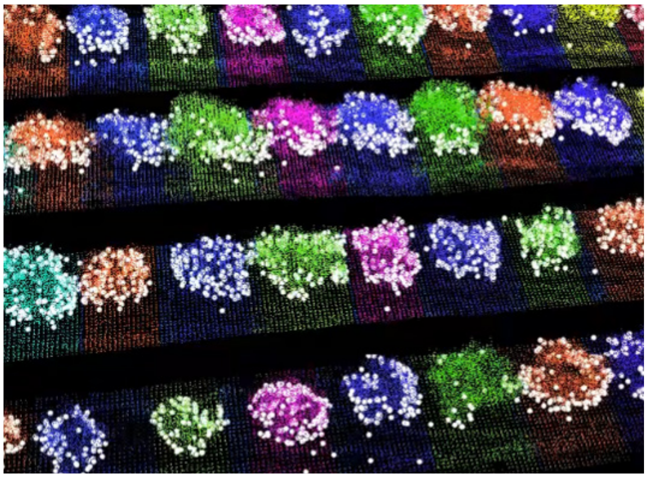
Individual fruit identified by machine vision.

The 'Rural Research and Development for Profit' scheme provide a unique opportunity for various research organisation, specialising in very different technologies to work together for the purpose of delivering a required output for industry. Yield forecasting and mapping for Mango provides a perfect example of this.

Example of fruit yield map derived from each sensing platform. The 'hotter' the colour the higher the fruit yield per tree

Coinciding with the evaluation of satellite imagery for the improved yield forecasting of mango (UNE), a number of additional approaches were investigated over Simpson Farms Pty Ltd., mango producers within the Bundaberg growing region. The University of Sydney 'Australian Centre for Field Robotics' evaluated a 'Robotic UGV with day/ night imaging and LiDAR', whilst Central Queensland University investigated a 'Low cost night imaging system mounted on a utility vehicle'.

All three methods produced prediction accuracies within 90% of actual yield harvested from the orchard. Considering the importance of accurate pre-harvest yield forecasting and the currently absence of a commercial yield monitor for Mango, the results achieved from this project offer significant benefit to the mango industry, both domestically and internationally.



LiDAR map of each individual tree and fruit

Case Study 2.
Avocado Tree Health
/2019

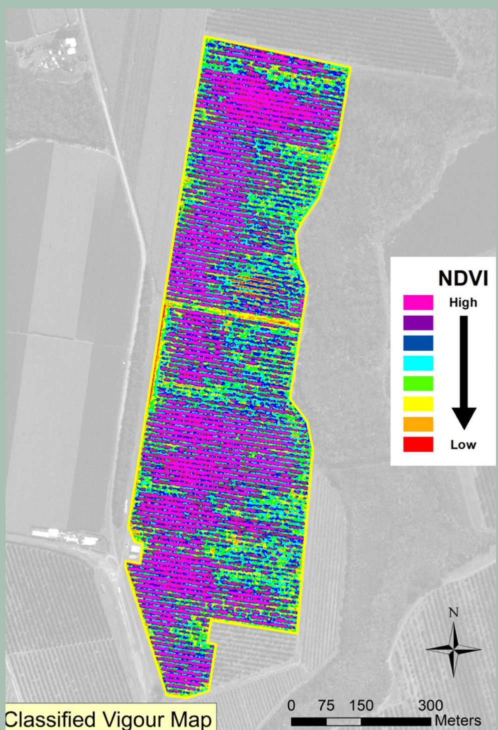
Case Study 2:

Improved mapping and forecasting of Avocado tree health and yield. A Bundaberg perspective provided by Chad Simpson (E.E. Muir, formerly agronomist at Simpson Farms, QLD).

66,000 tonnes of Avocado were grown in Australia during the 2016/ 17 growing season, worth an estimated value of ~ $400 million. 10% of that volume was produced in South East Queensland. Simpson Farms, located within South east Queensland, is one of the largest producers of Avocado in Australia.

Simpson Farms Pty. Ltd. have been involved in the evaluation of satellite imagery for monitoring avocado tree health for a number of years. Through the 'Rural Research and Development for Profit' project 'Multi-scale monitoring tools for managing Australian tree crops - industry meets innovation' a number of additional applications from satellite imagery were investigated. These included improved yield forecasting at the orchard level; ability to map the spatial variability of fruit size and yield across orchards; and the ability to better detect variations in tree health including those suffering from Phytophthora. These applications have direct benefits to our nutritional and pruning management of trees as well decision making around harvesting logistics and forward selling.

Standard commercial practice: collect and bulk soil and plant samples from each irrigation block, in this example, the orchard has 8 blocks. (False colour satellite image of avocado orchard)



Improved targeted practice: collect and bulk soil and plant samples from the 3 zones of crop vigour, high, medium and low. (Classified tree vigour map of avocado orchard)

Improved monitoring of tree health:

The high resolution satellite imagery was extremely accurate in mapping the spatial distributing of tree vigour (size and health) across each orchard block and the entire farm. This information has allowed us to identify irrigation inefficiencies, the presence of Phytophthora and to better coordinate our soil and leaf sampling to match high, medium and low growth regions.

Improved samping for orchard nutritional status:

For the orchard provided in the example above, bulked soil and plant samples would have historically been collected from each of the 8 irrigation blocks within an orchard. This would have taken around 4 hrs to complete at a labour cost of ~ $140. By using the classified tree vigour map, soil and plant samples that better represent high, medium and low growth trees could be collected, reducing the number of samples to 3 at labour cost saving of $90. The chemical analysis of plant and soil samples costs ~ $200 per sample, so a reduction from 8 to 3 samples has an additional saving of $1,000. Considering Simpson Farms has over 170 orchard blocks the savings from this stratified sampling approach based on imagery as opposed to commercial practice can be significant.

Yield forecasting and mapping from satellite imagery:

Understanding total orchard yield and yield variability prior to harvest, offers significant benefit to Australian avocado growers. Yield forecasting at the orchard level is currently undertaken by an 'eye ball' fruit count of a limited number of trees. However, accuracies can vary especially if the trees selected do not represent the majority of the orchard. The culmination of satellite imagery and the targeted fruit counting of selected trees i.e. 18 trees per orchard has presented as an accurate method for yield forecasting at the block level. With this information more informed decisions regarding harvesting logistics, storage and packing, fungicide requirements etc. as well as forward selling can be made. Understanding yield variability across an orchard also offers significant benefit, and in the absence of a commercial yield monitor, the satellite imagery is producing exciting results.

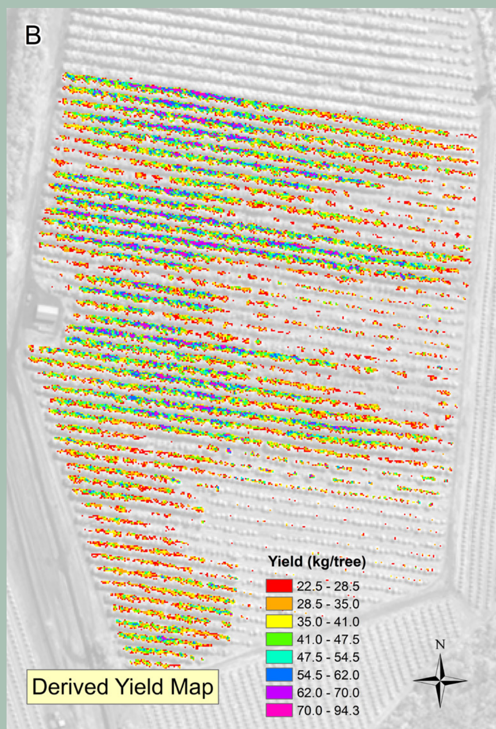
Mapping of fruit size:

The potential of remote sensing for mapping the spatial distribution of avocado fruit size was also a useful outcome from the project. During the harvest season the market dictates what fruit size is required e.g. 25 or 28 fruit per tray or 220 g and 200 g fruit respectively. In response, orchard blocks are strip harvested with the required fruit size segregated from the total harvest, boxed and distributed to the seller. There is the risk that a particular block may have a low quantity of the required fruit size and as such more blocks need to be harvested to fill the order. By having a better understanding of fruit size across an orchard creates the opportunity to selectively harvest those blocks where the majority of fruit meet the order requirement. This saves time, labour and the risk of not filling orders.

Pruning schedule:

Currently, contractors assess all trees within an orchard to determine those that are unhealthy and therefore candidates for pruning. The ability to map the spatial variability of tree health provides growers and contractors with the opportunity to adopt a more strategic pruning schedule and therefore save both time and labour.

Standard commercial practice: collect and bulk soil and plant samples from each irrigation block, in this example, the orchard has 8 blocks. (False colour satellite image of avocado orchard)



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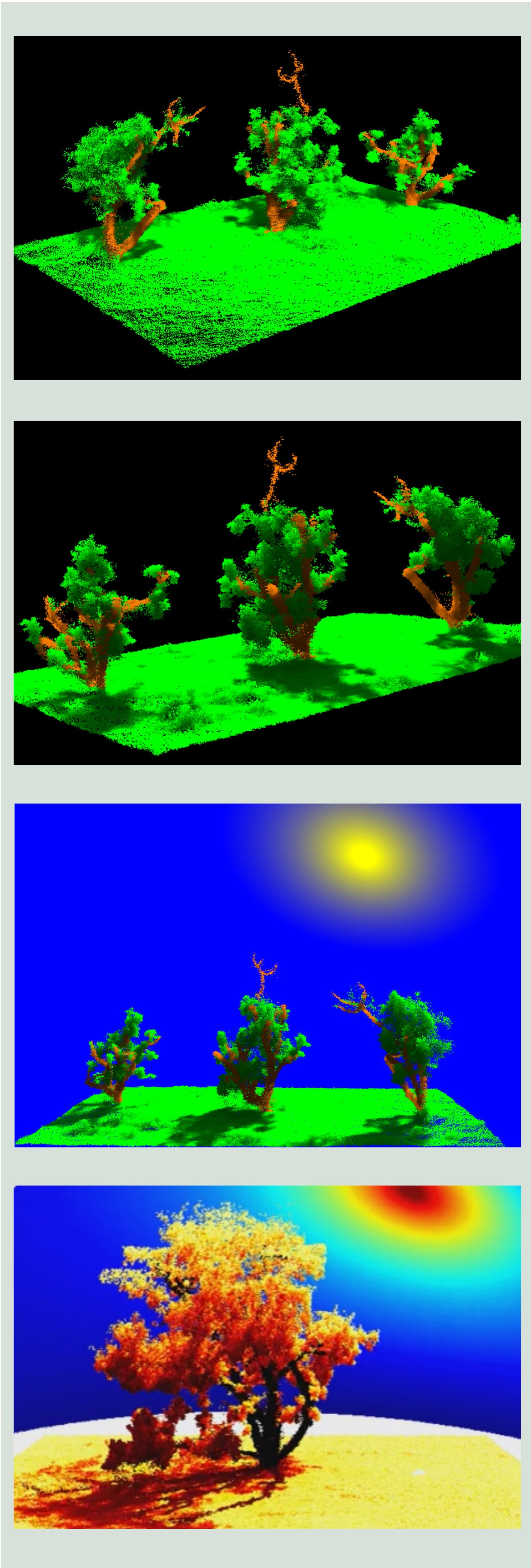

Additional research by the University of Sydney and University of Queensland identified the potential of ground based LiDAR sensing for mapping avocado tree structure. By modelling canopy density and light interception there is the potential for this technology to be used for targeted limb removal, therefore ensuring optimal growth conditions for future production.