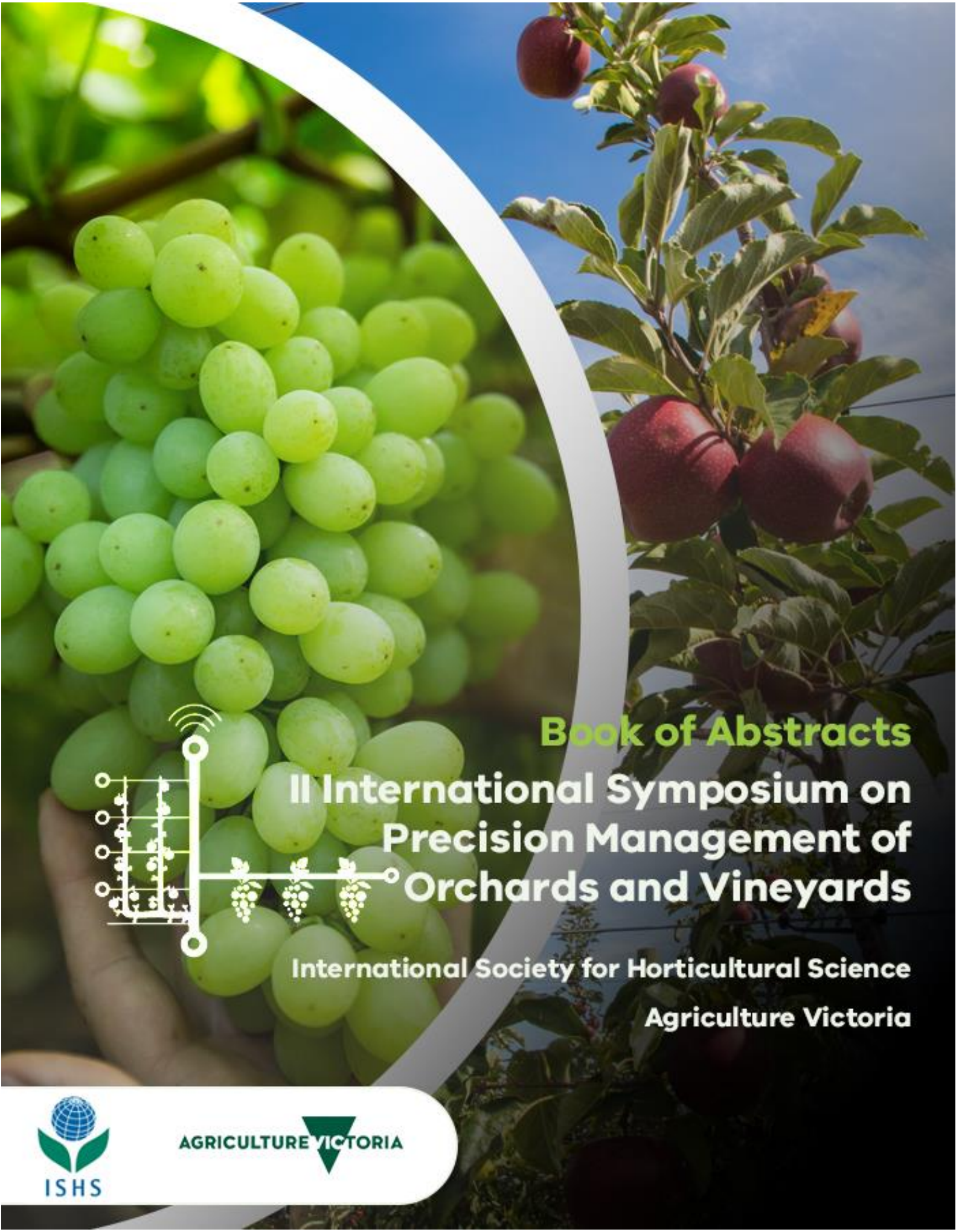

Book of Abstracts

II International Symposium on Precision Management of Orchards and Vineyards

International Society for Horticultural Science

Agriculture Victoria

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Division Temperate Tree Nuts

Division Tropical and Subtropical Fruit and Nuts

Division Temperate Tree Fruits

Division Precision Horticulture and Engineering

Division Vine and Berry Fruits

Division Physiology and Plant-Environment Interactions of Horticultural Crops in Field Systems

Workgroup Precision Management of Orchards and Vineyards

Foreword

The 2nd International Symposium on Precision Management of Orchards and Vineyards brings together scientists, industry experts and leading growers working on disciplines related to Precision Management of Orchards and Vineyards to present and discuss the latest Agritech in:

- Irrigation and water relations
- Yield, traceability, harvest monitoring and supply chain logistics
- Mapping and decision support systems
- Canopy management, soil management, fertility and nutrition
- Disease and pest detection and/or control
- Fruit physiology, growth, ripening, quality and postharvest
- Mechanisation, automation and robotic management of harvesting, pruning, thinning and spraying
- SmartFarms, IoT, digital orchards and vineyards

The Symposium will share interdisciplinary knowledge about the implementation and application of contact, proximal and remote sensing systems, mechanization and robotics and control systems for precise real-time management of orchards and vineyards with reference to the most relevant field operations, such as irrigation, nutrition, pest and disease control, flowering, pruning, fruit quality, harvesting, product traceability and soil health.

The Symposium will explore synergies between 'technology for crops' and 'crops for technology', known as the 4th Agricultural Revolution (Agriculture 4.0). Precision management offers improved resource efficiency, optimal yields, reduced environmental impact, and enhanced profitability for horticulture.

As Convenor I'm delighted and honoured to warmly invite you to participate in this Symposium. We are well supported by my research agency, namely, Agriculture Victoria, together with the International Society of Horticultural Science (ISHS), Australian Society for Horticultural Science (AuSHS), and a team of dedicated colleagues on the local Organizing Committee.

We hope that you will come to Tatura to engage in discussion on the latest findings and technologies around precision crop management, enjoy stimulating field days, and make or reconnect with friends and colleagues from around the world. The Symposium will provide an opportunity, after difficult pandemic years, for renewed personal engagement between researchers, academics, industry technical experts, leading growers, and refreshing and inspiring travel to a sunny climate.

We look forward to welcoming you in Tatura, Victoria, Australia.

Dr Mark O'Connell

PMOV2023 Convenor

Agriculture Victoria, Tatura, Australia

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Keynote presentations

Crop water stress sensing for improved management in orchards and vineyards

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Accurate assessment of crop water stress and overall water status is a prerequisite in precision agriculture, especially in arid and semiarid areas that often face water scarcity. In this scenario, water management is essential for the sustainability of irrigated systems. Remote sensing has become the main avenue to develop tools for assessing crop water status and managing agricultural inputs over large areas. Thermal-derived indices are particularly suitable for determining crop water status because of the close relationship between canopy temperature and transpiration. The case of orchards and vines is particularly challenging, given that discontinuous canopies require high spatial resolution to isolate vegetation from background soil. Despite this, developing tools to manage water in these crops is especially relevant as permanent crops, in most cases, require watering to ensure survival. Several sensors and methodologies currently available are useful for assessing water status. These sensors will be reviewed, highlighting their pros and cons. The algorithms and methods developed for orchards and vineyards must consider the architectural features as they affect the interactions of the canopy with the atmosphere. Tall and rough canopies with complex architectures, such as these crops, are well-coupled with the atmosphere. Thus, the transpiration proceeds essentially at the imposed rate and responds significantly to changes in stomatal conductance and VPD. The consequences of this effect on crop water stress sensing and water management will be considered. The relevance of ETo as a suitable measure of the evaporative demand in these crops will be discussed, together with the significance of the measurement error in the computation of water stress indices.

Keywords: water scarcity, irrigation, canopy temperature, CWSI, stress indices, canopy architecture.

Digital twins for mitigation of orchard spray drift

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The annual sale of agricultural pesticides in Australia had doubled from 2010-11 to 2021-22. While an analysis found 73% of the total value of Australian crop production in 2015-16 related to herbicides, fungicides and insecticides, it is well known that a large proportion of the application miss the right targets and become “spray drift”. For horticulture, according to previous studies, about 50% to 70% of the applied chemicals can either land directly on the ground or drift into the air. The off-target spray brings no gain to growers but instead unnecessary waste, unnecessary pollution, and unnecessary risks in potentially damaging neighbouring farms. Many growers hope to maximise the use of their existing sprayers with minimal cost before considering retrofitting or replacing them in future. To facilitate this objective, a digital-twin-based solution has been developed to simulate orchard characteristics and spray processes that closely mirror reality. It enables high simulation fidelity and aims to serve as a decision-support tool for practical operations. This approach is powered by high performance computing to ensure both accuracy and complexity, without compromising one for the other. It had been field-tested in a tropical research orchard with a strong correlation to real-world measurement. A subsequent digital-twin-based investigation has demonstrated that the spray drift in the same orchard environment can be reduced by 36% through simple modifications of sprayer settings. Such outputs can not only be used to optimise the adjustment of traditional equipment, but can also be loaded to robotic/automatic sprayers to make them more precise, more responsive but simpler and cheaper. In addition to reviewing the pain points in reduction of spray drift, introducing the digital-twin solution and reporting insights that have been gained from it, the research investigates potential development pathways for similar digital twins in a broader range of orchard and vineyard systems.

Keywords: digital agriculture, orchard management, pesticide, sprayer, AgTech.

Variable nitrogen management in vineyards

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Precision viticulture (PV) allows addressing problems related to spatial and temporal variability at the within-field scale. Numerous studies have ground-truthed vigour maps and identified soil as the main driver of variability. Within-field heterogeneity reduces the efficiency of traditional management encouraging a site-specific approach. Indeed, variable rate (VR) fertilization is a promising tool aiming at optimizing vine balance even if few experiences validating this hypothesis are available. Moreover, few examples of fully automated protocols are now implemented in viticulture. Focusing on site-specific N management, the paper aims at: a) describing recent advances in VR fertilization; b) assessing its physiological background and economic affordability, and c) describing novel VR solutions for reducing environmental impacts of viticulture. Since 2012, long-term effects of VR N-supply have been assessed in Italian vineyards. VR application of the prompt-effect urea fertilizer reduced spatial variability over four years as confirmed by proximally sensed Canopy Index values at year 4 whose variability assessed as coefficient of variation dropped from 8.2% in fixed rate to 1.42% in VR. A Controlled Release Fertilizer (CRF) allowed faster responses in low-vigour zones fostering desired increasing in total leaf area and yield. Contrariwise, in high and medium vigour areas vines were rather unresponsive to the applied N demonstrating that fertilization was not required. VR application of hi-tech CRF allowed improved efficiency of vineyard fertilization, reduced N waste in high-vigour zones and lowered environmental impact with a potential fertilizer saving up to 33% of the rate supplied as standard practice. Moreover, side-benefits related to a more homogeneous vineyard need to be carefully valued as well as the combination of ground fertilization with fertigation is expected to be highly efficient. Most recently, the introduction of winter cover crops characterized by different C/N ratio emerges as a valuable solution for managing N needs in organic vineyards.

Keywords: precision viticulture, vigour, vine balance, mineral nutrition, winter cover crops.

Precision viticulture for better vineyards

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Precision viticulture (PV) holds the potential to significantly enhance vineyard yield and grape quality. It enables grape growers to tailor their practices to the specific needs of each zone in the vineyard, optimizing resource allocation and minimizing waste. This potential has already been demonstrated at both the experimental and farm level. Nevertheless, its implementation is slower than what could have been expected and, at least in Europe, the sensation of PV as a hype is probably greater than for other crops. In addition to the classically identified barriers that may hinder farmers from PV adoption (resistance to change, high initial costs and technical complexity, farm size and scale), there might be the perception that PV is not going to result in better vineyards. The most technically advanced growers have tried to introduce PV in their farms, but even the most science and technology enthusiasts do not fully implement PV-based management, and only adopt the simplest tools. As in any other area, when end-users feel that a tool will make their life better, growers would certainly use PV as central to their management if they knew their vineyards were going to be better. Increased implementation of PV in wineries will require to analyse not only the most evident facts but globally considering what a better vineyard means. Aspects related to global cost, yield and grape composition are crucial, but those associated with everyday management, sustainability, and also those related to company perception by consumers in a sector as specific in consumption and buying decision patterns.

Keywords: viticulture, implementation challenges, sustainable grape growing.

Bringing the packhouse to the orchard – a mango dreaming

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Advances made in the past three decades in in-line grading will be reviewed in context of sensors and the use of machine learning. Commercial sorting capability has expanded from weight to external colour and shape sorting, and then to external defect recognition, while internal defect detection has been enabled through use of UV and particularly NIR wavelengths. Disparities between commercial application and the scientific literature base will be highlighted. The potential for packhouse use of other non-invasive sensor technologies will be explored, primarily in context of at-line biosecurity applications. The translation of technologies from packhouse to orchard will also be described, in terms of instrumentation for assessment of optimum harvest timing through assessment of fruit maturity, e.g., using handheld spectroscopy, and harvest load, i.e., fruit size and number. These technologies also provide a foundation for development of other capabilities in the orchard, including automated harvesting. These topics will be illustrated with application examples from the Australian mango industry.

Keywords: fruit quality, harvest forecast, non-invasive, review, sensors.

Automation and robots for tree fruit orchards

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AI and Robotics have been and will continue to play a key role in reducing farming inputs such as labor, water and fertilizer and increasing productivity. Modular sensing, automation and robotics technologies developed in recent years (including mobile device-based Applications), decreasing cost and increasing capabilities of sensing, control and automation technologies such as UAVs, robust AI tools such as deep learning, and increasing emphasis by governments around the world in advancing AI-empowered smart and automated technologies have created a conducive environment to develop and adopt smart, robotic farming systems for the benefit of agricultural industries around the world with a wide range of farming scale and environment. In this presentation, the author will first discuss the importance of AI-empowered precision and automated/robotic systems for the future of farming (Smart Farming, Ag 4.0). He will then summarize past efforts and current status of agricultural automation and robotics in fruit orchards including examples from apple harvesting and fruit tree pruning, followed by an introduction of the novel systems being developed in his program. In the end, major challenges and opportunities in agricultural robotics and related areas including potential future directions in research and development will be discussed.

Keywords: robotics, harvesting, pruning, thinning, pollination.

Oral presentations

Relationships between canopy radiation interception and LiDAR-derived geometry features in pome and stone fruit

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Solar radiation is a fundamental resource for the productivity of horticultural crops. The most adopted tree training systems worldwide aim to achieve the best trade-off between maximum canopy radiation interception and light distribution in the canopy and compatibility with the cultivar fruiting and vegetative habit over the productive cycle. Accurate measurements of canopy radiation interception can be used to characterise tree growth, adjust spray volumes, optimise cropping levels, inform pruning management and tailor irrigation to crop water requirement. Traditionally, canopy radiation interception has been estimated using linear ceptometers either handheld or mounted on trolleys. Recent advances on Light Detection And Ranging (LiDAR) technology have enabled fruit growers and scientists to estimate canopy geometry features. This work aimed to predict canopy radiation interception using LiDAR-derived geometry features in apple, pear and stone fruit trained to different canopy architectures. Relationships between canopy radiation interception and tree geometry from orchards at the Tatura SmartFarm, Victoria, Australia were developed. The reliability of predicted data and implications of LiDAR applications to improve precision orchard management are discussed.

Keywords: canopy density, leaf area, light interception, training systems, tree architecture.

Evapotranspiration and water stress assessment in sweet cherry orchards using in-situ and remote sensing techniques

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Fruit trees water consumption associated with growth stages is crucial and understanding of water stress effects on tree functionality and the time of the year when stress levels are high can be estimated using remote sensing techniques. Evaluation of NDVI and other parameters lead to the understanding of the sweet cherry tree stress management under rainfed conditions. The study aimed to determine the water requirements and analyse the water stress levels during different growth stages of sweet cherry trees under rainfed conditions over the eastern free state in South Africa, using remote sensing. In-situ in the area where the orchard is located. There is an imminent need for reliable methods that provide information about the temporal and spatial variability of crop water requirements, allowing farmers to make irrigation decisions at the field scale. This study estimates the evapotranspiration and water stress of sweet cherry orchards in the eastern Free State region of South Africa during the 2016/17, 2017/18, 2028/19 and 2029/20 growing seasons by combining a simple surface energy balance model with remote sensing data. A dataset of the vegetation index NDVI derived from Landsat-8, and Modis was used to facilitate the estimation of the basal crop coefficient (Kcb), water stress coefficient (Ks), Evapotranspiration and normalised differential vegetation index (NDVI) was derived from remotely sensed canopy thermal-based methods. Verification and validation of the surface energy balance algorithm (SEBAL) Model daily evapotranspiration estimates were done using eddy-covariance data collected in the same orchards, yielding an $R^2 \geq 0.8$ and average root mean square errors (RMSE) of 0.96 mm·day−1. It is concluded that the combination of crop evapotranspiration models with remotely sensed data helps determine the stress levels of sweet cherry trees at different growth stages and will be used as an extrapolation tool for agricultural water management and planning in other parts of South Africa, where they are producing sweet cherries and in need of improving irrigation information from plant to field scale.

Keywords: irrigation, water stress, remote sensing, evapotranspiration, SEBAL.

Traceability and fruit quality sensing on a platform harvester

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Temperate fruit tree industries in Australia are striving to improve production efficiency and packout yield to maximise profitability. A critical component is to reduce the variability in fruit quality across an orchard block. In addition, regulatory, biosecurity and consumer-driven product traceability are changing the complexity and data requirements for fruit growers. Advanced sensing systems and machine learning approaches offer non-destructive, real-time fruit quality appraisal. Combining sensors, machine learning, orchard traceability and mechanisation into a system that captures fruit quality data when and where it is picked was undertaken at the Tatura SmartFarm. The fruit quality assessment system comprised a fluorescence spectrometer, a reflectance spectrometer, an optical camera and a GPS system fitted in an enclosure attached to a conveyor arm on a platform harvester. The system also featured a Wi-Fi modem enabling cloud connectivity. Initially, optical imagery estimates of apple, pear and plum fruit diameter, shape and skin colour were compared to handheld calliper and colourimeter measures. Fruit quality prediction models from the spectrometers on the platform harvester were compared to previously established models using a handheld fluorescence-reflectance spectrometer. Field testing, including the validation of the fruit quality models to estimate starch index, ethylene emission, flesh firmness and soluble solids concentration is planned for season 2023–24. Non-destructive fruit quality sensing on the platform harvester, implications for traceability and improved precision orchard management are discussed.

Keywords: deep learning, fruit maturity, optical imagery, spectrometry.

Comparison of robotic precision thinning system and commercial air-blast sprayer for flower thinning on apple trees

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Thinning is one of the most important management strategies in apple orchards. Not only the fruit quality (size, color, sugar) of current season is influenced, but also the return bloom of the next season is influenced. Many apple varieties are sensitive to alternate bearding, if the thinning is inadequate or done to late in the season. To prevent or overcome alternate bearing in apple orchards chemical or mechanical flower thinning are the most effective management practices. Ammonium thiosulfate (ATS) is, beside Lime sulfur the most used chemical flower thinner in South Tyrol. The objective of this work was to 1) evaluate the thinning potential of ammonium thiosulfate (ATS) in 'CIVM49' apples (Malus domestica) trees and 2) to compare two different spraying systems. In our study, we compared the standard treatment method of ATS sprays using a commercial air blast sprayer with the robotic system ADAM, developed by Aigritec. The ADAM system utilized a robotic arm equipped with a single spray nozzle. Subsequently, computer vision technology was employed to detect flower clusters, enabling precise individual treatment of each open flower cluster on the apple trees. Our experimental findings revealed a significant improvement in thinning efficacy, with the ADAM system applying the ATS precisely to each flower cluster, resulting in more than double the effectiveness compared to the traditional commercial air blast sprayer.

Keywords: ATS, blossom-thinning, quality airblast-sprayer, alternate bearing.

Red-flesh kiwifruit inner quality scoring by a computer vision system

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Red-fleshed kiwifruits are a recent entry to the global market, and their nutraceutical properties have garnered significant consumer interest. This produces investment opportunities for industries, which must accurately assess the internal quality of these fruits, particularly when faced with long shipping distances and high-quality standards. Evaluating the redness of kiwifruit poses a complex challenge due to the inherent variability in colour localization, as well as the wide range of red shades and intensities within each fruit. The current method employed to assess the colour quality of red-fleshed kiwifruit relies on visual inspections performed by experienced operators. However, this method suffers from subjectivity, limited repeatability, and a slow evaluation process. In this study, a computer vision system that utilizes unsupervised learning classifiers (K-means) was developed to score fruits according to red quantity and intensity. RGB images of sliced fruits were segmented into the Hue-Saturation-Value colour space to generate a mask, which was used to extract descriptors for the "red quantity" classifier. Simultaneously, the same mask was applied to remove non-red pixels from the input RGB image. The "red intensity" quality parameter was determined by a K-means classifier that assessed the descriptors derived from the conversion of the red-pixels' RGB images into the CIELAB colour space. Consequently, the fruits were classified into 25 categories based on the combination of red quantity and intensity quality parameters. The results demonstrated that this approach enables faster, more objective, and repeatable evaluations of red-fleshed kiwifruit quality. By providing a more efficient and reliable method for evaluating quality, this approach has the potential to benefit industry stakeholders in the red-fleshed kiwifruit market. Furthermore, the study confirmed that the internal colour variability of the fruits poses the primary challenge in assessing the quality of red-fleshed kiwifruit.

Keywords: image segmentation, fruit quality, post-harvest, unsupervised learning, automation.

Assessment of the temperature threshold for the occurrence of sunburn damage in Vitis vinifera L. 'Sangiovese'

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In the last decades sunburn damage occurrence in vineyards has been intensified due to climate change, causing serious consequences on yield and berry composition. Considering the importance of this emerging issue, the present study aimed to assess the temperature threshold causing the sunburn damages under different levels of cluster exposure and vines water status. The experiment was conducted in 2021 and 2022 on 'Sangiovese' vines, cultivated near Bologna and trained to VSP spur-pruned cordon. Treatments were arranged in a strip-plot design and the main factors were: cluster exposure (leaf removal of the basal leaves at veraison vs no leaf removal) and irrigation (irrigation from berry softening to the end of August vs no irrigation). Berry temperature was continuously recorded by thermocouples connected to a WSN and the evolution of the sunburn damages (i.e., necrosis and berry shrivel) was visually estimated every week. Yield parameters and berry composition were assessed at harvest and anthocyanin analysis was conducted by HPLC on frozen berries. In both years, the temperature of the exposed berries raised over 40°C for a total of 40 hours and the combined effect of light incidence and high temperatures caused the appearance of intense sunburn damages. On the other hand, no symptom was found on the berries shaded by the foliage. Moreover, irrigation mitigated berry temperature reducing the severity of the sunburn damage. The sunburn damage caused by leaf removal lowered cluster weight and thus yield but irrigation limited both the incidence of the symptoms and the yield loss. Finally, the concentrations of soluble solids and anthocyanins were lowered by irrigation. The results of this study will be used to realize a warning tech solution which will alert the growers on the risk of sunburn damage and will suggest the management techniques able to reduce the impact on the berries.

Keywords: berry shrivel, climate change, cluster exposure, necrosis, water management.

Harvest bin placement based on machine vision data in mango orchards

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New technologies providing information on spatial distribution of fruit load in tree crops offers potential for new orchard management functions. One harvest management task is the distribution of empty fruit bins through the orchard prior to harvest. A case study is provided for a mango orchard involving use of fruit load data derived from RGB-D cameras mounted to a ground vehicle-based platform for measurement of fruit size and fruit number some weeks before harvest, with a fruit growth model applied to forecast fruit weight distribution at harvest. A cumulative fruit weight along each row is calculated from fruit count and weight distribution estimates, with bin placement tied to a user defined bin capacity (nominally 400 kg). The system has inputs of cultivar parameters, fruit load distribution from machine vision mapping, average fruit size and bin size, and output of an in-field bin placement online map.

Keywords: machine vision, fruit count, fruit size, field bin, spatial location.

Machine vision with deep learning for non-contact in-orchard mango fruit sizing and size distribution

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Tree fruit harvest load is a function of fruit number and fruit size. Forecast of fruit load facilitates management of harvesting, packhouse function and marketing. The traditional method of fruit size assessment involves manual assessment, a labour-intensive process. On-tree fruit size estimation using machine vision requires detection and/or segmentation of fruit regions from images. Colour-based segmentation methods have been used where fruit colour is distinct to background colour, and real-world object size has been estimated from image pixel size using a background scale or using images taken at a known camera to object distance. The advent of depth cameras and convolution neural network (CNN) based object detection and segmentation methods provide new approaches. Eight low-cost depth cameras were characterised for this application, with recommendation of a time-of-flight based technology. Sizing was achieved to an RMSE of 4.7 mm for fruit length with use of sizing features with or without ellipse shape fitting using a neural network-based fruit segmentation method.

Keywords: fruit sizing, fruit segmentation, mango, shape fitting.

A novel methodology for reconstructing 'royal gala' planar cordon apple trees to assist precision canopy management

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Narrow row orchards utilizing two-dimensional planar cordon tree designs are beginning to be adopted commercially in New Zealand because of improved productivity, fruit quality, labor use efficiency, and amenability to automation and robotics. At Plant and Food Research we are currently developing new model-based tools and metrics to guide precision canopy management of planar cordon trees. We present a novel methodology for digitalizing planar cordon apple trees using ground-based laser measurements, stochastic branching modelling, and shoot growth simulations. A laser range station was used to reconstruct two planar cordon apples trees and to register bud and fruit positions within the tree. Nonparametric Kernel distributions of shoots were obtained from these datasets to infer the initial structure of the trees at the winter dormancy stage using upright height, diameter, and the number of buds per meter as initial constraints. Shoot growth simulations were performed to locate leaves within the canopy and to provide light interception information. Preliminary results showed that the proposed methodology and tools allowed a precise reconstruction of planar cordon architectures, which opens opportunities for studying the influence of canopy management on tree productivity. Future works include a comparison between pruning and thinning strategies that will be used to develop decision-making tools for assisting precision canopy management.

Keywords: planar cordon apple trees, stochastic branching, shoot growth, digital trees.

Water stress detection in a large olive orchard using high-resolution multispectral airborne imagery: assessment against CWSI

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Thermal imagery and derived temperature-based indicators have been proven successful remote sensing methods to monitor water stress in crops. The Crop Water Stress Index (CWSI) has been widely used to monitor water status, as it is directly related to the reduction of transpiration due to stomatal closure under water stress conditions. However, thermal imaging sensors provide lower spatial resolutions than multispectral cameras currently available on board drones and piloted aircraft. In addition, accurate canopy temperature retrievals require sensors' stability and calibration methods to avoid errors in calculating CWSI. Biophysical parameters such as pigments concentration and canopy structural properties, including leaf area index and leaf inclination distribution function, can be estimated via radiative transfer model inversion methods from hyperspectral data. In previous studies, CWSI and these plant traits have been used to differentiate between sources of pathogen infections and, more interestingly, to disentangle between biotic-abiotic spectral fingerprints, enabling the discrimination between biotic-induced symptoms and water stress. In this study, we used thermal and multispectral imagery acquired from a piloted aircraft over an olive orchard covering more than 5000 ha to derive CWSI at the tree crown level for the entire orchard to assess water stress at a large scale. The airborne multispectral imagery collected with ten spectral bands between 444 and 842 nm where coupled with machine learning algorithms to assess the potential of explaining the water stress variability observed by CWSI. The spectral bands for water stress detection using commercial sensors and the ability to extract biophysical plant traits from the multispectral bandset to detect water stress will be assessed. The results of this study will provide new insights into the use of multispectral imagery for the large-scale operational monitoring of water stress in crops. The findings could be used to develop new tools for precision irrigation.

Keywords: airborne thermal and multispectral, abiotic stress, large-scale monitoring.

Assessing large-scale almond field experiments using a mobile orchard phenotyping platform

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The South Australian Research and Development Institute maintains a suite of almond experiments at the Almond Board of Australia's experimental orchard. These plantings exceed 17ha (9000 trees) with treatments exploring almond response to density, training, scion cultivar, rootstock genotype and soil amendments. Repeated measures of canopy development metrics and light interception were needed, but the scale of the field experiments made traditional methods impractical. A ground based Mobile Orchard Phenotyping Platform (MOPP) was developed to facilitate the rapid measurement of canopy metrics. The MOPP integrated multiple sensors upon an All-Terrain Vehicle including a computer with bespoke data capture and processing software, a global positioning system with inertial measurement unit, light detection and ranging, normalised difference vegetation index sensors and a towed array of light sensors (ceptometer) adjustable to row widths from 4.5 to 6.5 m. Data was collated using geofencing and reported on a per-tree basis. Since its development in 2020, the MOPP has been deployed on a four-to-six-week cycle across multiple experiments measuring canopy metrics such as tree height and width, trunk diameter, light interception and canopy NDVI. MOPP data collection, at around 1.5 ha/hr, is faster than traditional methods allowing efficient repeated orchard assessment. It has demonstrated strong correlations between LiDAR and manual measurements of trunk diameter ($R^2 = 0.71$) and canopy height ($R^2 = 0.82$). The ceptometer has quantified differences in canopy light interception in response to genotype, planting density and tree age. Repeated surveys show interactions between genotype and planting density over time. The precision of SARDI's orchard phenotyping platform continues to be refined as experimental trees, and their associated datasets, grow. These datasets are compared against ground and aerial remote sensing systems with a view to securing a rapid, repeatable and reliable method for characterising canopy development metrics.

Keywords: light, canopy, yield, almond, cultivar, density, mobile platform, LiDAR, ceptometer array.

Integrated pollination traceability system for data sharing and transparency

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Recent occurrences of bee deaths during pollination events around New South Wales and Victorian borders have sparked concerns regarding the impact of chemical usage in orchards on the health of beehives. The European Union's digital product passport has recently emphasised the necessity for complete supply chain transparency to ensure sustainable practices. Similar future demands for traceability in food production are expected to increase further. This research work presents a novel pollination traceability system that is crucial to meeting those demands. The proposed pollination traceability system integrates existing industrial apiary and orchard management systems to enhance transparency and data sharing among stakeholders regarding orchard chemical usage and beehive monitoring. Unlike many other existing systems, such an integration-based traceability system is expected to result in a pull-based system adoption from farmers. GS1 global standards are employed to develop common information models for data storage and exchange. At the same time, a role-based access permission framework is designed to ensure controlled access and sharing of sensitive data. The proposed system is designed for deployment using microservices-based cloud infrastructure to ensure scalability, cost-effectiveness, and industry readiness. This pollination traceability system could transform apiary and orchard operations by promoting accountability and transparency in the supply chain. Furthermore, it can aid national pest and disease traceability in the event of an outbreak.

Keywords: traceability, pollination, beehives, orchards, chemical application.

A stereo-imaging system to assess plant water status in kiwifruit and grapevine: recent advances

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Kiwifruit and grapevine can quickly respond to environmental stresses and modify their leaf features. This study aims to further validate the correlation of leaf inclination response to water stress in grapevine and kiwifruit, through the use of an innovative stereovision system (named Wcam) that collects 3D images of the canopy. The system was tested in commercial vineyards and kiwifruit orchards in Veneto region (North-East of Italy) during three growing seasons (2020-2022). Here we report the results obtained in the last year of this study. In-field trials compared two irrigation managements: normal irrigation (NI) managed to keep plants in well-watered conditions, and reduced irrigation (RI) managed to induce a progressive water stress. Plant water status was monitored during the growing season, measuring midday stem water potential with a pressure chamber. Manual measurements of leaf inclination were collected every 8-10 days to validate the measurements performed by the stereo-camera. Comparison between manual- and Wcam- leaf angle measurements confirmed the ability of the stereo-vision system to correctly measure this canopy parameter. Data collected in 2022 provided further evidence of the significant correlation between leaf inclination and plant water status in kiwifruit and grapevine. Leaf angle measures can complement information from climate and soil moisture sensors to provide a more accurate assessment of the plant water status in vineyards and orchards.

Keywords: precision irrigation, leaf inclination.

Non-destructive sensors and modelling to detect apple fruit and tree properties

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At the applied research centre for pome fruit production in Southwest Germany different tools were constructed and programmed to monitor fruit and tree properties non-destructively. The work presented was achieved together with collaborators from forestry, medical and mechanical engineering research centres and companies. The overall aim was to connect preharvest growing conditions with the post-harvest sorting result within a black box modelling approach. We present data from a commercially available visible / near infrared sensor for proximal absorption values at the fruit skin. Additionally, we developed a sensor device to obtain scattering properties from the fruit. The tree structure with height, gap and volume information was obtained from a light detection and ranging sensor (LiDAR) mounted on a tractor sprayer. Furthermore, an electric trolley was equipped with a multi-channel PAR sensor beneath the tree branches and in the driveway which consecutively sampled light interception of the orchard. The different sensor set-ups with data processing will be presented.

Keywords: black box modelling, LiDAR, VIS/NIR.

Application of management systems for mechanization fruit cultivation process in South Korea

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Agricultural mechanization is considered as one of the solutions that can be applied to areas agriculture field facing labor shortages. However, agricultural mechanization in the Korean fruit industry is at an early stage, and there is a lack of research on fruit crops. The purpose of this study was to develop a cultivation system for mechanized operations, targeting apples (Malus × domestica) and peaches (Prunus persica), which are major fruit crops in South Korea. Mechanical defoliation was performed in apples, and peach trees were trained to be suitable for mechanical operations. The effects of output pressure and treatment timing on the defoliation rate were investigated by applying pneumatic defoliation. The defoliation rate was indicated to be 16.8% at 0.6 bar and 23.4% at 0.9 bar. Moreover, the efficiency of defoliation was increased at harvest time. The defoliation rates observed at 30 days before harvest (DBH) and 15 DBH were 20.6% and 32.0% respectively. The hunter a* value of fruit peel exceeded 20 in all treatment groups, while the control group showed 19.22. This indicates an enhanced color development effect of mechanical defoliation. In peaches, the early growth characteristics and management efforts of multi-leader trees were analyzed. The height of the 3-year-old multi-leader trees was 2.1 m, and the trunk diameter was 4.75 cm. On the other hand, open-center trees showed 3.32 m tree height and 6.80 cm trunk diameter. Similar tree growth was also observed in the 4-year-old trees. Therefore, cultivation management is necessary to promote the growth of multi-leader trees. Optimization of cultivation systems for mechanization is also being performed in pears and grapes. This study can be utilized in the application of mechanized cultivation systems for other fruit crops. (This work was carried out with the support of "Cooperative Research Program for Agriculture Science and Technology Development (Project No. RS-2021-RD009831)" Rural Development Administration, Republic of Korea).

Keywords: agricultural mechanization, *Malus domestica*, *Prunus persica*, mechanical defoliation, multi-leader tree.

An innovative robotic platform for integrated precise orchard management

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As global world population has exceeded 8 billion individuals, the strive for food production is becoming more urgent. In this context, it is necessary to increase efficiency of farms, increasing mechanization and automation not only for arable crops, but also for fruit production in orchards. This research paper aims to describe the integration between an innovative robotic platform that has been developed by the engineering automation group of the university of Bologna, and farming knowledge from the tree ecophysiology group of the same university that have set-up a dedicated planar orchard in the experimental farm of the university. The platform features fully electric locomotion and implement drive and autonomous navigation capabilities, both in an open field scenario and inside orchard or vineyard rows. The so-called in-row navigation is achieved without the GNSS information, as the estimation has proved to not be very precise due to the presence of anti-hail nets high poles, and possibly thick canopy. Row-change maneuvers are also automatically performed by lifting attached implements (when using mulchers or inter-row cutters) and adjusting their operation according to the estimated canopy size (for sprayers) or while actually traversing the row (for mulchers and inter-row tools). The developed planar orchard is meant to maximize the robotic platform exploitation, by providing a structured environment for navigation purposes, by minimizing at the same time canopy uncertainties. Furthermore, the reduced inter-row distance (about 2 meters) allows for robotic vehicle traversability, while conventional tractors may not be able to operate. The fruit exposure provided by the planar canopy enables also refined estimations in terms of canopy volume, fruit counting for harvesting predictions, and other applications.

Keywords: precision orchard management, planar orchard, automation, robotic platform.

Decoupling factor and transpiration partitioning of litchi (*Litchi sinensis*) orchard

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Elastic coupling between tree canopy and atmosphere which is expressed via the decoupling factor (Ω), allow canopy and stomatal conductance to characterize canopy transpiration. The level of coupling between vegetation and atmosphere allows the species water use and the interchange of carbon dioxide between the canopy and the atmosphere to be studied. Mature litchi trees that are planted in low density orchards (~ 70 trees per ha) in the Inkomati – Usuthu Water Management Area (IUWMA) in South Africa consume large volumes of water which is reflected by their high transpiration rates (maximum transpiration ~ 332 litres per tree per day). But the relationship between transpiration and stomatal closure is not yet fully understood for these trees. The aim of this study is to investigate the mature litchi decoupling factor pattern for which no information currently exists in order to improve tree transpiration modelling. Little is also known about how the litchi tree transpiration is partitioned between equilibrium transpiration and imposed transpiration. Orchard microclimate was measured using an automatic weather station that was installed close to the orchard. The decoupling factor was calculated using canopy conductance that was deduced by inverting the Penman-Monteith equation and aerodynamic conductance that was determined by upscaling the wind speed that was measured at the weather station. Orchard evapotranspiration (ET) was measured during selected periods using an open path eddy covariance system. The calculated canopy conductance was validated against the canopy conductance that was determined on selected days using measurements from a portable photosynthesis system (LI-6800) and leaf area index. Canopy temperature was measured using infrared thermometers that were mounted above the canopy. Preliminary results show that the leaf area index peaks at ~ 3.77 and leaf gas exchange in litchi was generally much lower than those in temperate fruit trees.

Keywords: aerodynamic conductance, canopy conductance, decoupling coefficient, Penman-Monteith equation, transpiration partitioning.

Precision crop load management of apple using digital technology

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Precision crop load management is a suite of strategies and machines to manage the number of fruits per tree to exactly the economic optimum. We have developed a series of strategies that include precision pruning guided by computer vision, blossom thinning guided by a pollen tube growth model, post bloom chemical thinning guided by a carbohydrate balance model and a fruit growth rate model aided by computer vision and finally hand thinning guided by computer vision. At each step in the process of reducing fruit bud load, flower load or fruitlet load, we are developing computer vision and other digital technologies to streamline the counting of buds, flowers and fruitlets. Our preliminary results show that: 1) we can digitally count fruit buds and use the information to guide precision pruning to leave a pre-determined flower bud load; 2) we can apply sequential chemical thinning sprays guided by the use of computer models to adjust the dose and timing of chemical application and to assess the effect of the chemical sprays shortly after application to inform re-application; and 3) we can digitally count fruitlets to guide human workers to leave an exact number of fruits per tree when hand thinning.

Keywords: *Malus* x *domestica*, fruit size, crop value, chemical thinning, pruning, computer vision, hand thinning.

The use of the Cartographer (Green Atlas) for determining physiological changes in avocado trees and consequent timing of orchard management toward fruit robustness

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Avocado fruit robustness is a fundamental concept in avocado that reflects fruit quality. It is measurable at harvest and describes how well an avocado fruit stands up to injury along the supply chain. At this time fruit robustness can only be estimated destructively at harvest or shortly before harvest with destructive tests for calcium (Ca) and nitrogen contents in the peel. Calcium is a driver for fruit robustness in avocados. However, its management is complicated as it is primarily taken into the fruit for a short time after flowering. Calcium uptake in trees is controlled by multiple factors including root, soil and mineral interactions, and the size and growth of the tree canopy. Current theory suggests that amount and timing of canopy growth modulate Ca partitioning into the fruit. The Cartographer platform is a fast mobile orchard scanning system. It uses cameras and LIDAR to quantitatively measure canopy parameters, such as leaf area, canopy density, tree height, and fruit number. Therefore, canopy growth of avocado trees may provide a quick non-destructive method for monitoring the timing of Ca absorption. Changes in canopy growth measured with the Cartographer could be coupled with destructive chemical analyses to help growers determine orchard management practice toward early fruit robustness interventions. The experiment was set up in several locations and climates in WA to determine the effectiveness and efficacy of Cartographer in producing growth-derived predictors of avocado fruit robustness as a practical management tool for avocado producers.

Keywords: calcium, LiDAR, electronic imaging, fruit quality, canopy growth.

Validation of the metric model for estimating evapotranspiration in drip-irrigated hazelnut orchards for precision irrigation management

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In water-scarce scenarios, effective management of irrigation is crucial in hazelnut cultivation to enhance water productivity (WP) while maintaining optimal nut yield and quality. Site-specific irrigation management (SSIM) has emerged as a potential solution to optimize water application in hazelnut orchards. This study aimed to validate the accuracy of the METRIC (Mapping EvapoTranspiration at high Resolution with Internalized Calibration) model in estimating actual evapotranspiration (ETa) in a drip-irrigated hazelnut orchard located in the Maule Region, Chile. To estimate ETa using the METRIC model, 30 satellite images (Landsat 7 ETM+ and 8 OLI) acquired during clear sky days were used for the 2019-2021 and 2020-2021 growing seasons. The statistical analysis revealed that the METRIC model tended to overestimate ETa values by approximately 10%, with a root mean square error (RMSE), mean absolute error (MAE), and index of agreement (d) of 0.98 mm d-1, 0.90 mm d-1, and 0.70, respectively. These results indicate the potential of the METRIC model as an irrigation tool for mapping the spatial and temporal variability of water requirements in the hazelnut orchard, which spans an area of 1,500 hectares. This validation study provides valuable insights into the application of the METRIC model for SSIM hazelnut orchards, enabling growers to optimize water use.

Keywords: evapotranspiration, crop coefficients, irrigation, hazelnut orchard.

Leaf nitrogen estimation in almond orchards using chlorophyll fluorescence and plant traits derived from airborne hyperspectral and Sentinel-2 imagery

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Accurate assessment of the nitrogen (N) status is required for a sustainable agricultural management strategy. This can be achieved with hyperspectral remote sensing, which allows the assessment of physiological indicators for explaining N variability in orchards. The standard methods for estimating leaf N variability rely on empirical models of chlorophyll and structural vegetation indices. However, transferability across scales and the saturation of indices at high leaf N levels prevent robust nutrient mapping across species and growing seasons. Alternatively, techniques based on quantitative estimation of plant traits are more transferable, measurable and traceable. As leaf photosynthetic pigments and solar-induced fluorescence (SIF) are closely related to plant photosynthesis, these traits are proposed for assessing leaf N variability. In this study, we evaluated the performance of N prediction models that utilize SIF and plant physiological traits derived by radiative transfer model inversion. SIF and plant traits were quantified at the tree level over a heterogeneous almond orchard using high-resolution airborne hyperspectral imagery throughout two growing seasons. For comparison, we examined the performance of the NIR and SWIR spectral regions from Sentinel-2 satellite data for N assessment. Results from the airborne hyperspectral datasets revealed that Cab and SIF contributed the most to leaf N estimation in both years. The performance of the leaf N prediction model was improved when SIF was added to Cab (e.g., R^2 = 0.83, RMSE = 0.09% across two-year data collection) in comparison to Cab alone (R^2 = 0.74, RMSE = 0.11%), outperforming any other combination of two plant trait predictors. The measure of the de-epoxidation state of the xanthophyll pigments (Cx) was the third most important indicator to explain leaf N variability in almonds. Given the coarse resolution of Sentinel-2, the results were reasonable, and conclusions from the comparison will be discussed in the context of monitoring large areas.

Keywords: leaf nitrogen, hyperspectral, airborne, remote sensing, almond, chlorophyll, chlorophyll fluorescence, SIF.

Unlocking precision horticulture with 3D canopy analysis for trait extraction

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The accurate assessment of fruit yield and biomass in orchards is essential for optimising agricultural practices, enhancing productivity, and enabling efficient resource management. Traditional methods of estimating fruit yield and biomass involve manual measurements, which are labour-intensive, time-consuming, and often prone to errors. In recent years, remote sensing technologies, particularly laser scanning, have emerged as promising tools for non-destructive and efficient monitoring of orchard crops. The study presented in this research demonstrates the effectiveness of a terrestrial laser scanning method in estimating canopy volume within a pear orchard. This includes fruit detection, such as identifying pears, as well as estimating leaf biomass and wood biomass in different cultivars. The extracted information from laser scanning was compared to conventional estimations commonly used in fruit cultivation and horticulture research. The ability to extract high-resolution information on canopy geometry (e.g., height, width, volume) and structure (e.g., light penetrability, leaf area, porosity) can significantly enhance decision-making in orchard management. Reliable data on canopy geometry and structure facilitate the development of decision support systems for irrigation, fertilisation, canopy management, and variable rate application of agricultural inputs, aligning with the principles of precision horticulture. Future research efforts aim to expand the application of trait extraction to diverse orchard crops and training systems, validate their performance, and further enhance decision support systems for precision agriculture in the fruit-growing industry.

Keywords: laser scanning, segmentation, canopy geometry, remote sensing, phenotyping.

The use of predictive technology to estimate yield from flower counts in high density almond (*Prunus dulcis* [Mill.] D.A. Webb) orchards

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The Australian almond industry has increased 17-fold between 2000 and 2022 with over 60 thousand hectares in plantings. Accurate seasonal yield prediction is necessary to assist in resource management, especially tree nitrogen demand, and aid in harvest logistics. To enable timely nitrogen management, accurate yield predictions need to be done early in the growing season. The ability to predict crop size from flower counts will assist in early season nitrogen application adjustments. Technology has rapidly increased in the capability to capture and analyse large datasets to assist in orchard management decisions and increase horticulture productivity. The ground-based platform Cartographer (Green Atlas) utilises RGB cameras, LiDAR and GPS to accurately determine tree attributes like flower counts as well as tree geometry at a commercial scale. The study was conducted on the Mildura SmartFarm higher density planting — an experimental orchard consisting of 36 cultivar, rootstock and tree density treatment combinations. This work validated the use of the Cartographer machine vision system to accurately estimate the spatial distribution of flower counts in almonds. Predicted flower counts were ground truthed with manual flower counts and related to the measured yield.

Keywords: almond flower prediction model, flower density, pollination, fruit retention rate, crop load.

Mapping grapevine trunk disease using a smart phone

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Smartphones have several advantages over specialist monitoring systems including ubiquity, price, and ease of implementing updates. The effective management of grapevine trunk disease relies on the accurately tracking its incidence in the vineyard over multiple seasons. Mapping grapevine trunk disease is a labour-intensive process that requires experience. An image analysis algorithm was developed for the assessment of dieback symptoms due to trunk disease which is applied on a smartphone mounted on a vehicle driven through the vineyard. Vine images and corresponding expert ground truth assessments (of over 13,000 vines) were collected and correlated over two seasons. This data set was used to train and verify YOLOv5 models to estimate the percentage dieback of cordons due to trunk diseases. The performance of the models was evaluated on the metrics of highest confidence, highest dieback score, and average dieback score across multiple detections. Eighty four percent of vines in a test set derived from an unseen vineyard were assigned a score by the model within 10% of the score given by experts in the vineyard. An interface based on two smart phones was used; one to initiate and track image capture from the vehicle cabin and the second mounted in a position to collect and then process imagery. The dual frequency global positioning system on the data collection phone allowed row level maps of trunk disease severity to be rapidly displayed on completion of the vineyard survey. Disease incidence data can also be exported for analysis in geographical information systems software. The algorithms form the basis of a system that will allow growers to scan their vineyards easily and regularly to monitor dieback due to grapevine trunk disease and will facilitate its management.

Keywords: trunk disease, YOLOv5, smart phone, grapevine.

Advanced methods for yield estimation in tart cherries: Tank change tracking and YOLO-DeepSort Fruit counting

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Monitoring fruit yield in orchards is crucial for optimizing production and resource management. Mechanical harvest of commercial tart cherry orchards was developed in the early 1960's. However, the lack of technology specifically designed for yield mapping has created a gap in information about orchard spatial variation. This study presents two distinct methods for yield estimation: tank change tracking and YOLO-DeepSORT fruit detection, each offering unique advantages and insights. The first method utilizes a unit-based approach using a proximity sensor integrated with a Raspberry Pi and a GPS module to track the position of each tank change during harvest. The second method presents a computer vision approach to yield mapping in tart cherries, utilizing the YOLOv8 object detection model, combined with the DeepSORT object tracker to count the number of harvested fruits per tree. This combined approach provides a fast and accurate framework for tart cherries fruit counting and has never been applied to small fruits. We compared the results from the state-of-art object detector YOLOv8 using the smaller size nano version and the extra-large version (YOLOv8x) as far as training time, inference time and evaluation metrics. The preliminary results showed that YOLOv8n achieved a mean average precision (mAP) of 95% on the validation data, with a 25ms inference time and total training time of 20 minutes. In comparison, YOLOv8x achieved a slightly higher mAP of 96 %, with an average inference time of 20 ms and a training time of 43 minutes. These results highlight the potential of using portables computers, such as Raspberry Pi, for real-time fruit counting and yield mapping using the presented approaches. The proposed methods offer significant advancements in yield estimation techniques, providing valuable insights for precision agriculture empowering farmers with accurate and spatially detailed information to improve efficiency in the orchards.

Keywords: computer vison, YOLO, object detection, deep learning, raspberry pi, fruit counting, yield mapping.

A computer vision approach for estimating fruit growth rate in orchards

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Fruit development information throughout the growing season is essential for effective orchard management. Repeated measurements of fruit size enable the tracking of its absolute growth rate (AGR), a key physiological parameter for yield prediction and assessment of stressing conditions. Caliper based AGR measurements can be labor-intensive while existing sensor-based solutions are limited by cost and low representativeness at orchard level. In this study, a novel Python-based computer vision system (CVS) that employs a depth camera and artificial intelligence algorithm to estimate fruit AGR directly in the field is presented. A total of 50 tagged apple fruits were monitored for their AGR throughout the 2022 growing season using a digital caliper. Images of these fruits were collected at distances of 1.0m and 1.5m from the tree row, capturing multiple time points during the season (> 10). The CVS has computed the AGR for each detected fruit in the images. Preliminary results from the ongoing analysis indicate a fruit detection rate of 90%, with a mean root mean square error (RMSE) of 7.5mm for single fruit sizing and a mean AGR estimation RMSE of 0.32mm/day. Current results are not in line with expected performance for field application, but further improvements in the system algorithm are currently ongoing. It is worth to note that results were obtained from the analysis of only 30% of the whole dataset, suggesting that even better results could be reached during further analysis stage. The presented approach wants to harness the large sample size analyzable (up to the entire fruit population), to mitigate errors associated with individual measurements and obtain robust fruit size and AGR estimations, at the orchard level.

Keywords: fruit size, apple, computer vision system, precision orchard management, fruit detection.

Towards a new generation of cider apple orchards in the Northeastern United States

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With a US$1.7B total economic impact in New York State, hard (fermented) cider has become an important value-added product in the alcohol beverage sector. Most of the state's cider producers are using NY-grown apples, but large-scale hard cider producers are also importing apple juice concentrate from overseas. However, a recent NY apple industry survey found that nearly 18% of all new apple orchard acres that will be planted in NY from 2020-2023 are projected to be specifically for cider production. Additionally, in a recent economic case study, we showed that the current prices for cider apples (cultivars that typically have high tannin, acid, and/or sugar concentrations) made five out of six cider apple orchard operations profitable in NY. My research program has conducted cost of production studies, characterized over 375 potential cider apple cultivars, and developed orchard management practices that leads to greater fruit and thus cider quality. We have identified a number of promising cultivars that appear to have the horticultural performance and juice quality attributes desired by regional cider producers. For high-density orchard systems, we found that many cider apple cultivars should have twice the crop load as culinary cultivars to achieve the greatest long-term yields, juice quality, and profitability. Furthermore, we found that the use of the exogenous plant growth regulators (ethephon and 1-naphthaleneacetic acid) did not increase return bloom, but 1-naphthaleneacetic acid and aminoethoxyvinylglycine can be used to manage pre-harvest fruit drop and harvest timing. Future work is focusing on developing cider apple orchards that are best suited to mechanical harvesting. In this presentation, I will review current management practices for growing cider apples in the Northeastern United States and propose a conceptual orchard design and management system for the next generation of cider apple orchards.

Keywords: hard cider, fermentation, *Malus domestica*, mechanical harvesting.

Predicting fruit set based on the fruit growth rate model with vision systems

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Chemical thinning is a common practice used in apple orchards. It entails an early reduction in tree crop load, resulting an improvement of fruit size, quality and return bloom. PACMAN (Precision Apple Crop Load MANagement) is an extremely effective method for successfully managing crop load. The fruit growth model is an essential tool in precision of crop load management. Currently, there are several private companies with digital tools to help use this model. The aim of this study was to evaluate two methods of predicting fruit set (Cornell MaluSim app and Farm Vision/Pometa digital scans). Trials were carried out in 18 orchards in Massachusetts, Michigan, New York, and North Carolina during two seasons (2022 and 2023). In each orchard block we selected 5 homogeneous trees and counted the total number of blossom clusters/tree. Fruit set was determined after natural fruit drop or at harvest. Standard chemical thinning spray applications were made in all trials between 6 and 8 mm fruit king diameter. The fruit diameters were evaluated every 4 and 7 days after application at all locations. There were significant correlations between final fruits harvested and predicted fruit set with both systems. The R^{2}'s were between 0.7 and 0.8. When the number of fruits at harvest was lower than 200 fruits/tree the predicted fruit set with both systems was very accurate (1:1). However, when the number of fruits at harvest was higher than 200 fruits/tree both systems overestimated the number fruits at harvest. These methods of predicting fruit set within 7 days of spraying a chemical thinner will allow growers to obtain actionable information to guide precision crop load management with less effort compared to the current manual measurement.

Keywords: *Malus* X *domestica*, Pometa, Farm Vision, computer vision system, trunk cross section area (TCSA), bloom intensity, fruit growth rate model, yield estimation.

Low-cost RGB-D/thermal platform for monitoring fruit temperature with spatial resolution

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Fruit sunburn damages in orchards is a growing concern exacerbated by climate change and more frequent heatwaves. As temperatures increase, the risk of sunburn intensifies due to excessive solar radiation and heat stress. This not only compromises the marketability of the produce, reducing growers' incomes, but also imposes indirect economic burdens from additional protective measures. Therefore, understanding the impact of heatwaves on fruit sunburn occurrence and severity is crucial for safeguarding crop yields and ensuring growers' profitability. This study is part of a European project aiming to create an alert system for fruit sunburn damage based on past, present, and forecasted weather conditions. One aspect of the project involved developing a low-cost platform that collects fruit thermal and spatial information to create a 3D thermal distribution of fruit temperature at both the plant and orchard levels. This to better understand the dynamics of fruit temperature in relation to sunburn damage occurrence. The system comprises consumer-grade depth and thermal cameras powered by Python and ROS2 (Robotic Operating System 2). The software aligns thermal, color, and depth images of the scene. Using these data, an artificial intelligence algorithm automates the detection of well-exposed fruit. For each identified fruit, the system extracts its temperature, corrects it for camera distance, determines the fruit's position as XYZ coordinates relative to the tree trunk, and provides a graphical representation. Additionally, if GPS information is available, the system can geolocate the collected data. Preliminary results indicated an image alignment error of ± 0-3 pixels, a fruit temperature estimation error of ± 3-10 °C (mainly influenced by the object's distance), and a fruit positioning error of ± 5-10 cm. The system is currently undergoing further development, and updated results will be available at the end of the 2023 season.

Keywords: fruit sunburn, thermal imaging, fruit temperature mapping, heatwaves, Python, ROS2.

Smart sensing and imaging systems for a digital twin of apple production

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The imagined digital twins for perennial horticulture will require physical sensing systems able to close the loop between the physical and virtual orchards. Plant and Food Research have embarked on a direction of work to build a digital twin of apple production and supply chain ecosystems. Smart Sensing and Imaging Systems is a programme of work within this direction which aims to deliver the technology advances in field-deployable measurement devices. We are exploring technologies to deliver tree level metrics suitable for Functional-Structural plant modelling at an orchard scale. Focusing principally on 3D reconstruction using rigidly mounted camera arrays we hope to be able to develop automated systems for organ level segmentation and measurement. We are developing micro-climate sensors to be able to explore high spatial frequency metrics of the environment, particularly for air conditions and light radiation. A proximal sensor system for rapid non-destructive assessment of fruit quality is also under development, as are field-deployable molecular and volatile measurement tools to enable plant-as-a-sensor type signals in the orchard.

Keywords: digital twin, digital technologies, orchard sensing, orchard imaging systems.

Optimizing water management in young almond orchards with heavy clay soils in southeastern Australia using proximal and remote sensors

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New almond plantations are significantly increasing in the Riverina region in New South Wales, Australia at a higher rate than in other regions. Soils in the Riverina are typically heavier than the ideal soils for almond production. Thus, optimum irrigation water management is crucial to manage the water resources efficiently and avoid soil water conditions that could impair crop performance. Drone-based Kc estimates, WiFi-based data loggers for real-time soil moisture monitoring and Wi-Fi smart switches for solenoid valve control were used in this study to deficit irrigate three-year old almond Nonpareil and Shasta trees grown on grey clay soils during summer. The response of Nonpareil and the relatively new self-pollinating variety Shasta to mild (DI1) and moderate (DI2) water stress in terms of water status, photosynthetic state, tree growth and yield were assessed and compared with the orchard practice (irrigated at 95% ETc). The DI2 treatment received ~11% less water than the orchard practice, reached the lowest stem water potential (SWP) values (-1.9 MPa) and the highest water-stress integral. No differences in chlorophyll fluorescence and photosynthesis-related parameters measured with a MultispeQ were observed among irrigation treatments. Deficit irrigation reduced trunk growth and kernel dry weight, but yield (t kernel/ha) was not significantly decreased due the variability observed in the total number of nuts per tree. Shasta trees showed less negative SWP values, consistently displayed a significant higher fraction of absorbed light lost to non-photochemical quenching during summer than Nonpareil trees and yielded the highest. Results from this study showed that proximal and remote sensing of tree water needs, and soil water status are useful tools for the precision water management of young almond orchards. It also shows Shasta with an average irrigation water productivity of 0.44 kg/m3 as an interesting cultivar for the semi-arid climate of the Riverina.

Keywords: grey clay soils, internet of things, drip irrigation, remote sensing, soil moisture, water stress.

Assessing vineyard and orchard variability through analysis of canopy images

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Canopies in vineyards and orchards are intrinsically variable. Understanding this variability could allow for more targeted management to apply inputs efficiently and assist in delivering consistent yield and quality of the crops. The assessment of variability can be challenging; possible approaches rely on the ability to monitor leaf area, canopy vigour and canopy growth. However, current methods for canopy monitoring are often based on subjective visual observations, laborious manual procedures or expensive remote sensing and the use of instrumentation that can be destructive, time consuming and is impractical outside of scientific research. In this study, we report case studies where canopy sizes of grapevines and almond trees were measured through the analysis of canopy images taken using a smartphone. Vineyard canopy assessments through image analysis confirmed links between canopy size, canopy temperature and light interception, yield components, and berry and wine sensory and chemistry. Given the results obtained in vineyards, the same image analysis tool was trialled in an experimental almond orchard where tree planting densities were compared. The results in almonds demonstrated that not only could the tool be used to easily capture orchard variability, but there was also a strong link between canopy size and yield. Results have demonstrated that the measurement of canopy size from canopy images could assist in: 1) identifying regions within orchards or vineyards of different performance; 2) assessing variability within and among seasons; 3) creating a site history; and 4) assessing the outcomes of different management interventions, both in vineyards and in almond orchards. This information could be used to direct precision management decisions.

Keywords: grapevine, almond, variability, canopy architecture.

Using remote sensing models to determine evapotranspiration of a Pomegranate Orchard in a Mediterranean climate

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Information about the atmospheric evaporative demand of pomegranate (Punica granatum L.) trees is crucial to guide irrigation practices. Based on a Normalized Difference Vegetation Index (NDVI), the study aimed to analyse the evapotranspiration of a 13-year-old Pomegranate orchard under irrigation in Wellington, Western Cape province of South Africa, using different remote sensing approaches. The reference evapotranspiration(ETo) calculated by using the FAO56 Penman-Monteith equation at selected growing stages from flowering to harvest ranged from 2.8 mm d-1 in September 2022 to 3.7 mm d-1 in March 2023. In contrast, ETo estimated using remote sensing-based eeflux ranged from 3.2 mm d-1 to 5.5 mm d-1, respectively. The NDVI was calculated based on Landsat 8 satellite data downloaded from USGS website and analysed using QGIS. The output from Landsat data indicated that the highest NDVI value of 0.6 was obtained during December and the lowest value of 0.3 in March, and NDVI estimated by eeflux indicated 0.7 and 0.6 respectively, during the growing season. There was a moderately strong correlation relationship between estimates of both methods for ETo (r= 0.67) and NDVI (r=0.54).

Keywords: eeflux, irrigation, QGIS, reference evapotranspiration, water use.

Vineyard design revised from first principles, to maximise yield, quality and mechanisation

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This presentation is a work in progress, a literature review to be separately published for vineyard audiences. This review has led us to a proposal for a modern vineyard design, briefly outlined here. The design is based on maximizing solar energy interception by grapevine canopies so managed as to maximise yield expression while maintaining the fruit microclimate to optimise quality. Most (¾) of Australian vineyards are very vigorous and grown in hot inland regions with plentiful irrigation. They are mechanically hedged as a form of winter pruning, or given 'minimal pruning'. They are typically trained on simple trellis systems in a wide row configuration. Shaded leaves and fruit predominate in the non-shoot positioned canopies. An improved design we propose uses narrow row spacing of say 1.3 m with wide in-row vine spacing of 4 m, creating 1,923 vines/ha, like the present. Narrow row spacing will increase sunlight interception, and the wider in-row spacing leads to higher bud numbers per vine/root system. Shoot devigouration occurs due to early season meristem competition for stored reserves. The potential exposed canopy surface area for our redesigned vineyard is ca. 26,920 m2/ha, some 290% greater than the present common 9,330 m2/ha. The vines would be trained to two vertical canopy tiers, one trained upwards and the lower downwards. Spur pruned Smart Dyson or Scott Henry will be used with one or two cordons per vine. Canopy shading is avoided by appropriate shoot spacing of about 16 shoots/m for each canopy. This facilitates fruit exposure, promoting ripening conditions favourable for wine quality. Mechanisation will be provided by over-row "straddle" tractors for all operations with onboard imaging systems to facilitate spur and shoot density measurement and adjustment, also canopy density analysis of fruit exposure and canopy gaps. We anticipate about doubling yield and improving quality.

Keywords: light pruning, canopy surface area/ha, over-row machinery, narrow-row spacing, wide in-row spacing.

Advancing high-performance apple production systems through digital twin modelling

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Amid escalating challenges of climate change, land use competition, labour shortages, escalating costs, and shifting consumer demands, the necessity for agricultural producers and supply chain operators to enhance productivity, sustainability and quality is becoming increasingly apparent. These improvements must encapsulate economic, environmental and social sustainability aspects, whilst ensuring consistent provision of high-quality produce that meets consumer requirements. To address these needs, Plant & Food Research initiated in 2021 a series of programmes to develop a digital twin of a narrow-row planar cordon apple orchard. Our goal is to dynamically couple physical and biological components of apple production and supply chain systems with their virtual analogues. In this paper we describe the progress for one of the programmes, which is generating the physiological knowledge of a new high-yielding apple production and storage system to subsequently develop and parameterise a functional-structural tree and fruit model. The programme has five research aims: (i) build a functional-structural apple tree model that will integrate our understanding of tree and fruit development in narrow-row planar cordon systems; (ii) quantify tree architecture development and manipulate the shoot architecture to optimise tree function and carbohydrate partitioning into fruit yield; (iii) investigate energy capture, conversion and distribution within planar cordon apple trees, (iv) develop new tools and methods to estimate parameters for modelling root growth, architecture and function, and (v) focus on fruit growth, to understand the on-orchard factors, e.g. light, crop load and climate, that affect fruit firmness at harvest and during storage. Ultimately, the digital twin will guide interventions to improve productivity and quality, enhance resource and energy use efficiency, and reduce fruit waste throughout the production and supply chain.

Keywords: tree architecture, functional-structural plant models, supply chains, digital technologies.

Replacing N fertiliser with under vine legumes reduces pruning weights without significantly impacting yield

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Nitrogen is the most important nutrient requirement for vineyard management because grape juice must contain adequate quantities of N for successful fermentation. Nitrogen is most commonly supplemented to vineyards in synthetic form, however recent fluctuations in fertiliser prices and the desire to reduce synthetic inputs has driven an increasing interest in alternative means of supplying N to vines. One possible solution is the use of legumes as living mulches within vine rows. Not only do living mulches have the potential to reduce fertiliser input by depositing high N containing plant debris directly onto the vineyard floor, they have also been shown to increase soil organic carbon and aggregate stability when compared to the standard practice of bare soil maintained with herbicide. However, for under vine living mulches to be successfully implemented by growers, research is needed on the quantity and timing of N provided, as well as the effects on vine balance, water availability and soil quality. This study compared the effects of under vine living mulches on two contrasting top soils, a clay and a sandy loam, in southern Tasmania. Living mulch mixtures of Medicago polymorpha Simitar and Trifolium subterranean Mawson were sown with and without the grass Dactylis glomerata var. hispanica Sendace in Chardonnay vines for three years. Preliminary results indicate that pruning weights and yeast assimilable nitrogen were reduced by the living mulch treatments, however yield was unaffected.

Keywords: Cover crop, living mulch, legume, N fertiliser, viticulture.

Deficit irrigation and training system as adaptation strategies to climate change: the Portuguese Douro wine region as a case study

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The Douro Demarcated Region, a world-renowned winemaking region, is climatically characterized by hot and dry climate conditions, particularly during summer (Mediterranean climate), inducing grapevine water deficits. Furthermore, this region is likely to face a greater and intensified number of abiotic events in the near future. Adaptation strategies involving viticultural practices must be adopted to guarantee economic, social and environmental sustainability. In this way, commercial vineyards, planted with autochthonous varieties, were chosen to study the effects of (i) different levels of deficit irrigation (compared to traditional rainfed conditions) and (ii) different training systems (spur-pruned cordon vines, the most used system in this region, and Guyot-vines). Deficit irrigation had a positive impact on water status, leaf area and yield components compared to traditional rainfed vines. Guyot-vines presented higher whole-vine water dynamics (e.g., increased trunk diameter fluctuations), compared with the cordon-vines under low soil water availability and high atmospheric demand. The study exposed the adaptive potential of the Guyot system to the projected climate change in Mediterranean wine-producing regions.

Keywords: abiotic stress, Mediterranean viticulture, plant-based sensors, grapevine water management.

Innovative soil chemical mapping for nutrient management

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For over a century, soil physical and chemical testing has been utilized to inform nutrient management practices. Advancements in soil testing technology could provide opportunities for nutrient variable rate management to improved efficiencies. Two soil physical-chemical mapping tools were tested in a commercial 'Honeycrisp' orchard during the 2021 and 2023 growing seasons. The mapping tools included a gamma radiation sensor (SoilOptix®) and an electric conductivity (E.C) mapping system. The SoilOptix® generated variability maps for 27 physical and chemical parameters. The orchard exhibited varying levels of physical and chemical levels resulting in a wide range of conditions. The SoilOptix® maps revealed weak positive correlations for pH, potassium and nitrate, but strong positive correlations for organic matter, calcium, magnesium and boron. When analyzed across different timings, only calcium, magnesium, boron and cation exchange capacity had a strongly correlation with laboratory test. However, SoilOptix® did not provide accurate absolute chemical values. The E.C mapping provided three levels of E.C across the orchard, correlated positively with laboratory E.C tests, but only during one sampling date. As such, the SoilOptix® and the E.C mapping were useful tools in mapping relative soil variability but should not be relied on to determine absolute values for soil chemical corrections. While the mapping tools provided valuable insights into soil variability, neither had any relationship with tree productivity or fruit quality. Despite this, the potential benefits of precision and variable rate management in perennial crops make these tools worth exploring further.

Keywords: soil chemistry, soil variability, variable rate, fertilization, nutrient management.

Machine vision methods for estimating mango crop forecast

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In mango farming, a forward estimate of both harvest maturity and fruit load are required by farm managers for planning of packaging material, labour, machinery resourcing, and market sales. Estimation of optimum harvest maturity can be achieved by using an automated calculation of orchard block accumulated growing degree days (GDD) from an early stage of flower development, however assessment of flowering is a manual task. Likewise, current practice for fruit load estimation involves manual counting of total fruit per tree. The current study was implemented to extend the use of an orchard imaging system in estimation of mango fruit load, working towards a method for implementation by farm management. A farm vehicle mounted machine vision system was used for estimates of both flowering level and fruit number, with correction based on a manual count. Estimates were undertaken on multiple orchard blocks in two growing regions, involving different cultivars. Mango panicle development was classified to three maturity stages using machine vision. Imaging of several rows per block were undertaken during the flowering period. The time of the peak in count of panicles in Stage 2 was used as the date of flowering 'event' in a given block and used in GDD estimates of harvest timing. A procedure for use of in-field machine vision-based count of fruit on tree in estimation of orchard fruit load was also established, based on use of imaging on two dates to capture fruit arising from different flowering events. The two imaging estimations were accurate estimates of total orchard fruit load as measured by packhouse count, with R^2 of 0.98 and slope of 0.99 across six orchards. A correction for late flowering events and for fruit occlusion are required. Further work is required to establish practical methods for estimation of these correction factors.

Keywords: imaging, yield prediction, deep learning, crop forecast.

Irrigatmo: open-source and no-moving parts system for feed-back and feed-forward irrigation scheduling

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Weather-based approaches represent the key element in determining crop water requirements (CWR) using a simplified agrohydrological model coupled with meteorological sensors. The FAO56 (Allen et al., 1998) is one of the most used bucket models for CWR. In this model, the daily ET0 is usually estimated by the FAO-Penman-Monteith (PM) which needs as inputs standard atmosphere forcings acquired from weather stations, that often are equipped with ordinary mechatronics sensors that require regular maintenance. An atmometer (ETgage) is an accurate sensor with no moving parts that continuously measures the ET0, based on a physical analogy of the crop reference. This study aims to design and validate an expert system, named Irrigatmo, to manage irrigation based on the combined application of the feedforward- (FFc) and feedback- (FBc) control irrigation scheduling protocols. The FFc protocol comprises a Kc-based mass balance model instructed with a modified atmometer and FDR sensors for sub-hourly ET0 and soil water content (SWC) measurements. At the same time, the FBc protocol uses the SWC to quantify the critical condition and the crop stress coefficient to adjust the Kc value used in the bucket model. The ETgage was modified by integrating a pressure transducer sensor, calibrated to continuously measure the water level and, therefore, estimate ET0 at a sub-hourly scale. An open-source single-board computer (Raspberry Pi) implements the two sensors and the water mass balance logic. To evaluate the performance of the open-source system a proprietary datalogger (CR300, Campbell Scientific Inc.) was used as a reference. The results showed that Irrigatmo detected accurately and rapidly the changes in atmospheric and soil water conditions. Based on these fine-detected dynamics, the system decided to turn on/off the irrigation valve according to the set irrigation thresholds. In this way, Irrigatmo is a promising tool to adjust precisely and automatically irrigation variables.

Keywords: atmometer, smart irrigation, hourly transpiration, open-source, soil water content, crop coefficient.

Precision canopy management strategies for sweet cherry orchards of the future

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Sweet cherry remains among the most labor-intensive temperate tree fruit crops, requiring large crews of skilled labor for harvest and pruning due to the large and generally chaotic tree structures of traditional orchard systems. Indeed, regional grower associations in the U.S. have identified the need to improve labor efficiencies among their highest priorities for more than a decade. As new sweet cherry orchards are planted around the globe, growers face a myriad of choices among cultivars, rootstocks, and orchard systems, and foremost in their minds are questions about fruit quality, system precocity, and productivity. Yet equally important are the effects their decisions have on labor efficiency and the potential to incorporate mechanization/automation, sensor technologies, and precision management strategies. The tree fruit physiology team at Washington State University has been developing and refining high efficiency orchard systems that are sustainable, consistently productive, yield superlative fruit and are well-suited to the adoption of precision management strategies. There is worldwide interest in the Upright Fruiting Offshoots (UFO) architecture due to its planar nature and the simplicity of pruning and training. This presentation will summarize the evolution of this training system and recent trials in precision orchard management strategies including artificial pollination, robotic pruning, and mechanical harvest systems - all possible with the development of fruiting wall architectures. The successful development of any orchard system will depend upon addressing the total system, with research at the intersection of biology and technology being key. This presentation will describe a two decade-long collaboration toward the development of high efficiency sweet cherry production systems and the vision we have for precision management of orchards of the future.

Keywords: training systems, pruning, harvest, fruit quality.

A review of the production challenges for sweet cherries grown under protected cropping systems

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Tasmanian grown sweet cherries are in high demand on international markets due to their premium quality, late season market access and minimal trade barrier. Australia has seen an increase in the investment of protected cropping systems (PCS) to mitigate the risks associated with the production of premium cherry fruit. In Tasmania, previous studies have shown that various PCS minimise fruit cracking improve fruit set and size. Despite the benefits of PCS, there are still challenges associated with growing cherries under PCS. Some of these challenges include softer fruit in some seasons, an increase in tree vigour as well as the difficulty in predicting irrigation and fertigation requirements to the trees growing in these novel microclimates. PCS modify orchard micro- and meso-climates generally by increasing temperature and relative humidity and lowering solar radiation and wind exposure. All these factors have shown to reduce tree water uptake resulting in the potential implications for the uptake of mineral nutrients (particularly calcium). Hence, greater knowledge of tree water and nutrient uptake, identification, and quantification of plant growth regulators may help gain an improved understanding of fruit quality and tree growth characteristic negatively associated with production under PCS (fruit firmness and tree vigour). This new knowledge would be invaluable to the cherry industry in ensuring high demand for quality sweet cherries grown under PCS remain on international market. There is a need for research to address these issues under PCS by identifying and quantifying eco-physiological constraints to further develop cultivar and PCS specific management practices.

Keywords: ecophysiology, microclimates, firmness, calcium, protected cultivation.

Transitioning from laboratory research to real-world application: encouraging results in the practical utilization of hyperspectral images for field detection of grapevine viruses

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Vineyards are affected by grapevine viruses, resulting in negative consequences such as hindered fruit ripening, diminished grape quality, and reduced crop yield. It is crucial to identify infected vines in order to prevent the spread of these viruses. Remote sensing offers an ideal solution by measuring the physical and biological properties of vegetation that are influenced by the disease. In this research, we assessed the potential of hyperspectral VIS/NIR imagery in detecting red-blotch infected vines. To accomplish this, we collected leaf samples in 2020 and 2021, utilizing PCR analysis to identify infections. We captured hyperspectral images of leaves infected with grapevine leafroll and grapevine redblotch. Simultaneously, but only for red-blotch infected vines, we captured images of the vine canopy sides using a tripod, as well as aerial images above the canopy using a drone. To classify the infection in leaf images in the laboratory, we compared Convolutional Neural Network (CNN) and Random Forest (RF). To classify the vine images in the field, we experimented with Partial Least Square Discriminant Analysis (PLS-DA), RF, and Support Vector Machine (SVM). Several ways to simplify the predictors number were tested using spectral binning and a Recursive Feature Elimination (RFE). On leaves images, when binarily classifying infected vs. non-infected leaves, the CNN model reaches an overall maximum accuracy of 87%. Based on a multiclass categorization of leaves to distinguish between leafroll and redblotch viruses, the models had a maximum accuracy of 77.7%. On field images, the best overall accuracy reached 73.3% using only 23 bands of 8nm width. In the late season, with visible symptoms, the accuracy increased to 76.6% with 18 bands with 16nm width. This method enables the detection of virus transmission and identification of potentially infected vines autonomously.

Keywords: phenomics, spectroscopy, *Vitis vinifera* L., intelligent phytoprotection, disease detection, deep-learning, machine-learning.

Enhancing sustainable water management: utilizing UAV-based NIR/SWIR hyperspectral imaging to evaluate grapevine water status in a variably irrigated vineyard

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In 2022, we embarked on a study focused on Cabernet Sauvignon vines located in the San Joaquin Valley, aiming to explore the potential of remote sensing as a crucial component of sustainable water management, particularly in capturing spectral and spatial information. To carry out this research, we implemented an automated irrigation system that enabled variable irrigation across forty-eight distinct watering zones. These zones encompassed twelve different irrigation regimes, each replicated four times in a randomized manner. Throughout the entire growth season, we collected spectral information from all the zones using unmanned aircraft vehicles (UAVs) equipped with hyperspectral imaging capabilities, specifically in the Near InfraRed (NIR) and Short-Wave Infrared (SWIR) range spanning from 900 to 1700nm. These wavelengths contain water absorption bands, which were utilized in machine-learning regression models to predict the water status of the plants. To validate the accuracy of the spectral information, we concurrently measured plant water status using techniques such as stem water potentials and leaf gas exchange. These measurements were performed every two weeks, starting from June until harvest, resulting in a total of five flights and approximately 1,000 individual readings in both 2022 and 2023. During data analysis, we employed highly accurate segmentation methods (> 99% accuracy) to extract the pure canopy signal from the images. This extracted information was then utilized to train machine learning models for predicting water status measurements. We applied Recursive Feature Elimination to reduce the number of predictors by 65%, resulting in a final set of eighty wavelengths for the 2022 dataset. The preliminary model for 2022 achieved a coefficient of determination (R^2) of 0.53 and a root mean square error (RMSE) of 0.12 MPa through a 10-fold cross-validation routine. This project represents a significant stride towards the development of innovative methods for precise monitoring and management of irrigation in vineyards.

Keywords: UAV, hyperspectral imaging, machine-learning, irrigation, internet-of-things.

Grape composition assessment using NIR/SWIR hyperspectral imagery acquired from a UTV

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Accurate assessment of grape composition plays a vital role in vineyard management, enabling the determination of optimal harvest dates and the implementation of cultural practices to achieve production objectives. Grape composition exhibits temporal and spatial variability due to the ripening process and is influenced by soil and climate conditions. Our research developed a field-based system to assess and map grape composition. We customized a UTV to lift the canopy and expose the fruits, equipping it with one hyperspectral camera covering the 900-1700nm range. The camera was integrated with GPS systems and halogen lights for night imaging. We captured images of a Merlot vineyard located in Madera, California. Concurrently, we collected grape samples which were subsequently analyzed in the laboratory to determine total soluble solids, titratable acidity, pH, and the anthocyanin profile. In total, approximately 650 samples were collected. Images were segmented to extract the grape signal from the sampled vines. Machine learning models were then employed to examine the reflectance of the grapes and identify correlations with grape composition. The performance evaluation of these models involved RMSE, R^2 in k-fold cross-validation. Additionally, feature importance and partial dependence plots were utilized to interpret the model and understand the relationship between wavelength predictors and the outcomes. This project marks the pioneering use of a SWIR camera mounted on a UTV to assess grape composition. Our findings demonstrate that SWIR images can be employed for classification purposes, accurately extracting the grape signal. The prediction of grape compounds using the refined spectral signal exhibits promising results with a prediction of Brix with an R^2 of 0.60 and an RMSE of 1.2 Brix using a Bayesian ridge regression model. The ultimate objective of this project is to assist growers in rapidly and spatially monitoring grape composition in the field, facilitating variable rate management decisions.

Keywords: hyperspectral imaging, machine learning, precision viticulture, *Vitis vinifera* L, grape composition.

Combining new rootstocks and training systems for a sustainable production in deciduous tree crops

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The total surface occupied by deciduous fruit crops in Spain in 2020 was 183,959 ha. Peach remains as the most important species with 72,070 ha (FAOSTAT, 2021). Cherry has also experienced an important increase accounting a surface of 27,911 ha. Among other Prunus species, almond surface raised 718,540 ha, only 18% placed in irrigated land areas. In pip fruit species, apple is the most important crop with an acreage of 29,490 ha. The common trend of all these crops concerning orchard design is the intensification combining mid to low vigour rootstocks with training systems based on bidimensional canopies. In peach, the use of size-controlling rootstocks, such as 'Rootpac®' series, with intensive training systems allowed earlier and higher cumulative yields, compared to the traditional open vase. However, and increase of skilled labor requirements was recorded when the number of axes increased from central axis to bi axis, tri axis and multi axis. In cherry, intensification with CiSelA® rootstocks combined with planar canopies resulted in a better efficiency in the use of labour and mechanization. In fact, planar canopies in peach, cherry and apple allows a more efficient use of mechanical flower thinning and mechanical pruning techniques, also improving the harvest rate efficiency, reducing the production cost and increasing fruit quality. In almonds, super high density (SHD) development, using the size-controlling rootstock 'Rootpac 20®', allowed very early yields, full mechanization of pruning and harvest, and a reduction of production cost compared with the traditional open vase. This was due partially to better efficiency of plant protection products reducing drift. In apple, new G® rootstocks from Cornell-Geneva allowed the increase of yield efficiency and net profit for growers. In addition, all these planar canopies resulted more adapted to precision technologies based on artificial vision (AV) and artificial intelligence (IA) for fruit counting, yield forecast or robotic harvest.

Keywords: deciduous crops, rootstocks, high-density, planar canopies, production cost, efficiency, sustainability.

Modelling fruit surface temperature by means of LiDAR 4D point clouds

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During the last years, the occurrence of marked heat waves had increased as a consequence of climate change. Such temperature hot spots can influence greatly to sunburn and other physiological disorders at fruit surface. By using remote sensing techniques, real-time fruit monitoring in orchards had proven to be a resource in adapting measures against triggers of physiological disorders, thus creating opportunities for resilient risk models in orchard management. Thereof, light detection and ranging (LiDAR) scanning provide geometric and radiometric information at fruit level by means of 3D point clouds. Most importantly, by merging LiDAR scanning and thermal imaging, 4D point clouds with temperature annotation can provide input for risk models that include heat transfer at the fruit surface. Local temperature at the surface of the scanned apples was assessed by using a geometric modelling approach based on Fourier series expansion, thus expressing the apple geometry as a 2D surface in spherical coordinates. Subsequently, a heat transfer model to predict fruit surface temperature was proposed at given climate and environmental conditions. The model considered radiation due to direct and diffuse beam at the fruit surface, which depended on occlusion on apple surface by other apples or leaves. Additionally, the effect of convection due to airflow around the apples, heat due to transpiration and conduction into the interior of the apple were considered. The model simulations were contrasted to measured values of absorption coefficient and water vapour resistance at fruit surfaces.

Keywords: LiDAR, 4D point clouds, Fourier series, heat transfer, radiation, convection, transpiration, conduction.

Experiment-modelling-integration of fundamental physiological processes towards digital twin: light-response of photosynthesis as an example

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Digital representation of tree crop orchards has been fascinating while challenging to horticultural researchers, industry technical experts and stakeholders all around the world. The challenges are multi-dimensional and multidisciplinary, to name a few: (1) the complexity of tree structure, (2) the discrepancies between modelling philosophies and approaches (e.g., mechanistic vs. empirical; simplicity vs. comprehensiveness), (3) a diverse range of technical bottlenecks (e.g., real-time and automatic measurement and integration of bio-physical properties and plant functioning across leaf, canopy, orchard and larger scales; physics-based computer simulations improving the modelling of energy transfer from sunlight to leaves; etc.), and (4) the gaps between experimentalists (i.e., understanding biological processes) and modellers (i.e., understanding modelling principles), and the scarcity of experiment-modelling-integration studies (e.g., model-oriented experiments and model-incorporation of observation-based quantitative physiological relations). Fortunately, over the past decade or so, industry-oriented planting system innovation (e.g., standardized 2D-multileader canopy structures), and technological advances (e.g., remote and proximal sensors quantifying real-time functions), have overlapped many challenges and gaps. In particular, the transdisciplinary transfer effort towards model representation of fundamental biological processes (e.g., functional–structural plant modelling), in the past two decades or so, have expanded greatly and fruited with a collection of dynamical growth and development models, at various scales (i.e., from microscopic to whole-plant and plant community scales), and for diverse fruit crops (e.g., apple, grapevine, mango). Despite considerable progress, given the classic equations or quantitative functions representing environmental responses of fundamental physiological processes – developed a few decades ago with the equations' limitations stated in the original papers – have rarely been revisited, the limitations persist, and to some extents are forgotten. This paper, using the classic non-rectangular hyperbolic model representing light-response of photosynthesis as an example, aims to highlight how the minor gap could potentially lead to major difference (e.g., overestimating maximum photosynthesis rate, and thus potentially the crop's growth and productivity).

Keywords: Light relation, light response curve, maximum net photosynthetic rate; photoinhibition; production system; saturation light intensity.

Poster Presentations

Monitoring stink bugs and assessing an attract-and-kill strategy to reduce their damage in apple orchards of Quebec, Canada

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Recent years have shown an increase in stink bug populations and damage within apple orchards of Quebec, Canada, even before the arrival of the brown marmorated stink bug (*Halyomorpha halys*). These new pest problems have jeopardized integrated fruit production programs and require new monitoring and control tools to assess the abundance of populations, to target interventions and to protect the crop. Few options are currently available in Canada to control pentatomids in fruit crops and the most effective insecticides are also those with the greatest impact on beneficials. The project's objectives were thus 1) to acquire knowledge on the seasonal abundance and species composition of stink bugs in four apple orchards using pyramidal traps and beating trays; 2) to adapt and test an attract-and-kill strategy based on the knowledge acquired in those four orchards. A total of 20 different species of stink bugs were identified from sampled sites, four of which being considered strictly phytophagous. *Euschistus servus euschistoides* represented 80% of all individuals captured overall by all monitoring techniques in 2019 and 2020. Predatory species represented between 0.5% and 2% of captured individuals between 2019 and 2021. Monitored numbers peaked at the end of August for *E. servus*. *Chinavia hilaris*, *E. tristigmus* and *Halyomorpha halys* arrived in second, third and fourth places respectively in terms of numbers monitored. Trece's multi-species pheromone lures (PHEROCON CSB + PHEROCON GSB + PHEROCON BMSB) caught the highest numbers of species and the highest numbers of individuals, and were thus chosen for attract-and-kill trials in 2021. We used those lures in association with sticky-coated yellow panel traps deployed every 30 m at the periphery of the orchards, from June until September. This was enough to trap many stink bugs (ca. 10000 individuals /ha) and reduce by half the proportion of fruit injured by stink bugs at harvest in two sites. Overall, the reduction of damage averaged 25% but did not translate into a statistically significant effect. While conducting our experiment, information was also collected regarding the appearance of damage to fruit caused by the occurring phytophagous species.

Keywords: attract-and-kill, IPM, pesticide-free control, mass-trapping, brown marmorated stink bug.

Various crop load management on columnar apple trees – first year results

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Research on optimising crop load management mostly deals with varieties of common growing types. Nevertheless, there is not much research work connected with crop load management on columnar apple varieties. After certain chill in interest, the columnar apple varieties are considered promising again, especially for 2D canopy systems. The interest in 2D systems is among others driven by the prospect of increasing robotization in orchard management. One of the main constrictions of introducing columnar apple varieties in common growing is the high tendency to alternate bearing. To handle this problem, we designed several thinning strategies in order to attain stable flower sets and yields on columnar apple variety ´Redspring´/M26. Three main strategies are tested. First, only the reduction of flower clusters is done. Second, the reduction of flower clusters is combined with following thinning on king fruit. Third, the reduction of flower clusters is followed by reduction of fruits on set crop load. In all three strategies, the levels of thinning are set to 20, 30, or 40 units per 100 cm of central axis. The results from the first year indicate that stronger thinning combining flower cluster and fruit reduction will be necessary to avoid alternate bearing in columnar apple varieties.

Keywords: *Malus* sp., thinning, flower cluster, fruitlet, yield, alternation.

Automated apple orchard blossom mapping from drone image analysis

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In this study, a software was developed in Python programming language to map the flower load density variability at tree level. The study aims in providing useful information for immediate field interventions, that could potentially help growers in either making informed decisions along with the orchard management or improving yield predictions. The software requirements were short computing time, apple-tree training system adaptation (2D-planar cordon and 3D-spindle bush), and full automation of the process between aerial data collection and information supply. The study was done in Italy, in a 1.6 ha 'Fuji' apple orchard with a planting distance of 3.0 m x 1.0m and super-spindle trained system. Aerial images of the whole orchard and georeferenced ground truth flowering data of 100 trees were collected in the same day. Results showed that image segmentation and direct georeferencing work well for mapping blooming variability. The system had an in-row geolocation RMSE of ±0.19-1.60 m for 3D and 2D training systems respectively. However, the implemented software reduced processing time by 89% compared to a previous solution. Results highlighted that the main constraints for a proper mapping were soil brightness, lighting conditions and presence of hail-nets hiding the top of the canopy.

Keywords: precision orchard management, computer vision, geoprocessing, flowering, apple.

Imaging technology for identifying hull rot hot spots in almond orchards

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Remote multispectral and thermal imagery was investigated for determining the risk of hull rot disease expression within Australian almond orchards. Ceres Imaging have developed a predictive model based on images collected prior to disease expression which identified zones of high and low risk within orchard blocks. The predictive model was validated over two seasons within the Sunraysia region. Across all seasons, the model identified multiple areas of high and low risk within an orchard. For the 2019/20 season the model was developed using data collected in a single fixed wing flight in November, while for the 2020/21 season cumulative data from multiple flights (Sep-Jan) was incorporated. GPS mapping of the predicted zones was used to pinpoint specific areas within the orchard for assessment. In the field, hull rot disease severity was visually assessed prior to harvest in each of the identified high and low risk areas. In season 2019/20 three low risk and three high risk replicates were selected within a single block at a Lake Powell orchard. In season 2020/21 eighteen high risk and low risk sites across six blocks (three each per block) were chosen for visual hull rot severity assessment within the same orchard. Across both seasons, areas designated as high risk had significantly ($P < 0.001$) greater disease severity than low risk areas. The Ceres Imaging model for hull rot prediction shows considerable promise and has the potential to provide significant improvements to orchard disease management practices. However, further validation across multiple orchards and growing regions is required.

Keywords: disease, *Rhizopus*, remote multispectral imagery.

Investigating the potential of drones to improve precision agriculture in cranberry production

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Recent technological improvements in drones offer opportunities for improving precision agriculture. The objective of the research was to explore various ways drones can aid in cranberry production. Three experiments were conducted 1) Explore the use of thermal imaging to improve the placement of the temperature sensors used for frost protection, 2) Investigate the use of visible and multispectral imaging to map and detect insect damage and 3) Investigate the use of multispectral imaging for detecting the efficiency of rotary spreader fertilizer applications. Data was collected for the thermal imaging experiment using a long-wave infrared camera, and temperature measurements were calibrated to adjust for environmental conditions affecting emissivity, reflected radiation, and atmospheric transmissivity. For insect damage and fertilizer application efficiency experiments, data was collected using a multispectral drone connected to a high-accuracy mobile base station that applied RTK corrections to image position metadata. The multispectral camera was calibrated with a calibrated reflectance target before the flights. Orthomosaics and digital surface models were stitched from raw images using photogrammetry software. Results from the thermal imaging experiments allowed us to pinpoint the coldest spot on the bog with high precision. The results were then used for the precision placement of the frost temperature sensors. The orthomosaics from the RGB and multispectral cameras showed the extent of Putnam scale damage. The information from insect damage orthomosaics was utilized to create maps for spot or variable rate applications, reducing insecticide usage. Both visible and normalized difference vegetation index orthomosaic maps seemed to suggest that traditional ground-based rotary spreader fertilizer applications were shown to be inefficient, and results from tissue analysis confirmed this. The orthomosaics were utilized for creating maps for variable-rate input applications to achieve bog uniformity. In conclusion, drones have the potential for various uses in cranberry production to improve precision agriculture.

Keywords: *Vaccinium macrocarpon*, remote sensing, digital agriculture, unmanned aerial vehicle (UAV).

A LiDAR 3D point cloud analysis based non-destructive approach to predict ripening class and to estimate chlorophyll content in tomato

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Tomato (*Solanum lycopersicum*) fruit undergoes physiochemical process during ripening that involves degradation of chlorophyll pigment content. Thus, visible change of colour from green to red occurs during ripening and based on the fruit colour, ripening stage is defined. In this study, a new approach is proposed utilizing 3D point cloud-based intensity analysis acquired by light detection and ranging (LiDAR) laser scanner to determine the ripening stage of tomato and to estimate chlorophyll content. Freshly harvested tomato fruit (n = 100) of six ripening stages (mature green, breaker, turning, pink, light red, and red) according to USDA standard, were analysed using a linear conveyor mounted LiDAR scanner system in the laboratory. Each fruit was scanned from 1 m distance with the LiDAR system emitting at 660 nm wavelength. Subsequently, tomato samples were analysed chemically in laboratory for the determination of chlorophyll content and this result was used as reference. Intensity of the tomato point clouds were calibrated using standard black and white colour coated boards. Geometric correction of calibrated intensity was performed to correct for the curvature of individual tomato samples. The obtained average corrected backscattered intensity values from all point clouds were showed a linear correlation (R^2 = 0.61) with reference chlorophyll content. Finally, a linear model was built which able to estimate the total chlorophyll content with a root mean squared error (RMSE) of 4.97 mg per 100 g dry mass. Additionally, intensity histogram of pre-processed data was used for building a partial least squared regression model to predict ripening classes related to the colour of the fruit. The results showed that the average accuracy of detection of ripening stages of tomato samples achieved 75%. This proposed approach showed encouraging result for non-destructive and non-contact analysis of tomato fruit pigment and ripeness by means of LiDAR laser scanner.

Keywords: tomato, intensity, chlorophyll content, laser scanner, LiDAR.

Assessment of canopy development in almond trees with the use of fixed cameras

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The VitiCanopy app was used to provide canopy architecture data on a field trial investigating two different training techniques for young almond trees. While historically the use of this app has required images to be taken manually with a smartphone or other image capturing device on a periodic basis, this project provided a novel application of the technology by applying the software to images taken with remote capture trail cameras. The utilisation of images captured by time lapse allowed for new daily canopy development data streams including plant area index (PAI) and provided a clear trackable progression of seasonal vegetative growth. Images were also captured manually with a smartphone approximately every two weeks to allow for a whole block comparison, as well as an assessment of the representativeness of the data sourced from the time lapse cameras. Differences between applied training techniques were clearly evident for both methods of image capture. The time lapse cameras in particular were successful in capturing and quantifying the response to pruning and trimming events. While canopy parameters are known to impact metrics such as water usage, canopy size and development are rarely considered for irrigation scheduling. Having easy access to canopy development data on a daily basis may provide growers with a tool allowing for more informed orchard management decision making.

Keywords: canopy architecture, image analysis, almonds.

Precision agriculture techniques for evaluating tart cherry tree health

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Precision agriculture techniques have not been used to assess tart cherry tree health, due in part to the low-input and relatively low-value nature of the crop. However, current techniques for tree health monitoring are labor intensive and often fail to detect issues before yield and fruit quality are impacted. The increasing affordability of precision agriculture technology presents unique possibilities for assessing tree health in a low-input horticultural crop. We tested high-resolution ceptometry, soil electromagnetic induction (EM) mapping, UAV-mounted RGB and multispectral imagery, as well as satellite imagery for correlations to tree health parameters. Traditional scouting was also carried out to assess tree nutrient status and incidence of powdery mildew and spider mite damage. These combinations of data have shown that higher canopy density is correlated with higher pest and disease incidence. The relationship between soil EM values and tree health differed by symptom and location. Emerging precision agriculture technologies may provide management opportunities for lower-value orchard crops such as tart cherry.

Keywords: powdery mildew, two-spotted spider mite, tart cherry, precision agriculture.

Aphids and the natural enemy complex in an orchard with flower strips

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Apple orchards are regularly disturbed by pesticide applications that influence insect population dynamics and pest natural control. In a broader context of fostering biocontrol to reduce pesticide usage, and specifically to increase biodiversity and conserve natural enemies, blocks of untreated apple trees were managed in an experimental orchard. Flower strips composed of 12 species of biennial and perennial plants were established in the alleys between rows of apple trees. Their effects on green aphid biocontrol were compared with unmanaged control plots. Green aphid colonies and their natural enemies were monitored weekly during two seasons in apple trees located in the central rows of each plot. Aphid colony size was similar between treatments in the first year of sampling, but in the second year, colonies were larger early in the season in the managed plots. Predator numbers were similar in both treatments in the first year and significantly higher in the managed plots than in the unmanaged plots in the second year. The composition of the aphid predator guild was more diverse in the first year than in the second year. However, a significantly greater predominance of Cecidomyiidae was observed in the second year, in the managed plots compared with the control plots. The study did not allow us to demonstrate the expected beneficial impact of establishing flower strips on the natural biological control of aphids.

Keywords: *Aphis pomi*, *Aphis spiraecola*, flowering plants, habitat manipulation, companion plants.

Effects of mechanical defoliation on fruit quality of 'Picnic' apples

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Recently, due to the declining population and increasing aging of rural areas, it is necessary to reduce labor in apple cultivation. Accordingly, interest in mechanization technology is increasing as a way to replace workforce. As a way to replace workforce in apple cultivation, there is mechanization of defoliation, thinning, pruning and harvesting. In this experiment, the effect of mechanical defoliation on apples was studied. The mechanical defoliation was performed with a tractor attached to a pulsed-air leaf remover. The tractor speed was set at 2.5 km/h, and the air pressure set at 0.9 bar. The mechanical defoliation was performed at 15 days before harvest, 30 days before harvest, 15 days+30 days before harvest. The defoliation rates were 17.1 % at 15 days before harvest, 28.2 % at 15+30 days before harvest and 8.7 % at 30 days before harvest. The solar irradiance was highest at 30 days before harvest. The hunter a values of apple did not show a significant difference in the 3 treatments but tended to be higher than control. Therefore, mechanical defoliation had an effect on coloring. Also, the sugar content was highest—14.76 °Brix at 30 days before harvest. The mechanical defoliation is thought to be one of the ways to replace workforce. And there will be a continuous need for research that can be mechanized as well as mechanical defoliation. (This work was carried out with the support of "Cooperative Research Program for Agriculture Science and Technology Development (Project No. RS-2021-RD009831)" Rural Development Administration, Republic of Korea).

Keywords: apple, mechanical defoliation, leaf removal.

Assessing the relationship between soil variability, canopy density, and yield in Utah tart cherry orchards

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Tart cherry trees (*Prunus cerasus*) are commonly cultivated in Utah, USA at the foothills of mountains to take advantage of the favorable microclimate. Consequently, orchard blocks in this region exhibit highly diverse soil conditions, posing challenges for achieving uniformity in tree growth and yield potential. This study aimed to assess the spatial variability of soil and its relationship with canopy density and yield in four orchards located in Santaquin, Utah. In 2022, soil maps for each orchard were generated by surveying apparent electrical conductivity (ECa) using an electromagnetic induction meter. The resulting ECa maps guided the selection of sampling locations for measuring soil texture, salinity, and organic matter. Canopy density was monitored monthly during the 2022 and 2023 growing season using ceptometry and drone imagery. The soil sampling results revealed significant correlations between ECa and the percentages of sand, silt, and clay. Preliminary results additionally indicate that canopy characteristics (size and density) are closely correlated with variations in soil texture. We hypothesize that these canopy differences will directly impact yield variability and that soil ECa can be used to predict areas of maximum yield potential. The findings from this study will contribute to a better understanding of the relationship between soil characteristics, canopy density, and yield in tart cherry orchards, and can inform orchard management practices to optimize fruit production.

Keywords: canopy density, soil variability, tart cherry, yield.

Using LiDAR and machine vision to measure almond tree size and yield in a high-density pruning experiment

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Mobile sensor platforms combined with image recognition techniques are powerful research tools that can be used to efficiently collect accurate tree response data in field experiments. In this study, LiDAR and optical images were used to measure the effects of cultivar and tree pruning on productivity in a young high-density almond orchard. An experiment was established at the Tatura SmartFarm in 2019. The experiment compared the performance of two cultivars ('Nonpareil' and 'Shasta') and four pruning treatments. Pruning treatments consisted of an unpruned control (C), an annually pruned hedgerow (H), an annually pruned hedgerow with one-side branches removed prior to the fourth growing season (H+BR), and a manually pruned central leader where branches were thinned prior to the third growing season (BT). Canopy features such as density and cross-sectional leaf area (CSLA) were measured in the second (Y2), third (Y3) and fourth (Y4) growing season after planting using a LiDAR mounted on an all-terrain vehicle (Green Atlas Cartographer). Light interception was estimated from CSLA. Nut yield (at 4.5% moisture content) in Y3 and Y4 was calculated from in situ fruit counts detected using optical images collected with Cartographer and a hand-harvested subsample to determine nut dry weight. Fruit counts from the analysis of optical images were adjusted for obscuration and double counts by comparing sensed data to manual nut counts from two trees per plot in Y3. Results showed that 'Shasta' yield was 15% greater than 'Nonpareil' in Y3 but then 20% less in Y4. There was no difference in yield between C and H pruning treatments. BT yield was approximately 30 and 20% less than C in Y3 and Y4, respectively. Similarly, the H+BR reduced yield by 20% compared to C in Y4. Difference in yield in terms of light interception and the potential long-term impacts of the pruning treatments will be discussed.

Keywords: hedgerows, central leader, branch removal, leaf area, light interception, 'Nonpareil', 'Shasta'.

Development and testing of a Smartphone Application for forecasting the water requirements of apple orchards one to ten days in advance

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In semi-arid countries like South Africa commercial fruit production is entirely dependent on irrigation. Water allocation to different orchard irrigation blocks is usually planned at least one week ahead to get the various logistics in place. Yet there are currently no reliable tools for predicting the orchard water requirements even for the next few days ahead. In this study we developed a Smartphone Application (hereafter APP) for estimating the water use of apple orchards using readily available data. The APP forecasts the daily reference evapotranspiration (ETo) for a user specified location 1 to 10 days in advance using the FAO Penman-Monteith equation. Weather forecast data are obtained from an online data source (www.darksky.net). The orchard water use is calculated as the product of ETo and a crop coefficient (Kc). The crop coefficients are estimated using readily available data for the orchard e.g. fractional vegetation cover, average tree height, wetted soil fraction, soil type, orchard ground cover status, etc. The APP's water use forecasts were validated with field measurements of orchard level transpiration determined using sap flow sensors and evapotranspiration using an open path eddy covariance system. While the forecast ETo closely matched the observed trends, the APP tended to slightly overestimate the reference evapotranspiration on hot dry days by just over 1.0 mm/d. In high density orchards in which individual tree canopy volumes were small, the APP's forecasts of orchard transpiration were fairly accurate with the root mean square error less than ±1.0 mm/d. However, in mature orchards with wider row spacings in which trees had large canopies, the APP significantly under-estimated the transpiration rates, possibly because of the inaccurate estimates of the fractional vegetation cover. Work is still ongoing to improve the accuracy of the APP in partnership with fruit growers in the Western Cape Province, South Africa.

Keywords: crop coefficients, fractional vegetation cover, reference evapotranspiration, sap flow.

Potassium management in almond: where we have been and where we need to go

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In almonds, K-fertilization represents a substantial expense for the grower; based on 2022 prices, the K off-take in an average crop of 300-400 kg K ha represents > $100,000 fertilizer cost. Several studies find K as the most variable macronutrient element, varying markedly between samples, dates, and space, even in visually uniform orchards. Because of the absence of more reliable methodologies, growers largely base their K fertilization decision on July leaf analysis, which is however highly variable and difficult to interpret, and leads to excessive applications of K and to the adoption of leaf nutrient guidelines that are frequently more than the scientifically established critical nutrient value. A grower-accepted mid-season leaf K CV of > 2% is indeed routinely used to avoid the risk of K deficiency in high-value crops, despite repeated demonstrations that the scientifically established CV is 1.4% K. The lack of widely available technologies for site-specific determination of K demand and the lack of variable rate application, as well as sampling and interpretation uncertainty, results in grower K-applications at uniform high rates across orchards, regardless of the different plant requirements and local soil K availability. However, as fertilizer prices are increasing, this is wasteful and not economically viable. Improvements in the K management practices have long been limited because of the difficulty of precisely determining plant K-availability and the soil response to applied K fertilizer. We will report on the use of direct, proximal, and remote sensing technologies to understand the extent and causes of K field variability and its relationship to factors such as soil moisture, clay mineralogy, history of previous treatment, plant uptake rate, and fertilizers uniformity distribution. The goal is to understand the causes of variability and utilize that information to develop guidelines to improve fertilization strategies and the reliability of soil, plant, and sensor-based tests and to develop new integrated methods and models, which ultimately would help increase K-use efficiency while reducing K-related costs.

Keywords: within orchard variability, potassium management, almond orchard.

Applying a solar model to LiDAR images of an agrivoltaic pear orchard

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Agrivoltaic farming is the practice of growing crops underneath solar panels. Using photovoltaic arrays above tree canopies can potentially save water by limiting transpiration, protect trees and fruit from damage (extreme heat, sunlight, hail), and avoid plant water stress in the hottest periods of the day. The aim of this study was to simulate tree total and localised light interception under different configurations of photovoltaic arrays and in relation to control trees (no photovoltaic arrays). The study was conducted in an experimental pear orchard at the Tatura SmartFarm (Victoria, Australia). Trees of the Australian blush pear 'ANP-0118' trained to an open Tatura trellis (V) were used for the experiment. LiDAR (Laser Imaging Detection and Ranging) and RGB images of trees (on the east and west sides of the row) were obtained with the Leica-BLK360 scanner in three different treatments: a control with no photovoltaic arrays, above-canopy photovoltaic arrays angled at 45° to the west, and above-canopy photovoltaic arrays angled at 5° to the west. A solar radiation model was applied to LiDAR-point cloud images obtained in the three treatments to simulate the solar radiation interception. The utility of the sensor for canopy radiation interception modelling and for additional uses such as leaf area and fruit number estimations will be discussed.

Keywords: precision agriculture, solar radiation simulator, tree leaf area, proximity sensing.

High performance computing for explicit simulation of orchard spray practices

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Computer virtualisation has been expected as an alternative to physical objects for studying agricultural spray practices. Some computational models allow the simulation of explicit movement of individual droplet from nozzles to targets. However, the utilisation of such simulations has been limited due to programming and computing constraints. The conventional serial programs can only use one compute core at a time, regardless of the availability of multiple cores in a computer (including powerful supercomputers with thousands of cores). Consequently, the complexity and details of simulation are often compromised for efficient computing, or vice versa. The oversimplification of virtual experimentation results in reduced accuracy and reliability, while the prolonged implementation times are also intolerable by end users. There have been studies using commercial CFD (Computational Fluid Dynamics) software tools equipped with robust computing capabilities for simulation of spray processes, but such platforms are usually very costly and require programming skills and/or good knowledge of fluid dynamics, which prevents its adoption by the majority of agronomists and growers. In this research, we have developed a high performance computing approach allowing users to achieve both good efficiency and high accuracy in the simulation process. The technology has been tested and verified on an ordinary desktop computer with commodity components, to ensure its affordability and accessibility. It has been used to power digital twins for mitigation of orchard spray drift, where every single droplet can be traced and the sprayer settings (such as spray angle, nozzle direction and tractor speed) can be easily adjusted and assessed against spray drift. The technology can also be deployed on high-end computing clusters to further boost the acceleration and enable remote access for large-scale applications.

Keywords: digital twins, digital agriculture, orchard management, pesticide, sprayer.

Characterising tree architectural traits in pear selections using LiDAR

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Phenotyping fruit tree architectural traits using modern technology is pivotal to accelerate genotype selection in modern breeding programs. Parameters such as leaf area, trunk diameter, shoot length, fruit bearing pattern and fruit density are key architectural features for fruit trees to adapt to high-density training systems and climate uncertainty. LiDAR (Light Detection and Ranging) scanning is a modern technology that has great potential to be used for fruit tree phenotyping and can provide information on spatial coordinates of detected features to derive their within-tree spatial variability. The aim of this study was to characterise architectural traits in 19 pear genotypes by extracting features such as leaf area, shoot length, number of lateral shoots, fruit bearing patterns (in long shoots and in short spurs), fruit density (no. fruits per cluster and per lateral). Data were collected from the pear repository located at the Tatura SmartFarm (Victoria, Australia). Nineteen selections were shortlisted from a pool of over a hundred selections, based on their promising features for the Australian pear industry. Scans were obtained on east and west sides of pear trees trained to a V-trellis using a Leica-BLK360 LiDAR. Two scans per tree were joined to obtain bundles. Results on accuracy and precision of estimations, differences in architectural traits between genotypes and the implications of using quantitative traits for genome sequencing studies are discussed.

Keywords: fruit bearing pattern, leaf area, phenotyping, precision agriculture, remote sensing.

Canopy management in cocoa (*Theobroma cacao*) in reference to yield under high density planting

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Cocoa is produced primarily by smallholder farmers in developing nations in the equatorial tropics. In Far north Queensland, the cocoa industry is in its infancy and growers have expanded either into value-added chocolate making “tree to bar” and agritourism ventures or established their cocoa plantations to supply pods to chocolate producers thus diversifying their production base from sugar cane or bananas. Improving productivity through labour efficient growing systems is a key driver for a prosperous and long-lasting cocoa industry in northern Australia. Production methodologies in Australia are intensive with cocoa grown under intense management system; grafted, full sun, fertigated and mechanically pruned. The effect of high-density planting on different training systems in reference to yield was studied. This included two selections of cocoa planted alternately in a six-row espalier trellis system structure at the Centre for Wet Tropics Agriculture, South Johnstone, Queensland in March 2018. Treatments were: Conventional trees (Control), Horizontal training (HT), Angular 45° branch training (AT) all trees planted at the density of 1100 trees/ha, Single Spindle training (SST) planted at 1600 trees/ha. Within each treatment a sub treatment either heavy pruned or light pruned was applied to half the trees in the plot. Over three full seasons, the highest number of pods/ha and the highest tonnes of dry bean equivalent/ha was achieved under the SST system (1600 trees/ha). However, at the lower density (1100 trees/ha) planting the highest number of pods/ha and the highest dry bean equivalent/ha was achieved under the HT system. Heavy pruning reduced yields in all treatments. This poster describes the research underpinning the development of a high yielding cocoa industry in the wet tropics of north Queensland. These systems not only make for more production/ha but also provide potential resistance to cocoa plantations in the event of severe weather conditions including cyclones.

Keywords: growing systems, high-density, cyclones.

Alternative post-harvest drying and storage systems for almonds

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The almond industry needs to migrate to shake-and-catch harvesting systems to address food safety and dust pollution concerns in current harvest practices. Higher density planting systems would not only accommodate shake-and-catch overhead harvesters, but also reduce resource use and allow for better precision management of orchards. To reduce windfall fruit will need to be harvested earlier than traditionally harvested. Efficient drying systems will be required to dry these fruit to the required levels for processing and to avoid spoilage. Current stockpiling systems, where fruit is stored in bunkers under tarps, does not allow for controlled drying and fumigation is furthermore not effective. The study evaluated novel drying systems — a hybrid between a stockpile bunker and grain silo referred to as almond drying and conditioning pods. A smart controller regulates the intake air flow according to the ambient conditions. The drying capability of the system was evaluated with high-moisture almond fruit. Multiple sensors monitored the conditions within the drying pods and the fruit drying characteristics were ascertained through manual sampling.

Keywords: almond, drying.

Low-cost IoT solutions for orchard monitoring and management

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Technology developments offer advanced sensors in horticulture and allow data streaming in real-time into a cloud or an Application Programming Interface (API). Communication protocols such as LoRaWAN, 4G, and 5G more recently play a significant role in the application of the Internet of Things (IoT) for orchard management. Data can be accessed via dashboards and curated by deep learning techniques so that the end user does not need a sophisticated technical understanding of data processing. Water flow meters, soil moisture probes, trunk dendrometers and weather stations are examples of commonly used sensors in commercial orchards that can be interfaced with LoRaWAN transmitters and gateways. They provide valuable data on crop and environmental parameters such as temperature, humidity, solar radiation, soil moisture and irrigation inputs, and their smart data integration has great potential to inform precision management strategies for modern orchards. The aim of this work was to test and validate the accuracy of low-cost, off-the-shelf LoRaWAN-enabled sensors that would be valuable for horticulture research and commercial practices. A LoRaWAN gateway was installed at the Tatura SmartFarm and connected to the internet. Temperature, relative humidity and radiation sensors were connected to the gateway to stream weather data in real time. They were positioned near a trusted weather station to determine accuracy. In addition, LoRaWAN high-sensitivity water flow meters were tested against an industrial water flow meter commonly used in irrigation lines. Data were streamed into different cloud platforms for comparison. Results on accuracy and precision of the sensors will be presented and recommendations on additional sensors that could be added to the current network will be discussed.

Keywords: LoRaWAN devices, cloud platform, weather station, orchard management, precision agriculture.

Carry-over effects of long-term water deficit in nectarine

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Improved irrigation management is important to sustain agriculture faced with climate change and water scarcity. The aim of this study was to assess carry-over effect of long-term (6 years) deficit irrigation management in a nectarine orchard exposed to a full-irrigation recovery season. This study was conducted on mature high-density 'September Bright' (late cultivar) nectarine trees previously subjected to long-term irrigation treatments — irrigation with 100% (control) of crop evapotranspiration (ETc), 40% ETc, 20% ETc and no irrigation (0% ETc) at different fruit growth stages. A ground-based mobile platform sensor system equipped with RGB cameras, LiDAR, GPS and infrared temperature sensors for rapid measurements of tree and fruit metrics was deployed during season 2022–23 to assess drought recovery under 100% ETc irrigation. Despite full water supply in the recovery year, historical severe deficit irrigation regimes (0 and 20% ETc) had reduced tree size, greater trunk scaring, produced lower fruit number, were more likely to have reduced fruit skin redness development and exhibited higher levels of water stress under peak evaporative demand in clear sky conditions, measured by canopy temperature (Tc) and crop water stress index (CWSI). Fruit yield was not impacted by lower fruit number due to a compensation effect in fruit weight. Trees previously subjected to regulated deficit irrigation (RDI, 40% ETc during the fruit pit-hardening stage) returned to full production and had equivocal vegetative metrics and crop water status to control (100% ETc) trees. Our results highlighted that long-term deficit irrigation carried out in stages other than pit hardening has detrimental effects on nectarine orchard performance despite their exposure to full-irrigation recovery.

Keywords: drought recovery, *P. persica* (L.) Batsch, plant water status, precision agriculture, water stress.

The effect of cover crop vegetation on drought resilience in orchards

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In the Australian agricultural context, persistent drought conditions have a substantial effect on fruit production. Extended periods with insufficient rainfall reduce irrigation water availability, increase water cost, and can adversely affect the chemical and physical properties of soils, resulting in diminished crop yield and fruit quality. This study aims to investigate how cover crops can enhance drought resilience in orchards by improving the soil properties and conditions of inter-rows using different irrigation practices. The study uses a 'Beurre Bosc' pear (Pyrus communis L.) orchard near Toolamba in the Goulburn Valley, Australia. The experiment consists of three irrigation blocks (full irrigation, regulated deficit irrigation and no irrigation) and four cover crop treatments (control, lucerne, canola and tillage radish) with each cover crop treatment replicated four times and completely randomized within each irrigation block. A comprehensive soil monitoring system, comprising soil moisture probes and thermometers, has been implemented to quantify volumetric water content and soil temperature. Cover crop production and assessments of soil properties including compaction, penetration resistance, slaking, dispersion, and water infiltration will be undertaken. Concurrently, pear tree health and productivity parameters, including water status, canopy temperature, shoot length, flower density, fruit number, and fruit maturity, will be conducted employing specialized instruments such as dendrometers, pressure chambers, optical and thermal imaging, LiDAR and fruit maturity measurement tools. The study's primary significance lies in the integrated approach of using cover crops and deficit irrigation strategies to potentially present a practical solution for fruit growers to preserve water resources and sustain crop yields during drought periods.

Keywords: pear, deficit irrigation, soil properties, water stress.

Relationships between fruit quality and tree tissue metabolites in 'Ruby Matilda' apples under variable crop load management

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Crop load regulation is one of the most important aspects of apple orchard management due to its effects on yield, fruit quality and return bloom. While higher crop loads will result in higher yields, they will also negatively impact fruit quality, return bloom and potentially push susceptible cultivars into a biennial bearing cycle, resulting in inconsistent yields and fruit quality in future seasons. This work aimed to explore the effects of crop load on a range of fruit quality measures, return bloom and signalling compounds within 'Ruby Matilda' apples using a combination of conventional fruit and tree assessment techniques plus the high-resolution mass spectrometric analysis of various plant tissue extracts for potential compounds of interest. Relationships between fruit quality measures and tissue metabolites from a crop load experiment located in an orchard at Ardmona, Victoria, Australia were investigated. These relationships may provide useful insights which could help inform precision orchard management.

Keywords: signalling compounds, metabolomics, biennial bearing, return bloom.

Automated multi-system data integration implementing a novel data ecosystem: a fruit grading case study in horticulture research

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Sophisticated sensor systems are increasingly becoming an integral part in horticulture research experiments supporting data collection for experimental units and samples. These sensors may not always be deployed in-situ within an experiment and in some cases are used to take measurements on samples at facilities that may be remote to the experimental orchard. An example is the measurement of fruit quality using a fruit grading system. Currently, the critical linkage of this sample data to an orchard feature such as a plot, tree or individual fruit is largely done manually and lacks flexibility and precision. This affects research efficiency and creates issues in maintaining quality, precision, and resolution of research data. There is a need to improve and automate data integration across systems to help the researchers increase efficiency in data collection and retain its resolution whether it be collected from a plot, tree or individual fruit while enhancing latter analysis. This paper presents a use case study for the application of a research data ecosystem model, recently developed in the Agriculture Victoria Research, to automatically integrate multi sensor data from a fruit grader with experimental design data from Tatura SmartFarm research orchard in Victoria, Australia. Radio Frequency Identification (RFID) technology is used to identify and tag experimental units and containers and coupled with a traceability sub system within the data ecosystem to enable the connection of a container loaded at the grader back to an orchard feature (i.e., tree). An application was developed to coordinate these processes and associate fruit quality parameters estimated from the sensor systems with the orchard feature identifier to allow data linkage. This use case provides an exemplar model to enable linkage between fruit grading data at a processor and the commercial orchard features for production reporting and traceability.

Keywords: precision agriculture, fruit grader, data ecosystem, data integration, tracking, horticulture research, orchard management.

Compatibility of orchard sprayers with exclusion netting systems: a case study from apple orchards of Quebec, Canada

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The use of exclusion nets for apple orchards can offer protection against key pests without the need for pesticides. However, sprays such as fertilizers and thinning agents remain necessary, and some pests/diseases can also develop under the nets, requiring treatment. The first goal of this project was to determine spraying parameters to use in order to optimize the deposition rate, in the context of a row-by-row exclusion system using fine mesh (2.2x3.4mm) netting. Then, we measured the effectiveness of field applications of an aphicide, a thinning agent and fungicides through this system, made according to these parameters. The level of infestation of aphids, the occurrence and severity of apple scab and the crop load were measured before each application, made either through the net and in the absence of a net, and reassessed after full effectiveness of the treatment was expected. By validating the efficacy of a spraying technique optimized for exclusion systems, this project could facilitate its adoption by a greater number of growers and for a greater number of cultivars.

Keywords: apple orchards, low-input agriculture, pesticide spraying, physical control.

Assessment of hyperspectral-based physiological traits to establish relationships with biochemical components in apple fruit

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Apple leaf photosynthetic pigments including chlorophyll, carotenoids, xanthophylls and anthocyanins are important when studying fruit quality as they are involved in the same chemical metabolic pathway as polyphenols and terpenoids which determine flavour and aroma characteristics in cider. Air-borne hyperspectral imaging provides narrow-banded plant vegetation indices as proxies to model fruit biochemical components under water and nutrient stress, and their impact on fruit biochemical components. In this study, leaf and canopy spectral measurements and physiological traits retrieved via radiative transfer modelling will be used to assess relationships with biochemical composition in apple fruit. Hyperspectral images will be taken using visible and near- infrared hyperspectral sensor (Headwall Photonics, Fitchburg USA) and a thermal camera (FLIR A655sc, FLIR systems, Wilsonville, OR, USA) installed on board the aircraft operated by HyperSens Lab, University of Melbourne to fly over the Tatura Sundial Orchard at three phenological growth stages (BBCH 65, BBCH 71 and BBCH 81). In-field leaf spectral measurements will be performed using a SPAD and Dualex to ground truth the hyperspectral data. At harvest, analytical techniques will measure free and glycosidic bound terpenes in the fruit using headspace solid phase micro-extraction gas chromatography-mass spectroscopy and polyphenols will be measured using ultra-performance liquid chromatography to quantify and characterise compounds. Fruit biochemical components from different row orientations and rootstocks in the Sundial Orchard will be used to inform the horticultural industry of canopy management to produce quality apples and reduce the volume of waste product by repurposing the fruit for high value cider production.

Keywords: hyperspectral imaging, photosynthetic pigments, apples, biochemical composition.

Metabolomic study of plant tissue during floral transition in apple trees with different crop load levels

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Application of thinning agents to maintain consistent flower production, fruit quality and yield of biennial bearing apple cultivars is essential for fruit growers. Fruitlets are known to repress flowering buds, thus reduce fruit formation the following season. Conversely, the presence of leaves adjacent to buds can stimulate floral development. Previous studies have investigated compounds associated with floral induction (FI), when signals are believed to be received by vegetative buds to trigger flower development. These compounds include plant hormones such as cytokinins, salicylates as well as chlorogenic acid and its derivatives. However, related pathway metabolites in other plant tissue have not been investigated. This work aimed to identify potential promotors and repressors in leaves and fruitlets in 'Ruby Matilda' apples during the FI phase of flower meristem development. Different crop load levels were imposed to individual leader of bi-axis trees. Leaf and fruitlet samples were collected at 70 days after full bloom. The investigation may provide insight into precision crop load management strategies.

Keywords: *Malus domestica*, metabolomics, floral induction, biennial bearing.

Utilizing real-time data loggers to improve export supply chains of fresh fruit from Australia

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Victorian producers need to ensure fresh produce arrives in international markets in premium condition which can be difficult to achieve due to Australia's geographic location and competition from other southern hemisphere countries. Fruit growers and exporters can utilize new generation wireless SIM-based (4/5G) data loggers that are capable of measuring temperature, relative humidity, light, shock, and location in real time. Loggers autonomously upload data when connected to mobile networks that can be viewed on smart devices or computers with no need to retrieve loggers. Real-time alerts via email or SMS can be programmed to track produce locations during transit and arrival and departure times from specified points in the supply chain, as well as to track if consignment parameters fluctuate outside pre-set limits. GPS and light functions are added security in terms of food fraud and traceability as it indicates when shipping container doors or cartons have been opened. Geofencing around airports and accelerometers in loggers help switch devices to flight mode prior to take off. Agriculture Victoria has monitored over 150 sea and air freight consignments of table grapes, apples and stone fruit to Asian and European markets. Excessive transit times are usually the main issue with sea freight of many perishable crops hence cultivar selection, modified atmosphere packaging and an efficient cool chain are critical. Unforeseen delays during trans-shipping or at customs inspection points may inadvertently extend supply chain durations. Border closures and travel restrictions due to COVID-19 reduced air freight services and interrupted freight forwarder schedules; however, even under normal supply chain conditions, temperature fluctuations of up to 15 °C are not uncommon. Monitoring transit conditions can help exporters redirect produce to other markets or inform importers to prioritise the consignment for rapid sale. In addition, collected data may be used as evidence to determine the validity of claims or disputes.

Keywords: cool chain, GPS, temperature, fresh produce, fruit quality.

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