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Unveiling apple block variability using Green Atlas *Cartographer*

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Standfirst: [larger font overview at top] *New scanning and mapping technology has insights for managing crop load variability and fruit quality in apple orchards*

Excessive variability of crop load, fruit size and skin colour in apple orchards can cause loss of profit for growers. Currently there are no well-established methods to quantify crop load, fruit size and fruit colour variability objectively and accurately within orchard blocks or to inform and automate precision orchard management strategies. The apple cultivars marketed as Pink Lady® can have variable fruit quality, with some fruit not meeting marketing specifications. An adequate level of fruit redness is one of the key factors that determines premium price for the produce.

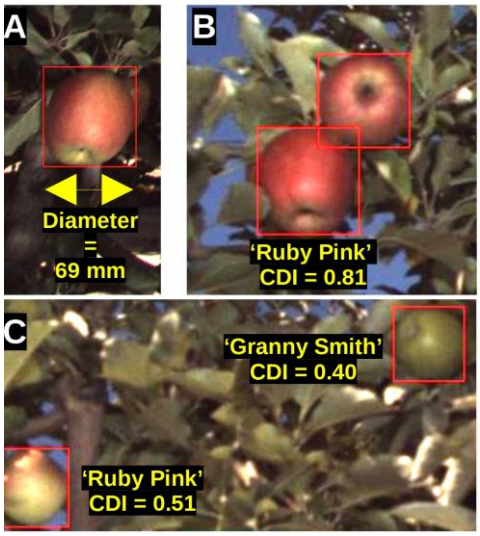
Pioneering research at Agriculture Victoria's Tatura SmartFarm, and in Goulburn Valley commercial orchards, is validating new technology to measure yield and fruit quality variability. The benefit of exploring this technology is it's potential to inform more efficient management options. The current work is part of the PIPS3 Program's *Advancing sustainable and technology driven apple orchard production systems (AP19003)* project led by Agriculture Victoria.

Measuring and mapping fruit number, fruit size and skin colour

The Australian company, Green Atlas, has commercialised the *Cartographer*, a ground-based platform that is equipped with a number of sensors (e.g., RGB cameras, LiDAR, GPS) used to estimate crop parameters such as flower and fruit number, and tree geometry attributes such as canopy height, area and density. The collaboration between Green Atlas and Agriculture Victoria aimed to validate the capability of the technology to accurately detect flower and fruit, after calibration against manual counts, and to test the accuracy and precision of fruit diameter and colour estimates from the detections.

In a recent study in 'ANABP 01' apples (marketed as Bravo™), the *Cartographer* was capable of predicting flower number, fruit number and yield with errors below 5%. Accurate detections of fruit are a prerequisite for accurate estimates of fruit size and colour with machine vision, as AI-derived detection boxes are used for the extraction of fruit diameter and colour attributes. Fruit skin colour was assessed using an intuitive colour development index (CDI), a colour attribute derived from hue angle that ranges from 0 (pure green) to 1 (pure red). 'ANABP 01' fruit diameter and CDI were predicted with an accuracy higher than 95 and 80%, respectively.

During the 2021-22 season, Agriculture Victoria scanned a commercial orchard of 'Ruby Pink' apples (Plunkett Orchards, Ardmona) for detections of fruit number, fruit diameter, CDI and tree geometry (canopy height, canopy area, canopy density and cross-sectional leaf area).



Examples of size and colour estimates of fruit detected by Green Atlas *Cartographer*: (A) 'Ruby Pink' fruit diameter, (B) 'Ruby Pink' colour development index (CDI), and (C) green 'Ruby Pink' (left) and 'Granny Smith' (right) colour development index (CDI).

The block was scanned in December (before thinning) and in April (before harvest). Fruit numbers per images were calibrated to generate estimates of fruit number per tree with errors of 7 and 6%, for the two dates, respectively. Spatial maps of crop parameters were generated and block averages and relative measures of spatial variability (coefficients of variation, %) were estimated. The relatively high variability of fruit number (> 40%) observed in the block, on both measurement dates, was mainly attributed to the very low crop load on 'Granny Smith' pollenisers that likely drove low pollination and crop load in 'Ruby Pink'.

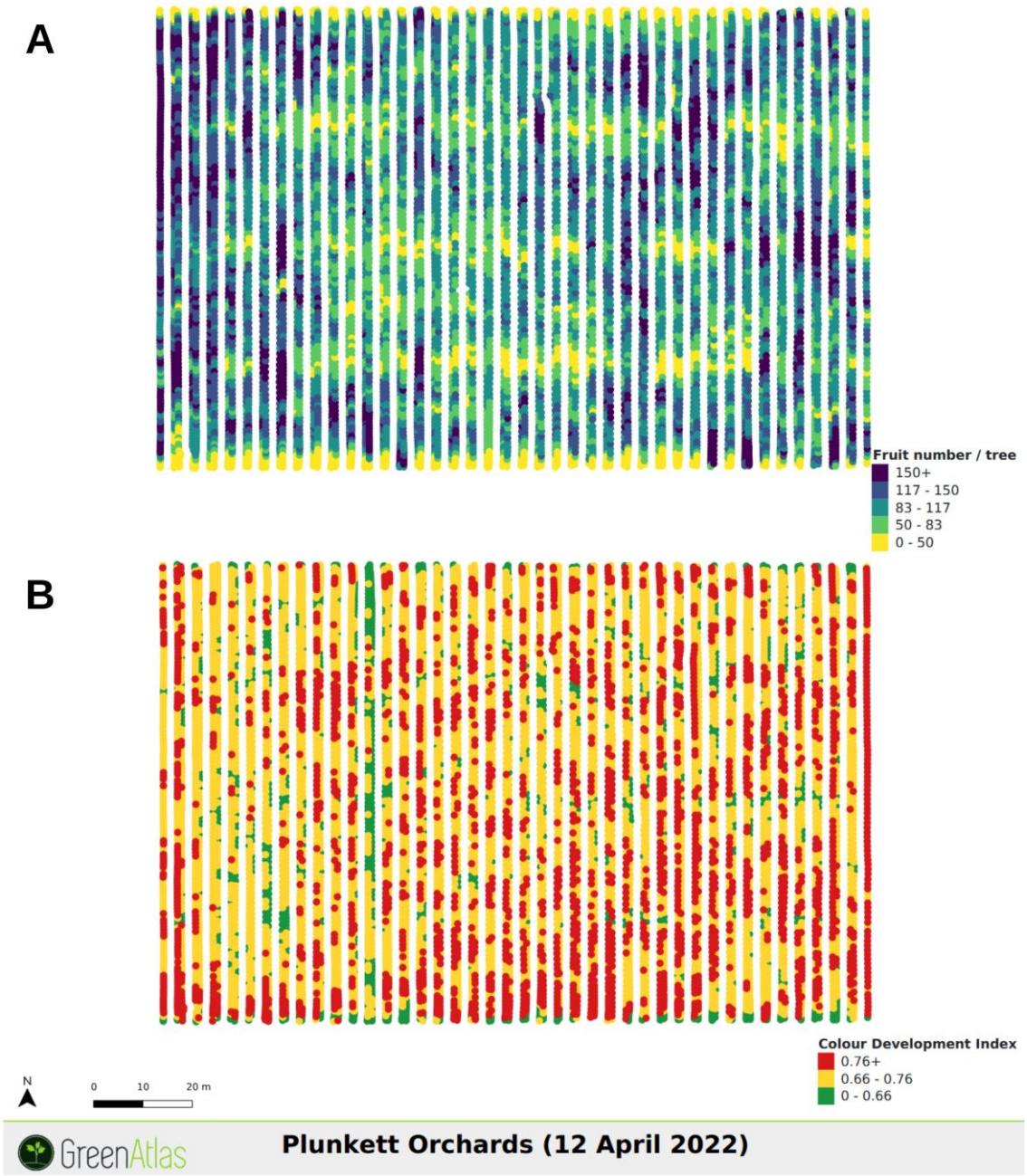
At harvest, fruit diameter and CDI had an average of 74 mm and 0.72 respectively, and relatively low spatial variability (coefficient of variation < 10%).

Average crop parameters and their variability (coefficient of variation) estimated using Green Atlas *Cartographer* in a commercial 'Ruby Pink' block (Plunkett Orchards, Ardmona) during 2021-22.

Measurement time	*Cartographer* output	Average in the block	Coefficient of variation (%)
Pre-thinning (December 2021)	Calibrated fruit number (n / tree)	173	49
	Fruit diameter (mm)	45	8.8
	Colour Development Index (CDI, 0 – 1)	0.41	8.8
Pre-harvest (April 2022)	Canopy height (m)	4.35	8.5
	Canopy area (m^2)	3.18	19
	Canopy density (0 – 1)	0.72	20
	Cross-sectional leaf area (m^2)	2.35	29
	Calibrated fruit number (n / tree)	101	42
	CDI (0 – 1)	0.72	8.9
	Fruit diameter (mm)	74	8.7

The fruit number map helped identify orchard hotspots with low crop load, mostly corresponding to pollenisers. There was a tendency for higher yields in the westernmost rows of the block. CDI was significantly reduced ($p < 0.001$) with higher canopy height, canopy area, canopy density, cross-sectional leaf area and fruit number per tree, and it was directly correlated with increasing fruit size. Interestingly, the CDI map unveiled a row in the block (thirteenth row from west to east) with greener fruit in which pruning and thinning were not

managed following the standards utilised in the rest of the block. This was due to an ongoing crop load experiment as part of the *AP19003* project.



Spatial maps of (A) calibrated fruit number per tree and (B) colour development index (CDI) in a commercial 'Ruby Pink' block (Plunkett Orchards, Ardmona) scanned in April 2022.

Growers should aim to obtain optimal fruit number, fruit size and colour while minimising the variability in the block. The maps generated by the *Cartographer* can be used to identify areas within a block that need additional management inputs (e.g., follow-up thinning) to produce high yields of quality fruit. In addition, packout yield can be forecast, irrigation requirements can be determined, and orchard automation and mechanisation can be better implemented using the *Cartographer* data. This data has great potential to be reutilised in other machines for spatially precise orchard operations (e.g., variable rate spraying, mechanical thinners, mechanical hedgers).

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Agriculture Victoria is currently conducting research on extracting zonal data generated from the *Cartographer*, to determine relationships between yield and fruit quality, and tree geometry parameters that can drive precision management strategies.

Further information on the utilisation of *Cartographer* can be obtained from Green Atlas (https://greenatlas.com.au/).

For videos on the research and outcomes to date of the Green Atlas Cartographer, head to the PIPS3 Program resources webpage: https://apal.org.au/programs/more-industry-programs/pips3program/pips3resources/

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