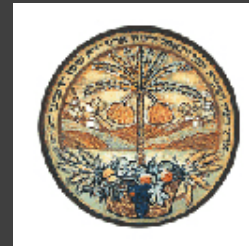


How Sensitive is Thermal Image-Based Orchard Water Status Estimation to Canopy Extraction Quality?



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Alon Ben-Gal

Michael (Iggy) Litaor

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Guy Lidor

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Stav Marzuk

Victor Alchanatis

Yafit Cohen

The 14th Dahlia Greidinger International Symposium,
28 February 2023

Differential irrigation of a peach orchard using thermal imagery to assess spatial tree water status

Introduction

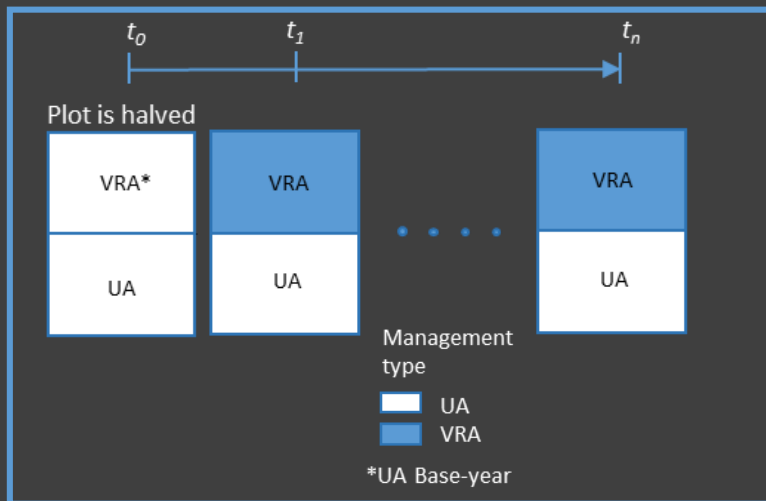
Objectives

Methods

Results and discussion

Conclusion

Methodology



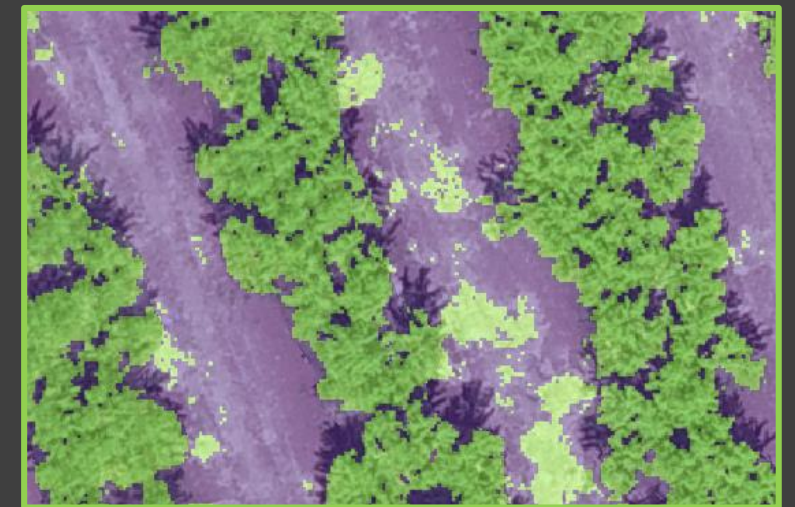
Protocol



Katz, L. et al. (2022b) A spatiotemporal decision support protocol based on thermal imagery for variable rate drip irrigation of a peach orchard. *Irrigation Science*, 1–19.

Katz, L. et al. (2022a) Spatiotemporal normalized ratio methodology to evaluate the impact of field-scale variable rate application. *Precision Agriculture*, 23(4), 1125–1152.

How Sensitive is Thermal Image-based Orchard Water Status Estimation to Canopy Extraction Quality?



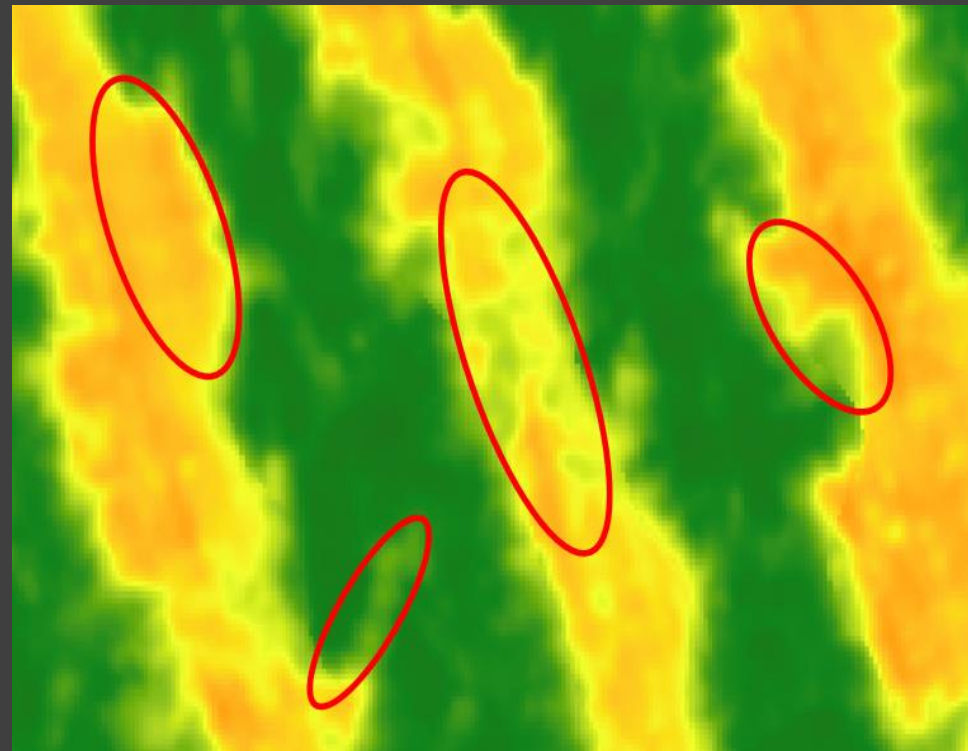
Accepted for publication in
Remote Sensing.

Accurate crop water status estimation necessitates the removal of non-canopy pixels

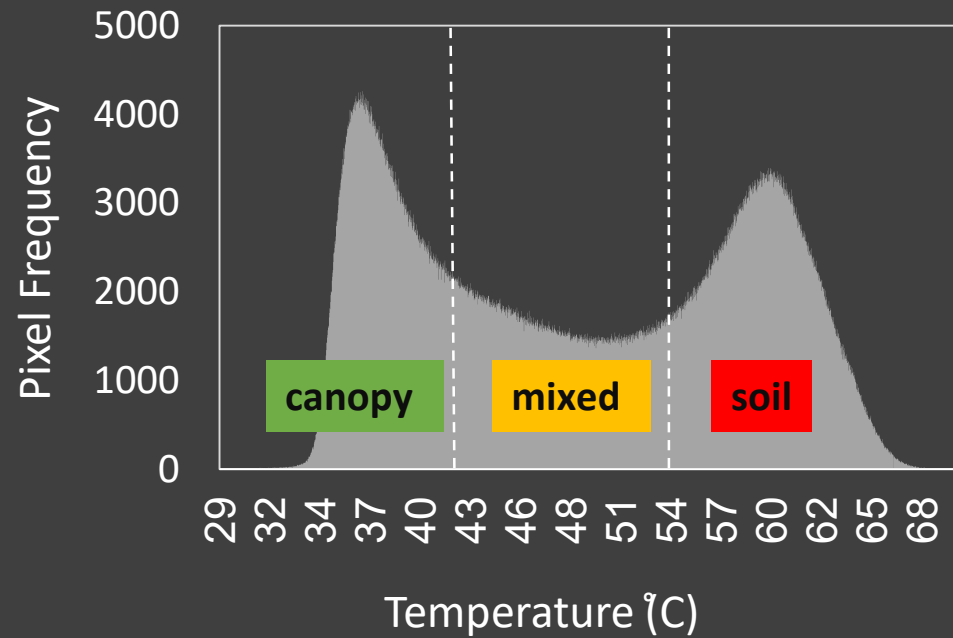
Visual (RGB)



Thermal infrared (TIR)



Crop Water Stress Index (CWSI)

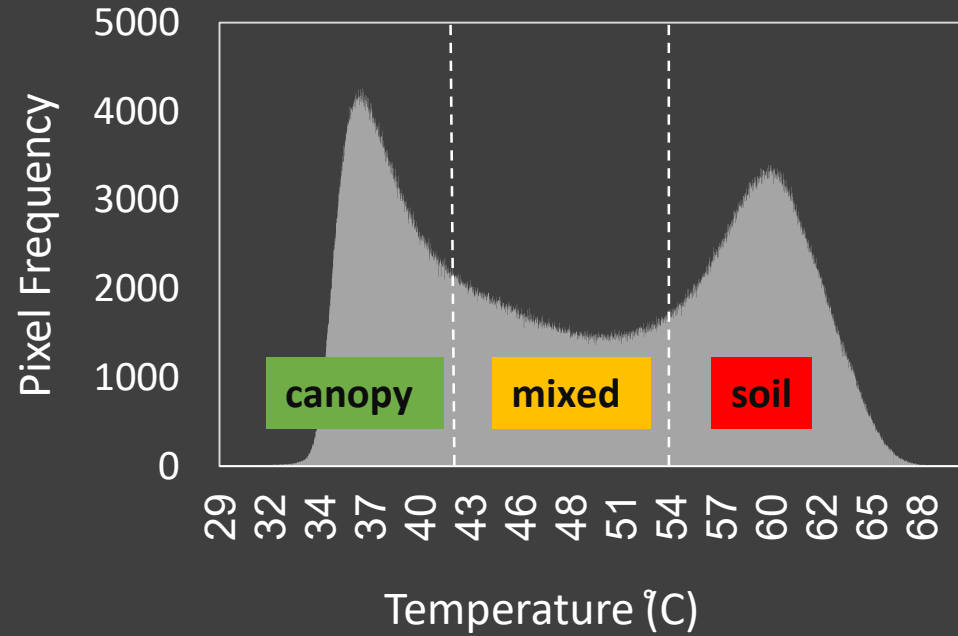


$$CWSI = \frac{T_{canopy} - T_{wet}}{T_{dry} - T_{wet}}$$

Jackson et al 1981

T_{canopy} – canopy temperature
 T_{wet} – fully transpiring canopy
 T_{dry} – non-transpiring canopy

Crop Water Stress Index (CWSI)



Currently, in literature,
 NO broad comparison of:

1. **Canopy extraction** approaches
2. **Canopy temperature** calculation approaches

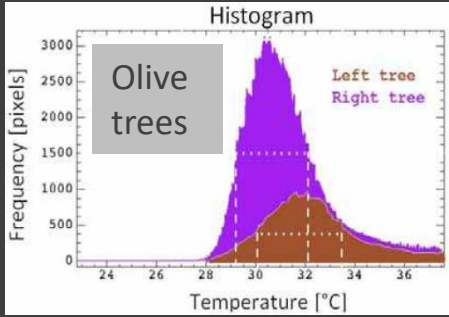
$$CWSI = \frac{T_{canopy} - T_{wet}}{T_{dry} - T_{wet}}$$

Jackson et al 1981

T_{canopy} – canopy temperature
 T_{wet} – fully transpiring canopy
 T_{dry} – non-transpiring canopy

Canopy Extraction Approaches

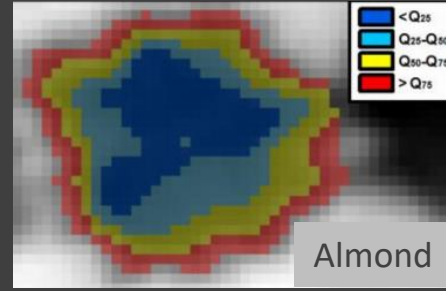
1-source (TIR)



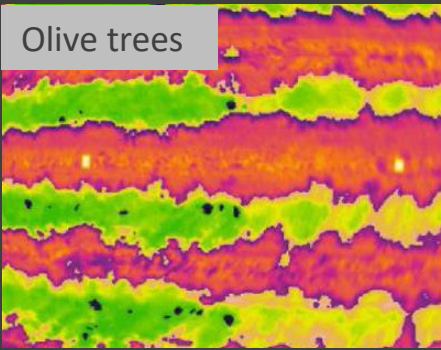
Rud et al. 2015



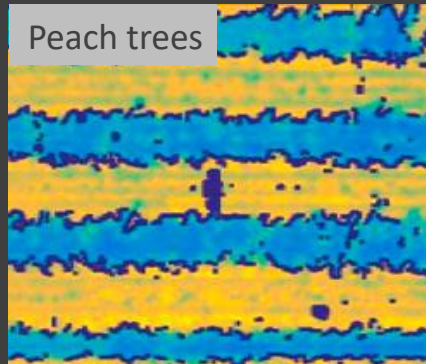
Cohen et al. 2012



Camino et al. 2018



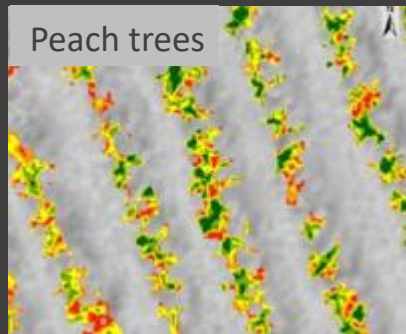
Egea et al. 2017



Park et al. 2017

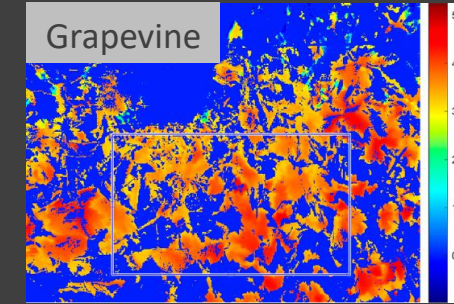


Baluja et al. 2012



Katz et al. 2022

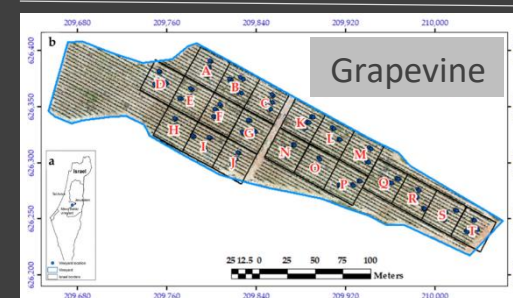
Multi-source (TIR, RGB/MS, other GIS layer)



Zhou et al. 2022



Osroosh et al. 2018



Bahat et al. 2021

Introduction

Objectives

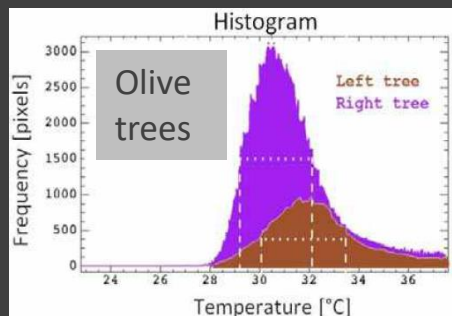
Methods

Results and discussion

Conclusion

Canopy Extraction Approaches

1-source (TIR)



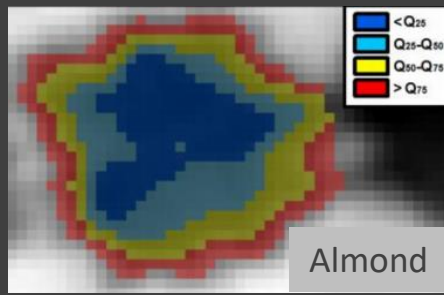
Rud et al. 2015



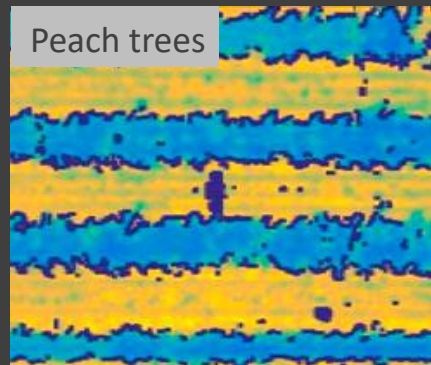
Egea et al. 2017



Cohen et al. 2012



Camino et al. 2018



Park et al. 2017

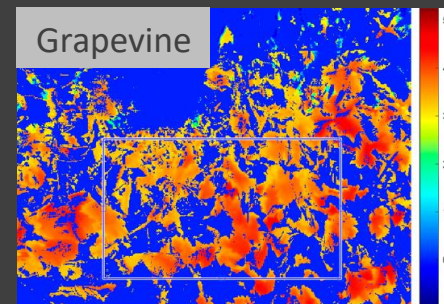


Baluja et al. 2012

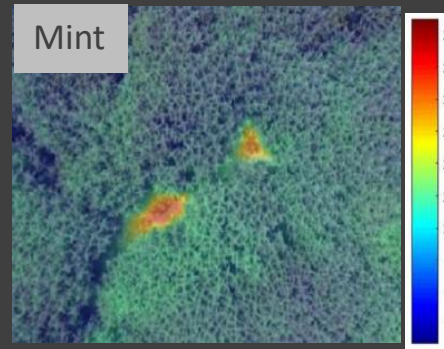


Katz et al. 2022

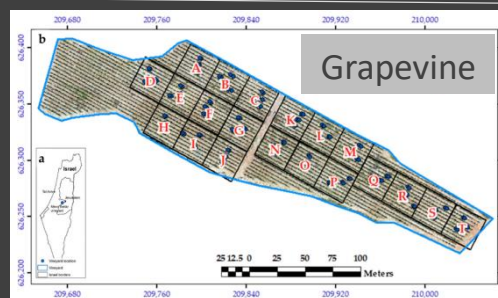
Multi-source (TIR, RGB/MS, other GIS layer)



Zhou et al. 2022



Osroosh et al. 2018



Bahat et al. 2021

Introduction

Objectives

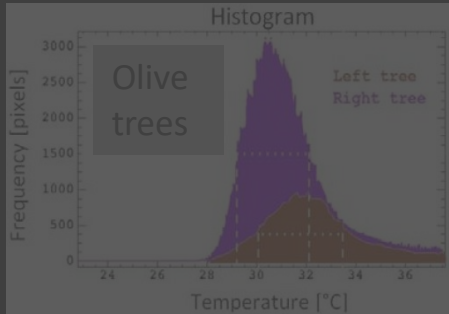
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discussion

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Canopy Extraction Approaches

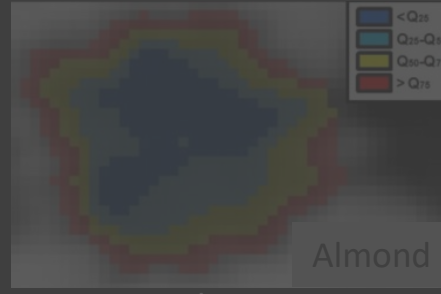
1-source (TIR)



Rud et al. 2015



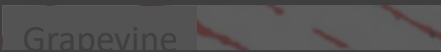
Cohen et al. 2012



Camino et al. 2018

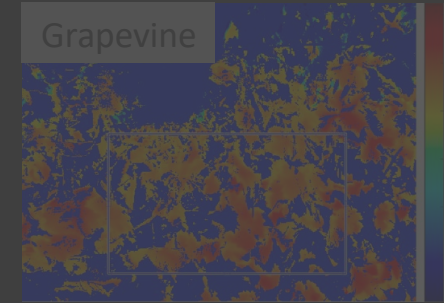


Peach trees



Grapevine

Multi-source (TIR, RGB/MS, other GIS layer)

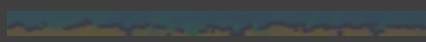


Zhou et al. 2022

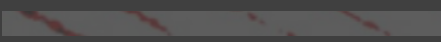
Currently, there is not 1 accepted **canopy extraction** method nor a comparison of **canopy extraction accuracy** in the context of orchard water status estimation.



Egea et al. 2017



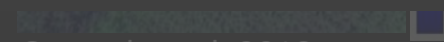
Park et al. 2017



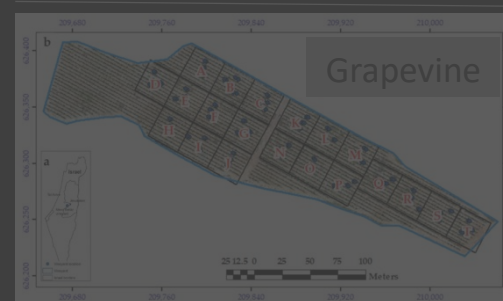
Baluja et al. 2012



Katz et al. 2022



Osroosh et al. 2018



Bahat et al. 2021

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Canopy Temperature Calculation Approaches

Introduction

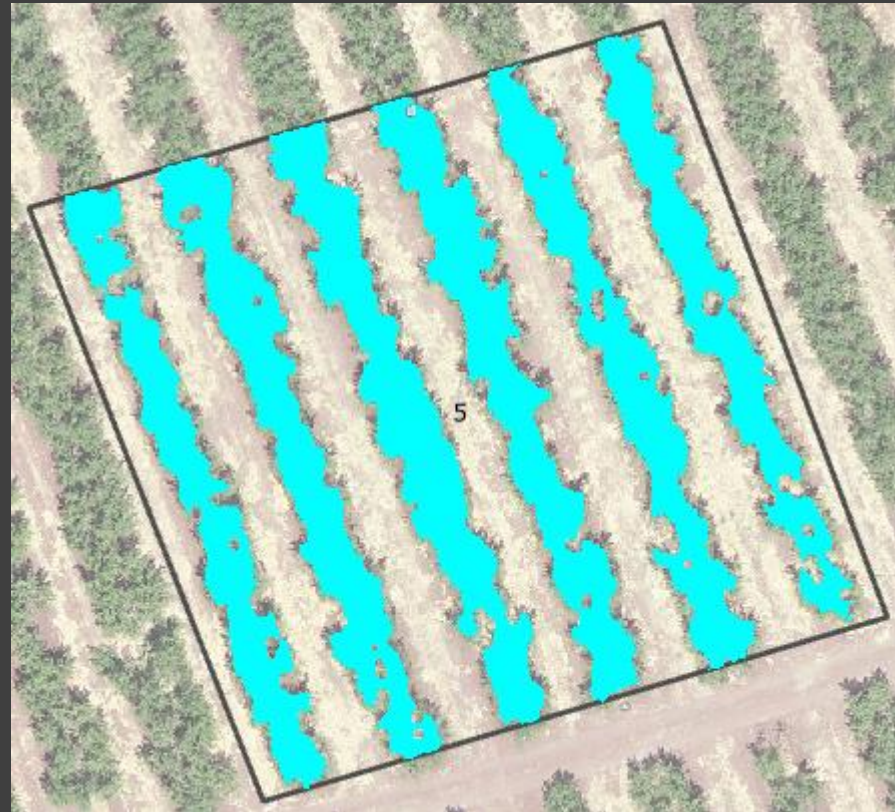
Objectives

Methods

Results and
discussion

Conclusion

T100%

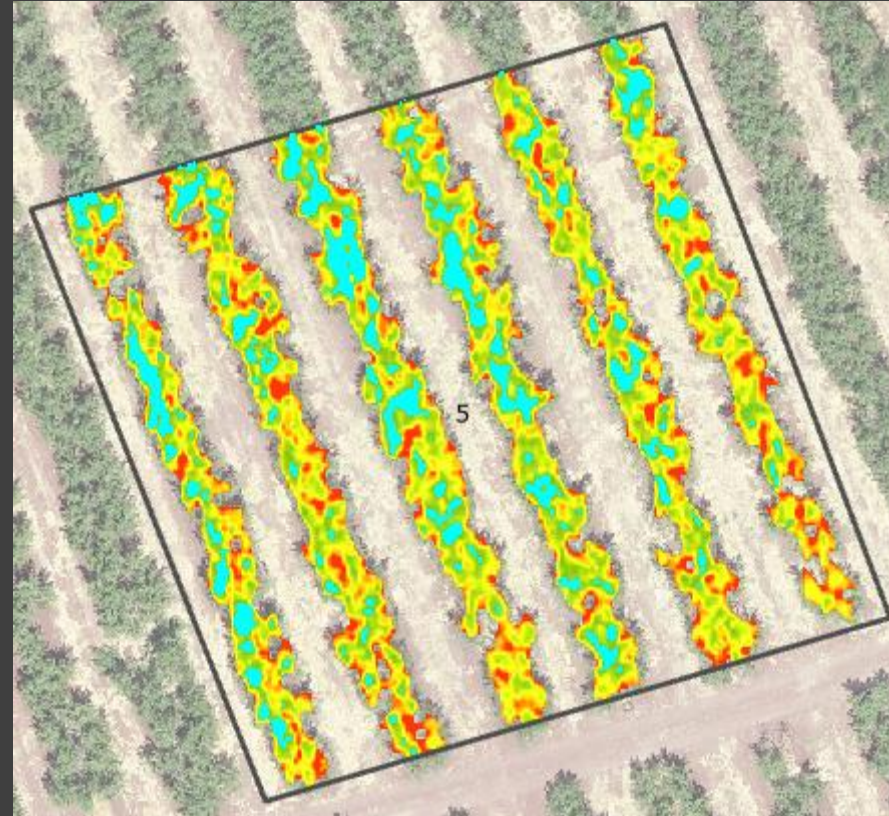


100% canopy temperature pixels

Gonzalez et al. 2013

Gonzalez et al. 2015

T33%



Coollest 33% canopy temperature pixels

Meron et al. 2010

Bahat et al. 2021

Katz et al. 2022

Canopy Temperature Calculation Approaches

Introduction

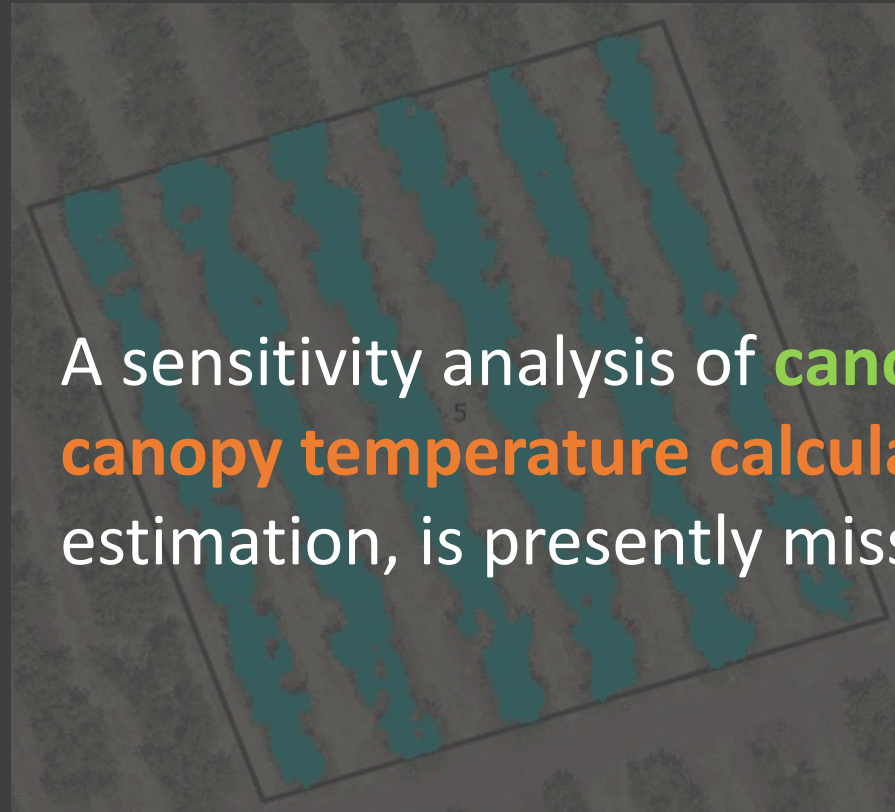
Objectives

Methods

Results and
discussion

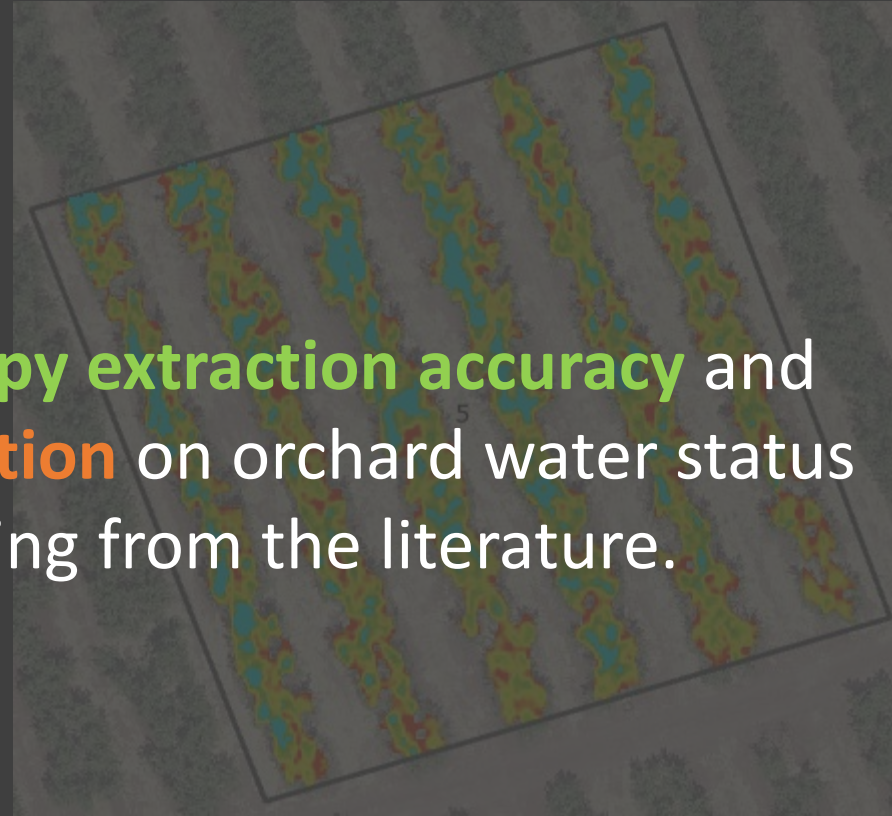
Conclusion

T100%



100% canopy temperature pixels

T33%



Coollest 33% canopy temperature pixels

A sensitivity analysis of **canopy extraction accuracy** and **canopy temperature calculation** on orchard water status estimation, is presently missing from the literature.

Hypothesis:

Thermal image-based orchard water status estimation is significantly sensitive to the canopy extraction quality and to the temperature calculation approach.

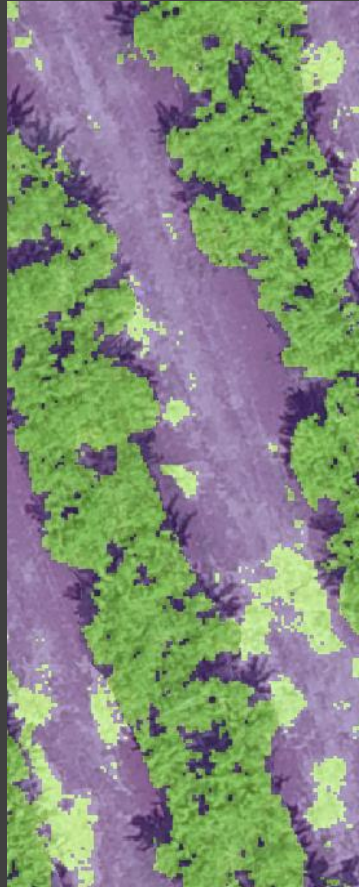
Objective:

To determine the sensitivity of thermal image-based orchard water status estimation to 4 canopy extraction methodologies:

- 1) 2- Pixel Erosion (2PE) (*1-source*)
- 2) Edge Detection (ED) (*1-source*)
- 3) Vegetation Segmentation (VS) (*1-source*)
- 4) RGB binary masking of thermal image (RGB-BM) (*multi-source*)

and to 2 canopy temperature calculation approaches:

- 1) T100%
- 2) T33%



Research area and database



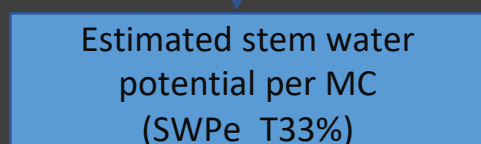
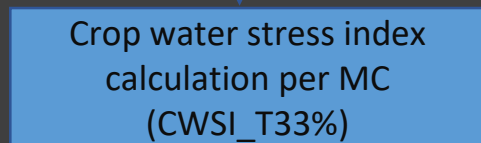
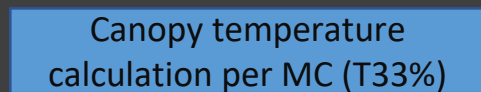
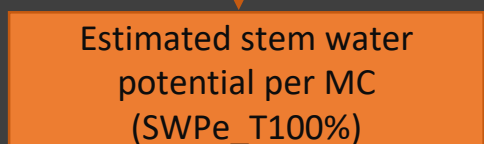
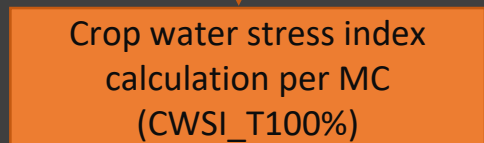
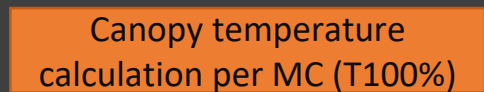
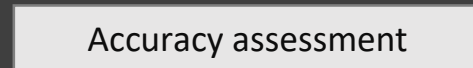
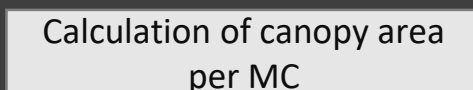
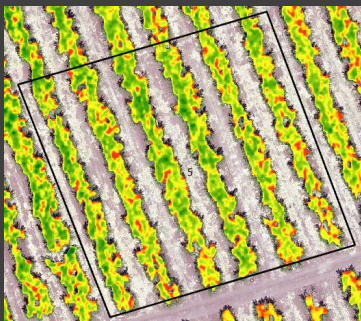
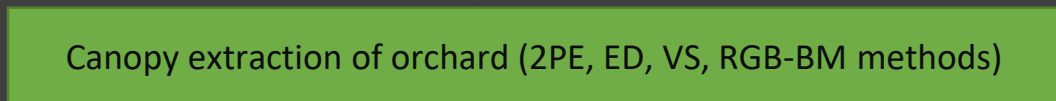
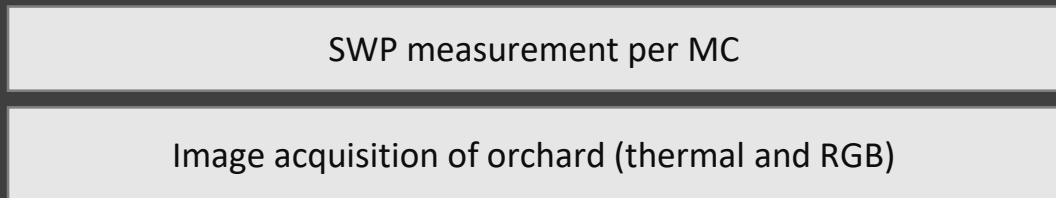
Mishmar Hayarden commercial orchard (4 ha)
22 management cells (MC) (~0.12 ha each)
Drip irrigation (VRDI for north subplot)

10 thermal images during stage III (21 July - 26 Aug 2019)
FLIR SC655
Flight height – 100 m
Spatial resolution - 7 cm

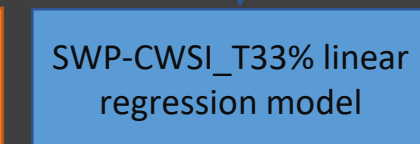
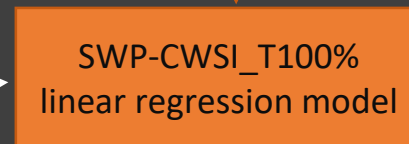
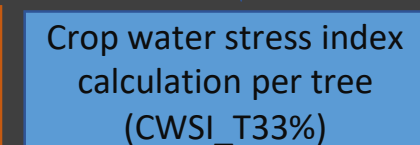
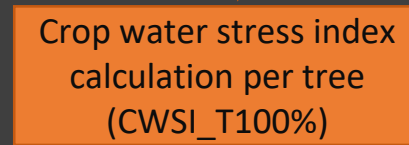
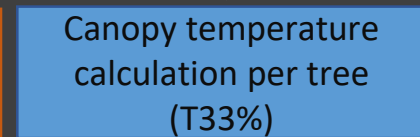
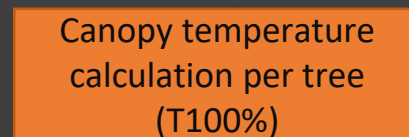
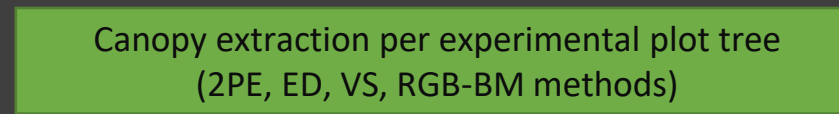
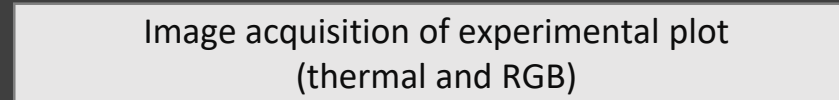
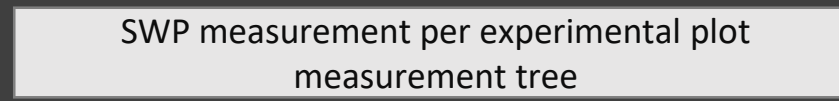
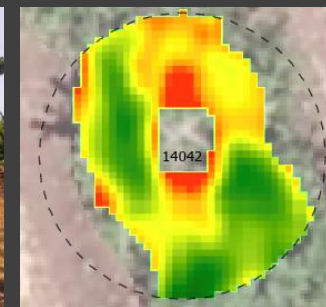
2 RGB images (21 July and 12 Aug 2019)



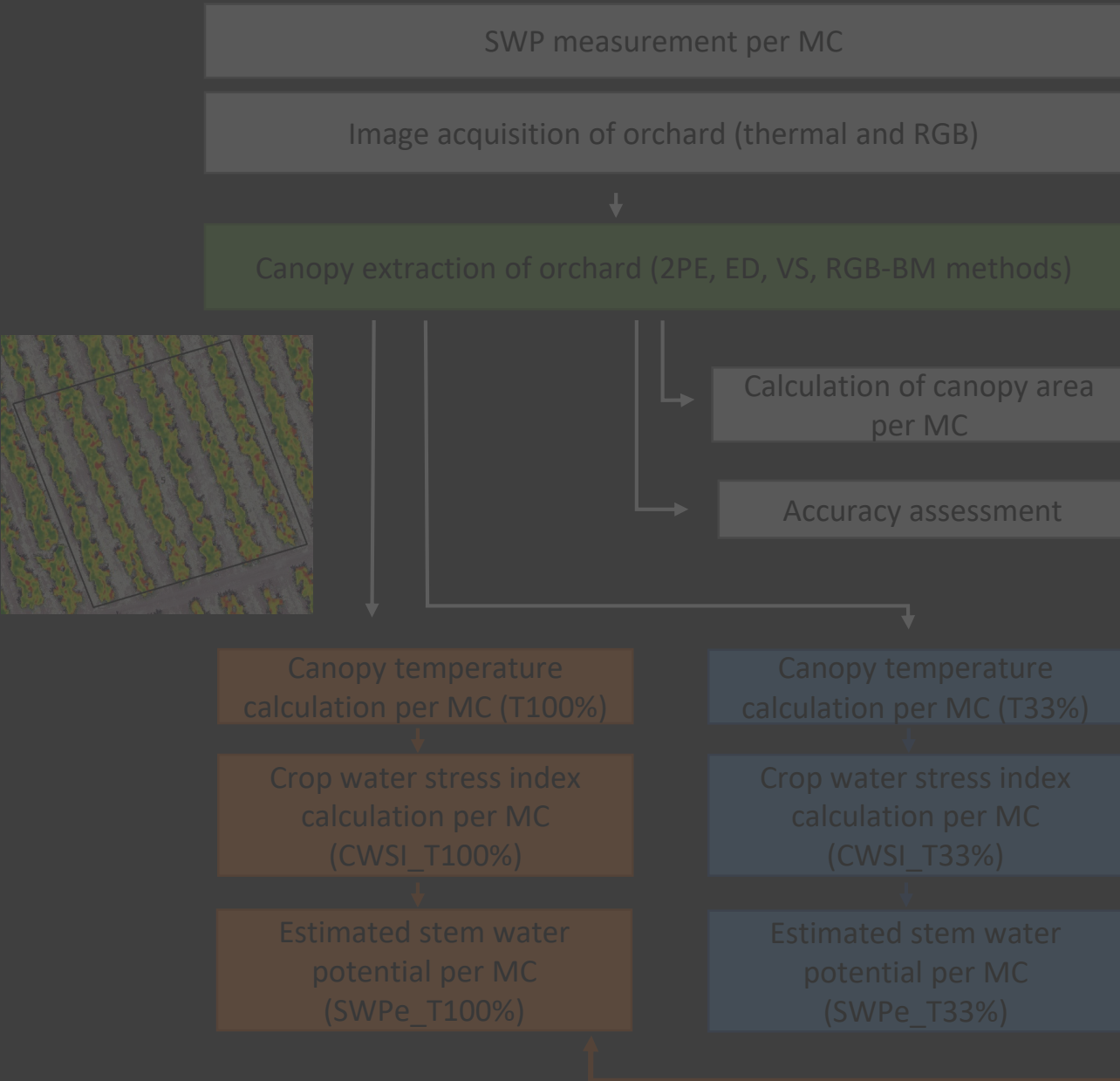
Orchard Canopy Extraction Accuracy and MC Canopy Temperature and Orchard Water Status



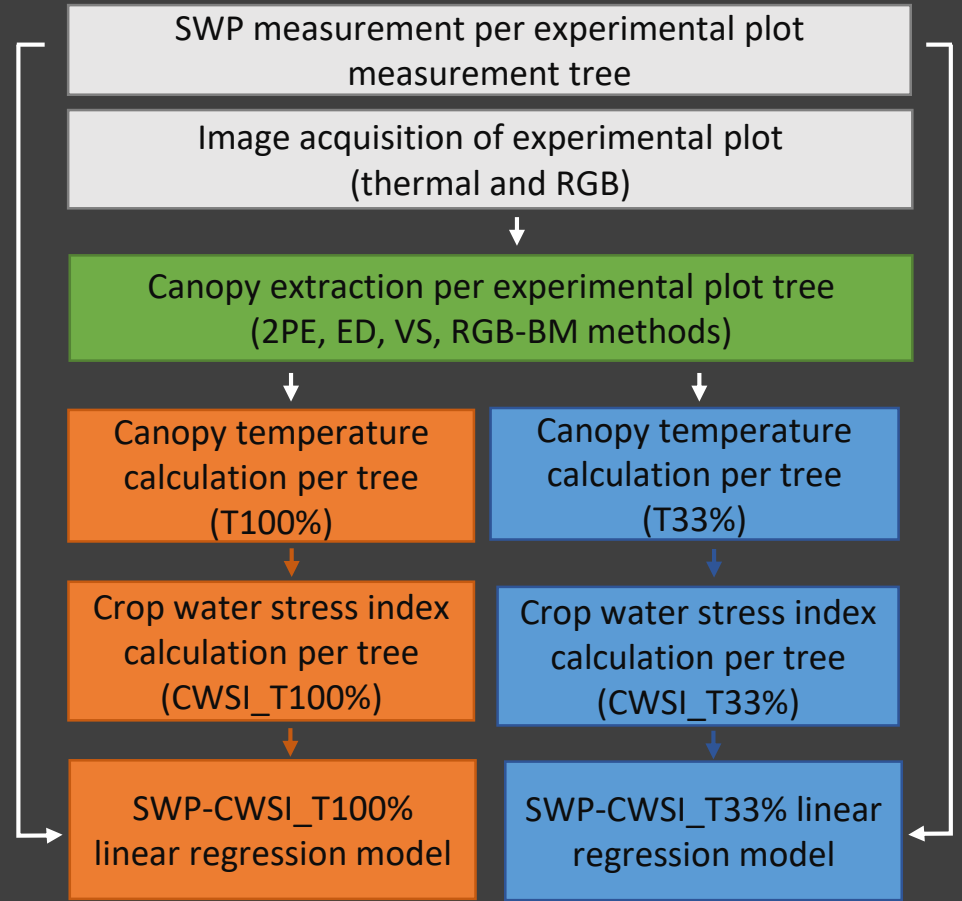
Establishment of SWP-CWSI Relationship



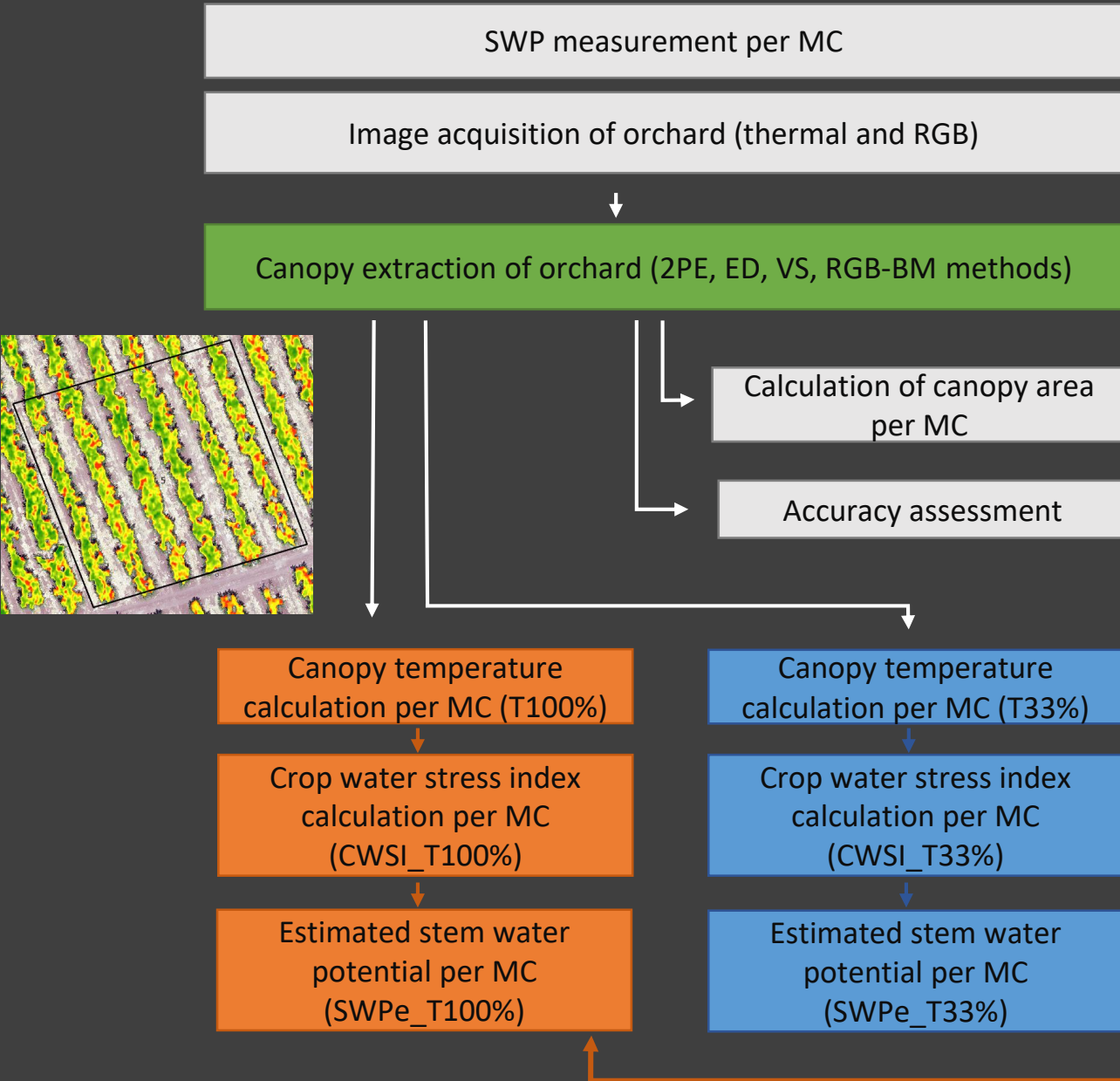
Orchard Canopy Extraction Accuracy and MC Canopy Temperature and Orchard Water Status



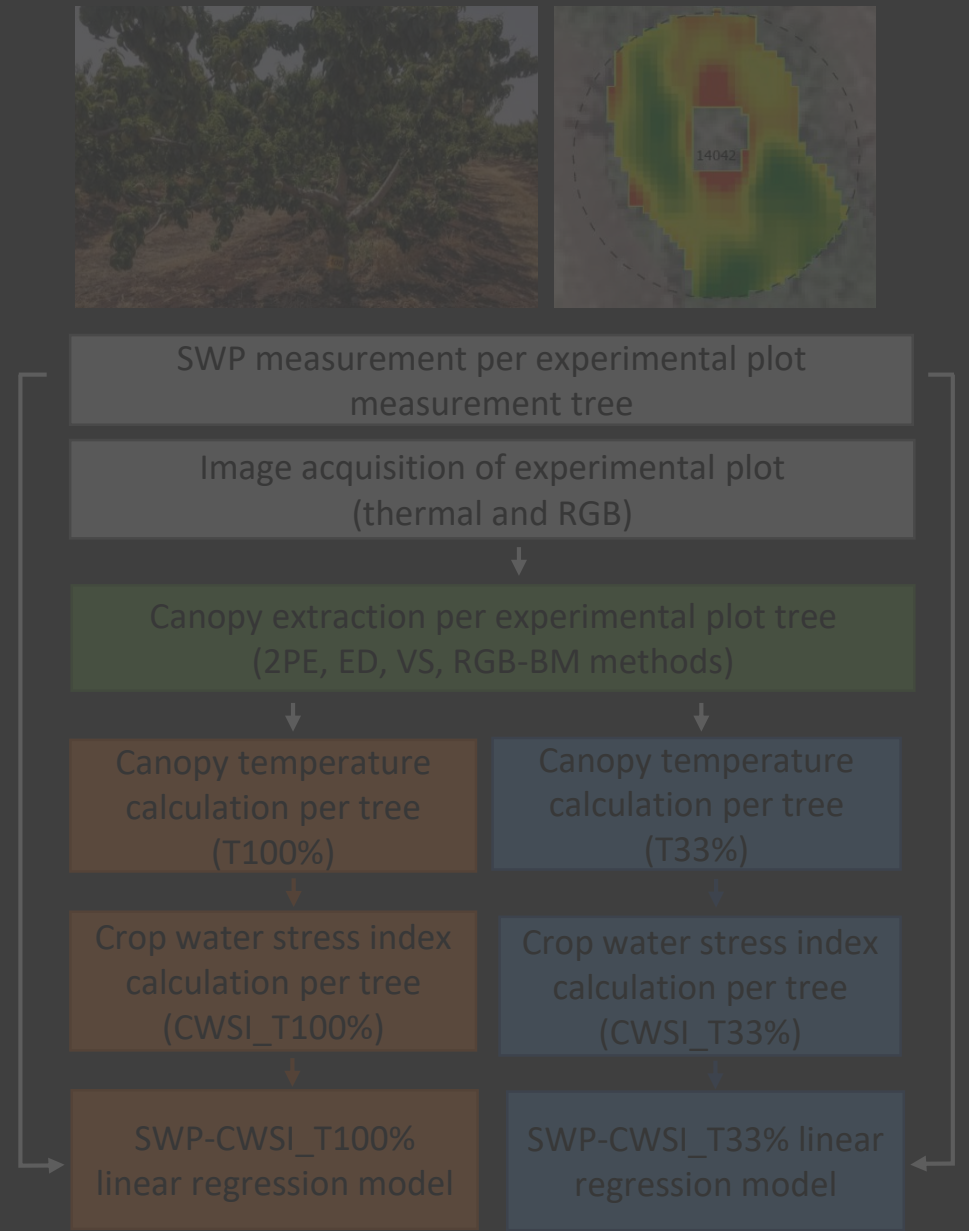
Establishment of SWP-CWSI Relationship



Orchard Canopy Extraction Accuracy and MC Canopy Temperature and Orchard Water Status



Establishment of SWP-CWSI Relationship



Orchard Canopy Extraction Accuracy and MC Canopy Temperature and Orchard Water Status

SWP measurement per MC

Image acquisition of orchard (thermal and RGB)

Canopy extraction of orchard (2PE, ED, VS, RGB-BM methods)

Calculation of canopy area per MC

Accuracy assessment

Canopy temperature calculation per MC (T100%)

Crop water stress index calculation per MC (CWSI_T100%)

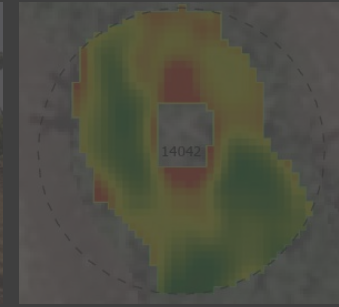
Estimated stem water potential per MC (SWPe_T100%)

Canopy temperature calculation per MC (T33%)

Crop water stress index calculation per MC (CWSI_T33%)

Estimated stem water potential per MC (SWPe_T33%)

Establishment of SWP-CWSI Relationship



SWP measurement per experimental plot measurement tree

Image acquisition of experimental plot (thermal and RGB)

Canopy extraction per experimental plot tree (2PE, ED, VS, RGB-BM methods)

Canopy temperature calculation per tree (T100%)

Crop water stress index calculation per tree (CWSI_T100%)

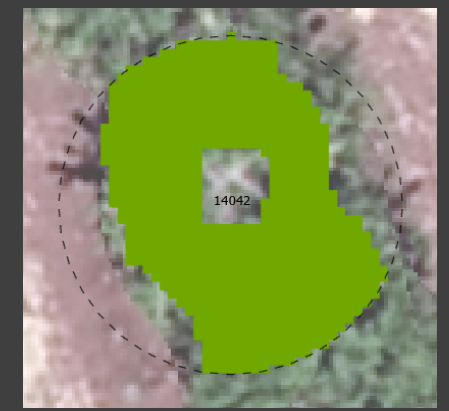
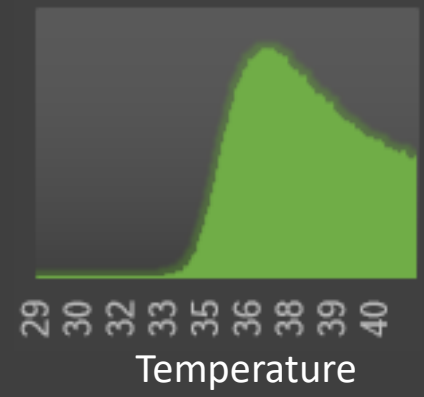
SWP-CWSI_T100% linear regression model

Canopy temperature calculation per tree (T33%)

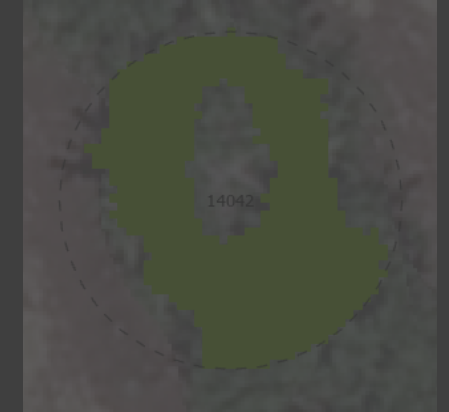
Crop water stress index calculation per tree (CWSI_T33%)

SWP-CWSI_T33% linear regression model

2-Pixel Erosion (2PE) Statistical + spatial



Edge detection (ED) Statistical + spatial



Vegetation segmentation (VS) Statistical + spatial



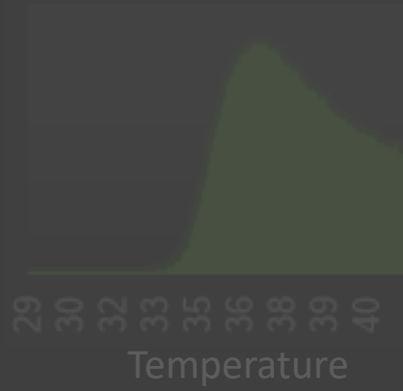
Method Analysis

Description

Canopy pixels of tree 14042

2-Pixel Erosion (2PE)

Statistical + spatial



Edge detection (ED)

Statistical + spatial

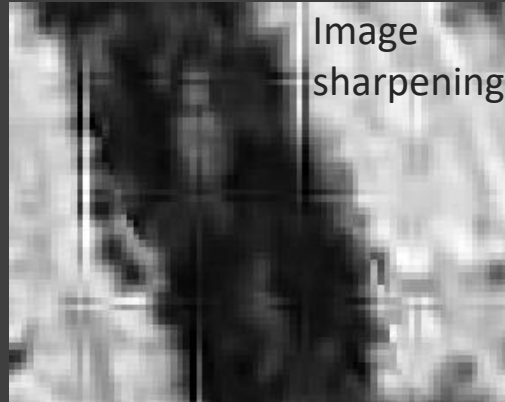
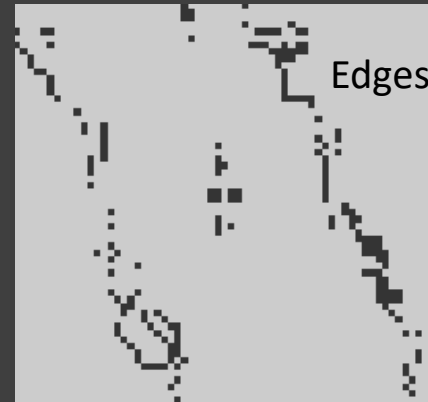
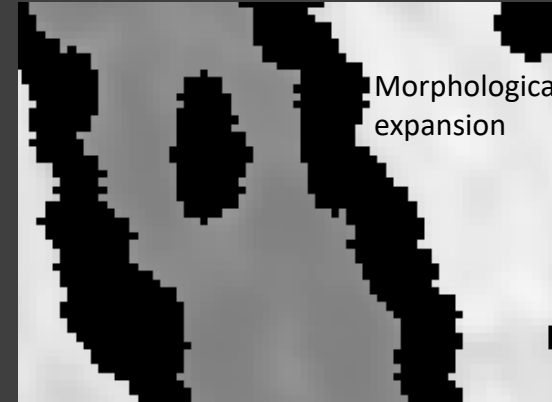


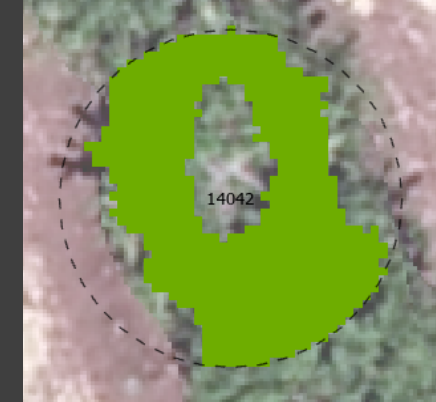
Image sharpening



Edges



Morphological expansion



Vegetation segmentation (VS)

Statistical + spatial



Thresholding

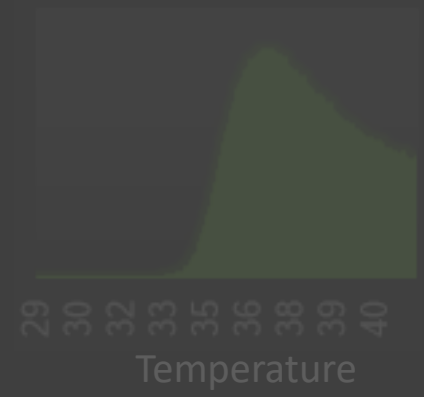


Watershed segmentation

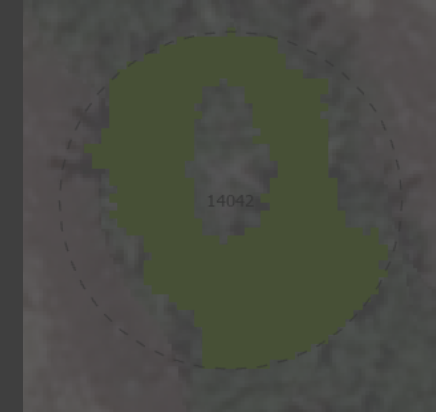


Method Analysis Description Canopy pixels of tree 14042

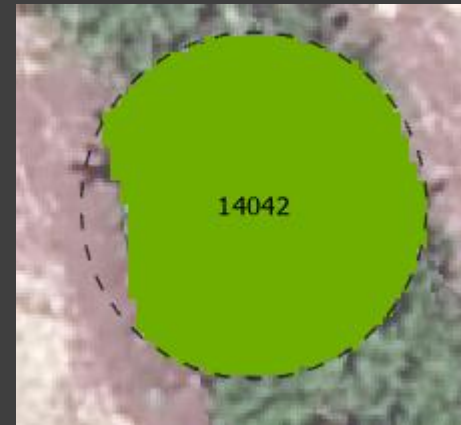
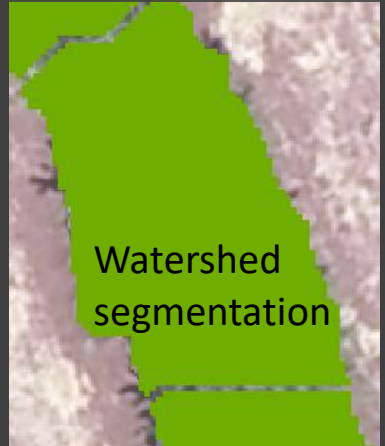
2-Pixel Erosion (2PE) Statistical + spatial



Edge detection (ED) Statistical + spatial



Vegetation segmentation (VS) Statistical + spatial



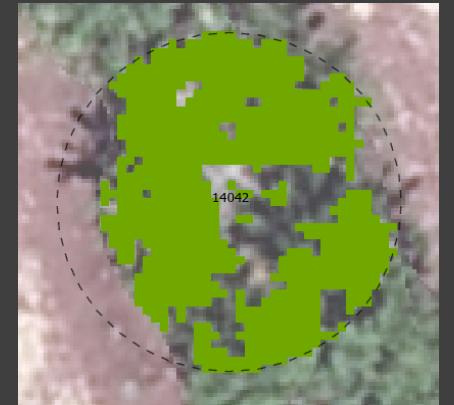
Method Analysis

Description

Canopy pixels of tree 14042

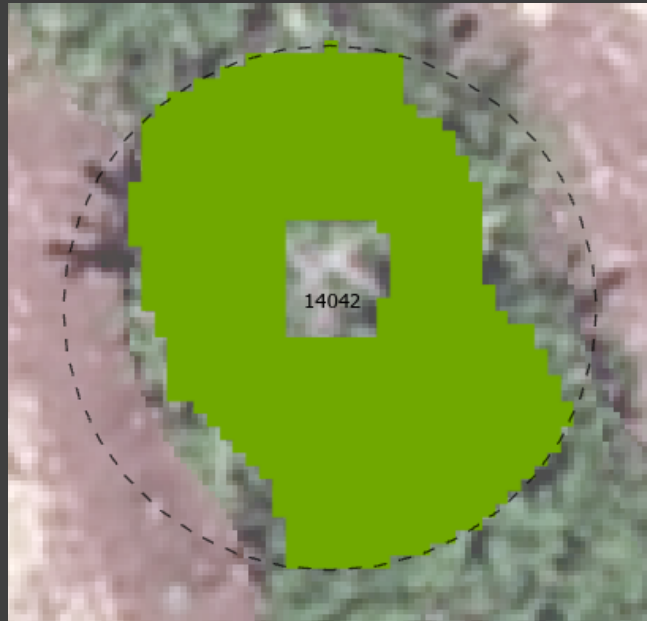
RGB binary
masking
(RGB-BM)

Statistical
+ binary
masking

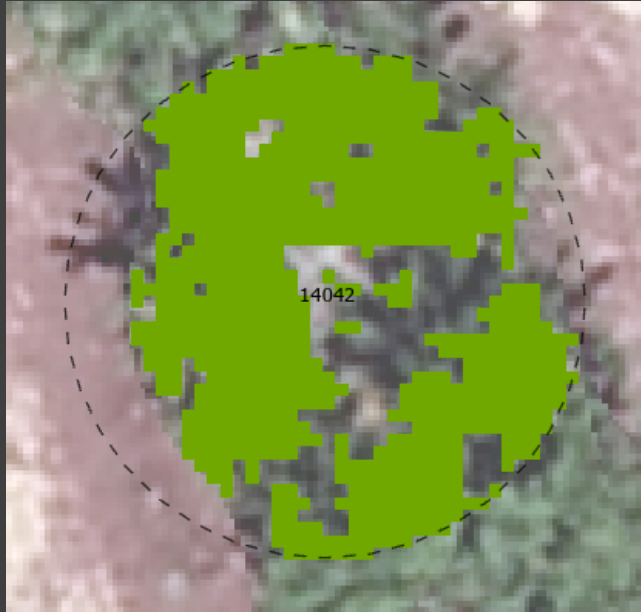


Canopy Pixels of Tree 14042

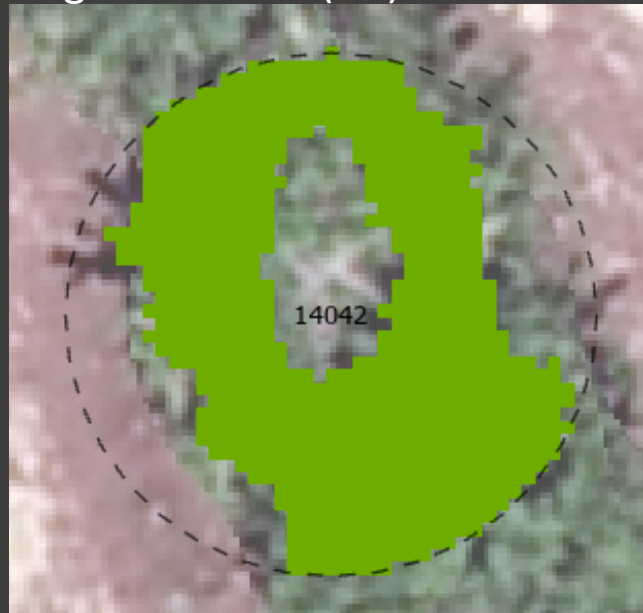
2-Pixel Erosion (2PE)



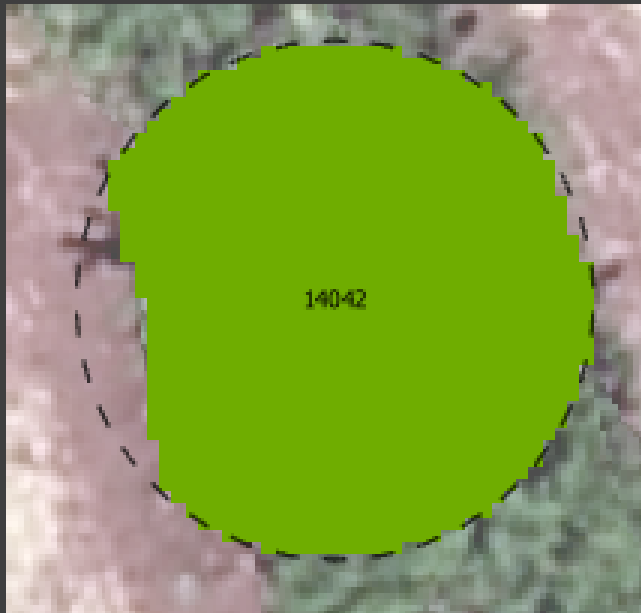
RGB binary masking (RGB-BM)



Edge detection (ED)



Vegetation segmentation (VS)



Introduction

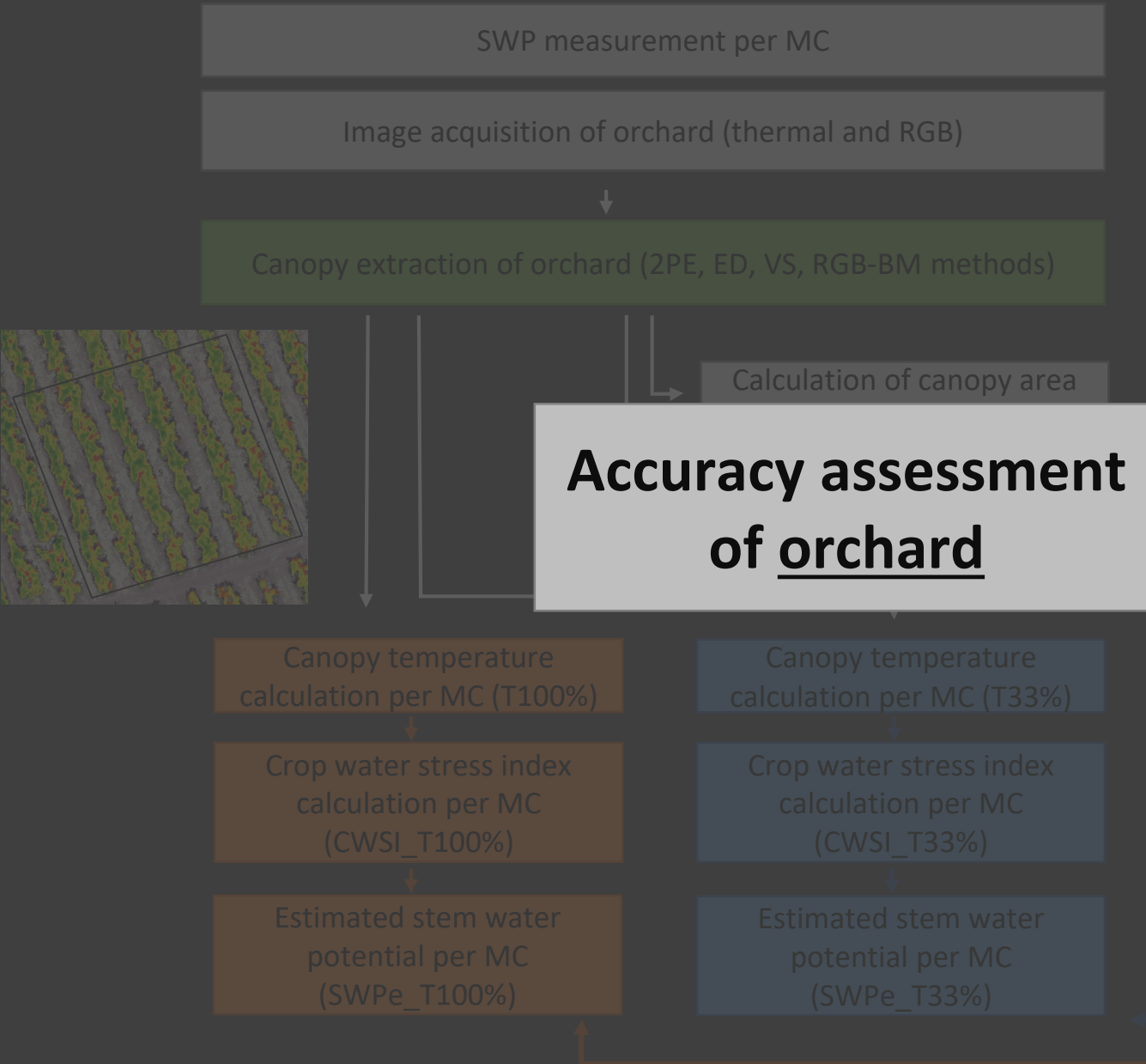
Objectives

Methods

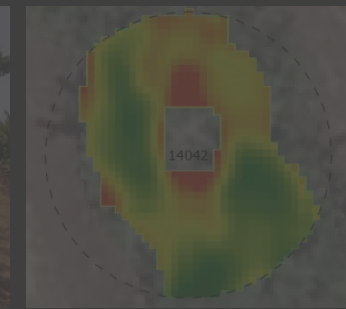
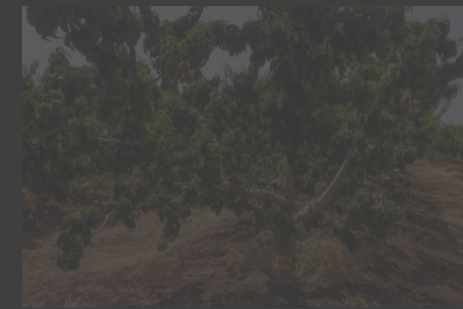
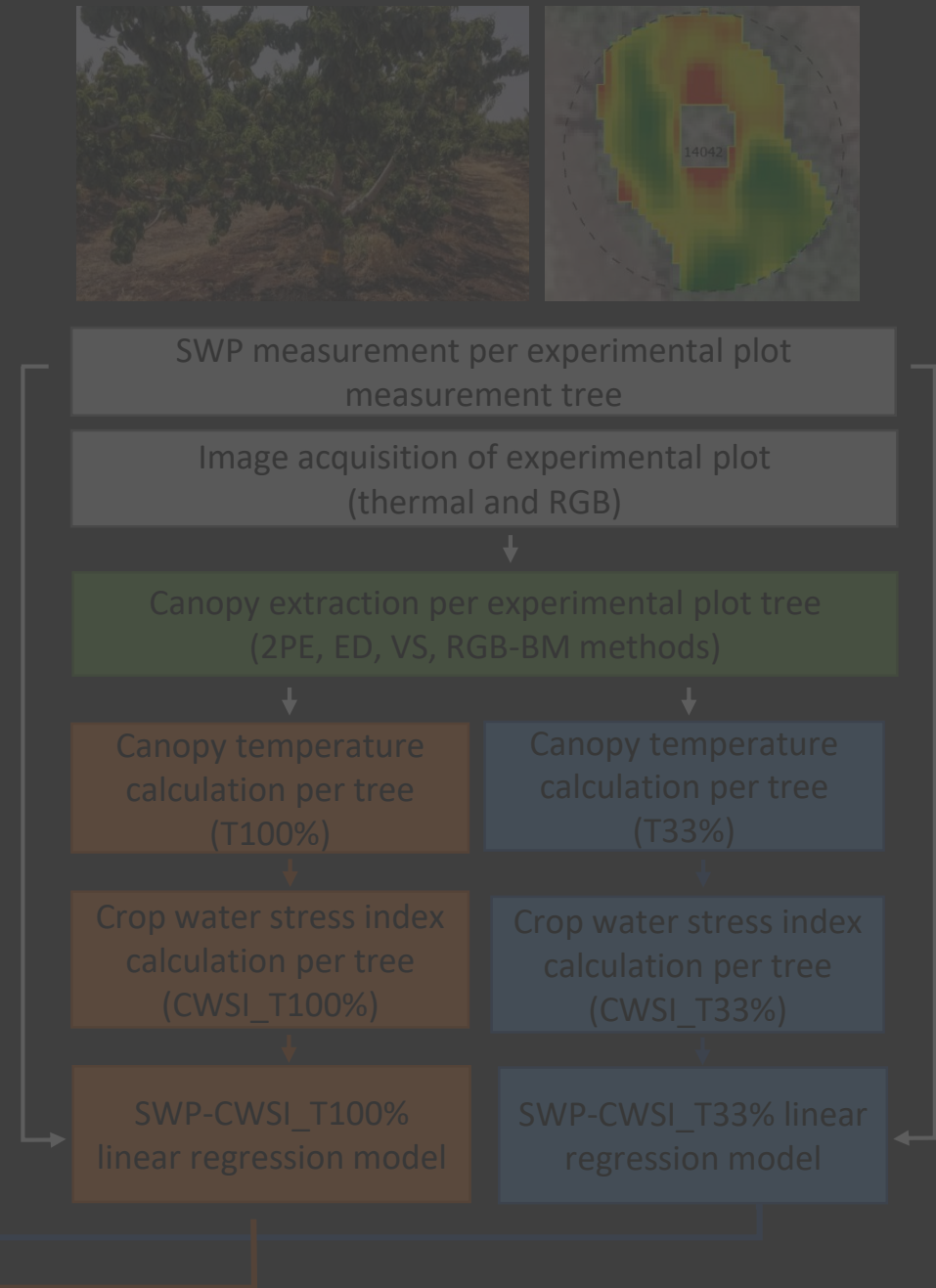
Results and discussion

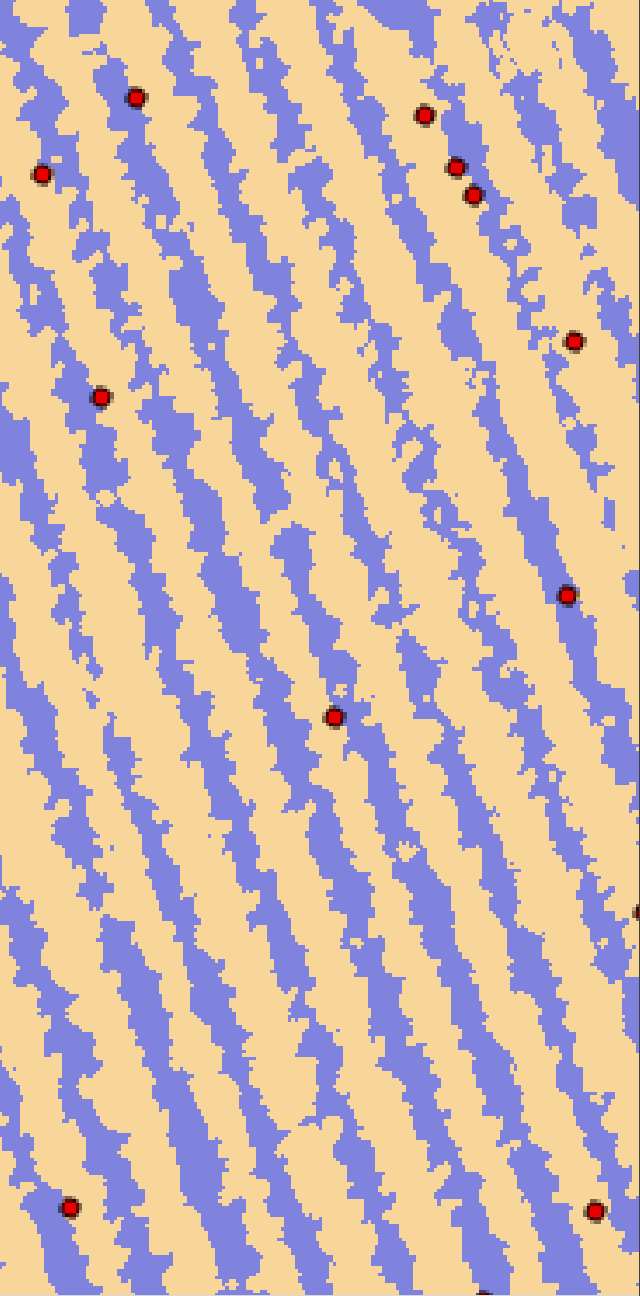
Conclusion

Orchard Canopy Extraction Accuracy and MC Canopy Temperature and Orchard Water Status



Establishment of SWP-CWSI Relationship



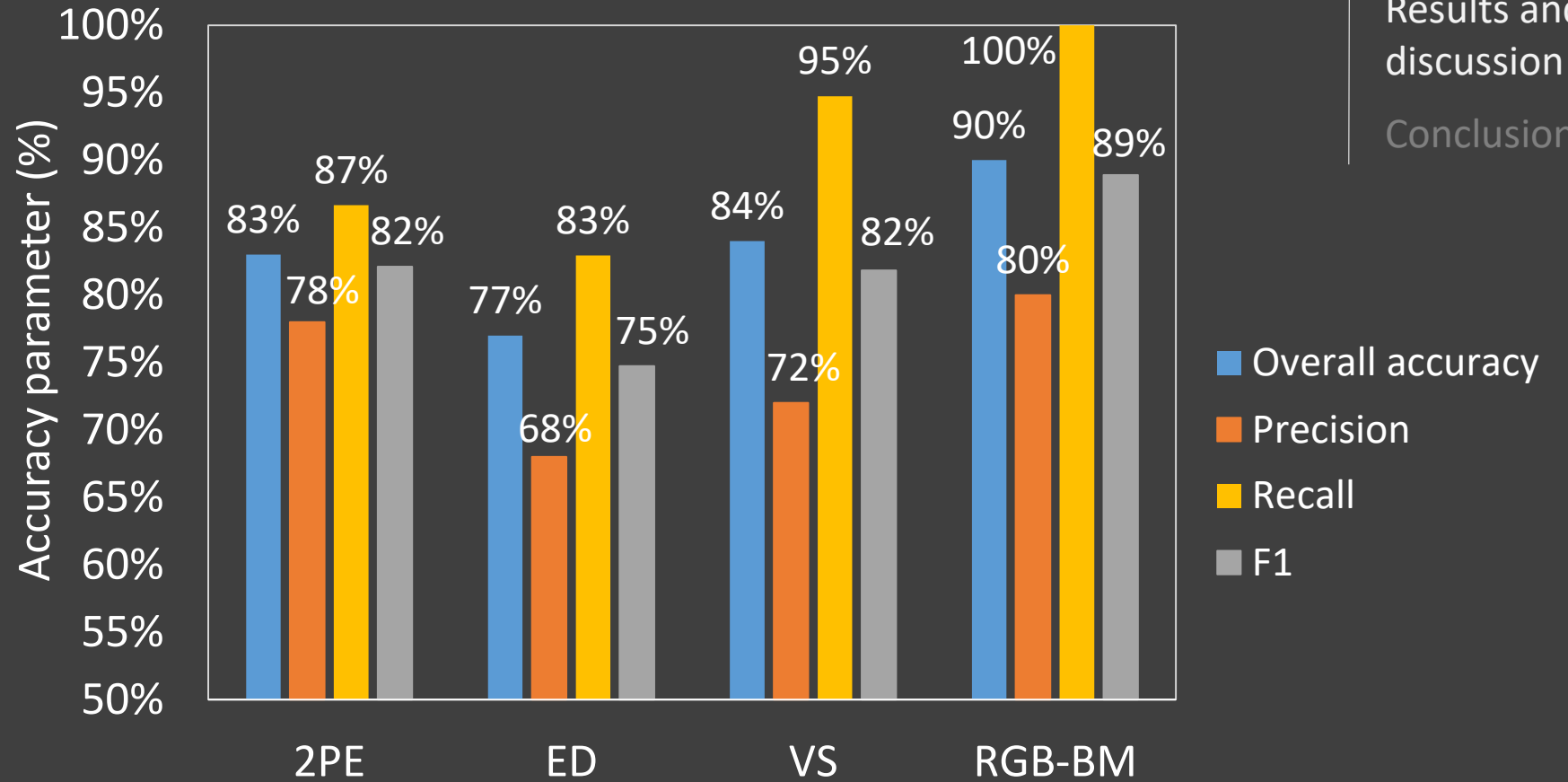


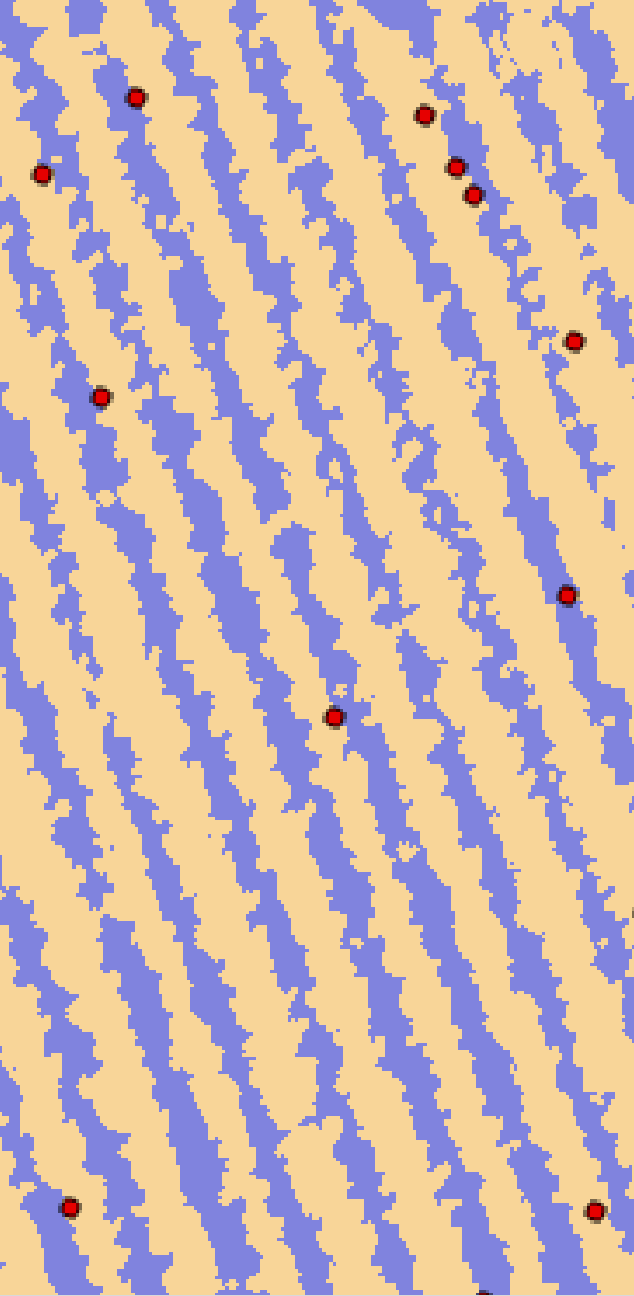
100 sample points per method

Accuracy Assessment – 12 Aug 2019

Confusion Matrix Parameters per Method

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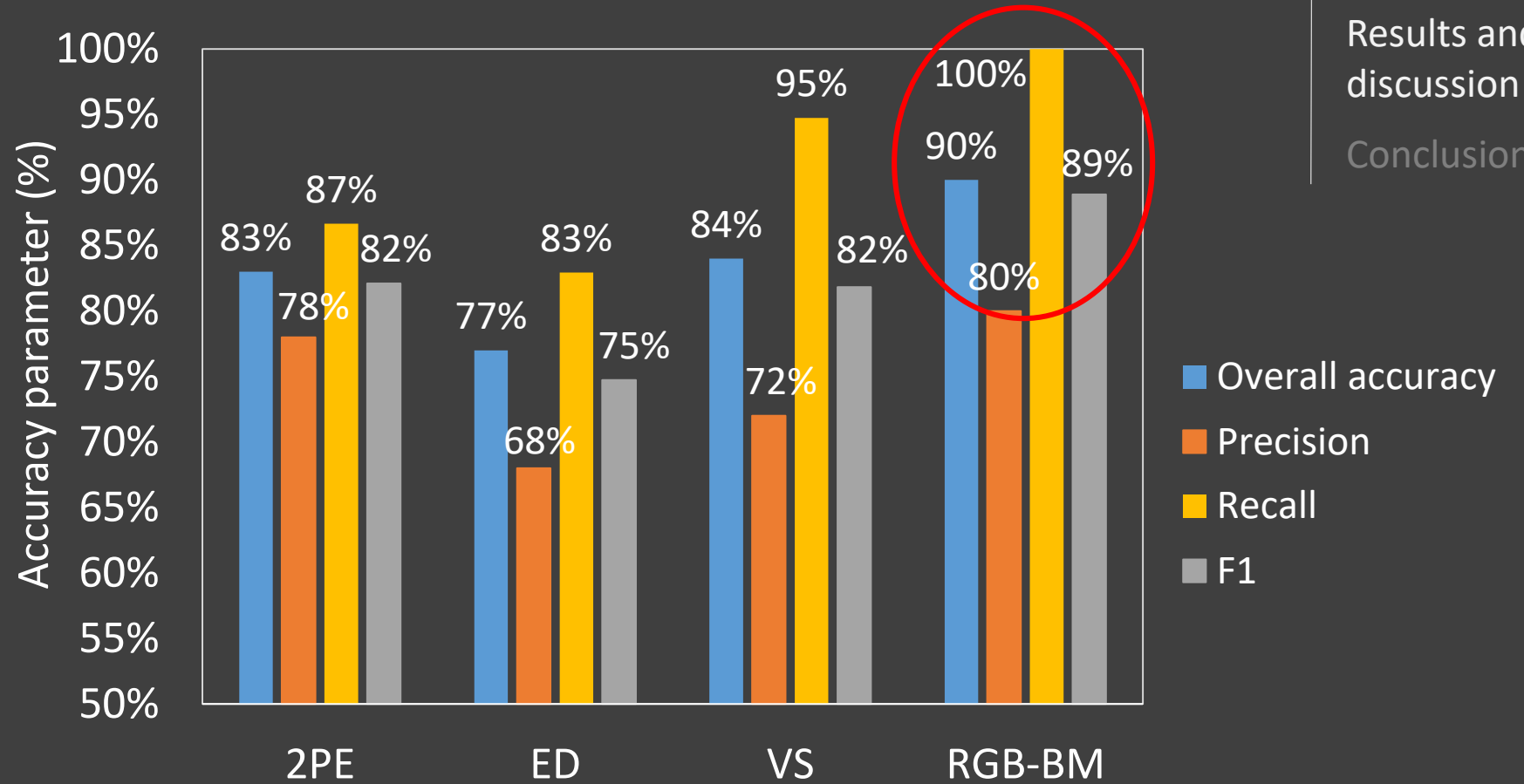




100 sample points per method

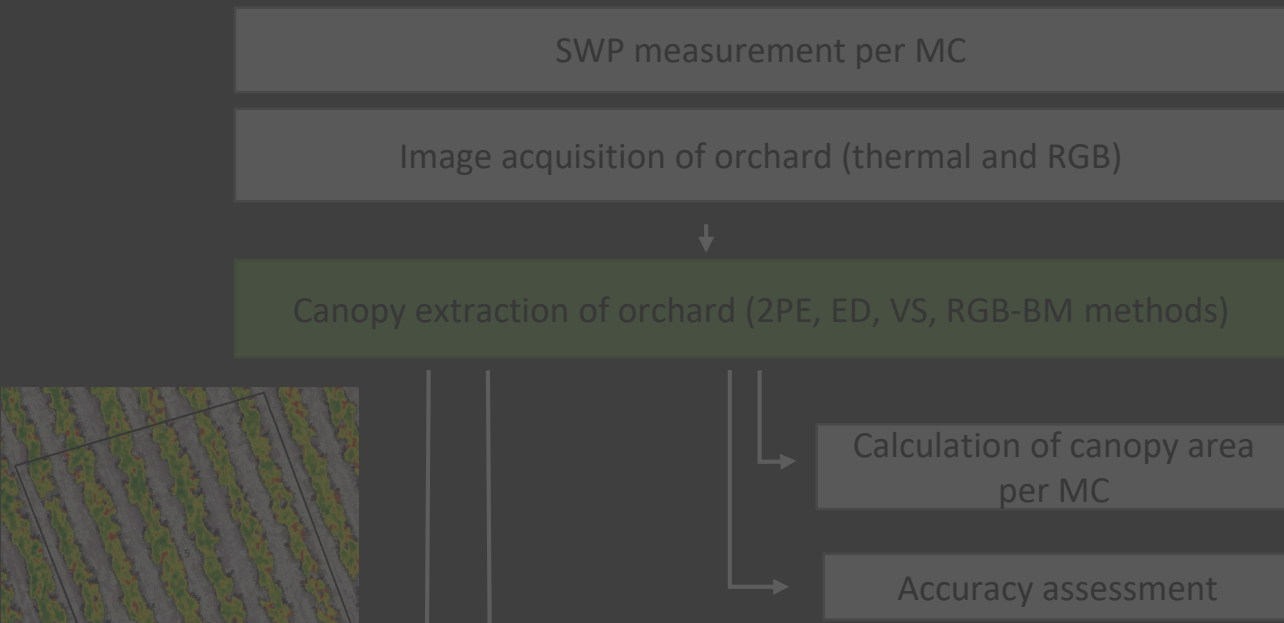
Accuracy Assessment – 12 Aug 2019

Confusion Matrix Parameters per Method

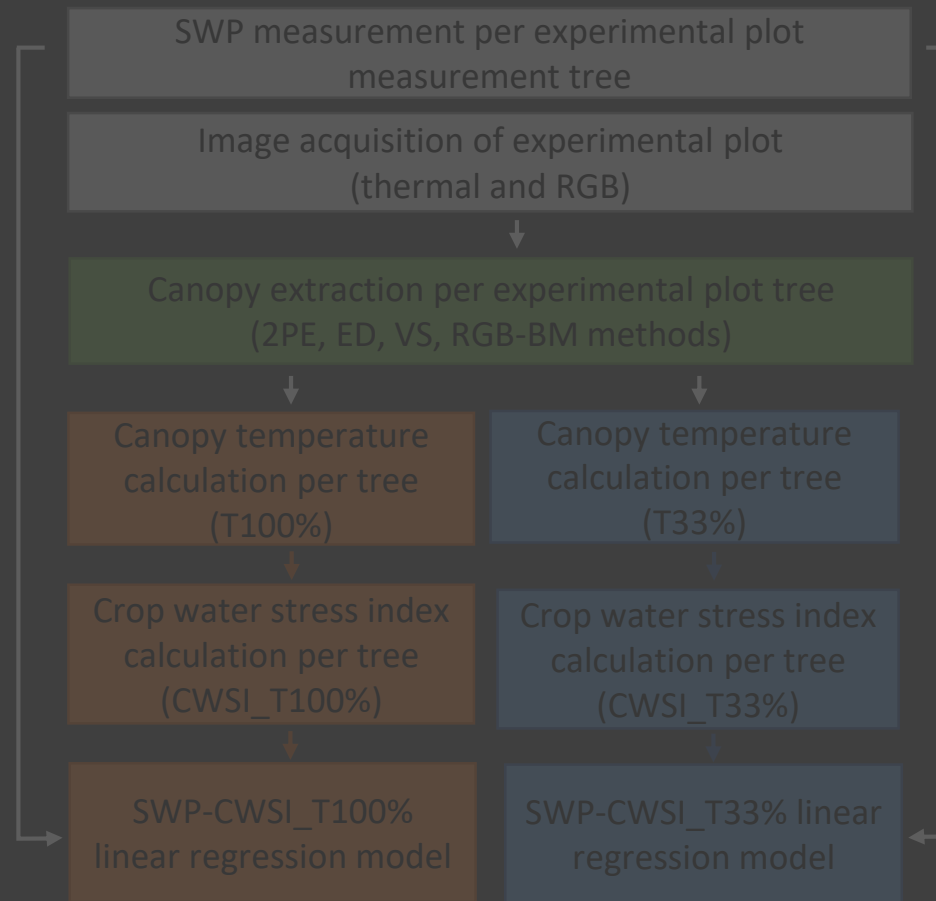
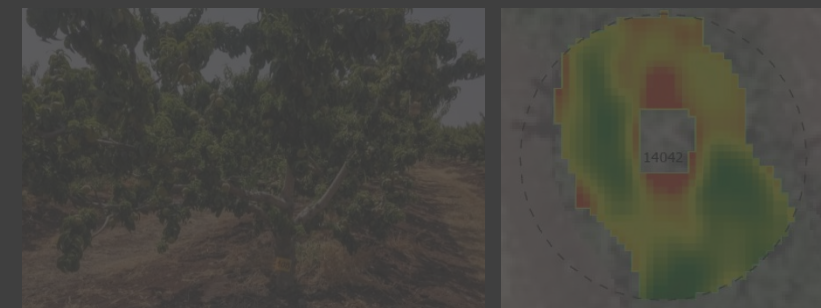


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Orchard Canopy Extraction Accuracy and MC Canopy Temperature and Orchard Water Status



Establishment of SWP-CWSI Relationship



Canopy temperature calculation per MC (T100%)

Canopy temperature calculation per MC (T33%)

Crop water stress index calculation per MC (CWSI_T100%)

Crop water stress index calculation per MC (CWSI_T33%)

Estimated stem water potential per MC (SWPe_T100%)

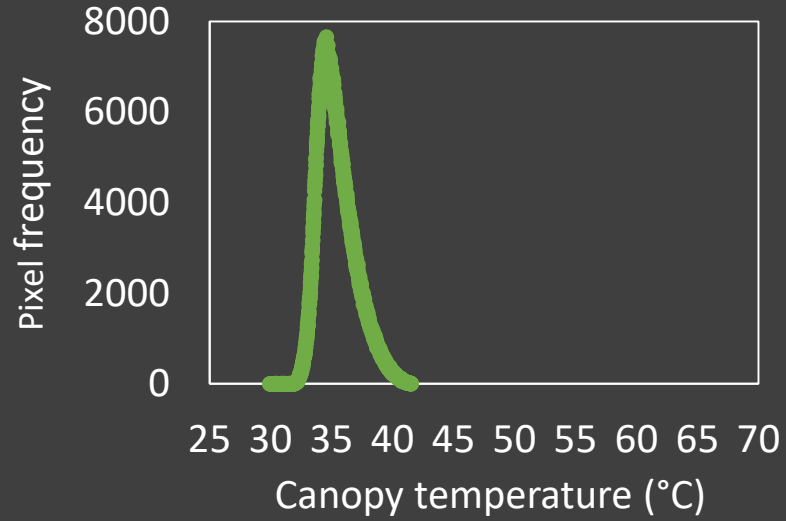
Estimated stem water potential per MC (SWPe_T33%)

Canopy Temperature Calculation - MC 5

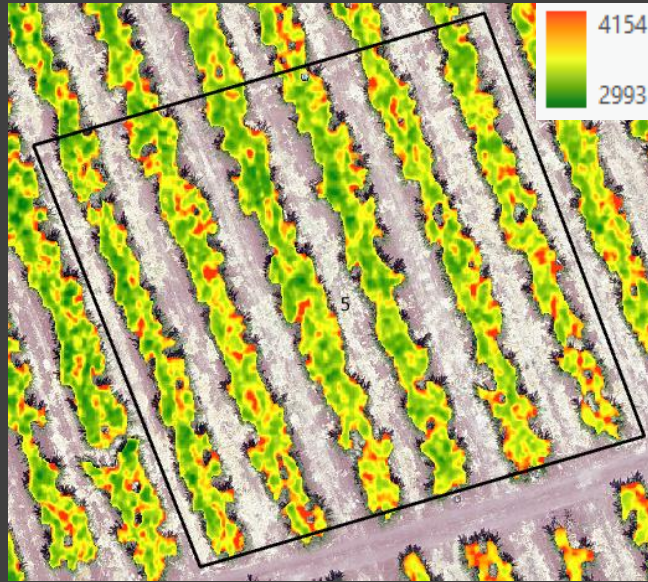
- Introduction
- Objectives
- Methods
- Results and discussion
- Conclusion

Temperature Histogram – Whole Orchard

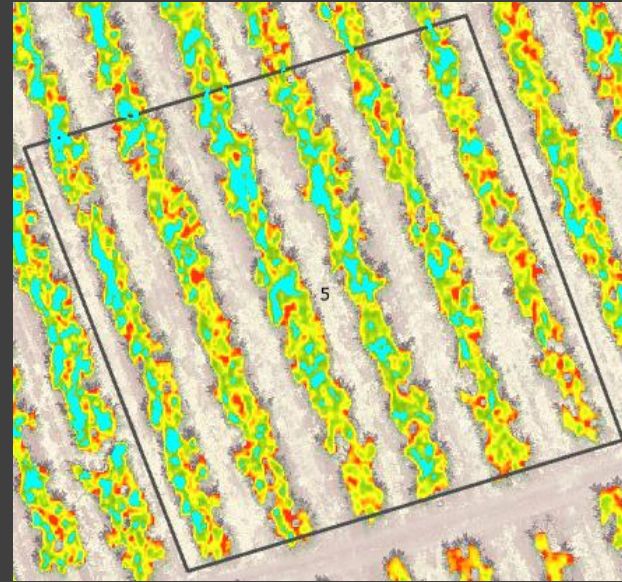
2PE



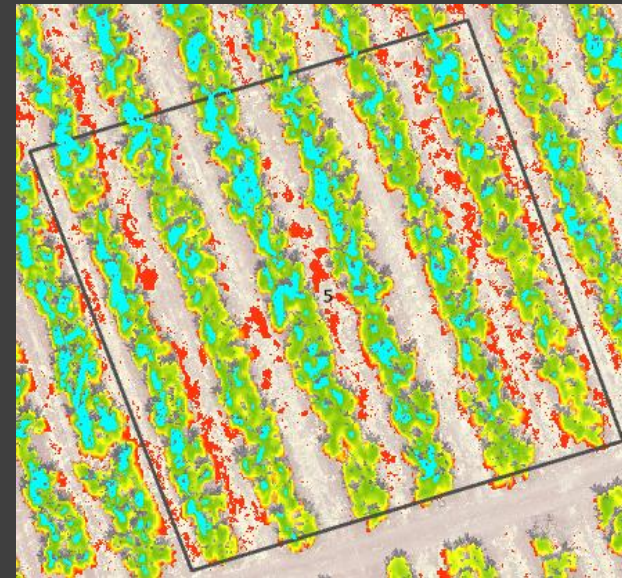
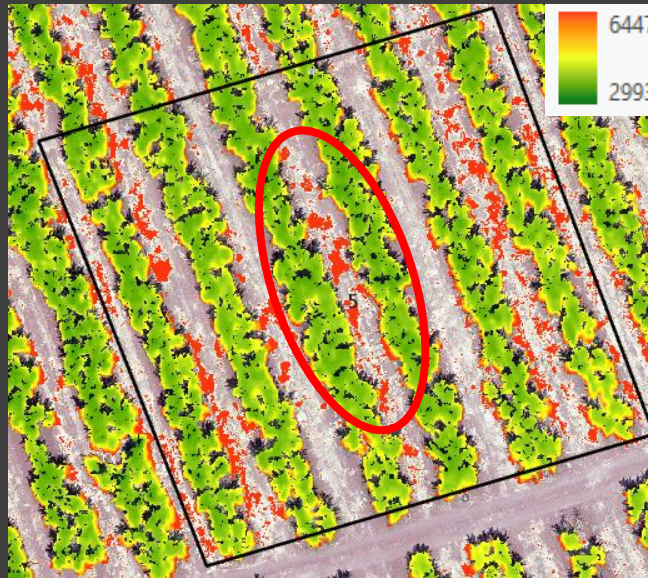
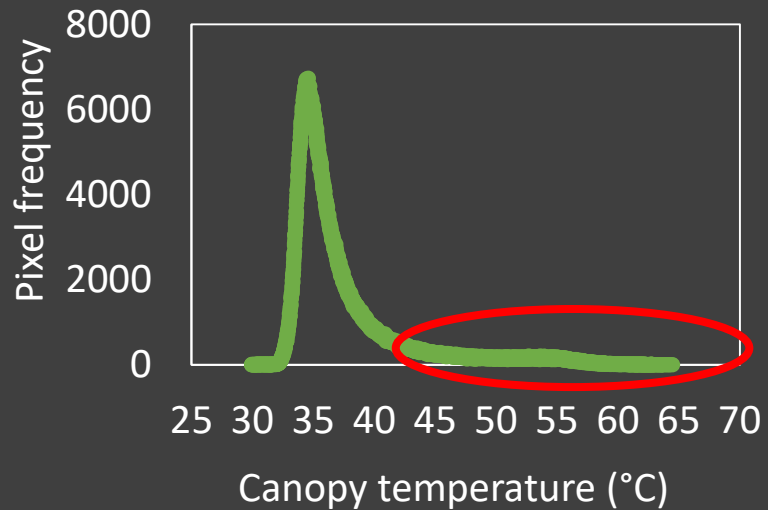
T100%



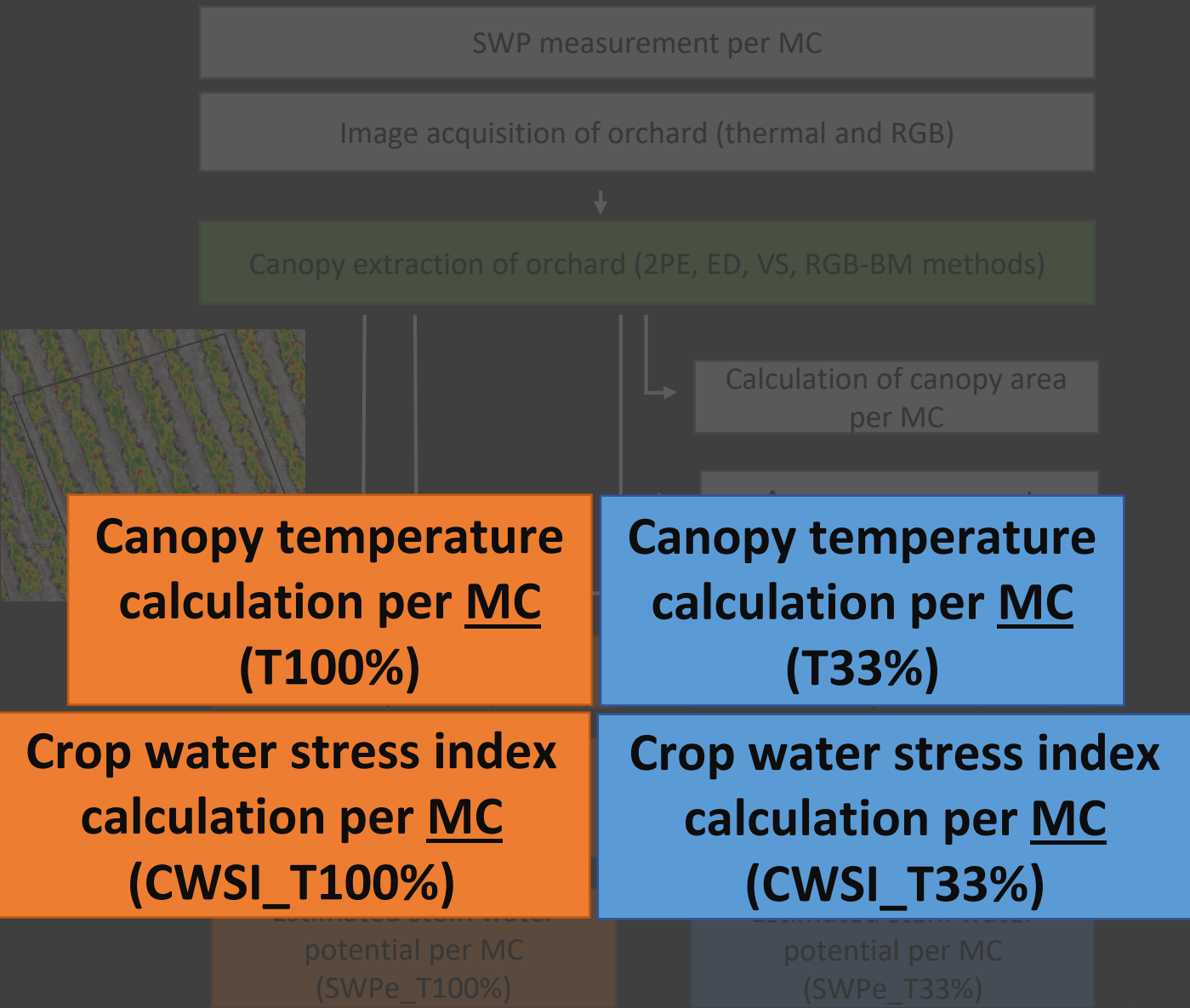
T33%



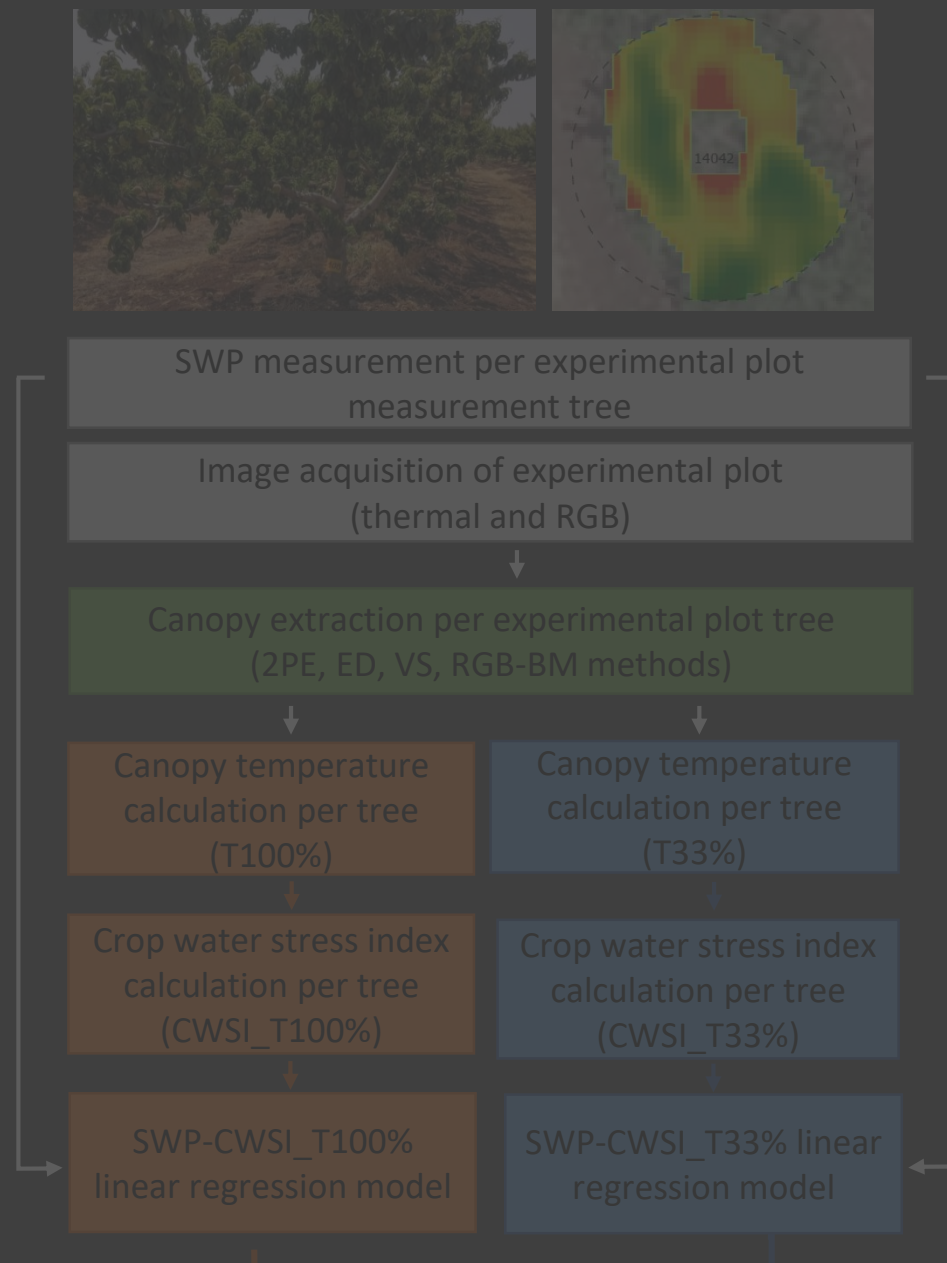
RGB - BM



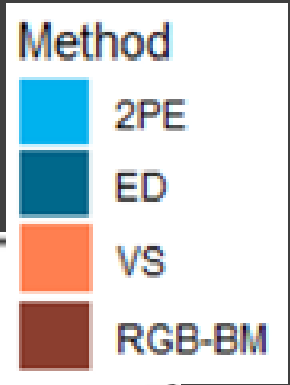
Orchard Canopy Extraction Accuracy and MC Canopy Temperature and Orchard Water Status



Establishment of SWP-CWSI Relationship



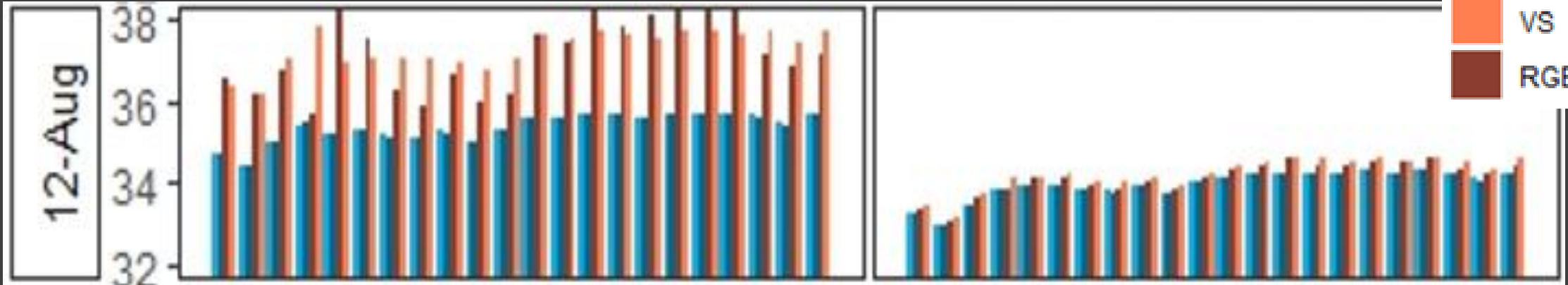
Canopy Temperature and CWSI – 12 Aug



Canopy temperature (°C)

T100%

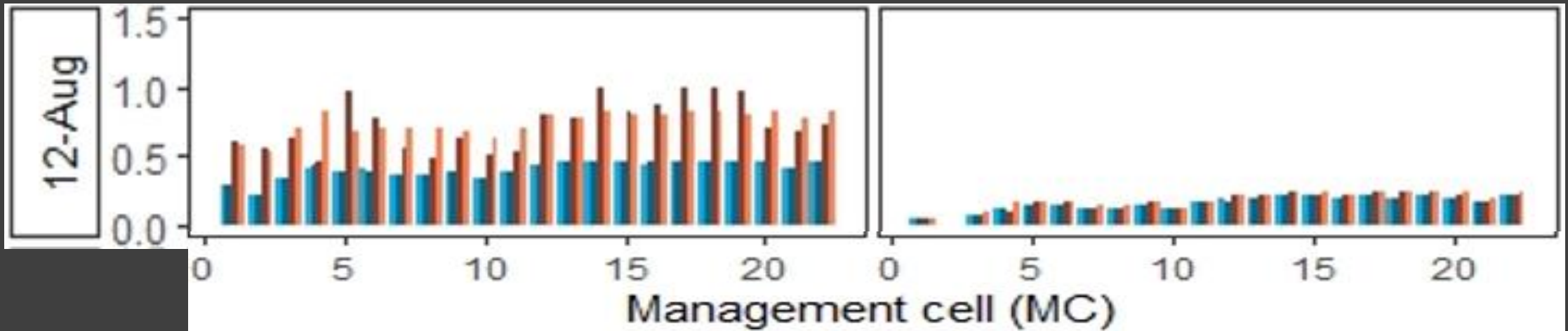
T33%



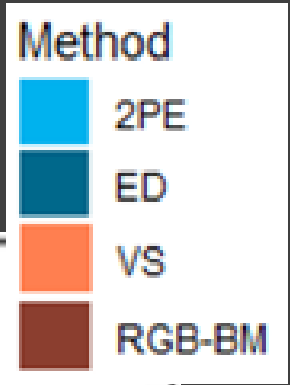
CWSI_T100%

CWSI_T33%

CWSI



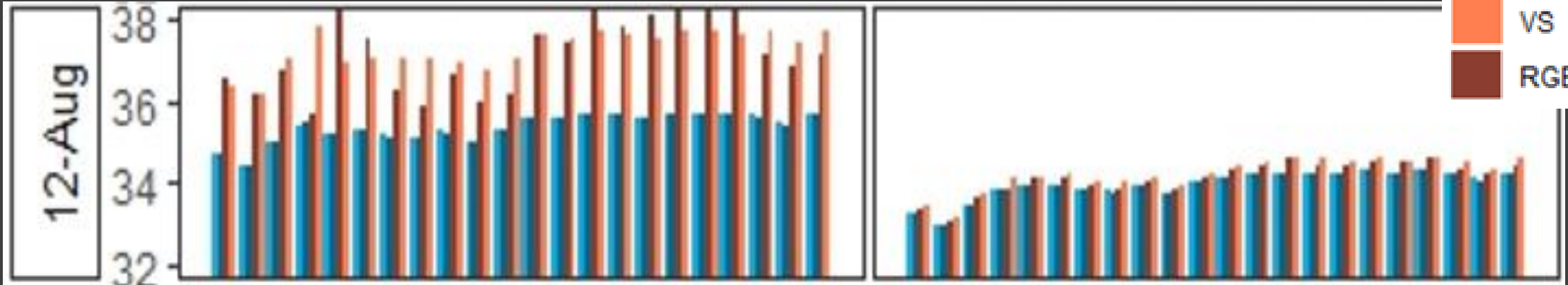
Canopy Temperature and CWSI – 12 Aug



Canopy temperature (°C)

T100%

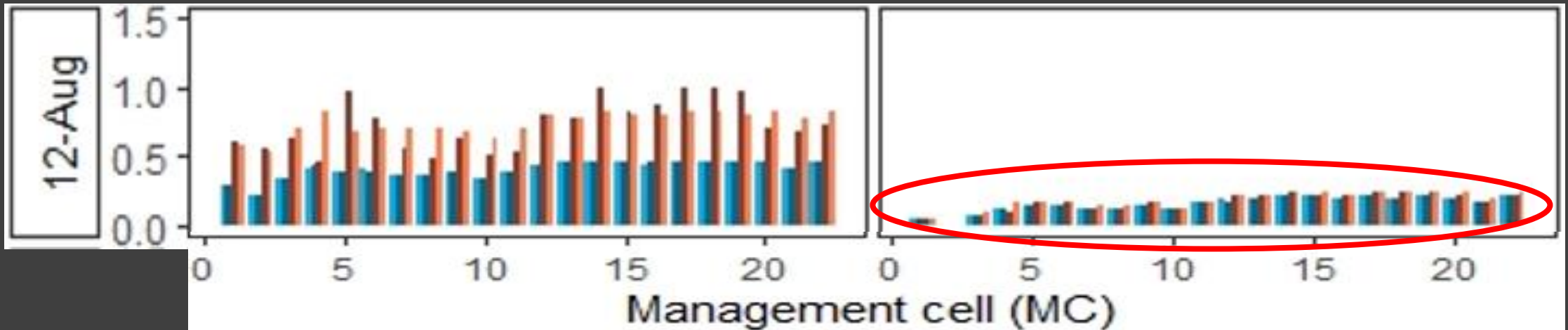
T33%



CWSI_T100%

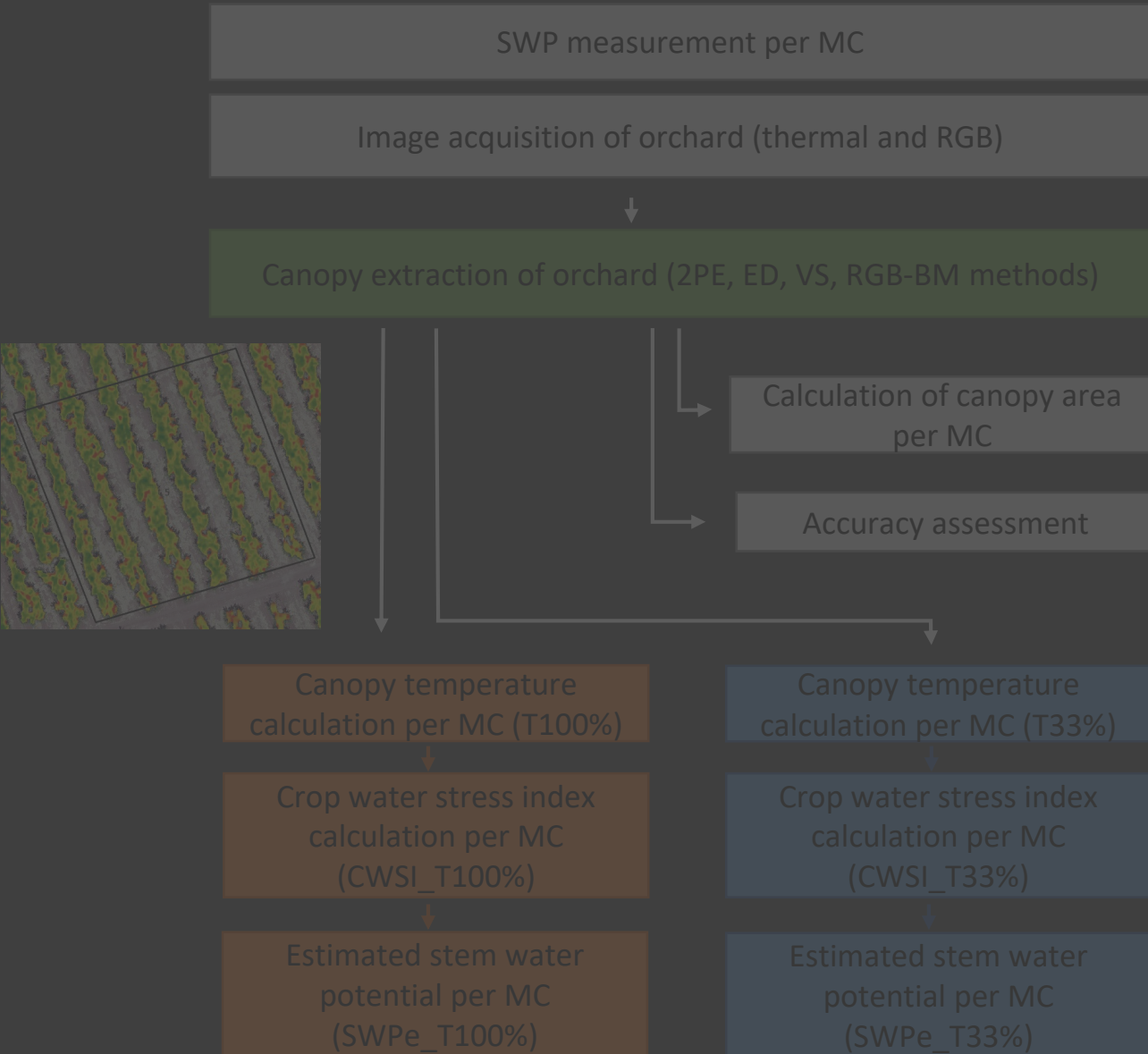
CWSI_T33%

CWSI

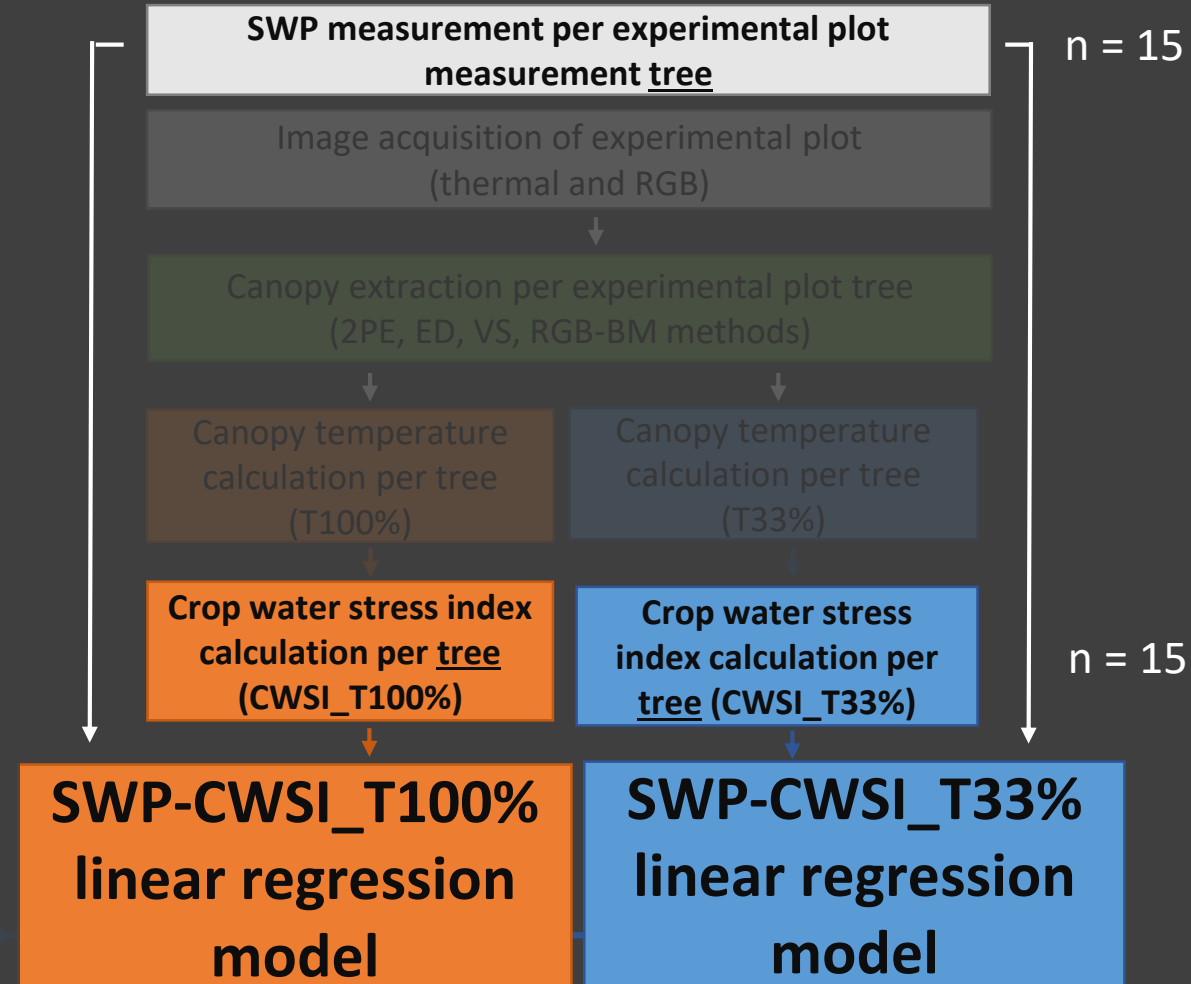


Management cell (MC)

Orchard Canopy Extraction Accuracy and MC Canopy Temperature and Orchard Water Status



Establishment of SWP-CWSI Relationship



Relationship Between SWP and CWSI

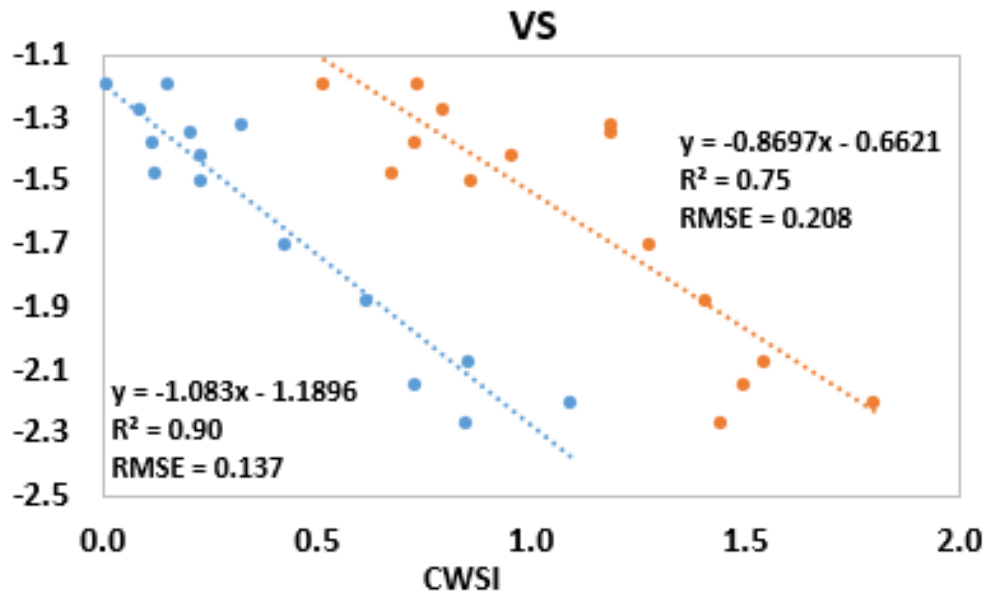
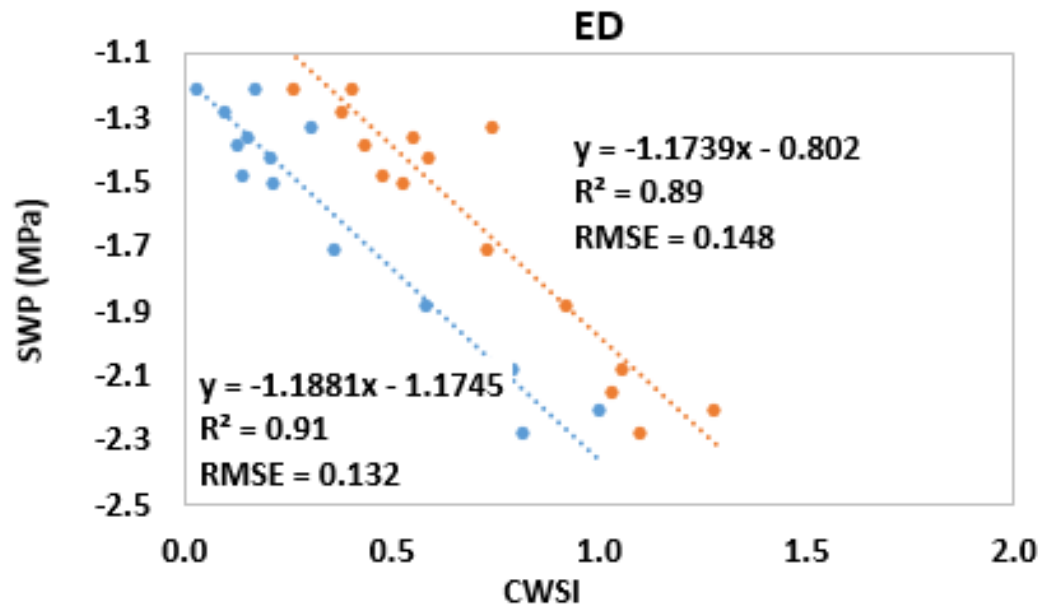
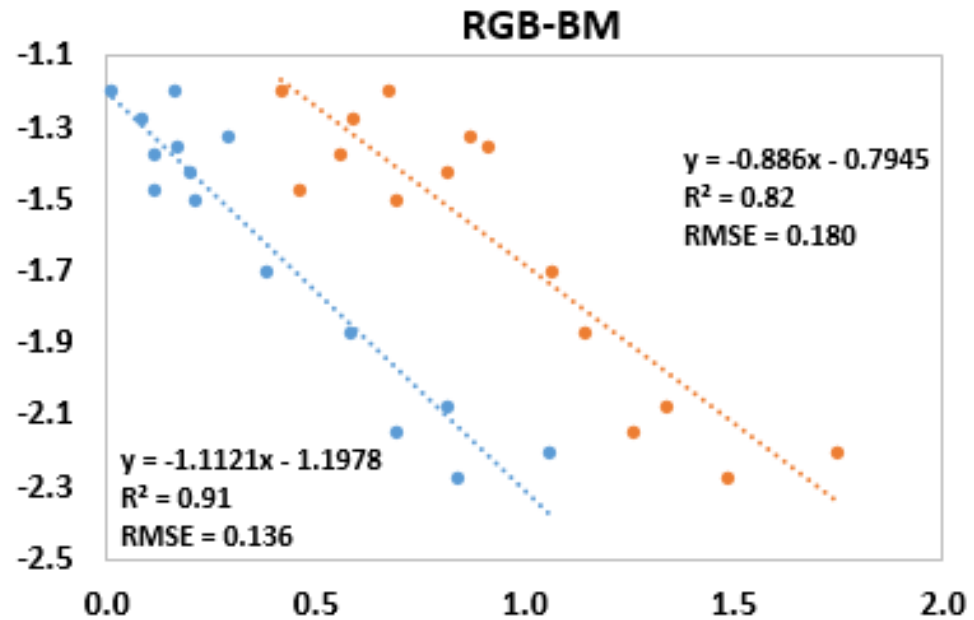
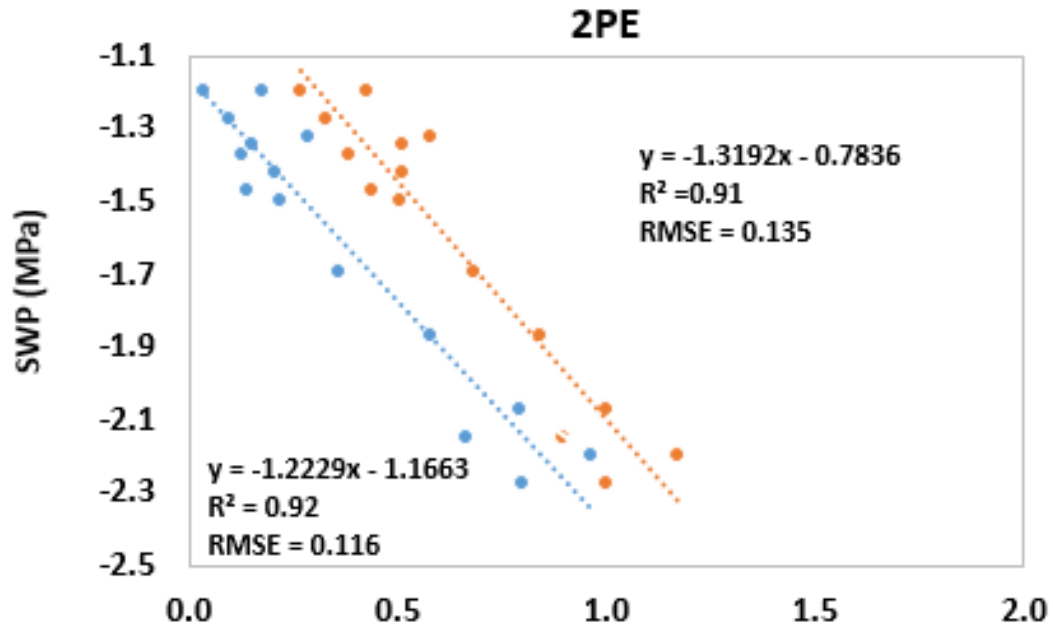
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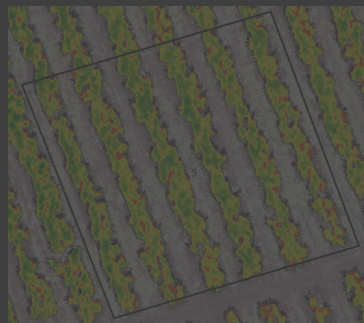
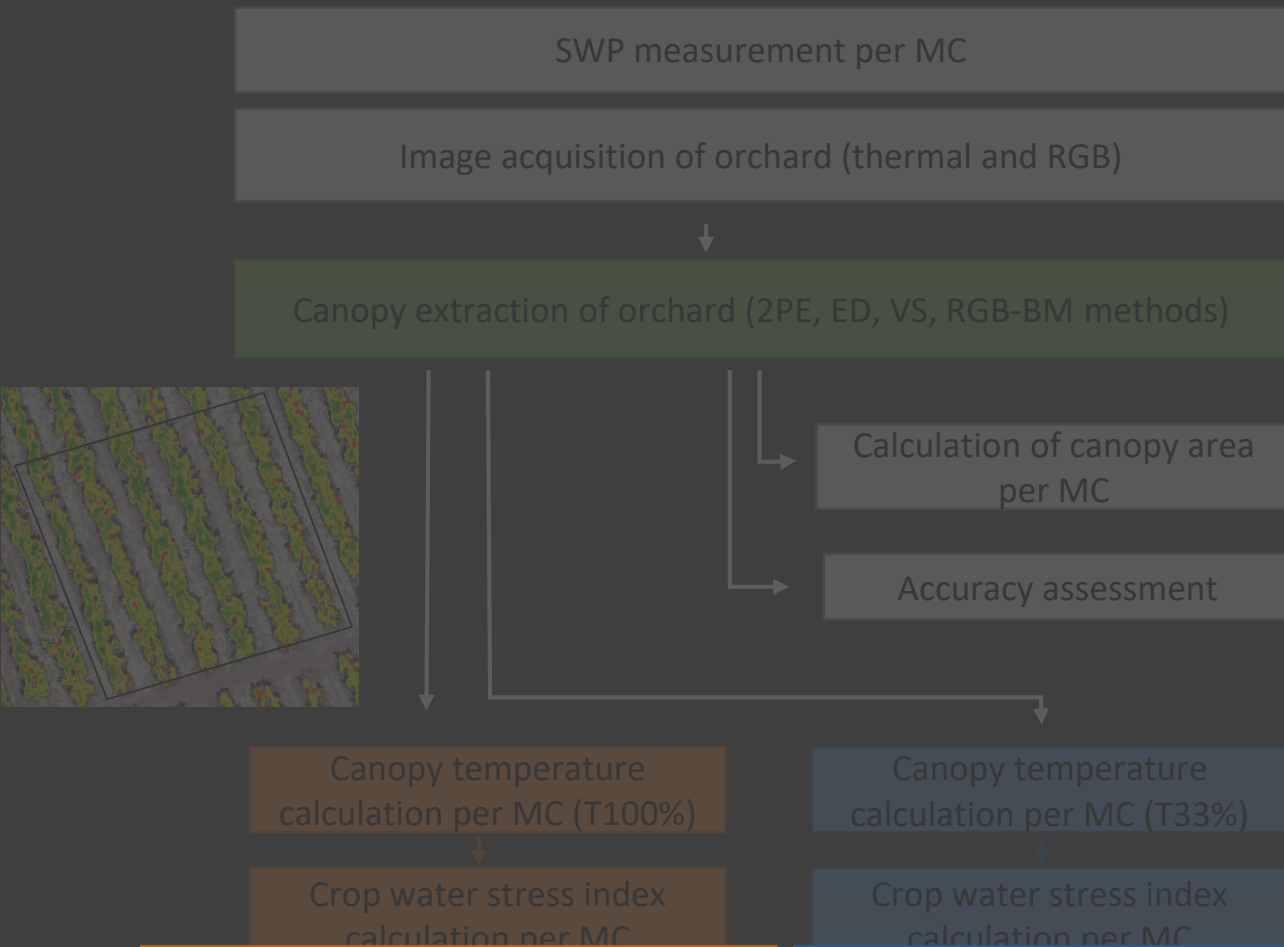
Conclusion



- T100%
- T33%

SWP – stem water potential

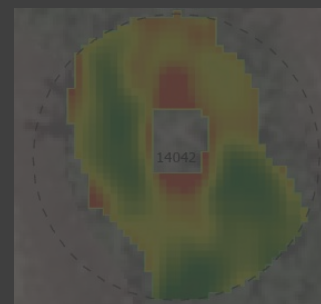
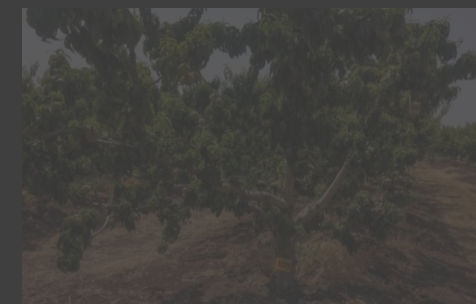
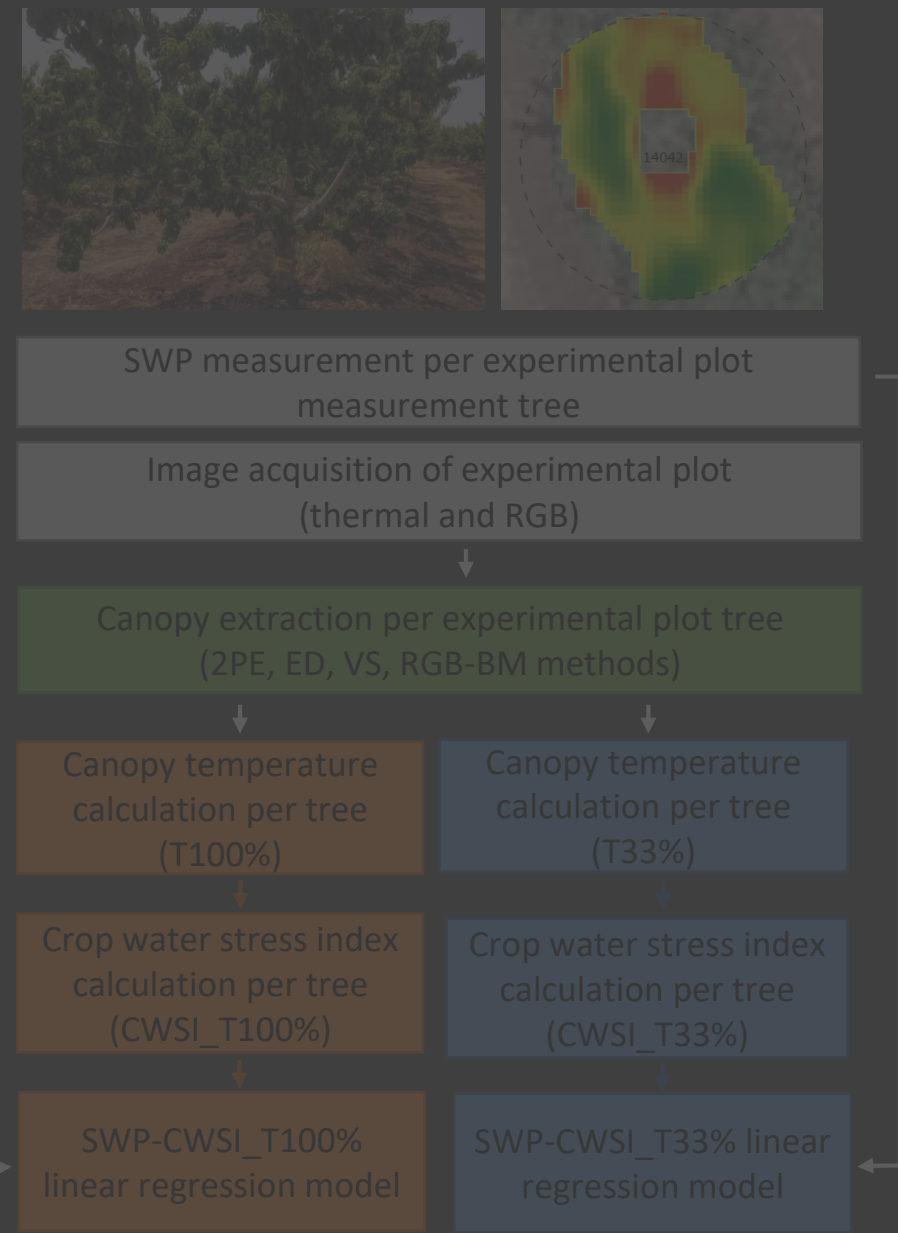
Orchard Canopy Extraction Accuracy and MC Canopy Temperature and Orchard Water Status



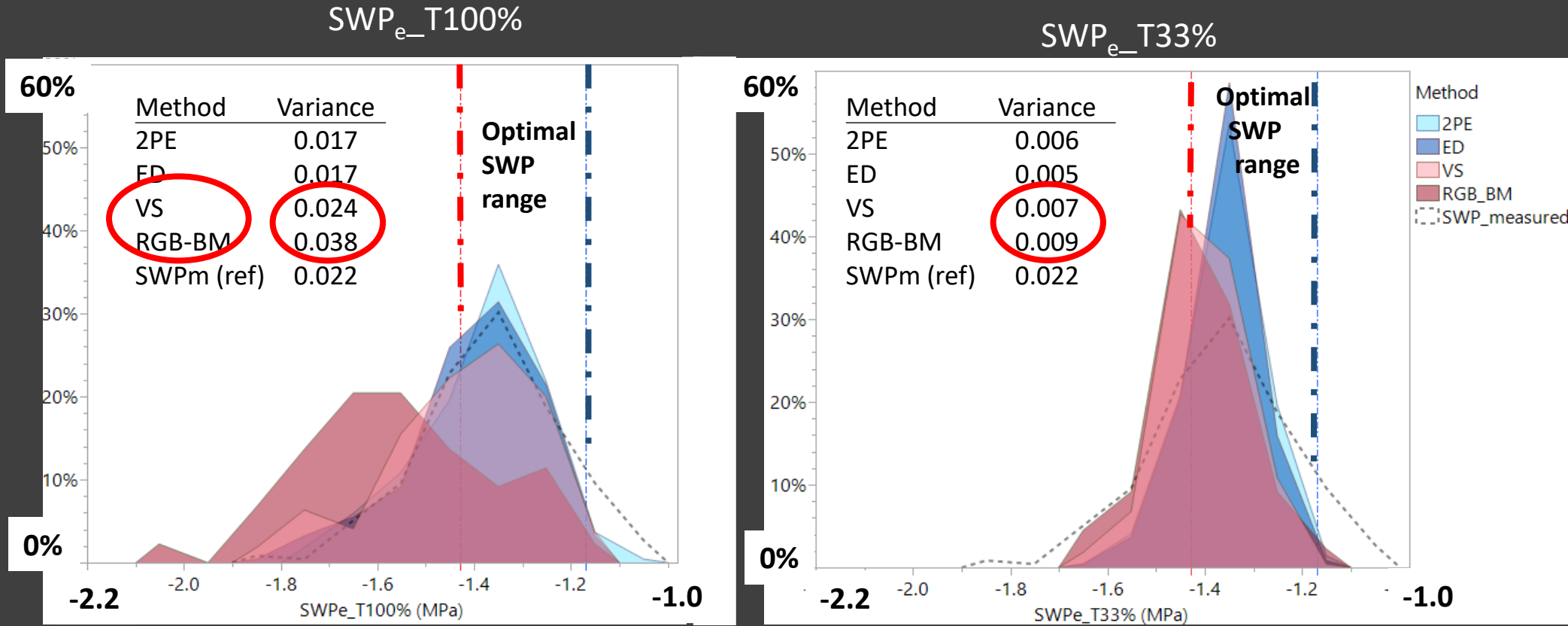
Estimated stem water potential per MC (SWPe_T100%)

Estimated stem water potential per MC (SWPe_T33%)

Establishment of SWP-CWSI Relationship

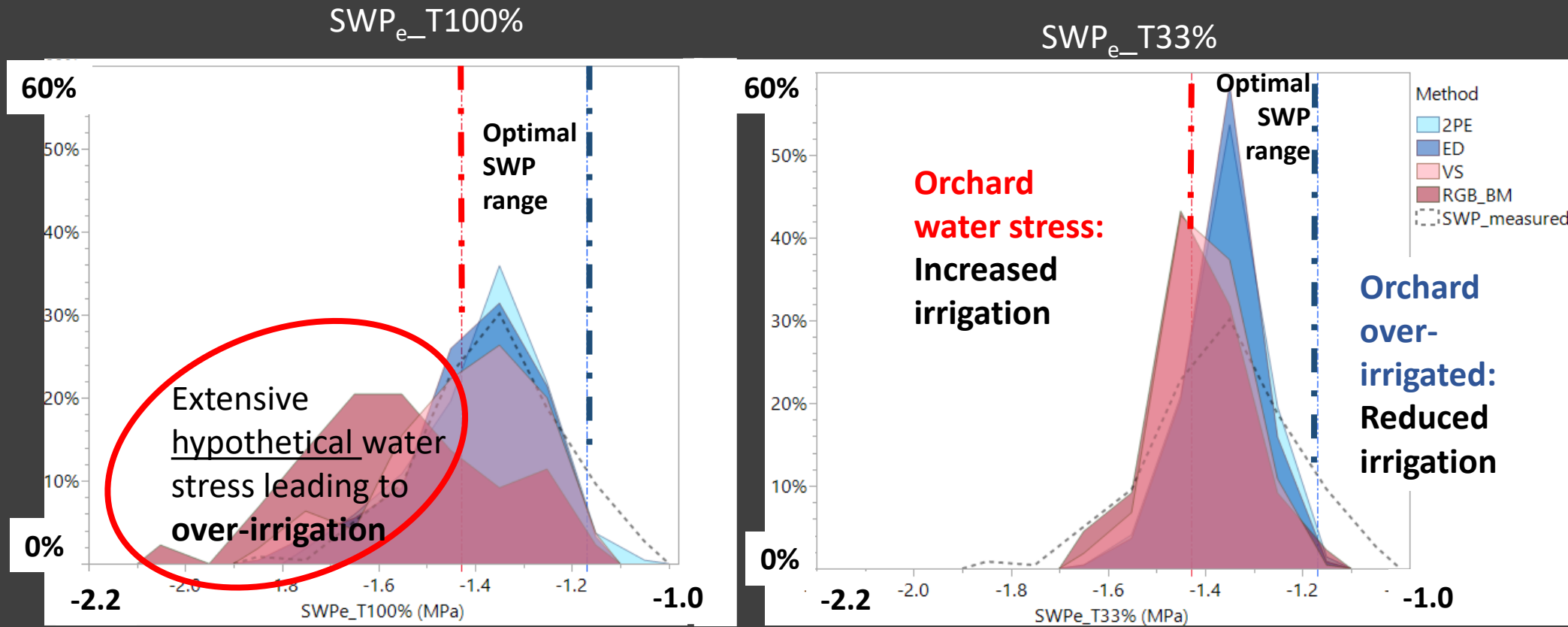


Estimated SWP (SWP_e)



Estimated SWP (SWP_e) – Possible Effect on Irrigation Decisions

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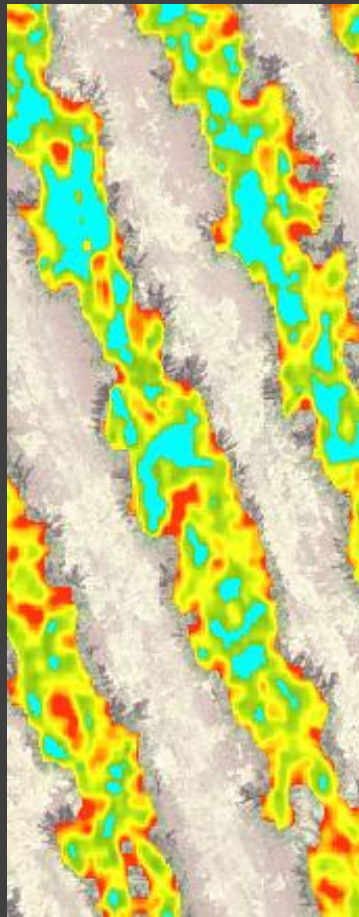


Main conclusions:

- The RGB image does not improve the quality of canopy extraction, rather good accuracy and quality can be obtained using a thermal image alone.
- The T33% canopy temperature calculation approach is more robust in comparison to T100%. Almost any canopy extraction method can be used together with T33% and similar results are obtained.

Future research:

- To what degree can thermal imagery accurately and reliably estimate areas of SWP_e overestimation and underestimation.
- To determine the relationship between SWP and CWSI on additional days, under different meteorological conditions, and over seasons to strengthen the estimation of orchard water status.



- **Research funding:** Kendel precision irrigation project, Ministry of Agriculture and project SHui, Managing water scarcity in European and Chinese cropping systems, EU Horizon 2020 Research and Innovation Programme
- **Northern R&D team:** Shimon Zait, Shlomi Kfir, Ayelet Sar Shalom, Menashe Levi
- **Operations and field measurements team:** Ohad Masad, Reshef Almakais, Tomer Hagai
- **Mishmar Hayarden orchard team:** Shlomo Cohen, Shai Cohen, Dubi Glick
- **Datamap team:** Rami Kopelman, Ido Rahav, Tom Ditchi
- **Kendel precision irrigation project team:** Uria Luzon
- **MIGAL Hydrogeochemistry Lab team:** including Dr. Oren Reichman

Thank you 😊

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