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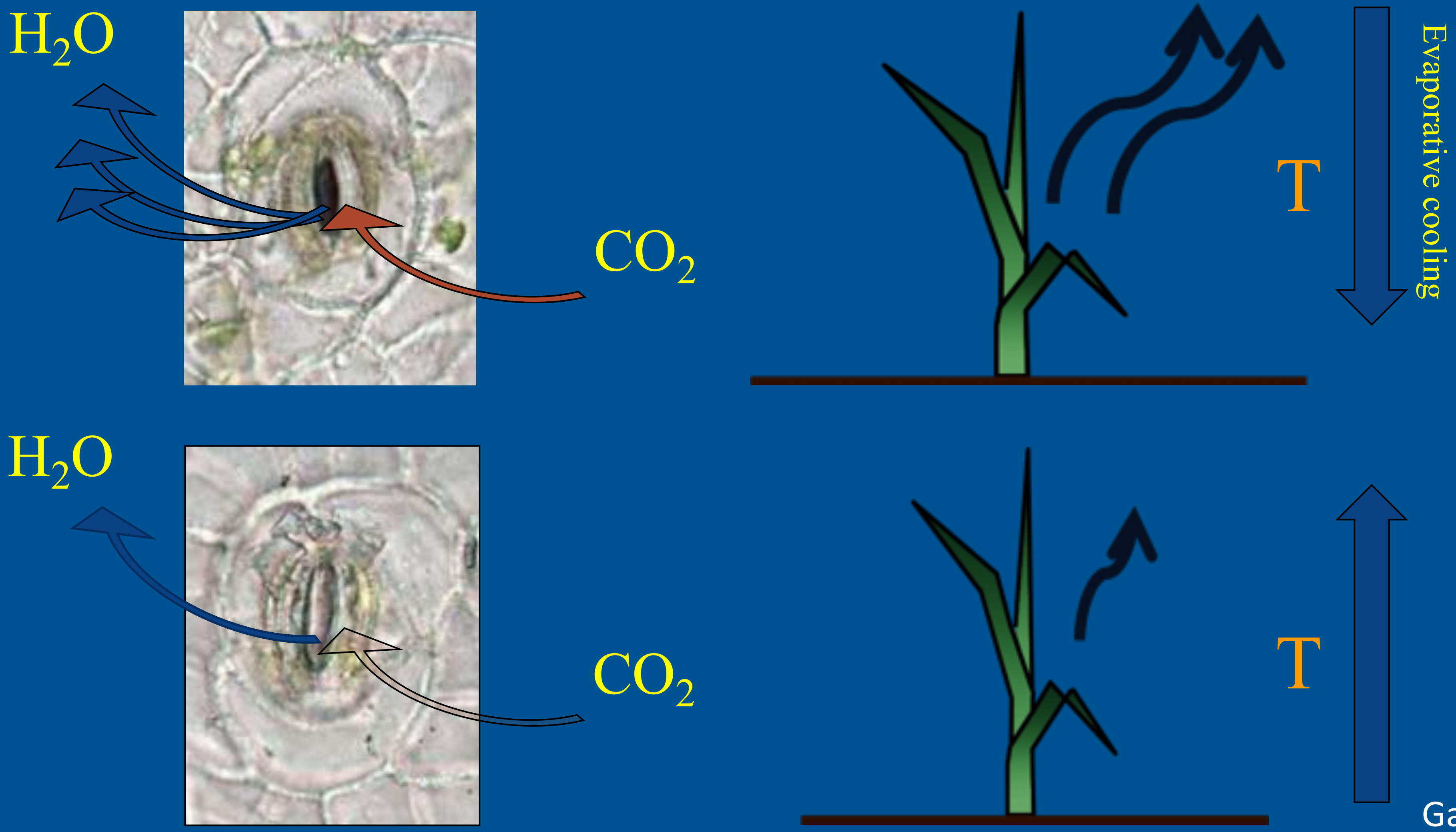
High-resolution thermal imagery holds critical plant physiological information: lessons learned on water stress and disease detection using airborne platforms

P.J. Zarco-Tejada, V. Gonzalez-Dugo, T. Poblete, C. Camino, R. Calderon, A. Hornero, R. Hernandez-Clemente, B.B. Landa, J. A. Navas-Cortes

University of Melbourne, Australia

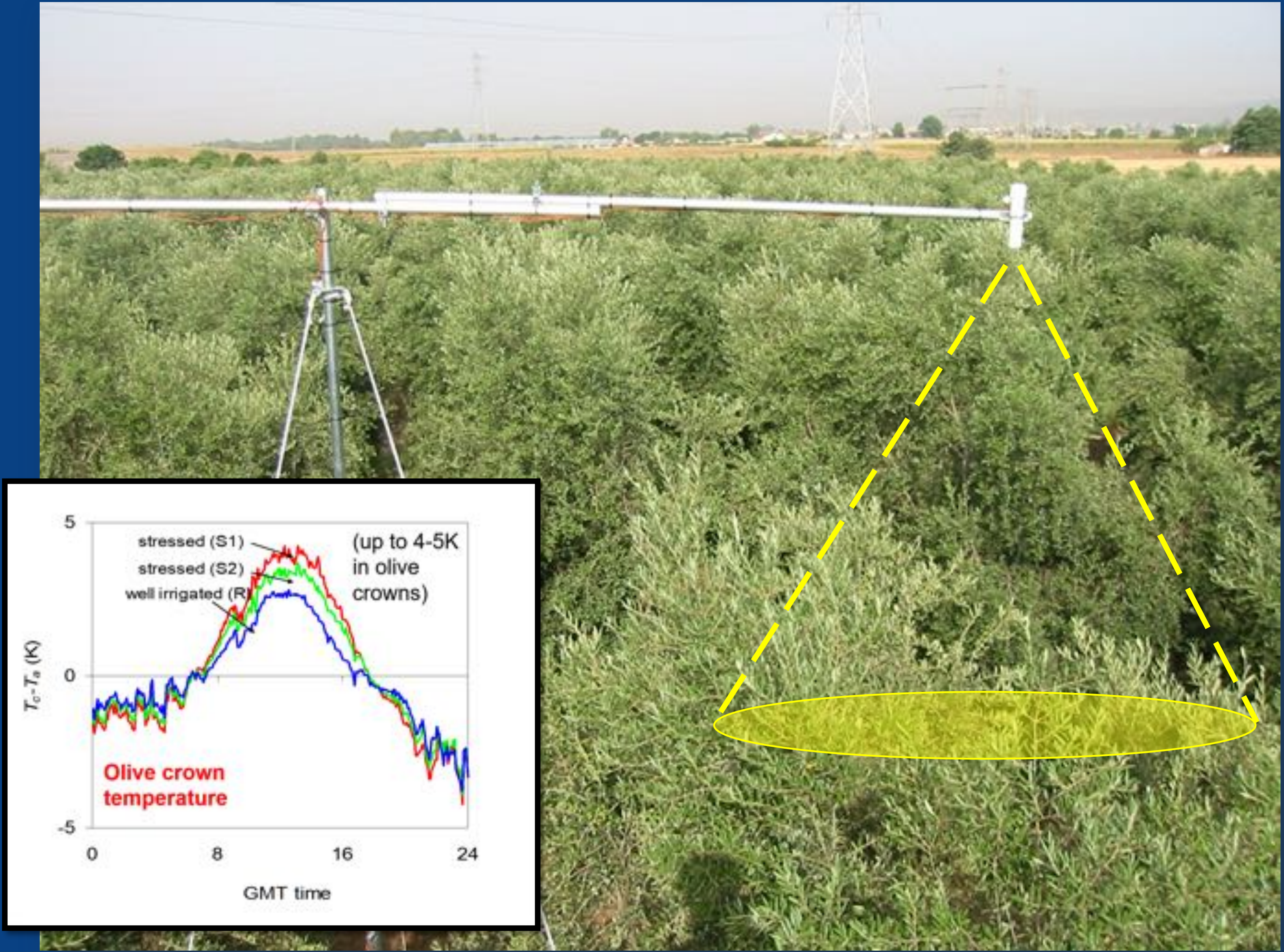
IAS-CSIC, Spain

Transpiration - Temperature



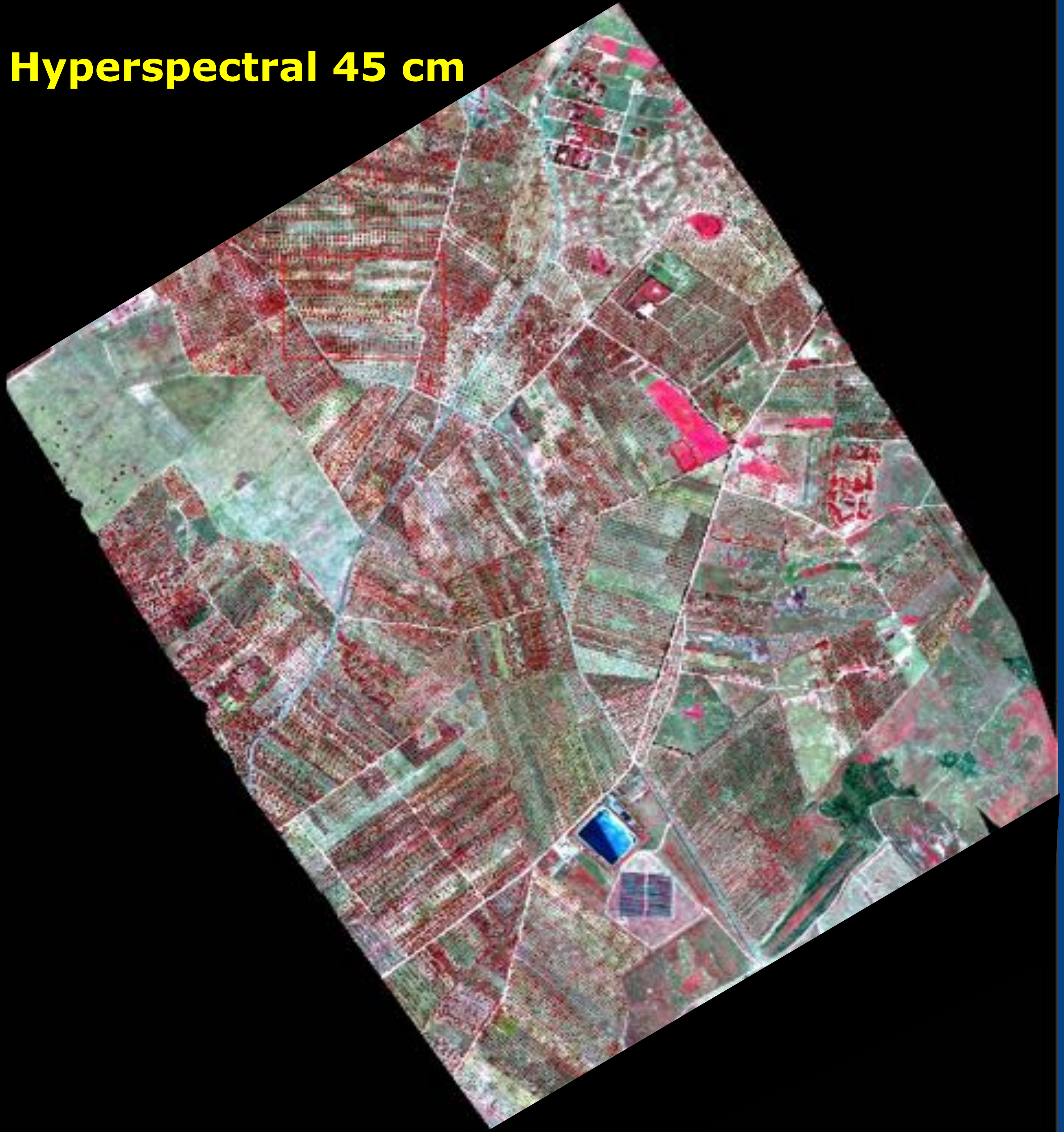
Gates (1968)
Jackson *et al.* (1977)

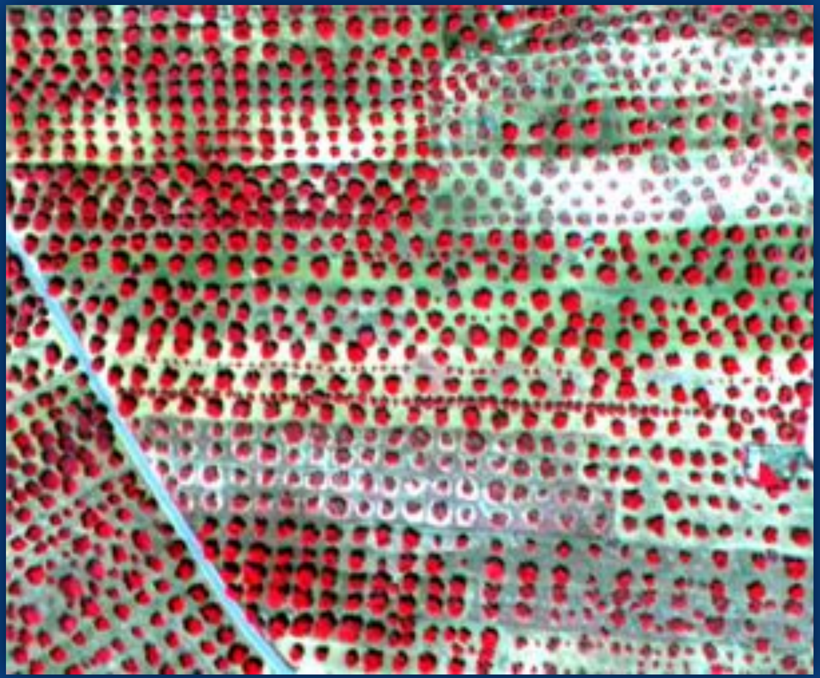
Tree crown temperature



Sepulcre *et al.* (2006) **(olive)**
Bellvert *et al.* (2015) **(vineyards)**
Gonzalez-Dugo *et al.* (2020) **(almond)**

Hyperspectral 45 cm





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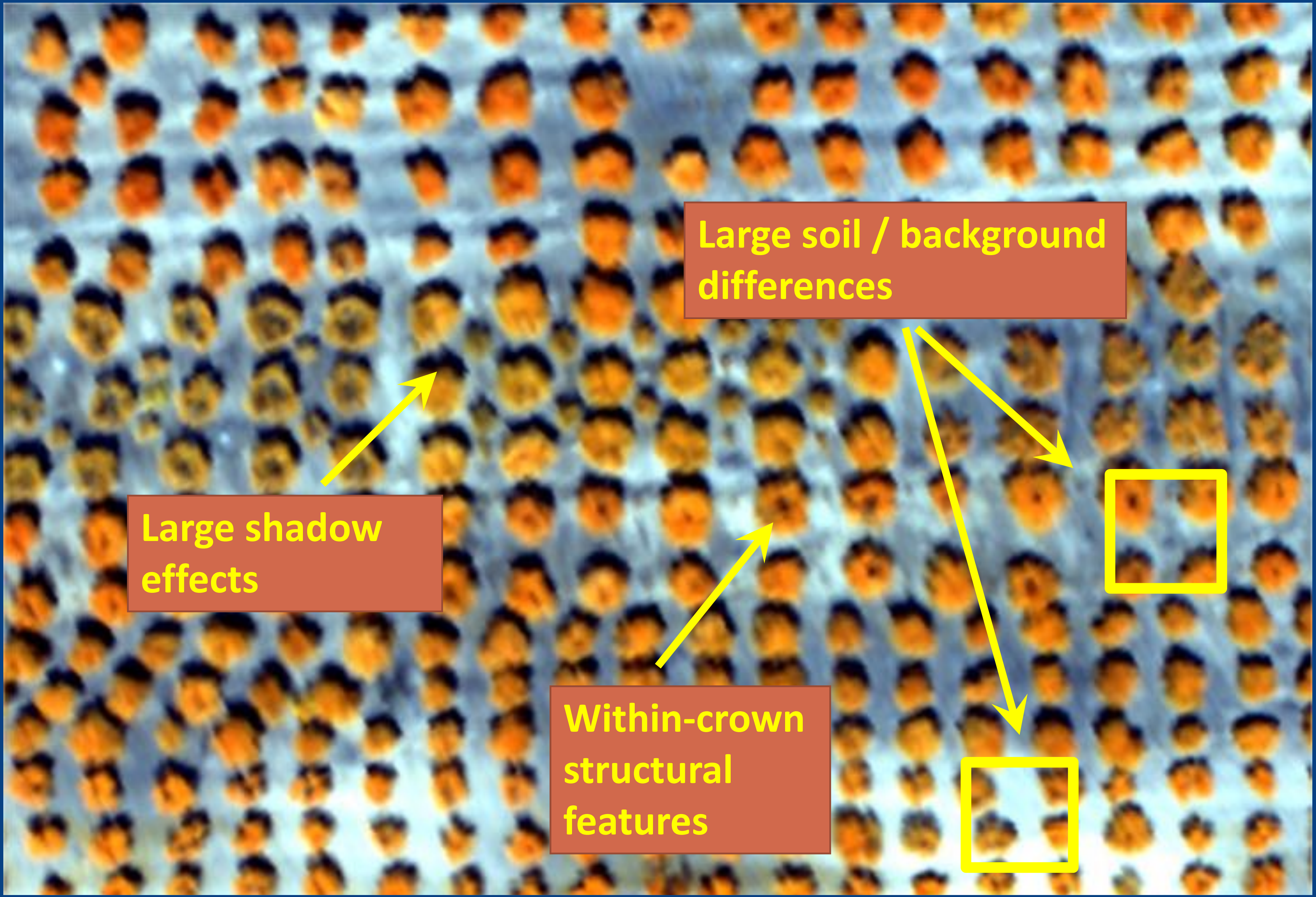
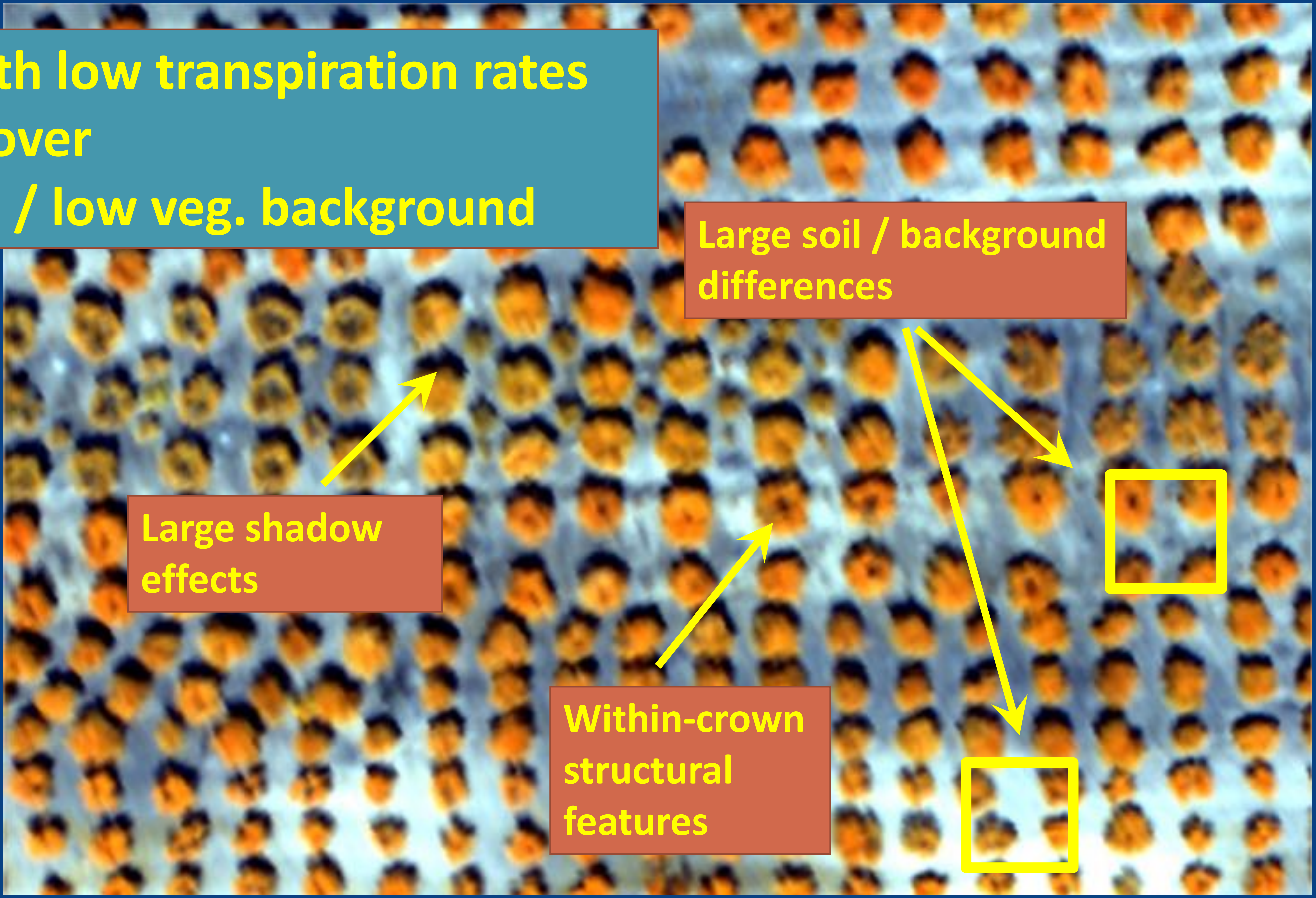
50 cm



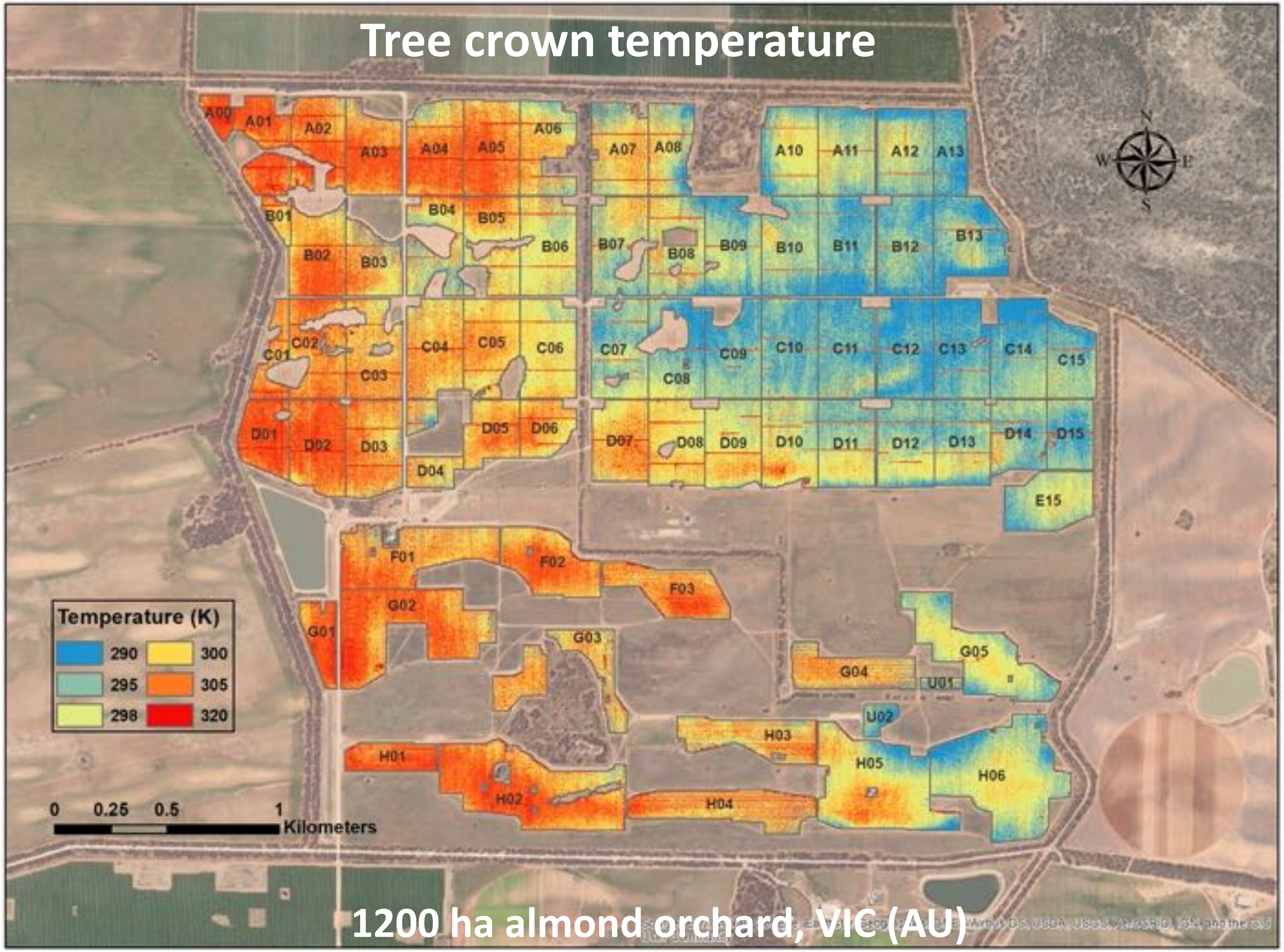
Trees with low transpiration rates

Low % cover

Bare soil / low veg. background

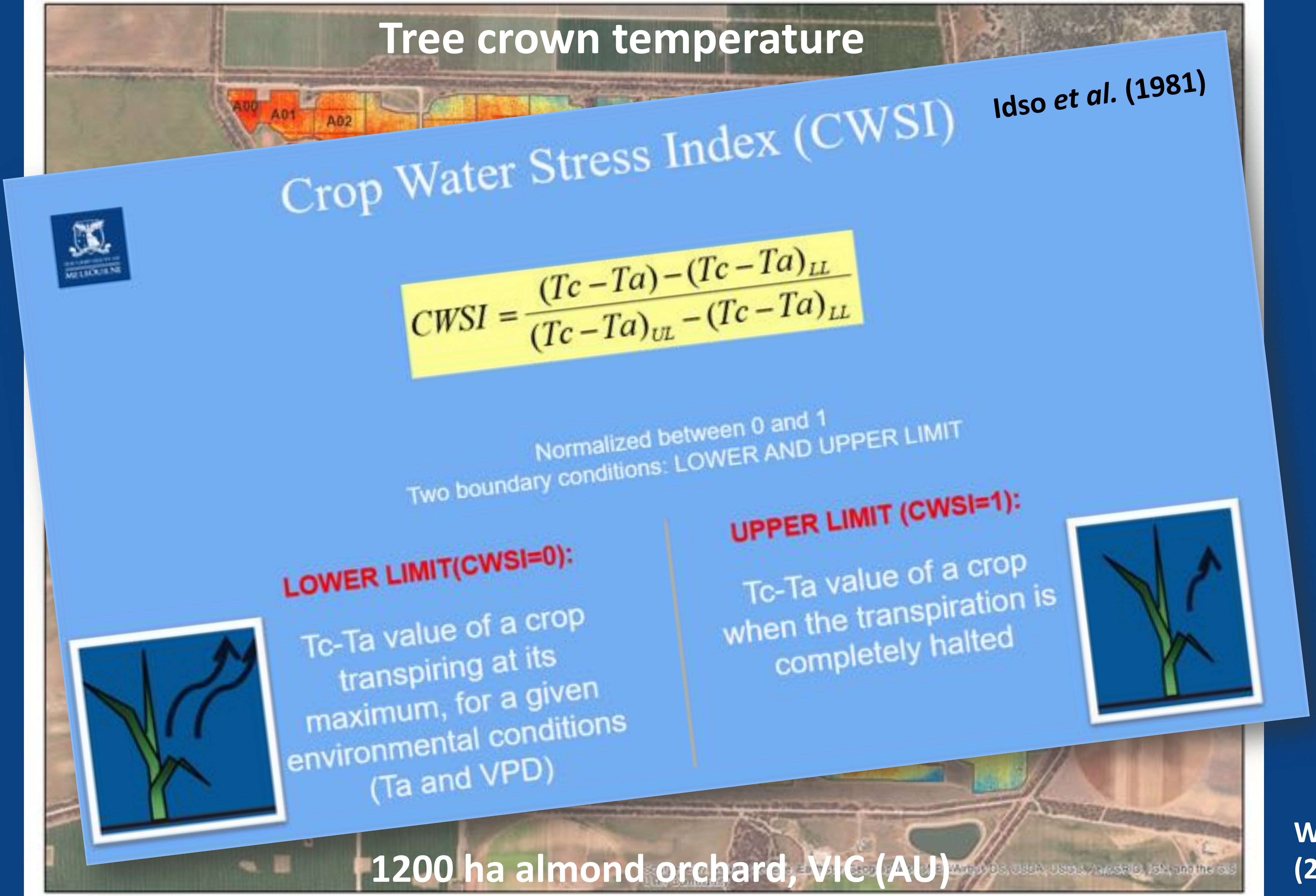


Tree crown temperature



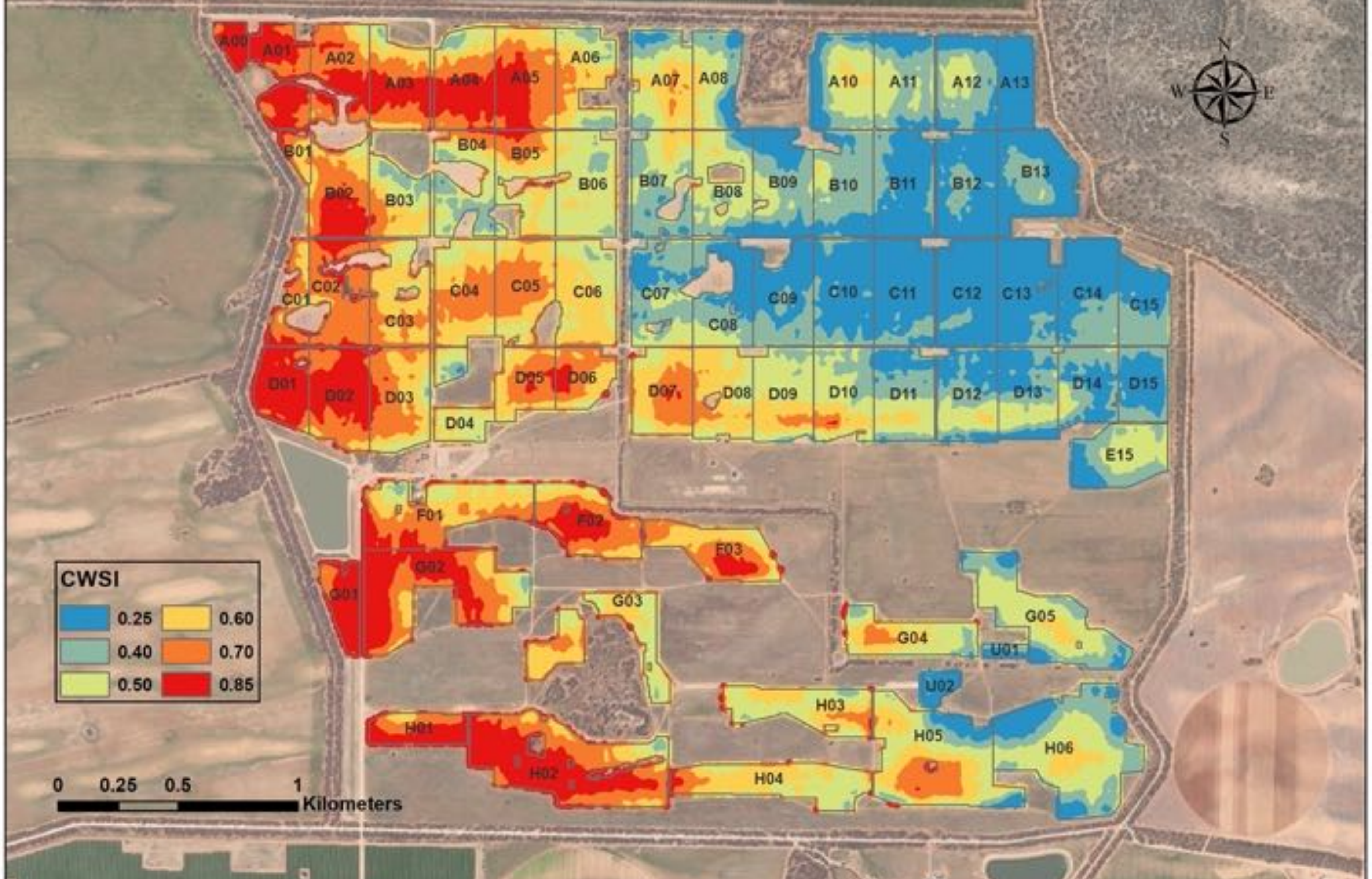
Wang *et al.* (2022)

Tree crown temperature



Wang *et al.* (2022)

Crop Water Stress Index (CWSI)



1200 ha almond orchard, VIC (AU)

Wang *et al.* (2022)

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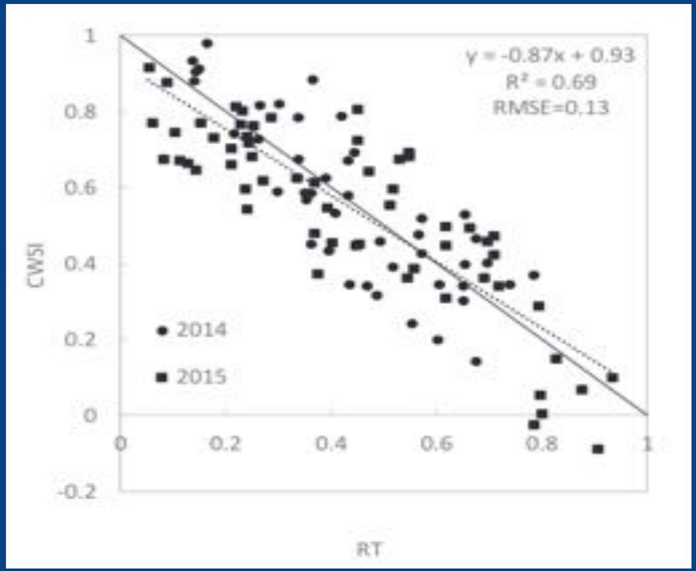
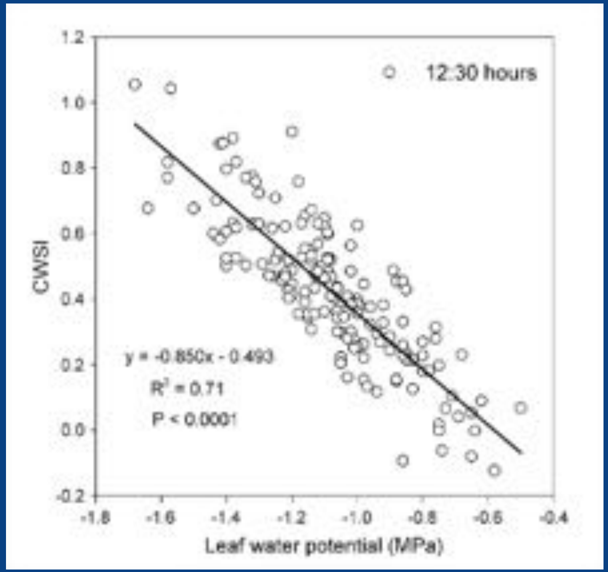
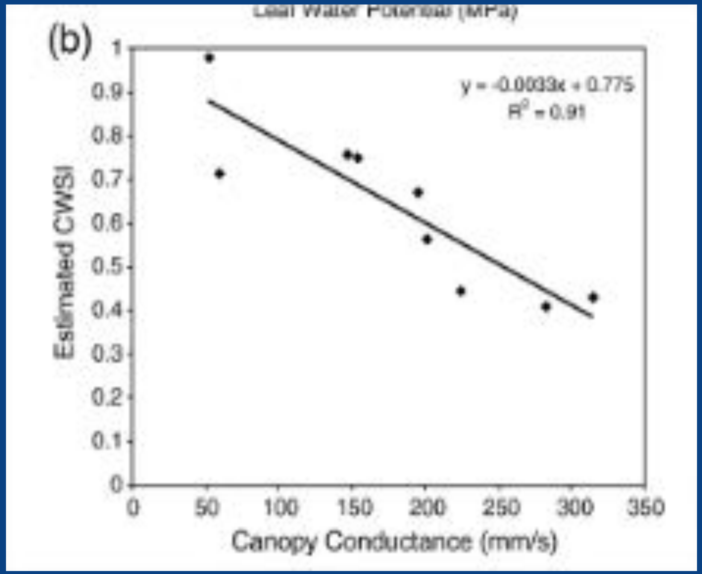
CWSI vs Ψ



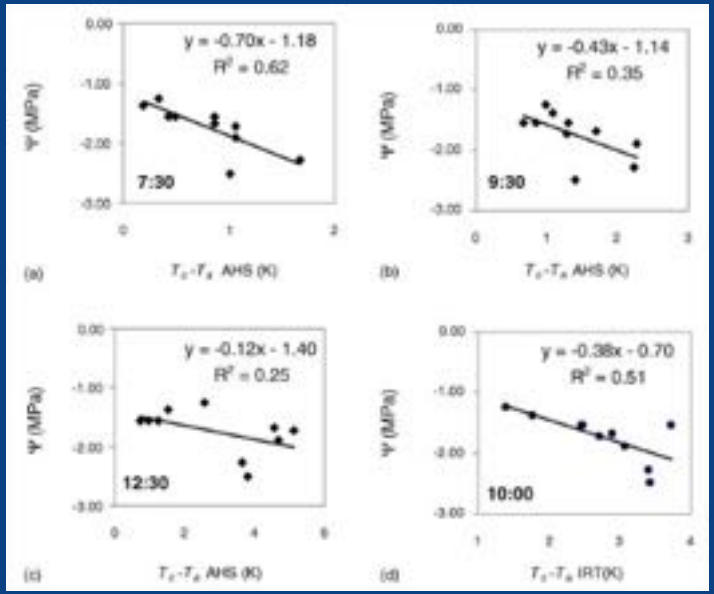
Gonzalez-Dugo *et al.* (2020) - almond



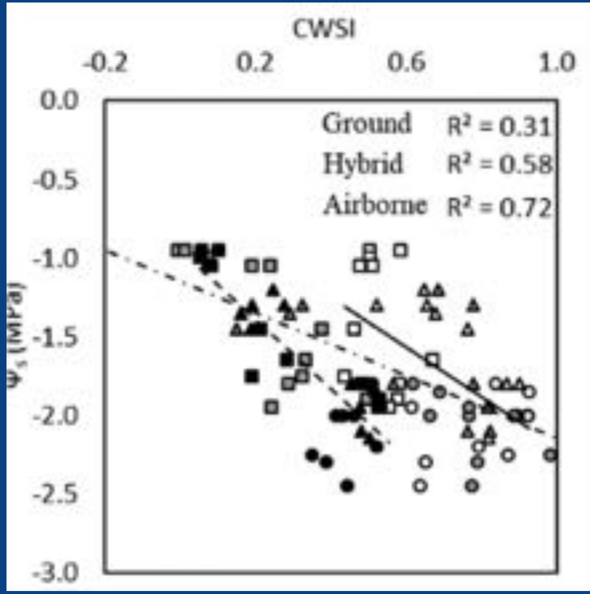
Bellvert *et al.* (2014) - grapevines



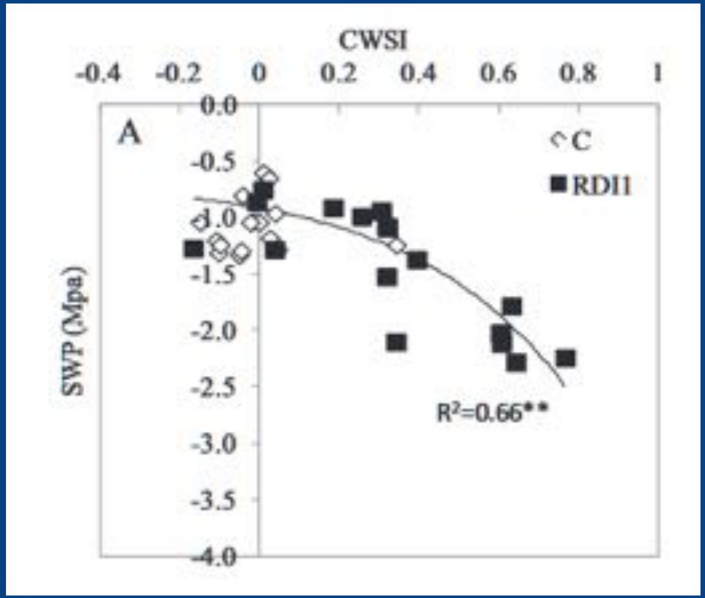
Berni *et al.* (2009) - olive



Sepulcre-Cantó *et al.* (2006) - olive

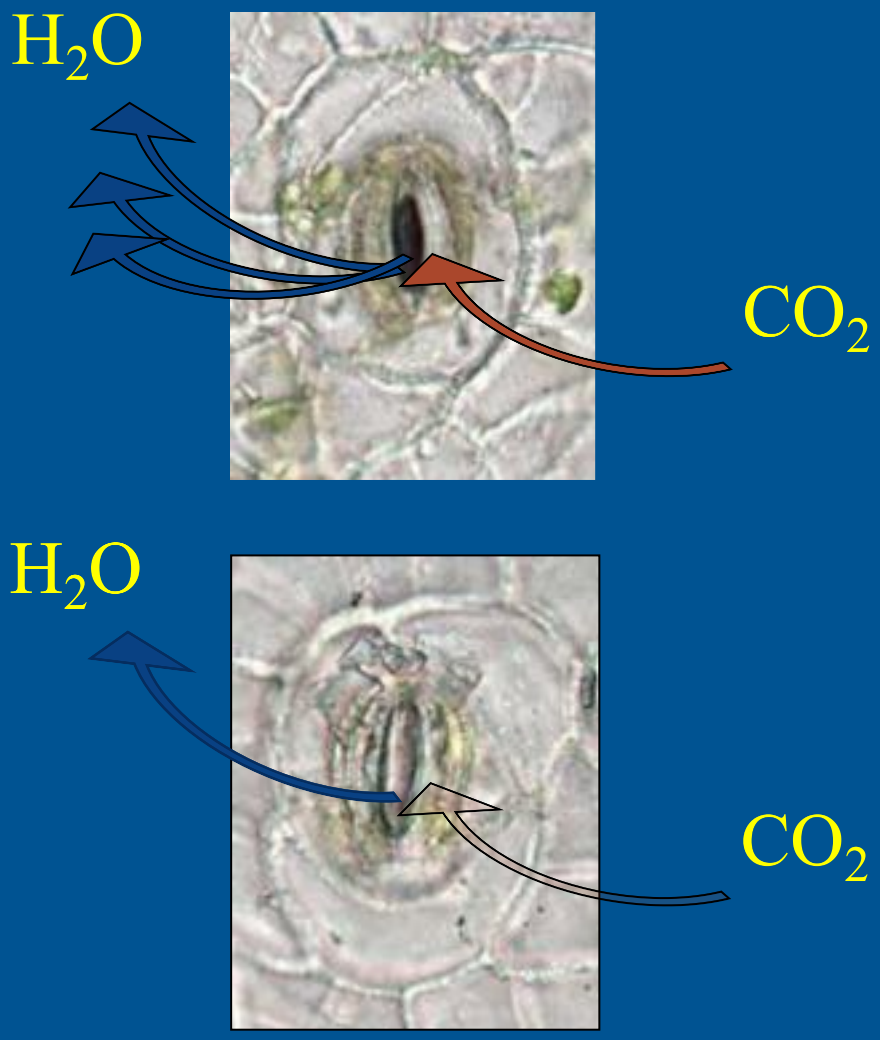


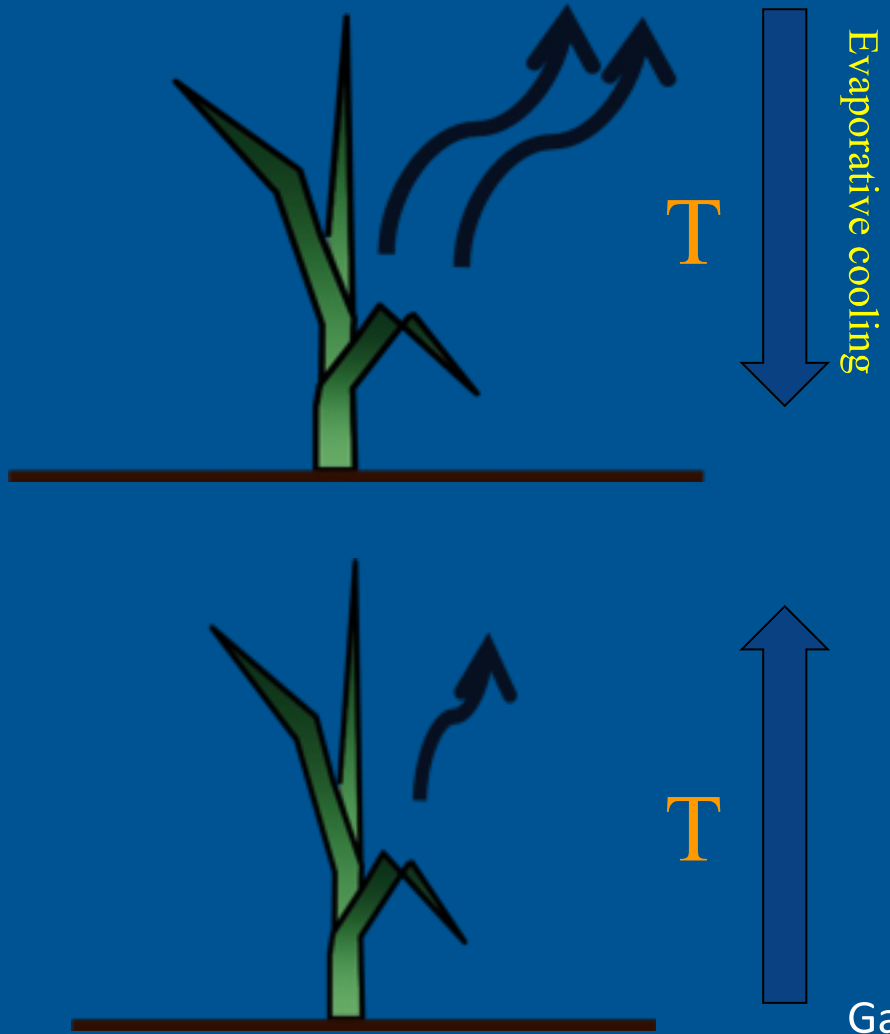
Ramirez-Cuesta *et al.* (2022) – peach



Gonzalez-Dugo *et al.* (2014) - citrus

Transpiration - Temperature





Gates (1968)
Jackson *et al.* (1977)

Transpiration - Temperature

Vascular plant pathogens:

→ **Colonize and block the vascular system → interfere with water and nutrients flow**

→ **Confounding effects with water stress**

Gates (1968)
Jackson *et al.* (1977)

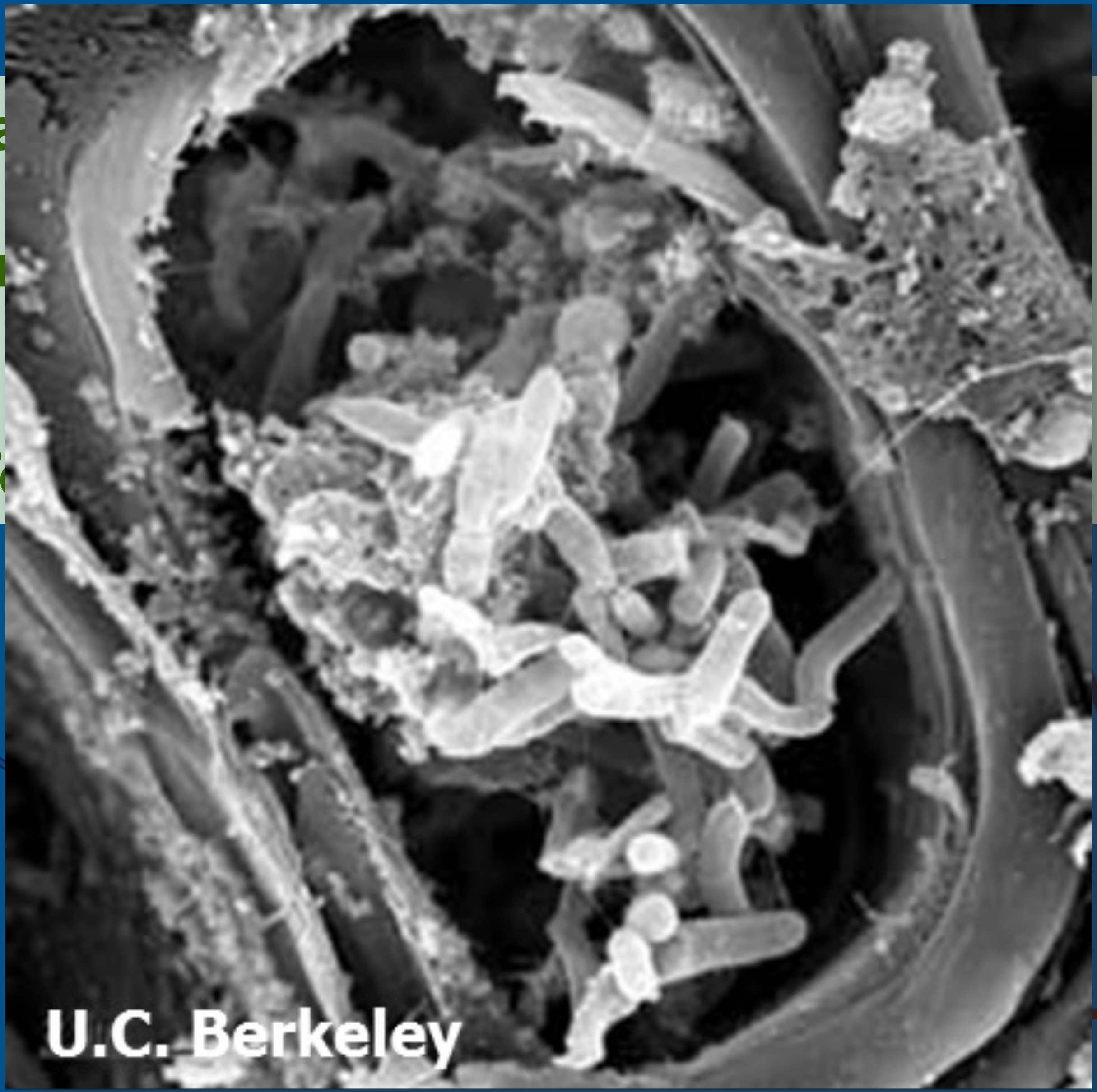
Transpiration - Temperature

Vascula

→ **Colo**
with

interfere

→ **Conf**



H_2O

T

Gates (1968)
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Transpiration - Temperature

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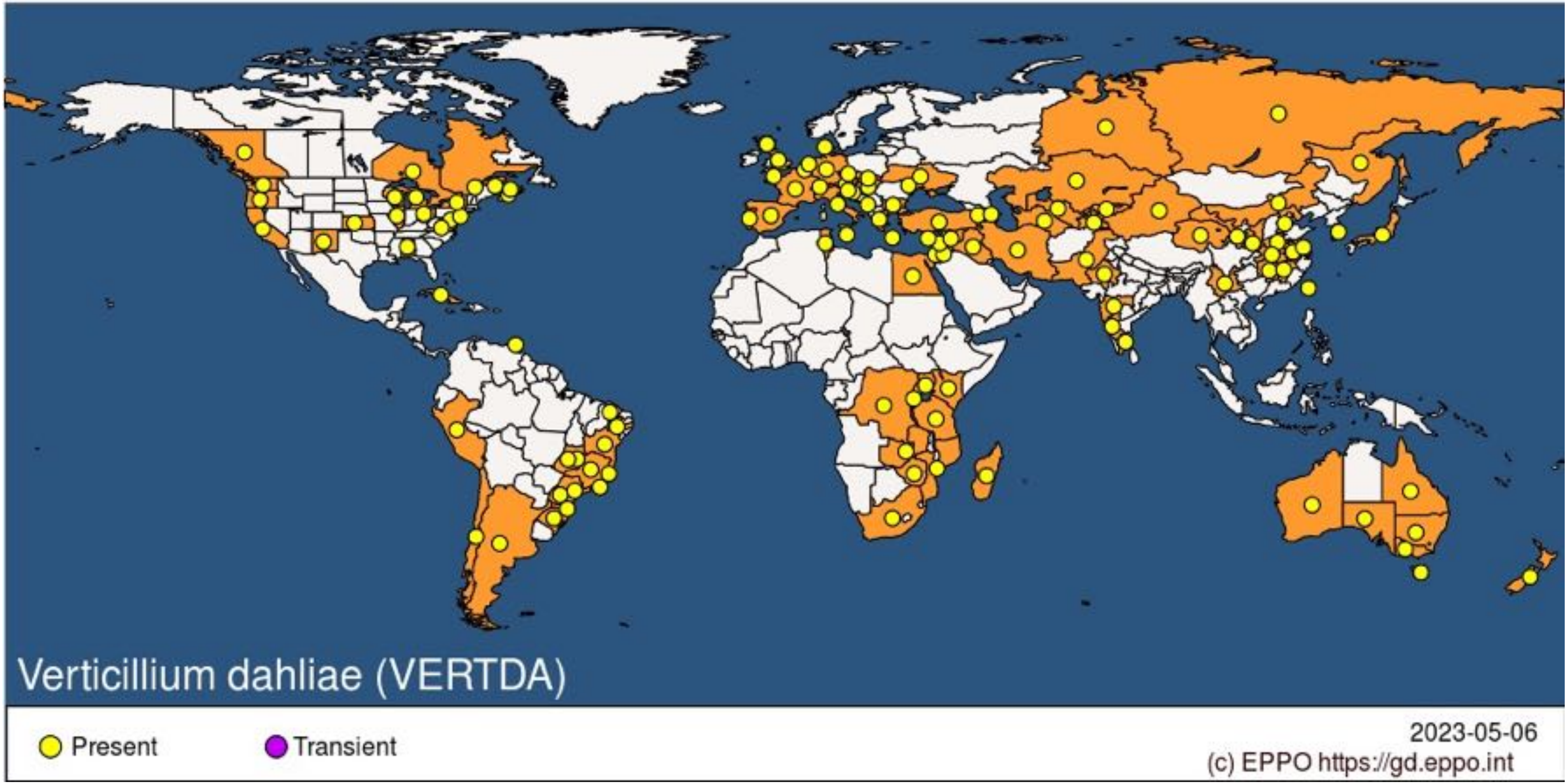
Gates (1968)
Jackson *et al.* (1977)

Vascular plant pathogens: *Verticillium dahliae vs Xylella fastidiosa*

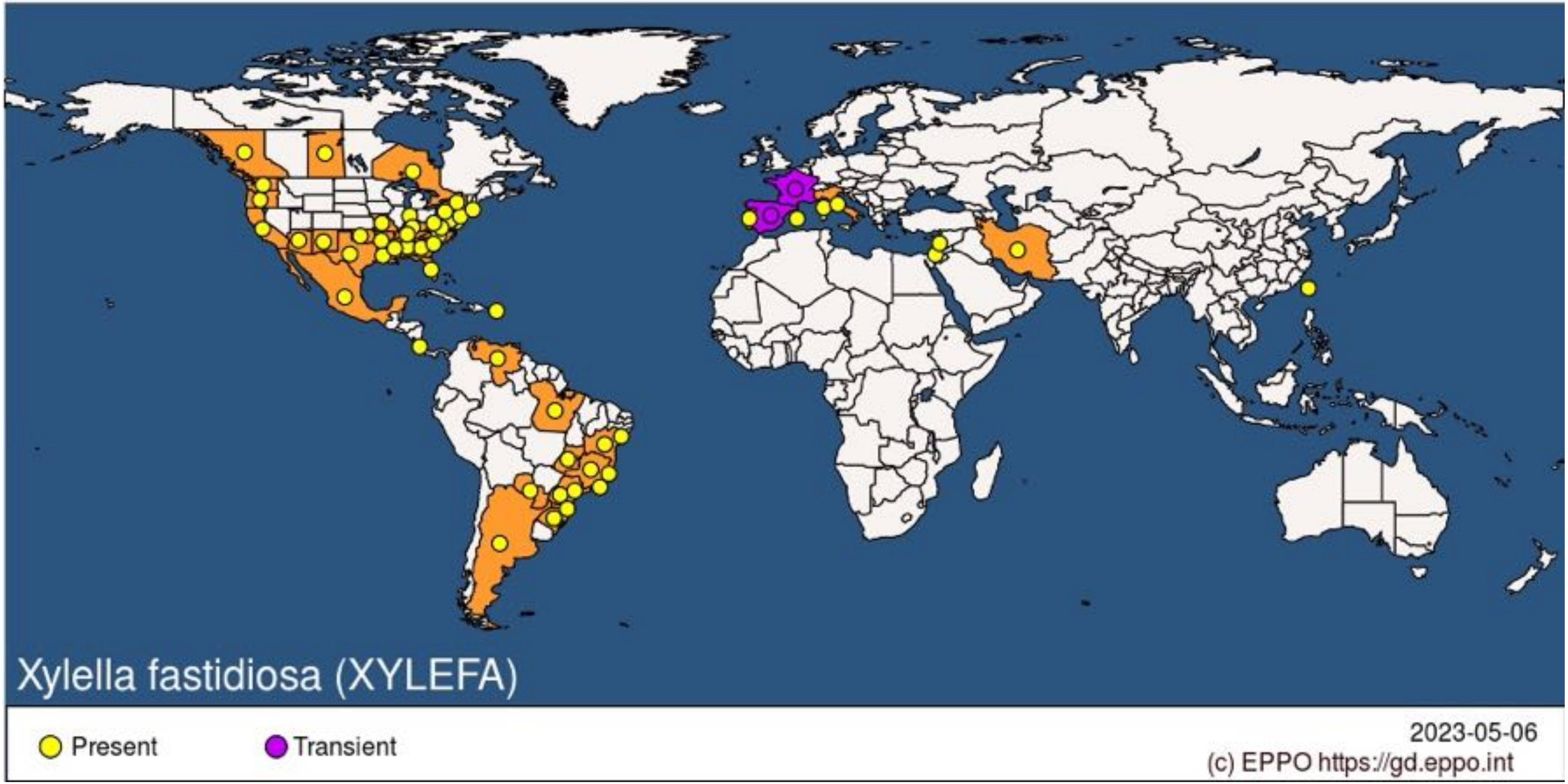
Verticillium dahliae

Xylella fastidiosa

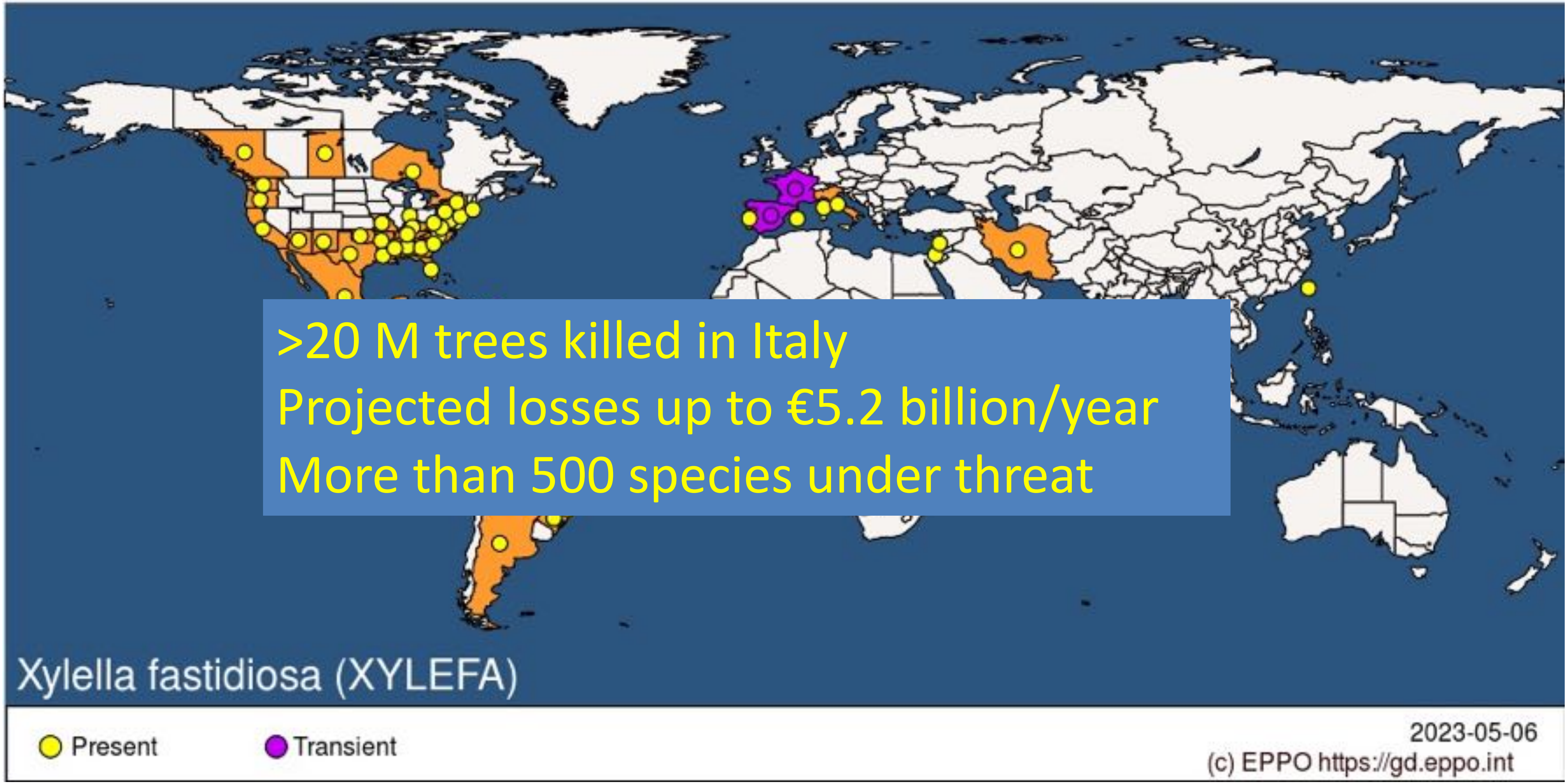
Verticillium dahliae global distribution map



Xylella fastidiosa global distribution map



Xylella fastidiosa global distribution map



>20 M trees killed in Italy

Projected losses up to €5.2 billion/year

More than 500 species under threat

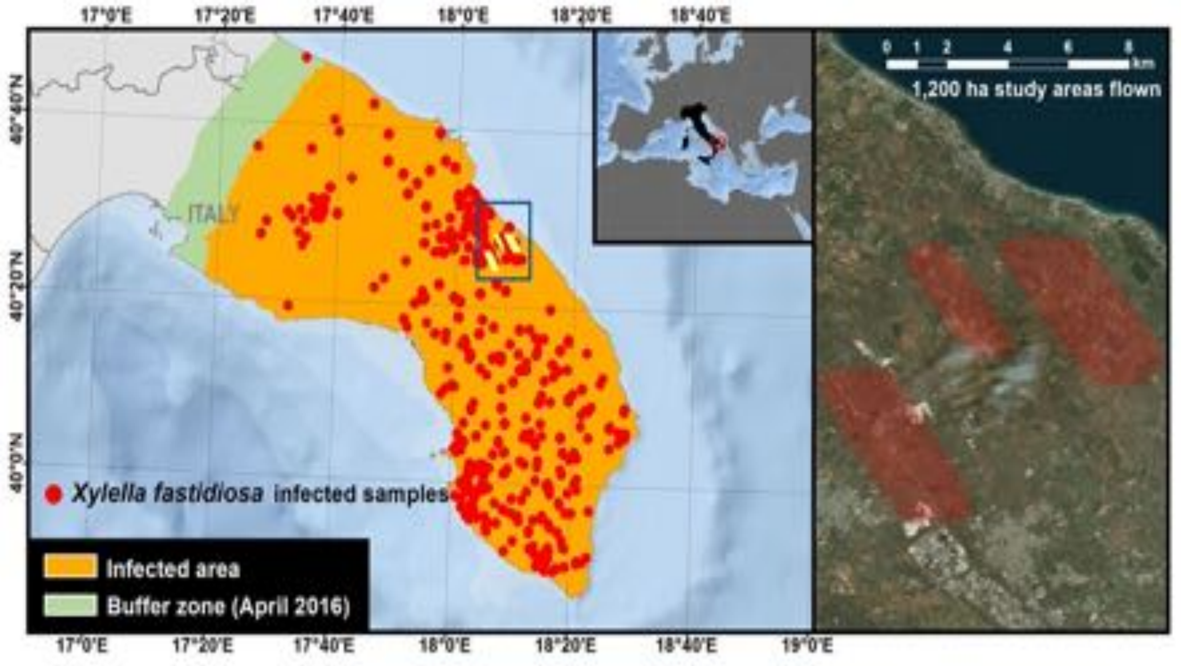
Objectives

1. Understanding the dynamics of thermal & hyperspectral-based traits under water stress

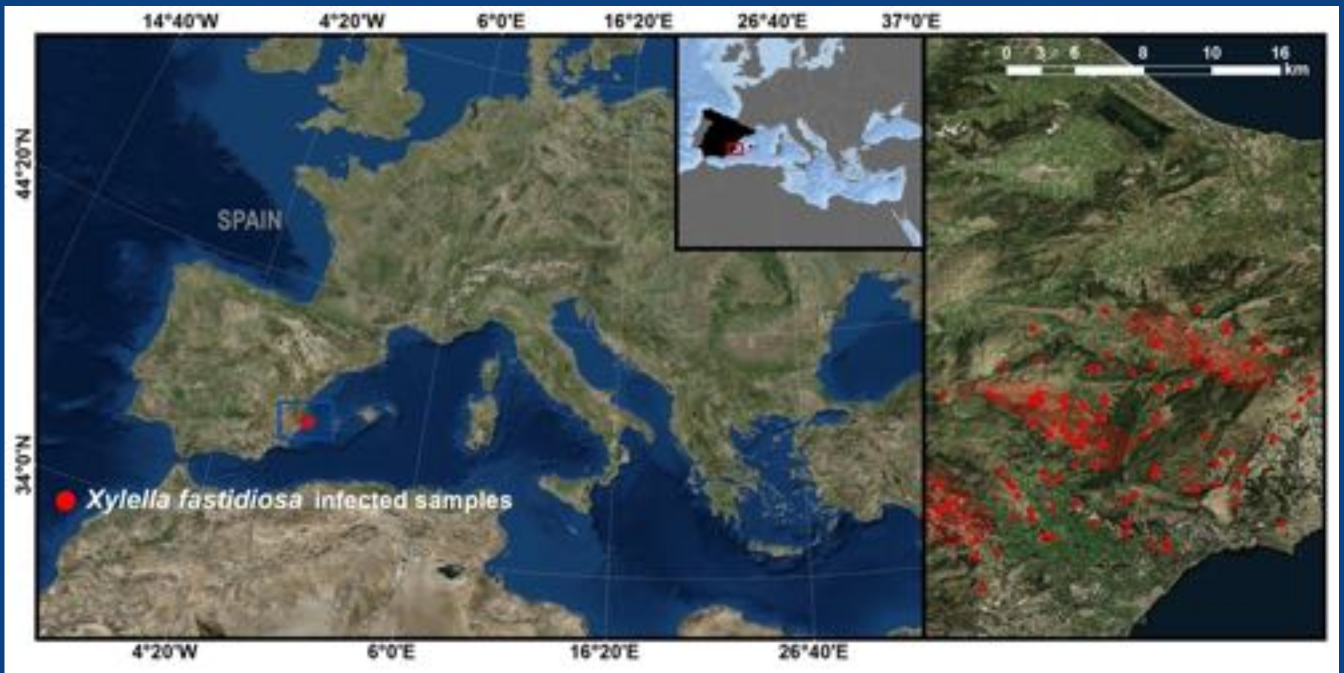
   - as a function of stress levels
   - across species

2. Disentangling biotic vs abiotic induced stress to improve disease detection

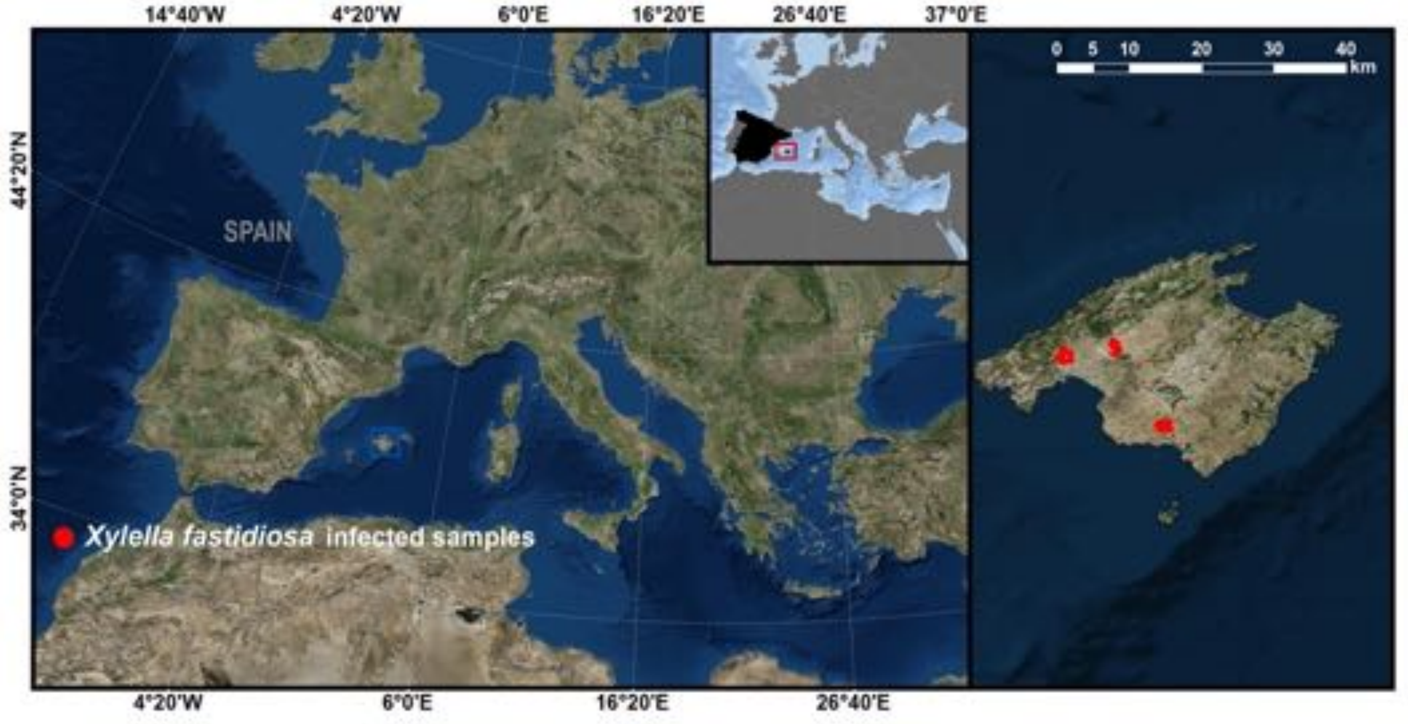
Xf airborne campaigns in Europe – 2016 - 2021



Airborne campaigns in the Puglia region, Italy

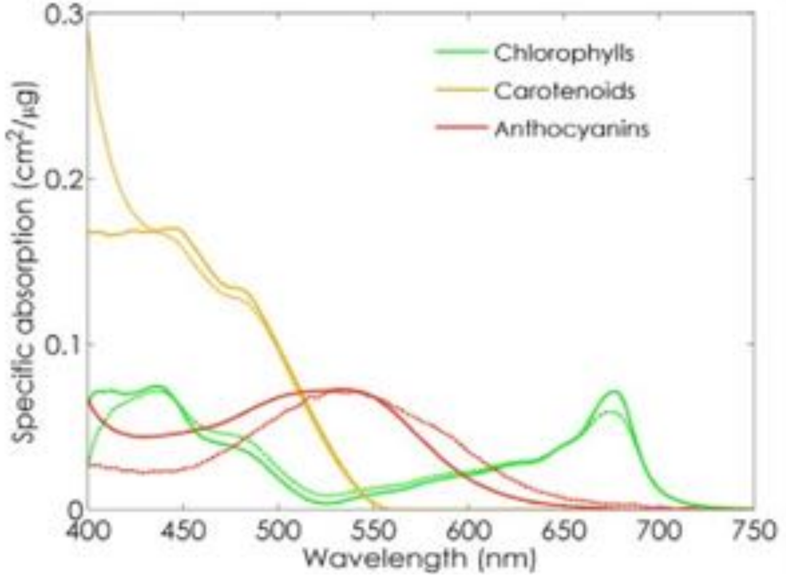


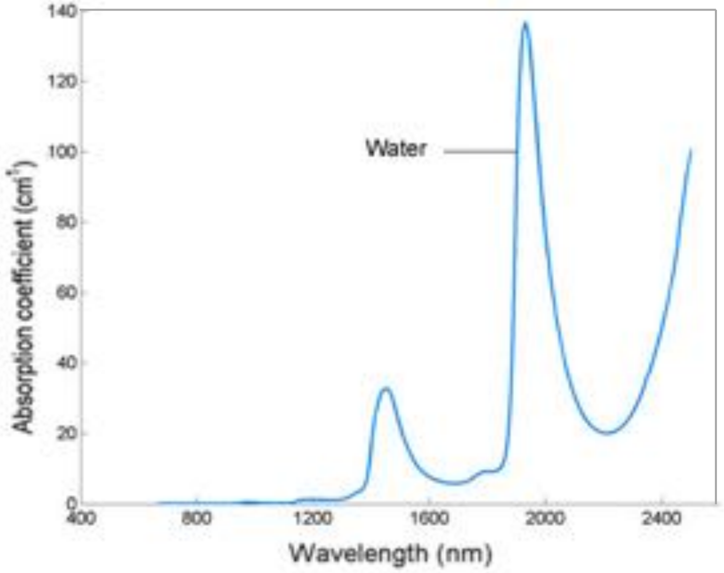
Airborne campaigns in Alicante region, mainland Spain

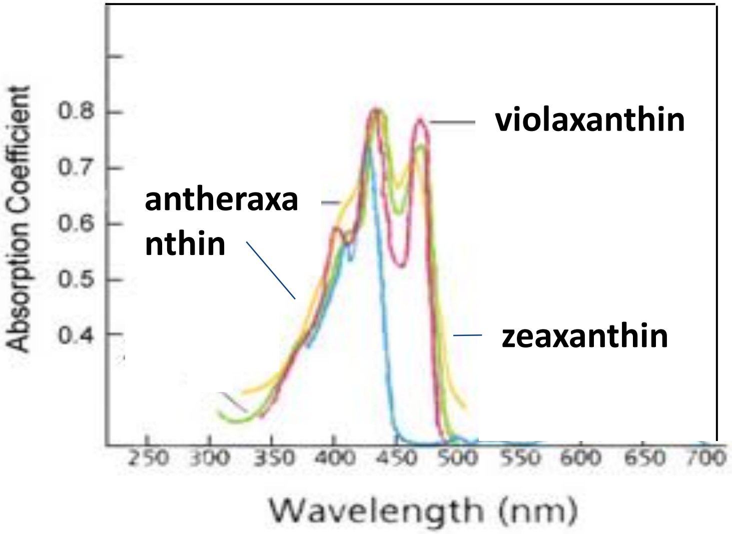


Airborne campaigns in the Balearic Islands, Spain

Plant biochemistry quantification with Radiative Transfer models





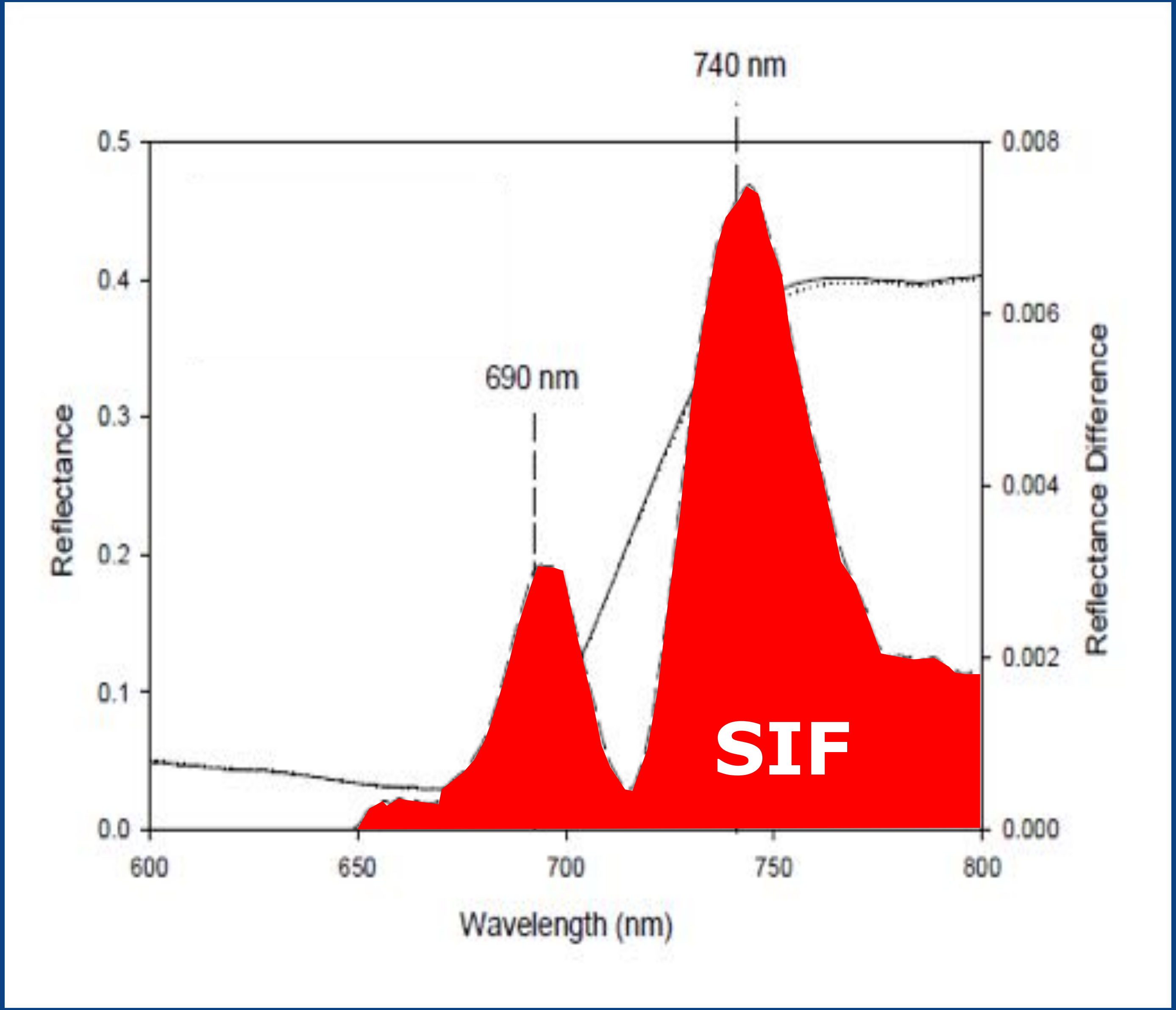


- Water content
- Chlorophyll, carotenoids and anthocyanins
- Xanthophyll cycle (V+A+Z)

PROSPECT
(Jacquemoud & Baret, 1990)
↓
Separation of total chlorophylls from total carotenoids
PROSPECT-5
(Feret *et al.*, 2008)
↓
Anthocyanins, chlorophylls and carotenoids
PROSPECT-D
(Feret *et al.*, 2017)
↓
Xanthophyll dynamics
Fluspect-CX
(Vilfan *et al.*, 2018)
↓
Leaf proteins and other carbon-based constituents
PROSPECT-PRO
(Feret *et al.*, 2021)

Solar-induced Chlorophyll Fluorescence (SIF)

→ ~2% of the total incoming radiation
→ Linked to photosynthesis
→ High spectral resolution required
→ Early indicator of stress



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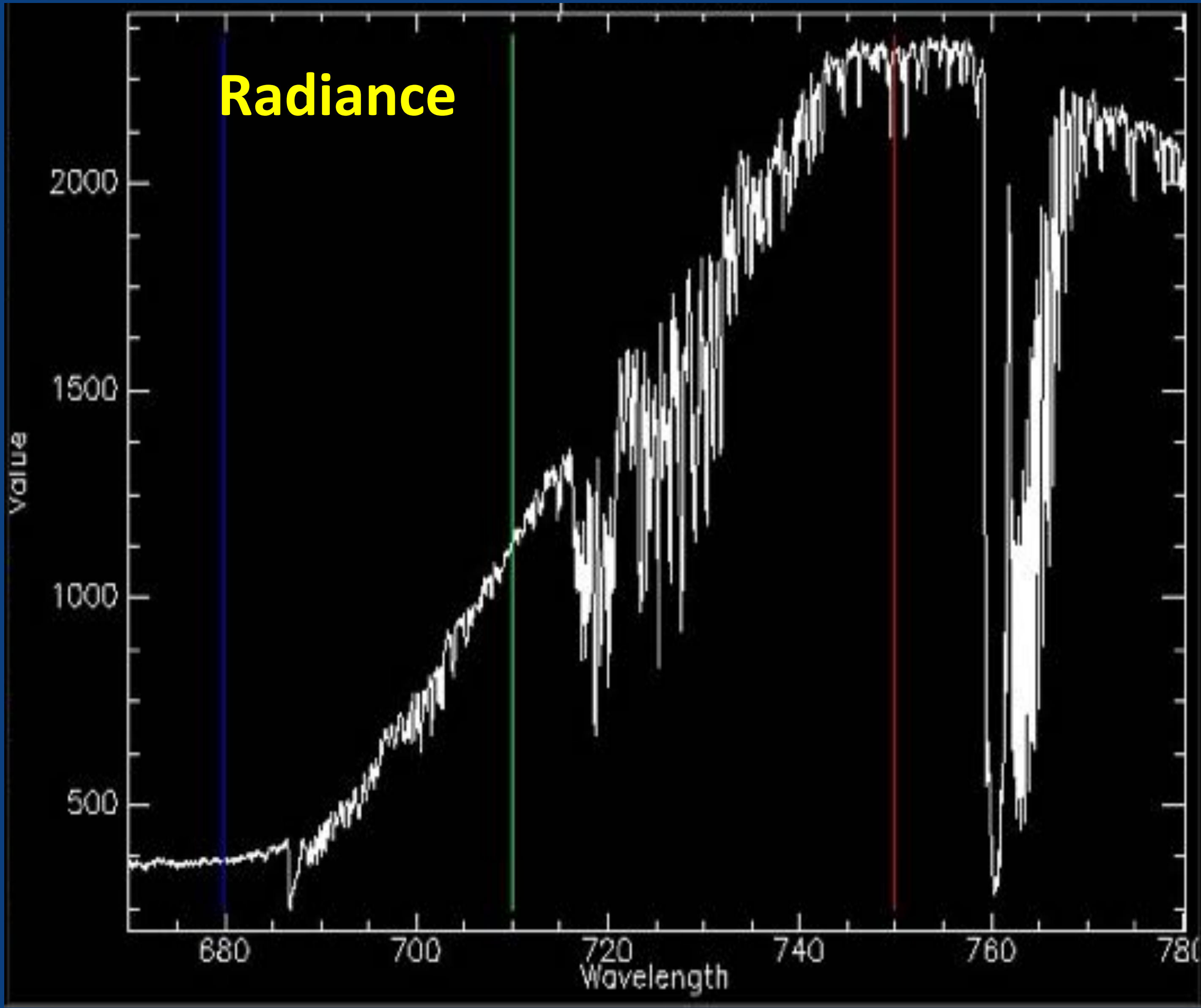

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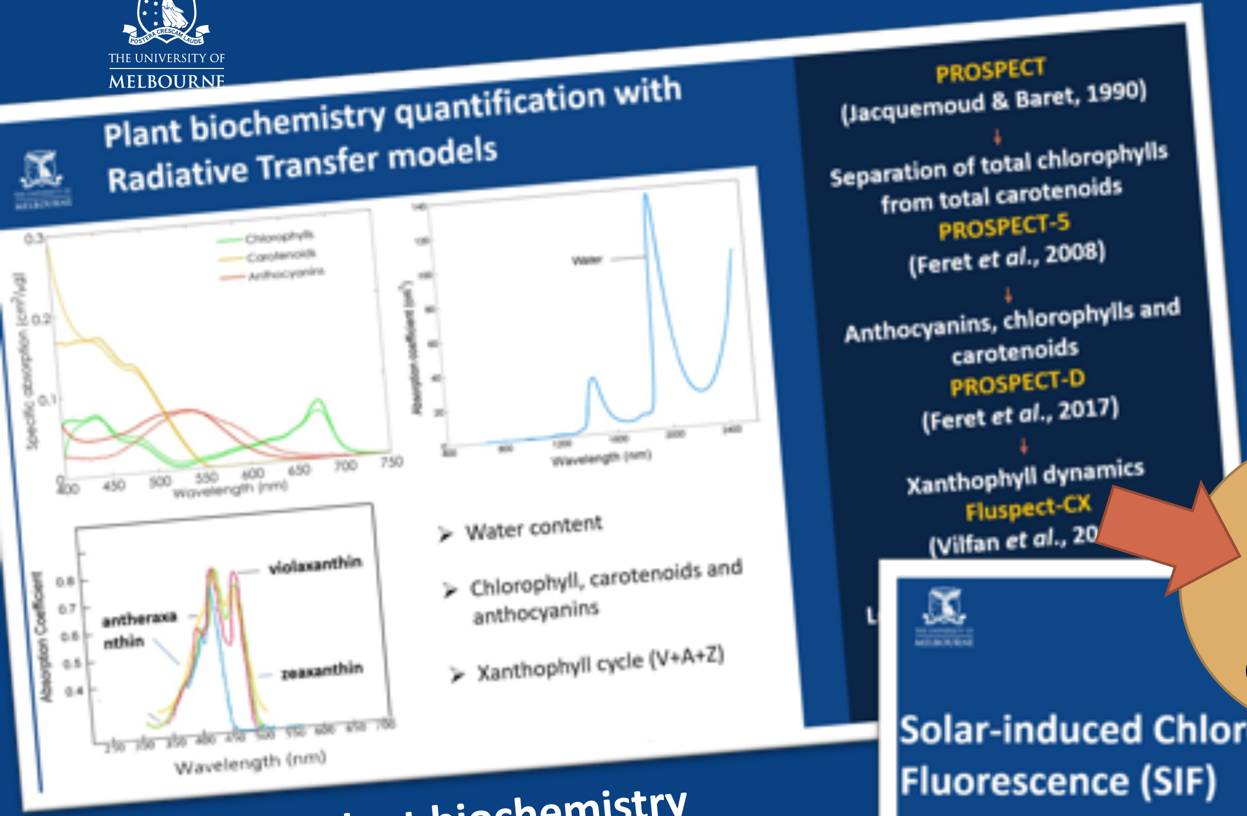
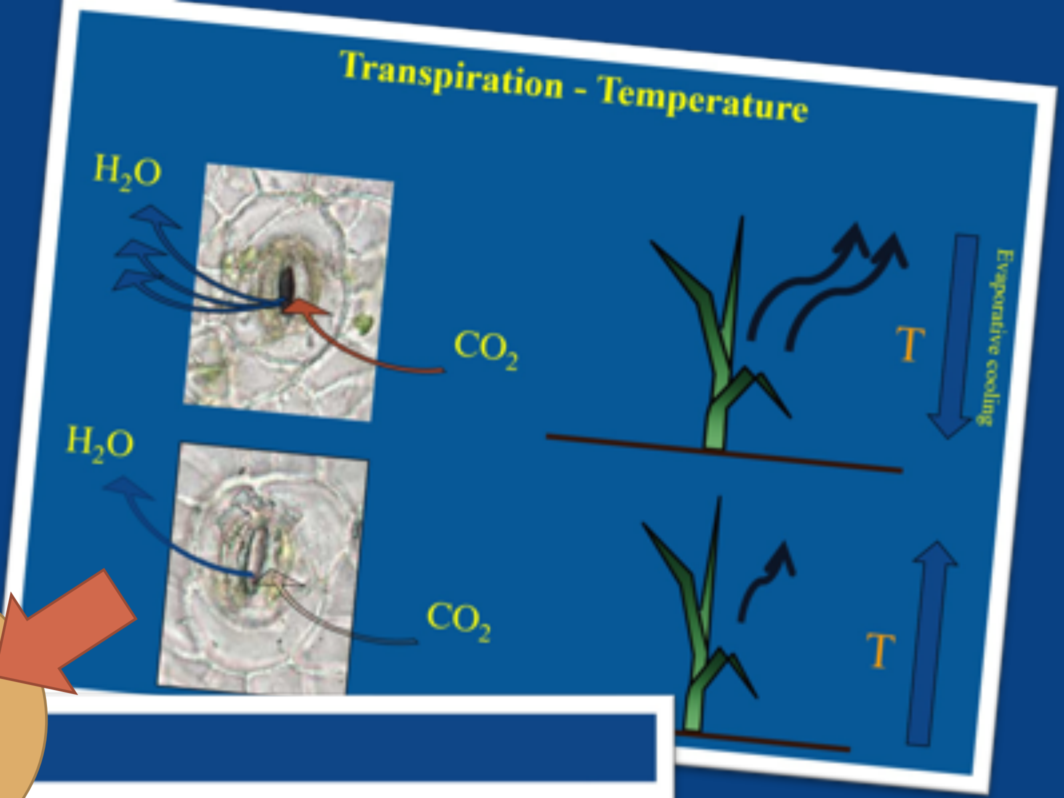
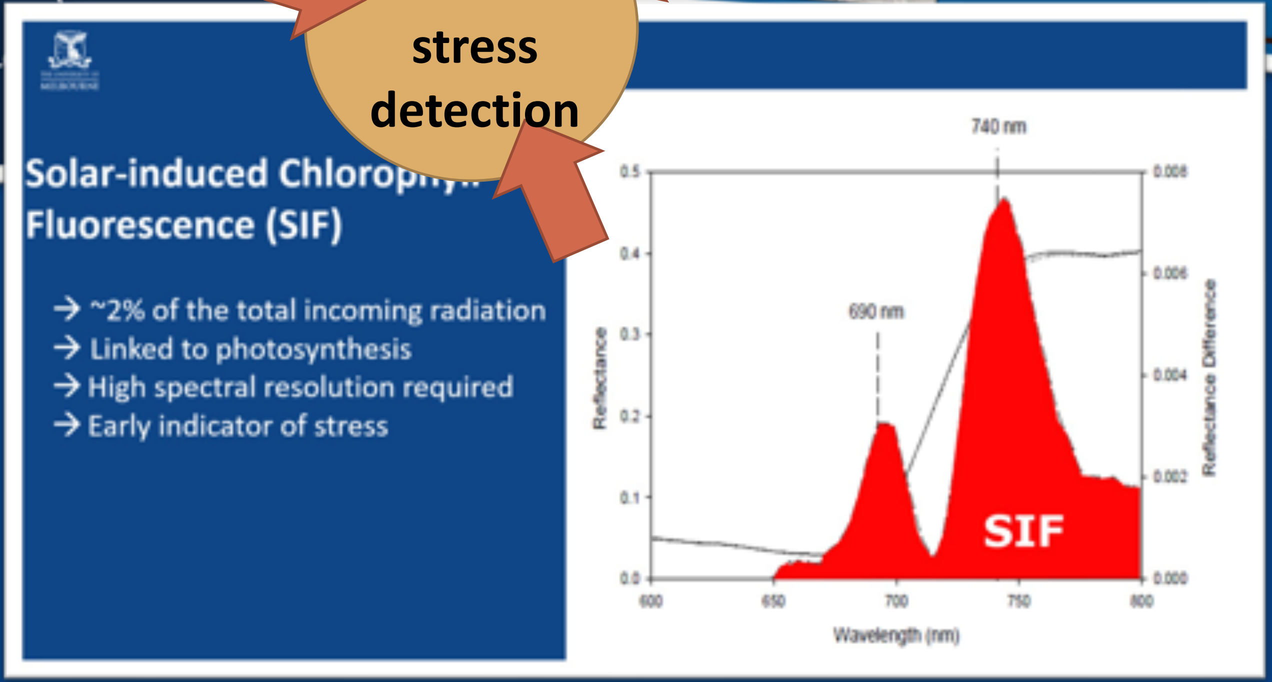


Plant biochemistry



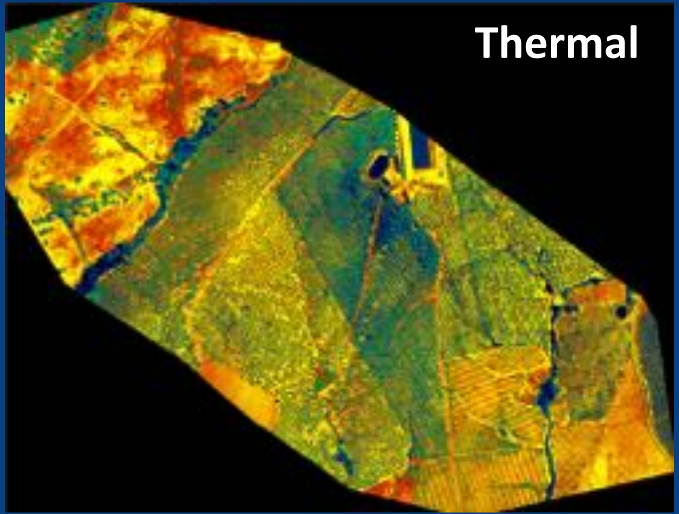
Biotic / abiotic stress detection

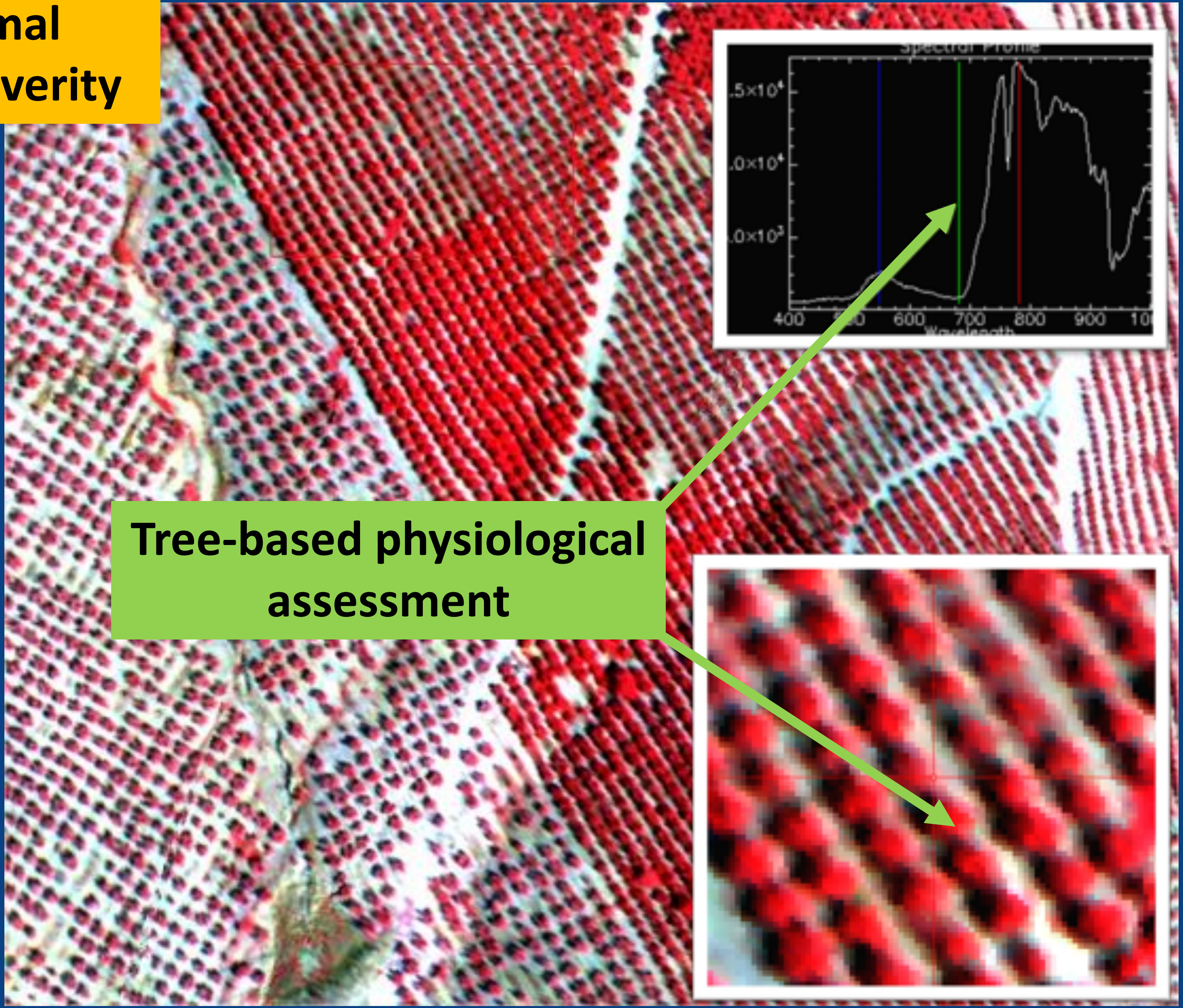


Fluorescence emission

Hyperspectral + thermal imaging of horticultural tree crops

>1 M trees scanned hyper + thermal
Varying water stress & disease severity





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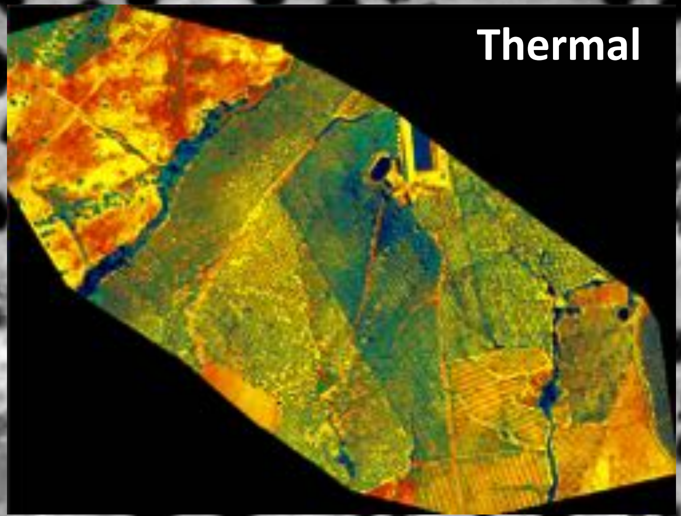

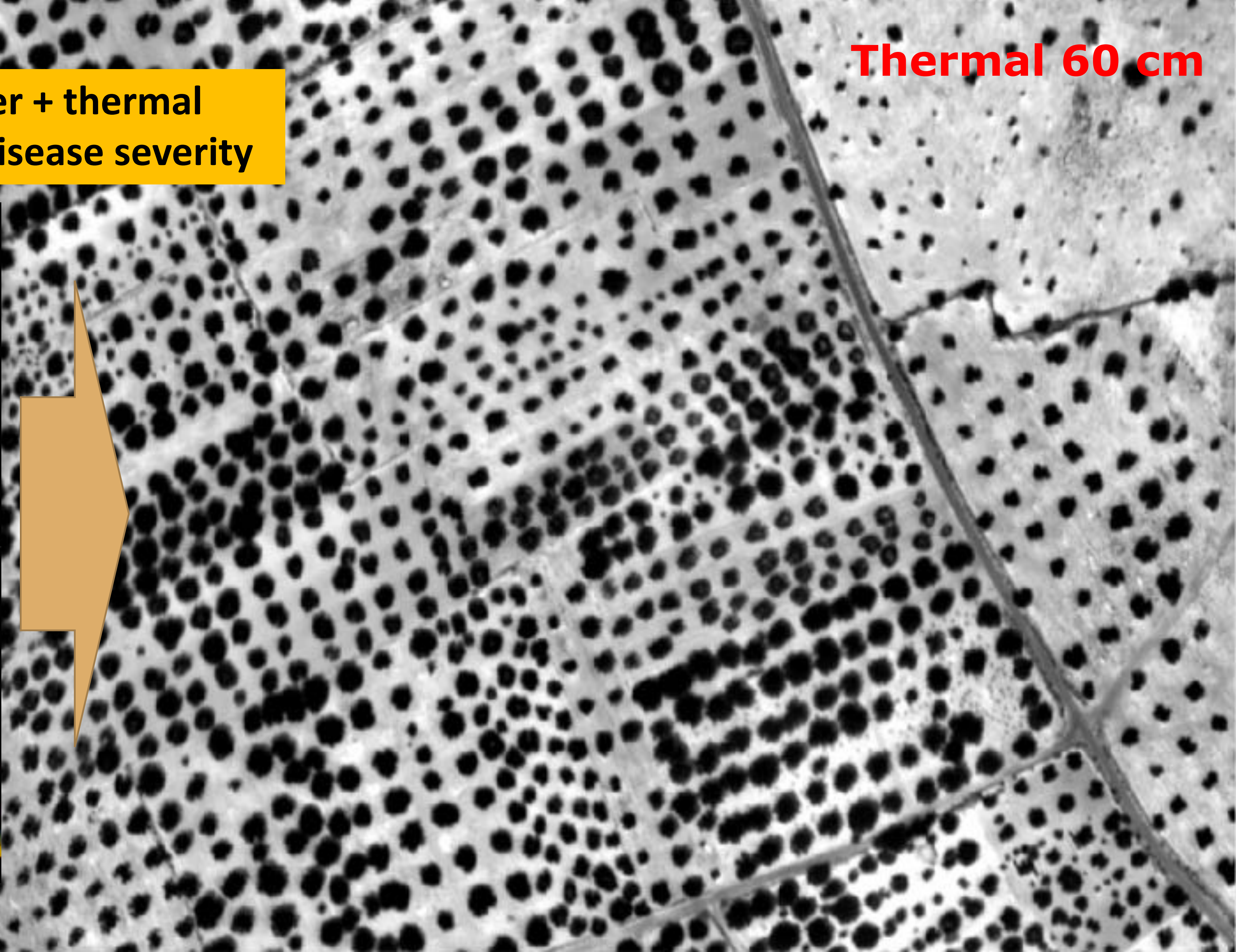

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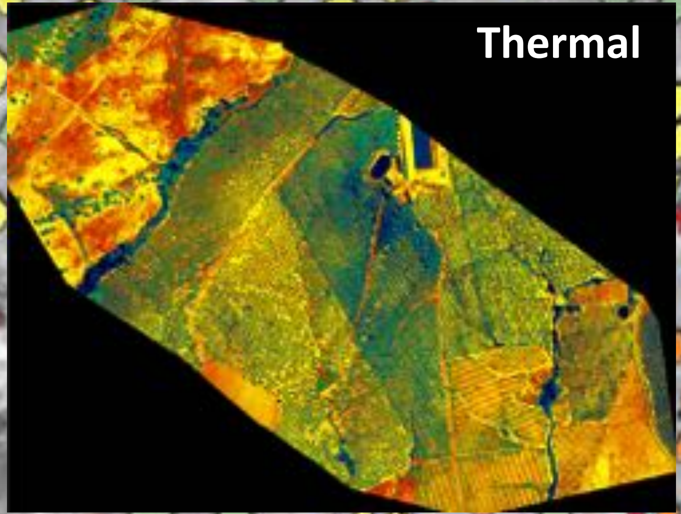
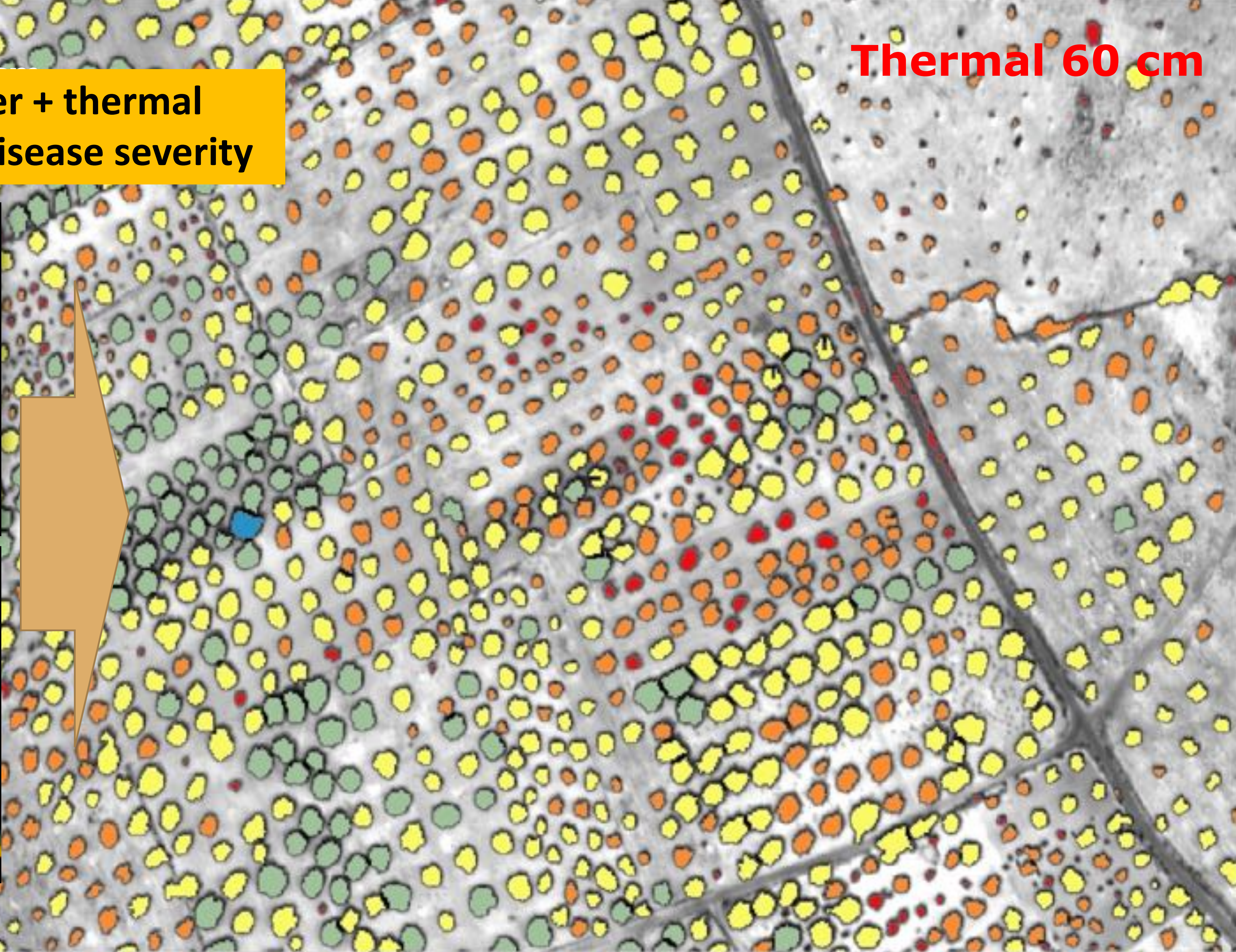
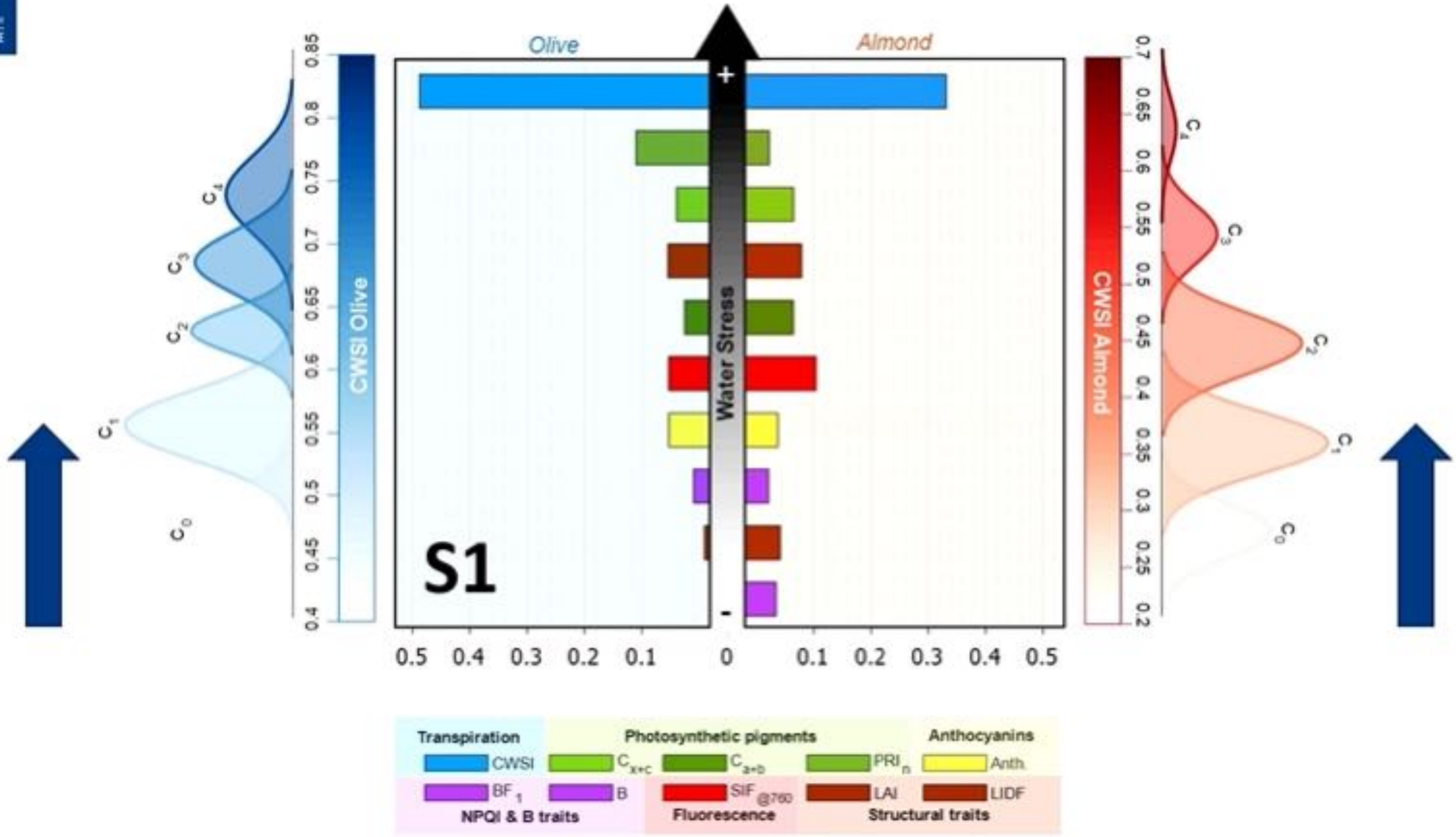




Importance of plant traits to detect water stress as a function of stress levels



Zarco-Tejada *et al.* (2021)

Dynamics of thermal & hyperspectral with water stress

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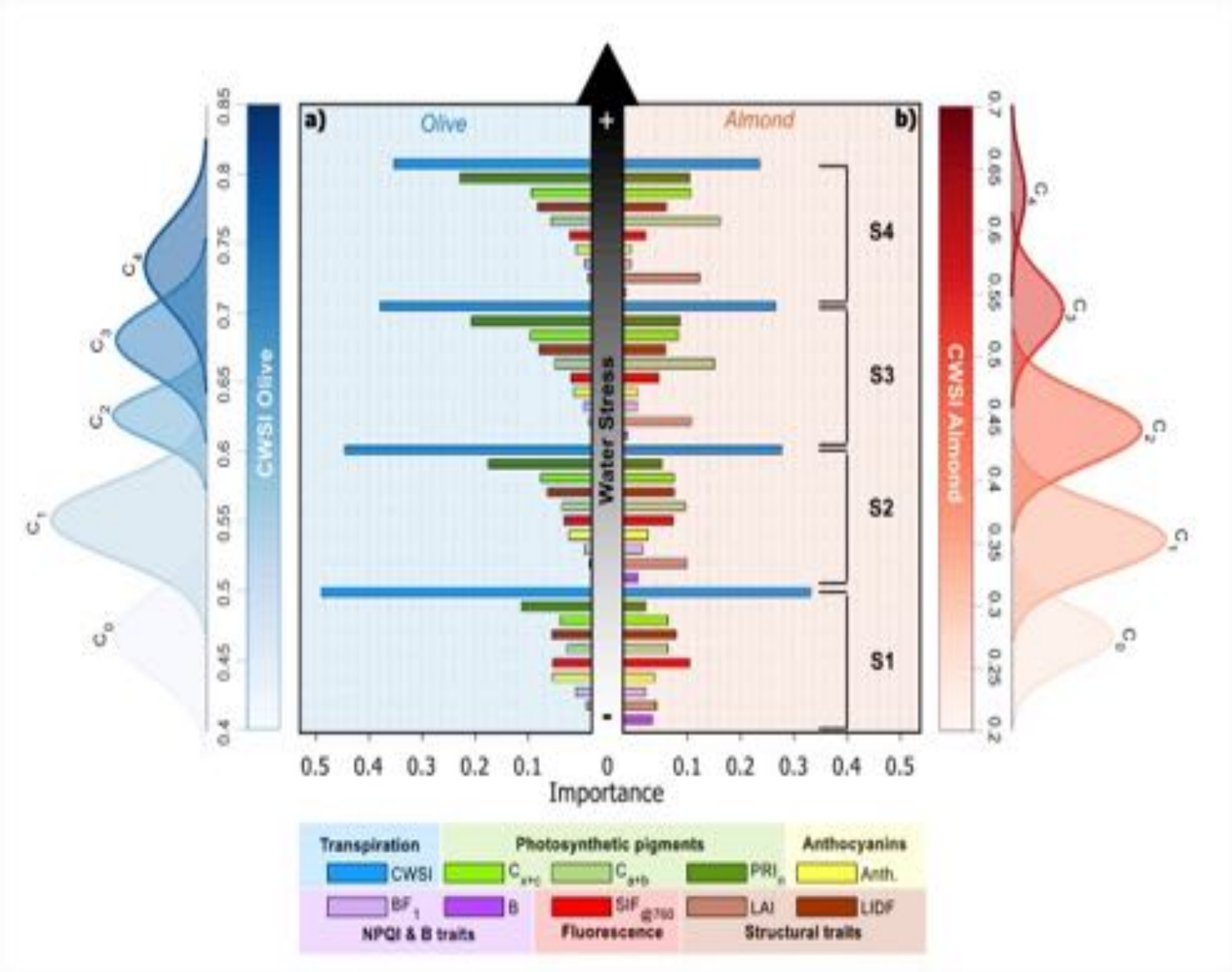

- As water stress ↑ the relative importance of thermal ↓
- At early stages, thermal is the most important water stress indicator
- After thermal, hyperspectral traits are highly sensitive to water stress:
  - C_{x+c}, xanthophylls ↑ with water stress
- Thermal and SIF → inverse trends with increasing water stress levels

Zarco-Tejada *et al.* (2022)

Thermal & hyperspectral traits with biotic stress

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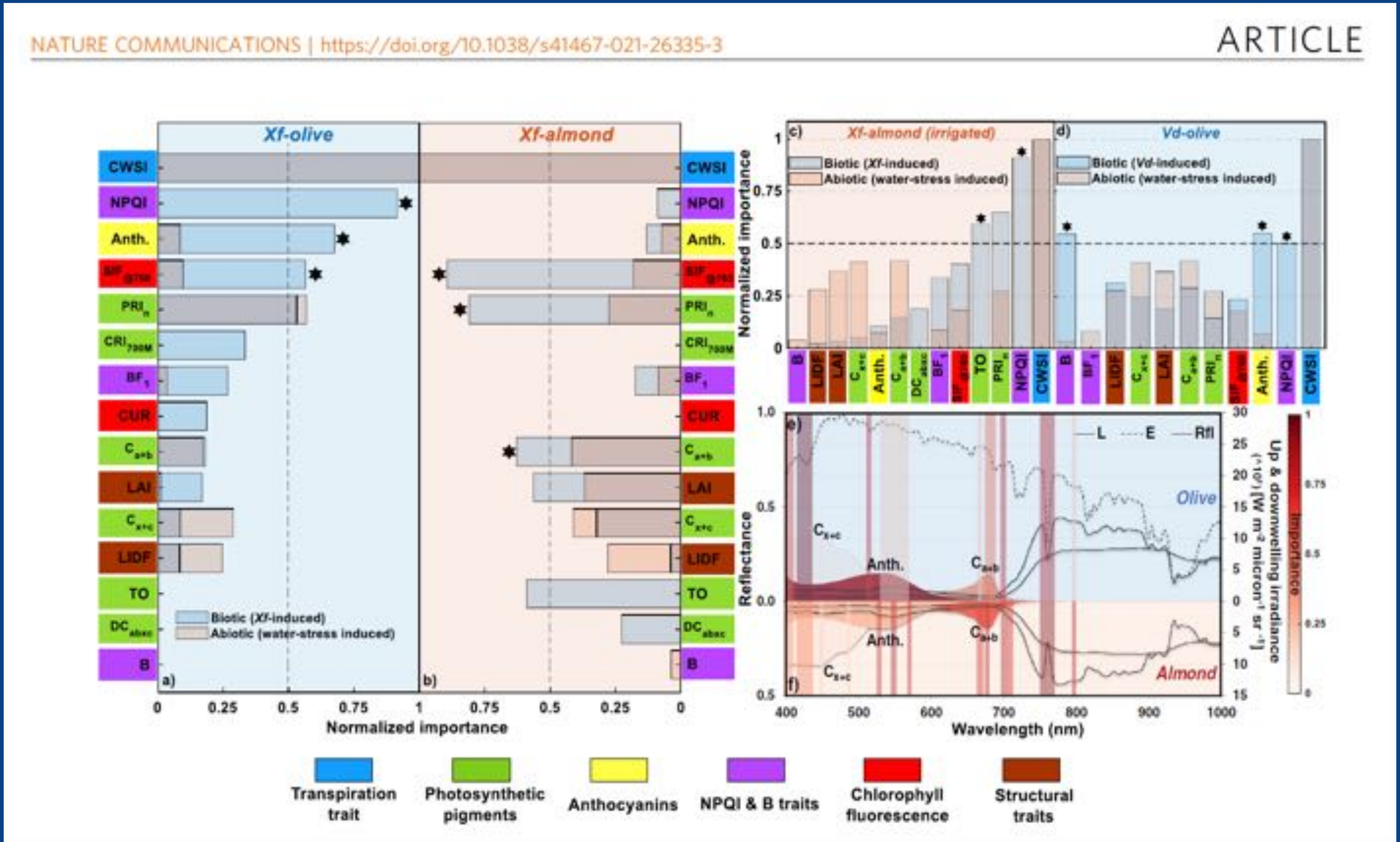
Specific spectral-based indicators across species *almond vs olive* and across pathogens *Xf vs Vd*

Accuracy > 92%



Zarco-Tejada *et al*. (2022)

Conclusions & Remarks

- Progress made is the last 20 years with thermal and hyperspectral for biotic-induced stress detection (OA>0.8-0.9; k>0.6)

- Thermal / CWSI is direct link with transpiration / water status
  SIF and plant pigments with rapid dynamics (C_{x+c}, Anth) contribute to stress detection

- Abiotic status is needed to improve disease detection performance (OA 80% → 92%)

- Thermal & hyperspectral together are required for water stress and disease detection → can't do it with thermal only

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