3rd European Conference on
Xylella fastidiosa and XF-ACTORS final meeting

Integrating an epidemic spread model with remote sensing for *Xylella fastidiosa* detection

28th April 2021

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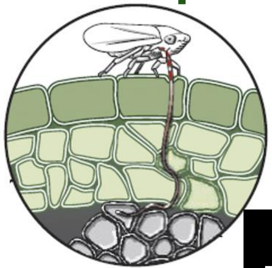
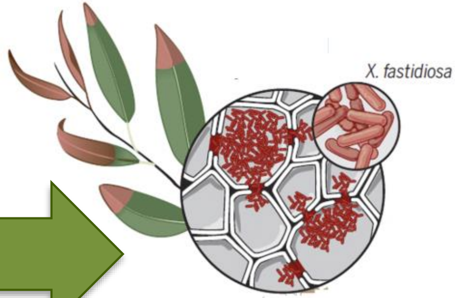
INTRODUCTION

Insect transmits the pathogen (*X. fastidiosa*)





Xylem vessels

To detect *X. fastidiosa* at early stages of development

Healthy olive tree

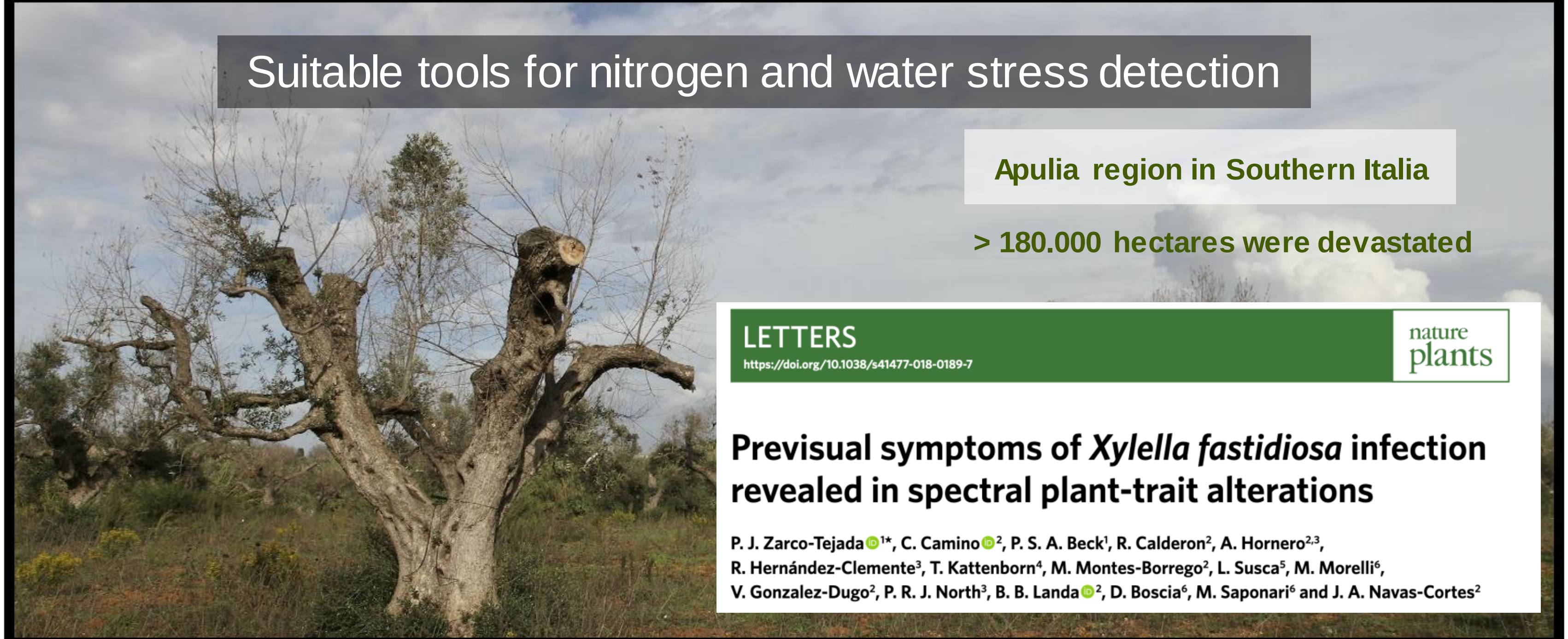
Healthy almond tree

~14 months

***Xf*-Affected olive tree**

***Xf*-Affected almond tree**

INTRODUCTION



Suitable tools for nitrogen and water stress detection

Apulia region in Southern Italia

> 180.000 hectares were devastated

LETTERS

https://doi.org/10.1038/s41477-018-0189-7

nature plants

Previsual symptoms of *Xylella fastidiosa* infection revealed in spectral plant-trait alterations

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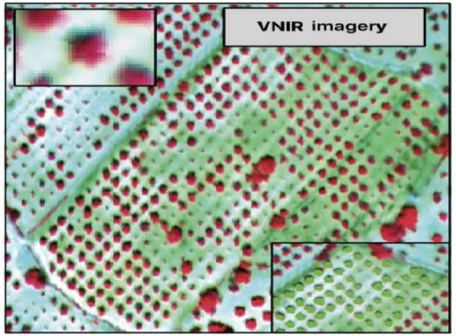
Useful machine learning approaches for the early detection of Xylella fastidiosa

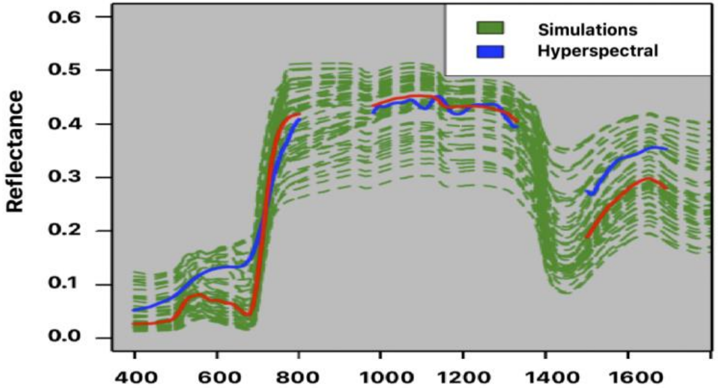
INTRODUCTION

Remote sensing method at tree-crown scales

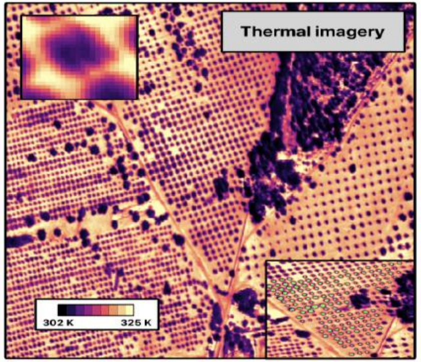
Hyperspectral sensor



Biochemical and biophysical parameters



Thermal sensor



Spectral indices
(NDVI, NPQI, TCARI ...)

Fluorescence emission

Chlorophyl
Carotenoids
Anthocyanins

Leaf protein (N)
Water content (C_w)

LAI and LIDFa

Tree- crown temperature

Reduce Multicollinearity between spectral indicators (variance inflation factor (VIF) and Wilks' lambda scores)

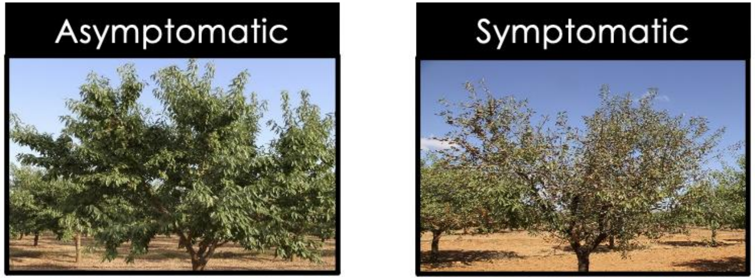
Supervised ML models (SVM)

INTRODUCTION

Coupling an epidemic spread model with ML models

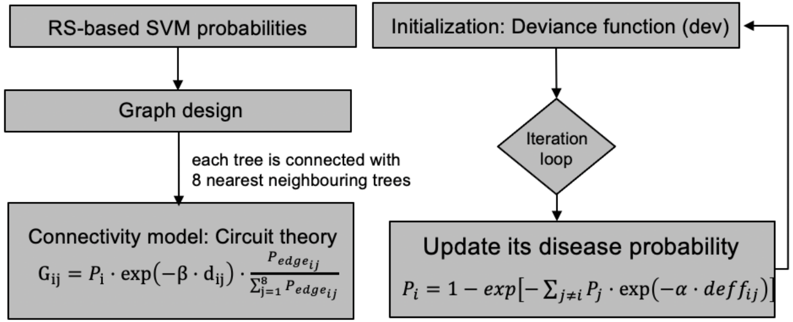
Remote sensing models

Based on ML models (SVM, RF NNE Deep ML)



Epidemic spread model

Iterative stochastic algorithm to estimate spatial distribution of Xf



not consider a priori information

- **pathogen's spatial distribution**
- **host landscape connectivity**
- **Epidemiological processes**

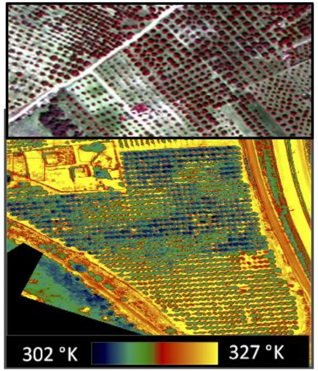
the contribution of host connectivity on the pathogen spread throughout the landscape using circuit and graph theories

OBJECTIVE

1

Develop a remote sensing method to **map the spatial dynamics of *Xf* outbreaks** and, specifically, to optimize the **early detection of *Xf*** infection in almond trees

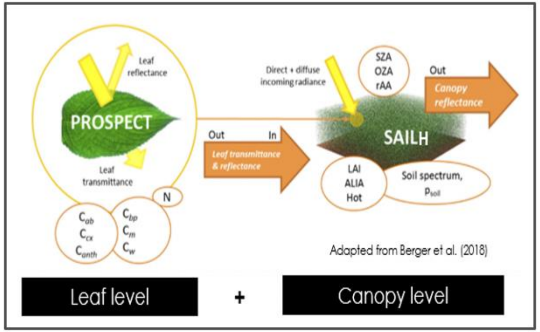
Images



Thermal & spectral indices

+

Radiative transfer models



Plant traits inverted with biophysical models

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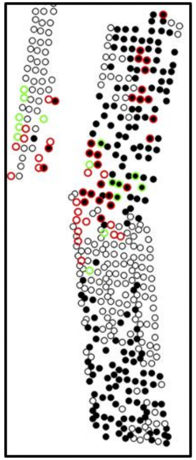
Epidemic spread model



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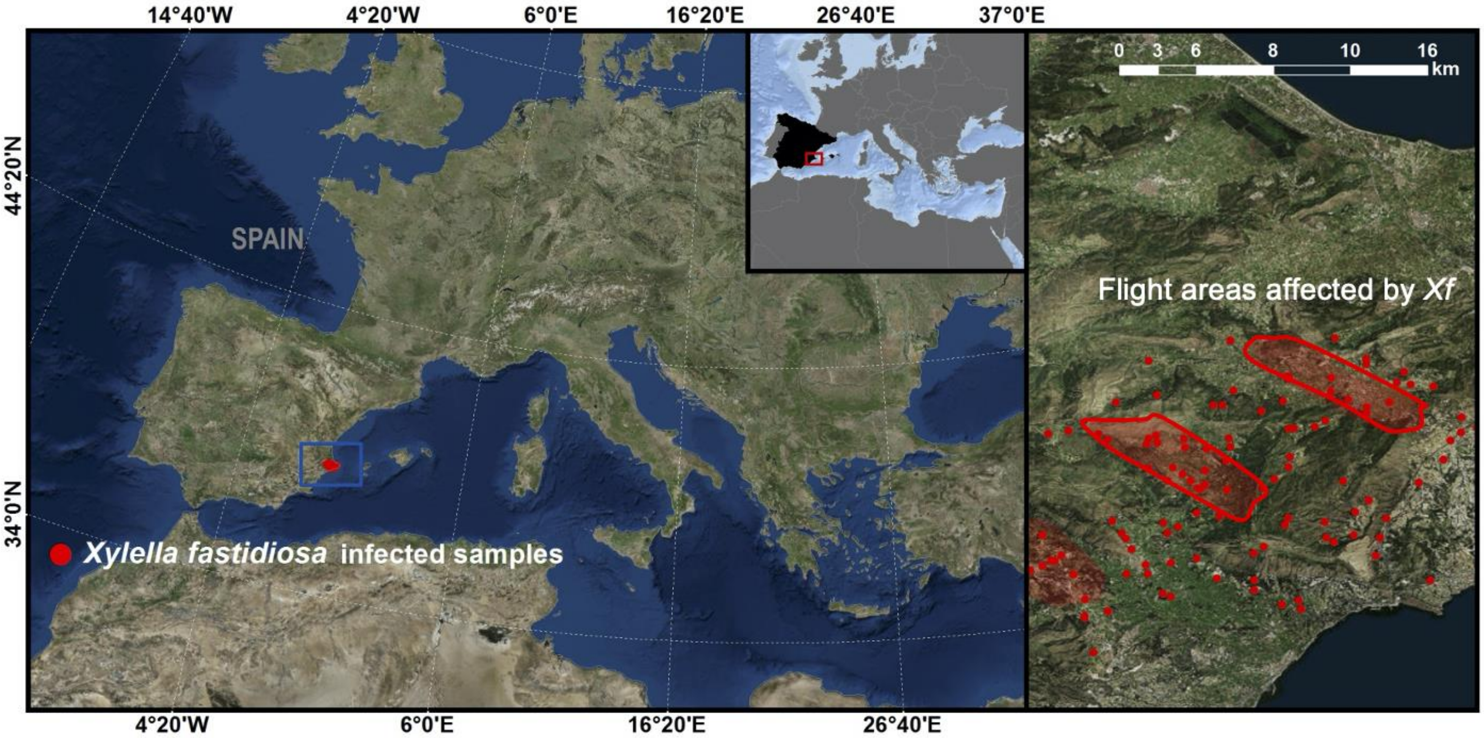
Early detection *Xf*

Asymptomatic trees

Symptomatic trees

Remote sensing-based classification model

MATERIAL AND METHODS



Airborne campaign carried out in Alicante province, Spain on July 2018

MATERIAL AND METHODS

Alicante, Spain (8-14 July 2018)

High-resolution hyperspectral

- Hyperspectral VNIR (0.4-0.8 µm)
- Hyperspectral SWIR (0.9-1.7 µm)
- Thermal (0.25 cm/pixel)

Field assessment

Visual inspections (~1420)

- qPCR (> 300 test)
- Physiological measurements (C_{ab}, A_{nth}, F_t, Leaf RFL…)

Physiological measurements at leaf level

Dualex

PolyPen RP400

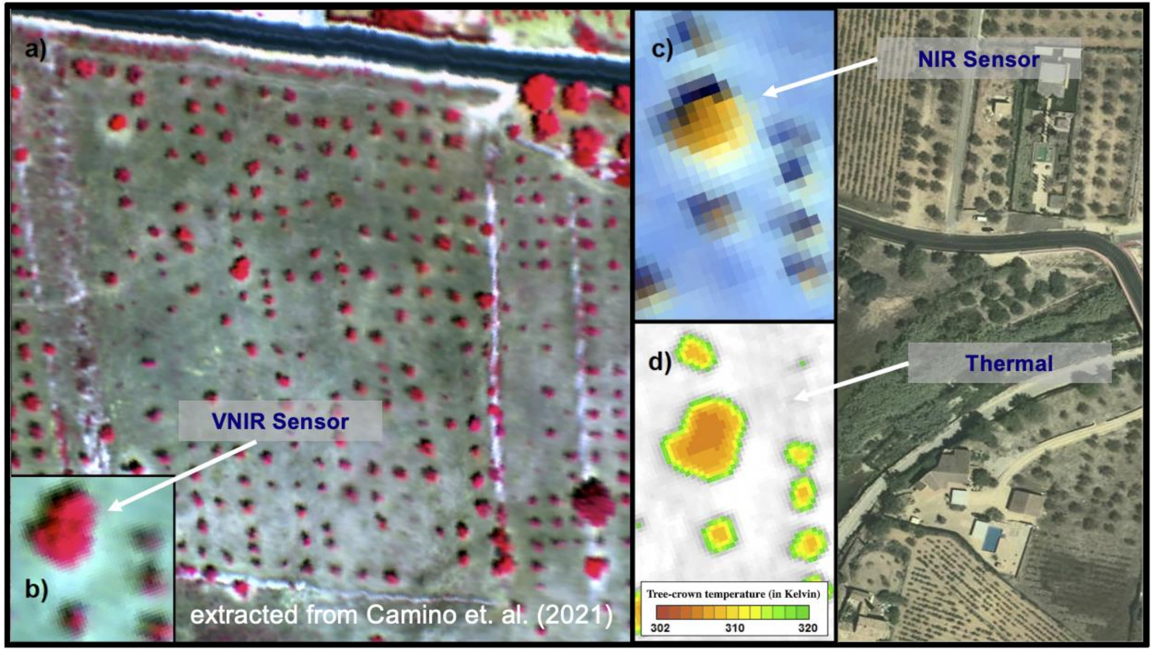
FluorPen FP100

Dualex → Chlorophyll content, flavonoids and NBI
PolyPen → Reflectance spectra (400-800 nm)
FluorPen → Fluorescence emission
Porometer → Stomatal conductance

MATERIAL AND METHODS

High-resolution sensors

	Hyper VNIR	Hyper NIR-100	FLIR SC655
FWHM	6.40 nm	6.05 nm	---
Spatial resolution	20 cm/pixel	60 cm/pixel	25 cm/pixel
N bands	260	166	1
Spectral region	400-800 nm	950-1750 nm	7.5 -1.4 µm



Overview of an almond orchard in Alicante, Spain.

MATERIAL AND METHODS

Visual inspections

Almond orchard under rainfed conditions

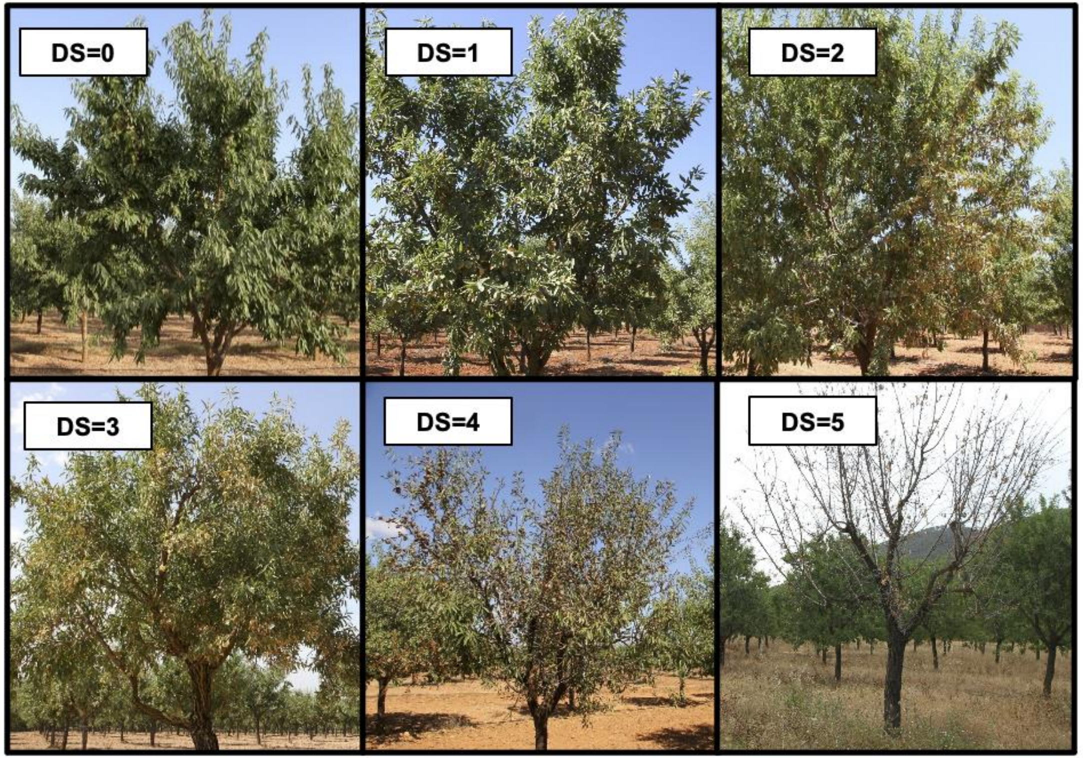
Orchards	DS_0	DS_1	DS_2	DS_3	DS_4
Rainfed	657	359	314	142	54

N = 1,426 almond trees

DS	DS_0	DS_1	DS_2	DS_3	DS_4
Classified	0	1	2	3	>4
% of visual *Xf* symptoms	0	1-25	25-50	50-75	>75

DS =Disease symptoms

asymptomatic trees (DS=0);
Symptomatic trees (DS ≥ 1)



MATERIAL AND METHODS

RS-based models for the early detection of *Xylella fastidiosa*

PS model

C_{ab} A_{nth} C_{ar} C_w LAI $LIDF_a$ VEG

PS + N model

C_{ab} A_{nth} C_{ar} C_w LAI $LIDF_a$ VEG Cp NI

PSN + T + F model

C_{ab} A_{nth} C_{ar} C_w LAI $LIDF_a$ VEG Cp NI Tc SIF

PSNFT model + epidemic spread model

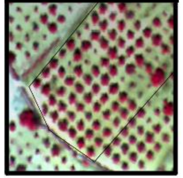
Pigments: C_{ab} A_{nt} C_{ar}

Water content: C_w

Structural : LAI LIDFa

VNIR indices: VEG

VNIR



20 cm/pixel

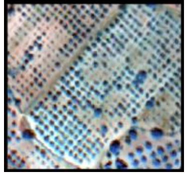
400-800 nm

Leaf protein : Cp

Nitrogen indices* : NI

* Bands 1510 nm

NIR/SWIR



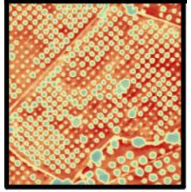
60 cm/pixel

950-1750 nm

Temperature: Tc

Fluorescence: SIF

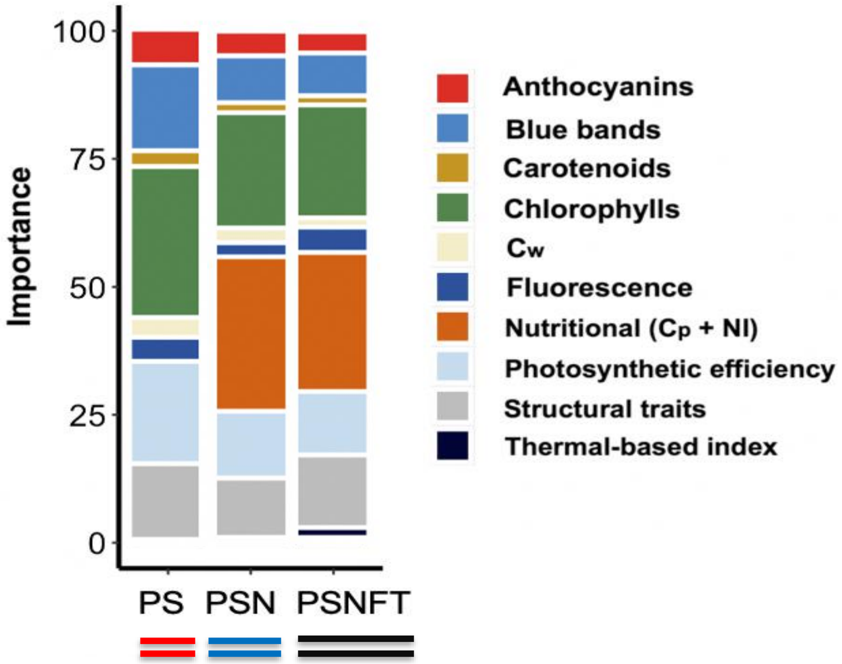
Thermal



25 cm/pixel

RESULTS

Contribution of the plant traits in the machine learning models



PS model

- Chlorophylls (30 %)
- Photosynthetic efficiency (20 %)
- Blue bands (17 %)
- Structural traits (15 %)
- Anthocyanins (7 %)

PS +N model

- Nutritional (Cp + NI) (28 %)
- Chlorophylls (22 %)
- Photosynthetic efficiency (13 %)

PSN+ FT model

- Nutritional (Cp + NI) (28 %)
- Chlorophylls (22 %)
- Thermal-based index (2 %)
- Fluorescence (5 %)
- Anthocyanins (5 %)

RESULTS

RS-based Models for the early detection of *Xylella fastidiosa*

PS model — OA = 73 %; kappa = 0.46

C_{ab} A_{nth} C_{ar} C_w LAI $LIDF_a$ VEG

* Adding **pigments**, **water content**, **structural** and **VNIR indices**

PS + N model — OA = 74 %; kappa = 0.48

C_{ab} A_{nth} C_{ar} C_w LAI $LIDF_a$ VEG Cp NI

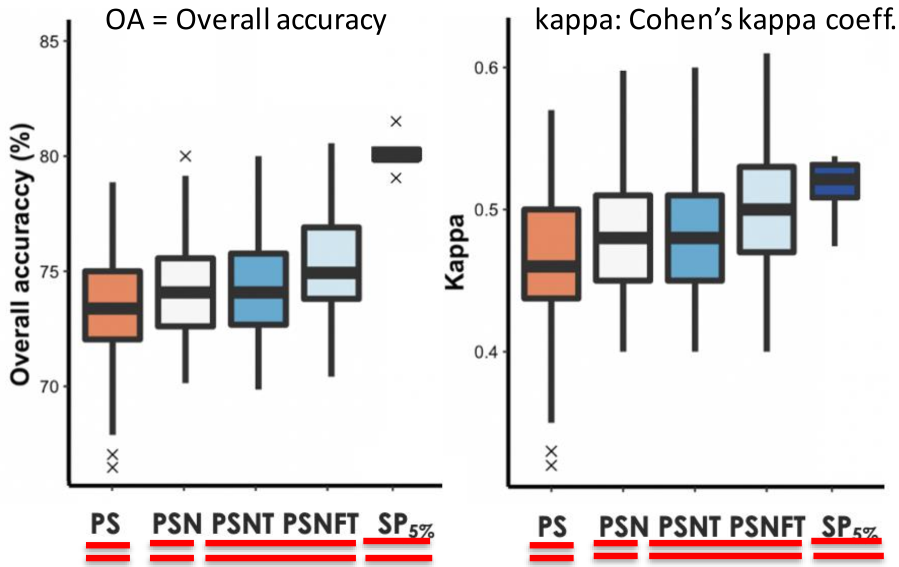
* Adding **leaf protein** and **Nitrogen indices based on 1510nm**

PSN + T + F model — OA = 75 %; kappa = 0.50

C_{ab} A_{nth} C_{ar} C_w LAI $LIDF_a$ VEG Cp NI Tc SIF

* Adding **tree-crown temperature** and **fluorescence emission**

PSNFT model + epidemic spread model — OA = 80 %; kappa = 0.51



- increased OA by around 7% with PS model
- increased OA by around 5% with PSNFT

RESULTS

Assessment of PSNFT model and coupled PSNFT-spread model with qPCR

Presence of *Xylella Fastidiosa: 78% positive; 22% negative* (*total* qPCR = 318 trees)

Models/ visual inspections	OA	kappa
Visual inspections	64.5 %	0.31
RS PSNFT model	63.4 %	0.26
PSNFT +Spread 5%	71.7 %	0.33

OA = Overall accuracy; **kappa**: Cohen's kappa coefficient

PSNFT-Spread model showed better OA (72%) for the sample size of 5% than for PSNFT model

PSNFT-spread model increased the % of well-classified trees with no visual symptoms and qPCR = positive

Xf infection?

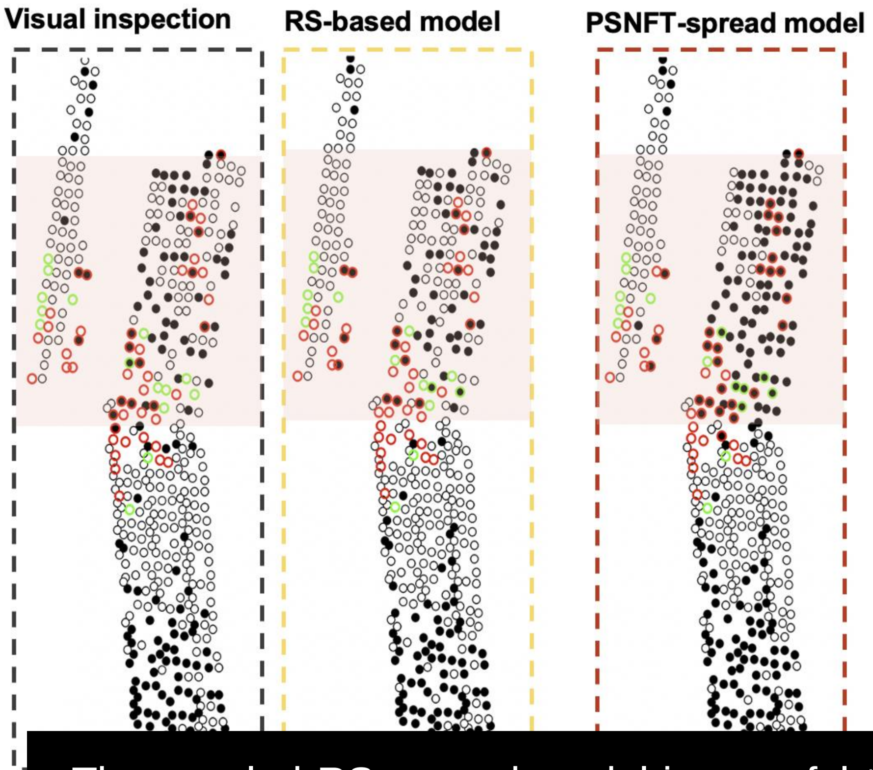
AF = Asymptomatic infections: proportion of trees classified as symptomatic by the PSNFT model and the coupled PSNFT-spread model that showed no visual symptoms in the field (**DS=0**) but were positive by qPCR (n=105 trees)

Visual inspection =Asymptomatic trees **qPCR = Positive**

RS model and Coupled RS +Spread classified as Symptomatic tress

RESULTS

Assessment of the coupled PSNFT-spread model in an orchard with low incidence of *Xf*



Symptomatic trees (299) ●
Asymptomatic trees (166) ○

qPCR:
- Negative test (green circle)
- Positive test (Xf) (red circle)

	% well classified trees
Visual inspections	55 %
PSNFT model	54 %
PSNFT +Spread 5%	**59 %**

% well classified trees according to the qPCR assays

qPCR = 72 assays; positive 56 and negative 16 trees

PSNFT-spread model

The detection of *Xf*-infected asymptomatic trees that did not show visible symptoms and were missed by the PSNFT model.

The coupled RS-spread model is a useful tool for detecting the *Xf* infection at early stage

CONCLUSIONS

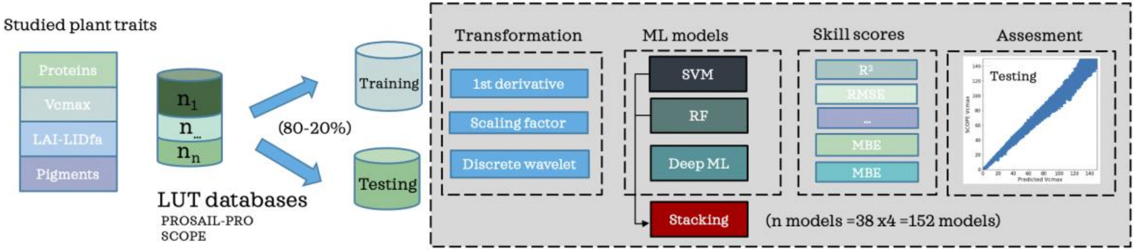
1 Coupling a remote sensing (RS) model with a stochastic epidemic spread model improves the detection of *Xylella fastidiosa* (*Xf*).

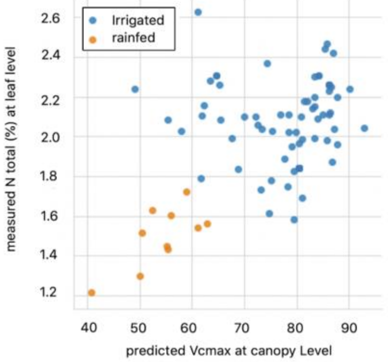
2 These promising results highlighted the suitability of this methodology for assessing the symptoms caused by Xf and other plant pests at large scales.

3 The integration of RS estimations in spatial spread modelling demonstrates accurate mapping of spatial correlations, typical for a vector-borne transmitted disease.

FUTURE WORKS

Machine learning approach





Airborne campaign carried out in Majorca island, Spain on July 2019

Parsimonious models

C_{ab} LAI Nitrogen Vcmax Tc

Asymptomatic

Symptomatic

* Using indicators related to pigments, structural, nitrogen, water stress and photosynthetic capacity

THANK YOU FOR YOUR ATTENTION !

Joint Research Centre

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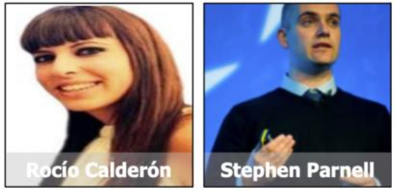
Consejo Superior de Investigaciones Científicas

Instituto de Agricultura Sostenible IAS 25 años

University of Melbourne

The University of Melbourne

University of Salford



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XF ACTORS

POnTE
PestOrganisms ThreateningEurope