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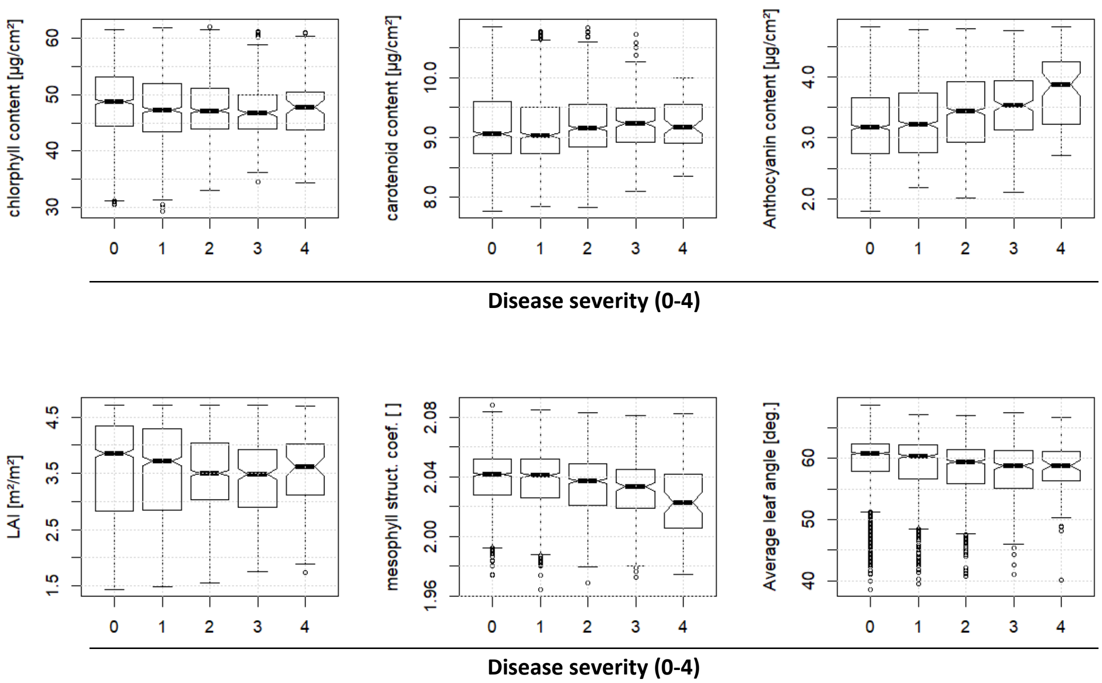
Previsual symptoms of *Xylella fastidiosa* infection revealed in spectral plant-trait alterations

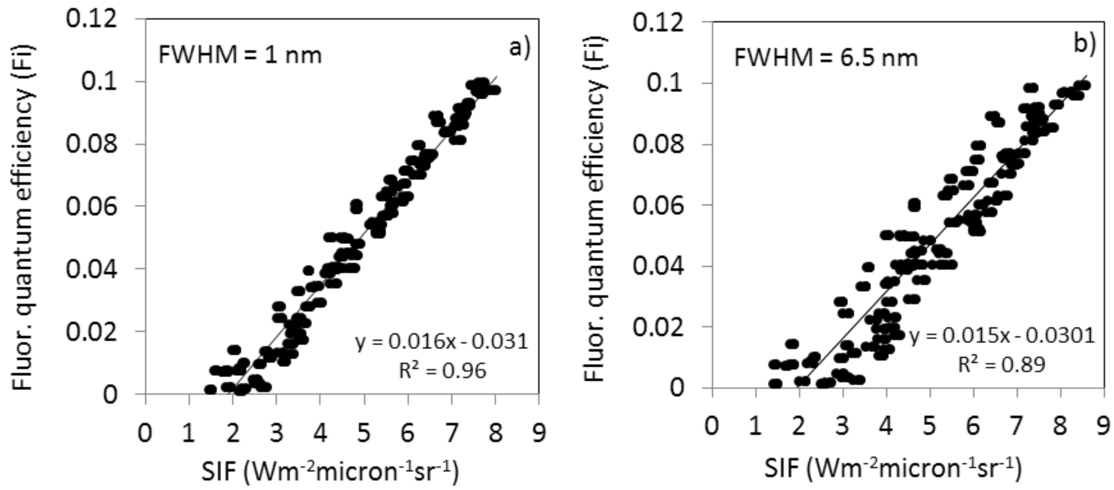
P. J. Zarco-Tejada[1*], C. Camino[2], P. S. A. Beck[1], R. Calderon[2], A. Hornero[2,3], R. Hernández-Clemente[3], T. Kattenborn[4], M. Montes-Borrego[2], L. Susca[5], M. Morelli[6], V. Gonzalez-Dugo[2], P. R. J. North[3], B. B. Landa[2], D. Boscia[6], M. Saponari[6] and J. A. Navas-Cortes[2]

[1]European Commission, Joint Research Centre, Directorate D-Sustainable Resources, Ispra, Italy. [2]Instituto de Agricultura Sostenible, Consejo Superior de Investigaciones Científicas, Córdoba, Spain. [3]Department of Geography, Swansea University, Swansea, UK. [4]Institute of Geography and Geoecology, Karlsruhe Institute of Technology , Karlsruhe, Germany. [5]Dipartimento di Scienze del Suolo, della Pianta e degli Alimenti dell'Università di Bari, Bari, Italy. [6]CNR, Istituto per la Protezione Sostenibile delle Piante, Bari, Italy. *e-mail: pablo.zarco@ec.europa.eu; pablo.zarco@gmail.com

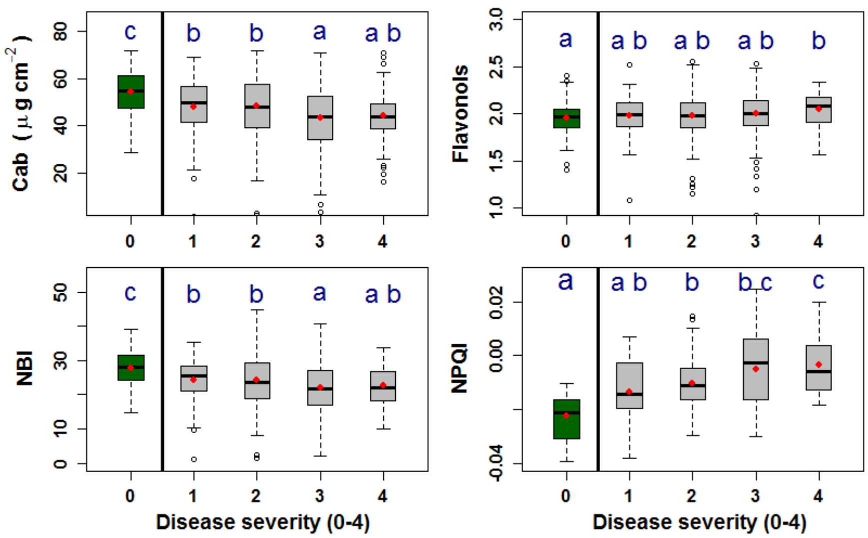
Supplementary Figures and Tables



Supplementary Fig. 1. Boxplots for each of the inverted plant traits from the hyperspectral imagery using radiative transfer models, as a function of *Xylella fastidiosa* disease severity. Notches were added to each box to highlight significant differences among a trait expression and *Xf* severity levels. In the box plots, the black line within the box represents the median, and the top and bottom of the box are the 75th and 25th quartiles, respectively. The whiskers represent the upper and lower limits based on the difference with the interquartile ranges (Q±1.5xIQR). The outliers, represented as circles, correspond to the values out of the upper and lower limits. The number of tree spectra used for the inversion of the plant traits was n=1,442 spectra (DS=0), n=762 spectra (DS=1), n=802 spectra (DS=2), n=250 spectra (DS=3), and n=72 spectra (DS=4).



Supplementary Fig. 2. Relationship between fluorescence quantum efficiency (Fi) calculated with FluorFLIGHT at 1 nm (**a**), and 6.5 nm (**b**) vs. solar-induced chlorophyll fluorescence (SIF) (n=300 simulations).



Supplementary Fig. 3. Leaf-level data measured in the field on asymptomatic and *Xylella fastidiosa (Xf)*-symptomatic plant material for chlorophyll *a+b* (C_{a+b}), flavonols, NBI, and NPQI indices as a function of severity levels (0 to 4). The sample size for C_{a+b}, flavonols and NBI measured using the Dualex sensor was n=1,473 leaf measurements. The sample size for the NPQI index calculated from the leaf reflectance measurements using the PolyPen RP400 was n=199 leaf spectra. The averages for each severity level were compared by one-sided Tukey's HSD test at 5%. Severity levels sharing the same letter were not significantly different in Tukey's HSD post-hoc test with a *p-value*<0.05. In the box plots, the black line within the box is the median, the top and bottom of the box is the 75th and 25th quartile, respectively. The whiskers represent the upper and lower limits based on the difference with the interquartile ranges (Q±1.5xIQR). The outliers, represented as circles, correspond to values out of the upper and lower limits. The average values are shown with a red point over the box plot.

Supplementary Table 1. Narrow-band hyperspectral indices (NBHI) derived from hyperspectral and thermal data included in this study and their formulations[13].

Hyperspectral indices	Equation	Reference
Structural indices		
Normalized Difference Veg. Index	$NDVI = (R_{800} - R_{670})/(R_{800} + R_{670})$	Rouse *et al*. (1974)
Renormalized Difference Veg. Index	$RDVI = (R_{800} - R_{670})/\sqrt{(R_{800} + R_{670})}$	Roujean & Breon (1995)
Optimized Soil-Adjusted Veg. Index	$OSAVI = ((1 + 0.16) \cdot (R_{800} - R_{670})/(R_{800} + R_{670} + 0.16))$	Rondeaux *et al*. (1996)
Modified Soil-Adjusted Vegetation Index	$MSAVI = \frac{2 \cdot R_{800} + 1 - \sqrt{(2 \cdot R_{800} + 1)^2 - 8(R_{800} - R_{670})}}{2}$	Qi *et al*. (1994)
Triangular Vegetation Index	$TVI = 0.5 \cdot [120 \cdot (R_{750} - R_{550}) - 200 \cdot (R_{670} - R_{550})]$	Broge & Leblanc (2001)
Modified Triangular Veg. Index 1	$MTVI1 = 1.2[1.2(R_{800} - R_{550}) - 2.5(R_{670} - R_{550})]$	Haboudane *et al*. (2004)
Modified Triangular Veg. Index 2	$MTVI2 = \frac{1.5[1.2(R_{800} - R_{550}) - 2.5(R_{670} - R_{550})]}{\sqrt{(2R_{800} + 1)^2 - (6R_{800} - 5\sqrt{R_{670}}) - 0.5}}$	Haboudane *et al*. (2004)
Modified Chlorophyll Abs. Index	$MCARI = [(R_{700} - R_{670}) - 0.2(R_{700} - R_{550})] \cdot (R_{700}/R_{670})$	Haboudane *et al*. (2004)
Modified Chlorophyll Abs. Index 1	$MCARI1 = 1.2[2.5(R_{800} - R_{670}) - 1.3(R_{800} - R_{550})]$	Haboudane *et al*. (2004)
Modified Chlorophyll Abs. Index 2	$MCARI2 = \frac{1.5[2.5(R_{800} - R_{670}) - 1.3(R_{800} - R_{550})]}{\sqrt{(2R_{800} + 1)^2 - (6R_{800} - 5\sqrt{R_{670}}) - 0.5}}$	Haboudane *et al*. (2004)
Simple Ratio	$SR = R_{800}/R_{670}$	Jordan (1969)
Modified Simple Ratio	$MSR = \frac{R_{800}/R_{670} - 1}{(R_{800}/R_{670})^{0.5} + 1}$	Chen (1996)
Enhanced Vegetation Index	$EVI = 2.5 \cdot (R_{800} - R_{670})/(R_{800} + 6 \cdot R_{670} - 7.5 \cdot R_{800} + 1)$	Liu & Huete (1995)
Pigment indices		
Vogelmann indices	$VOG1 = R_{740}/R_{720}$	Vogelmann *et al*. (1993)
	$VOG2 = (R_{734} - R_{747})/(R_{715} + R_{726})$	Vogelmann *et al*. (1993)
	$VOG3 = (R_{734} - R_{747})/(R_{715} + R_{720})$	Vogelmann *et al*. (1993)
Gitelson & Merzlyak indices	$GM1 = R_{750}/R_{550}$	Gitelson & Merzlyak (1997)
	$GM2 = R_{750}/R_{700}$	Gitelson & Merzlyak (1997)
Transformed Chlorophyll Absorption in Reflectance Index	$TCARI = 3 \cdot [(R_{700} - R_{670}) - 0.2 \cdot (R_{700} - R_{550}) \cdot (R_{700}/R_{670})$	Haboudane *et al*. (2002)
Transformed Chlorophyll Absorption in Reflectance Index/ Optimized Soil-Adjusted Vegetation Index	$\frac{TCARI}{OSAVI} = \frac{3 \cdot [(R_{700} - R_{670}) - 0.2 \cdot (R_{700} - R_{550}) \cdot (R_{700}/R_{670})}{((1 + 0.16) \cdot (R_{800} - R_{670})/(R_{800} + R_{670} + 0.16))}$	Haboudane *et al*. (2002)
Chlorophyll Index Red Edge	$CI = R_{750}/R_{710}$	Haboudane *et al*. (2002)
Simple Ratio Pigment Index	$SRPI = R_{430}/R_{680}$	Peñuelas *et al*., (1995)
Normalized Phaeophytinization Index	$NPQI = (R_{415} - R_{435})/(R_{415} + R_{435})$	Barnes *et al*. (1992) Peñuelas *et al*., (1995)
Normalized Pigments Index	$NPCI = (R_{680} - R_{430})/(R_{680} + R_{430})$	Peñuelas *et al*. (1995)
Carter indices	$CTRI1 = R_{695}/R_{420}$	Carter (1994)
	$CAR = R_{695}/R_{760}$	Carter *et al*. (1996)
Reflectance band ratio indices	$DCabCxc = R_{672}/(R_{550} \cdot 3R_{708})$	Datt *et al*. (1998)
	$DNIRCabCxc = R_{860}/(R_{550} \cdot R_{708})$	Datt *et al*. (1998)
Structure-Intensive Pigment Index	$SIPI = (R_{800} - R_{445})/(R_{800} + R_{680})$	Peñuelas *et al*. (1995)

Carotenoid Reflectance Indices	$CRI_{550} = (1/R_{510}) - (1/R_{550})$	Gitelson *et al*. (2003; 2006)
	$CRI_{700} = (1/R_{510}) - (1/R_{700})$	Gitelson *et al*. (2003; 2006)
	$CRI_{550\_515} = (1/R_{515}) - (1/R_{550})$	Gitelson *et al*. (2006)
	$CRI_{700\_515} = (1/R_{515}) - (1/R_{700})$	Gitelson *et al*. (2006)
	$RNIR \cdot CRI_{550} = (1/R_{510}) - (1/R_{550}) \cdot R_{770}$	Gitelson *et al*. (2003, 2006)
	$RNIR \cdot CRI_{700} = (1/R_{510}) - (1/R_{700}) \cdot R_{770}$	Gitelson *et al*. (2003, 2006)
Plant Senescencing Reflectance Index	$PSRI = (R_{680} - R_{500})/R_{750}$	Merzlyak *et al*. (1999)
Pigment Specific Simple Ratio Chlorophyll a	$PSSRa = R_{800}/R_{675}$	Blackburn (1998)
Pigment Spec. Simple Ratio Chl. b	$PSSRb = R_{800}/R_{650}$	Blackburn (1998)
Pigment Specific Simple Ratio Carot.	$PSRRc = R_{800}/R_{500}$	Blackburn (1998)
Pigment Specific Normalized Difference	$PSNDc = (R_{800} - R_{470})/(R_{800} + R_{470})$	Blackburn (1998)
Xanthophyll indices		
Photochemical Refl. Index (570)	$PRI_{570} = (R_{570} - R_{531})/(R_{570} + R_{531})$	Gamon *et al*. (1992)
Photochemical Refl. Index (515)	$PRI_{515} = (R_{515} - R_{531})/(R_{515} + R_{531})$	Hernández-Clemente *et al*. (2011)
Photochemical Refl. Index (512)	$PRI_{m1} = (R_{512} - R_{531})/(R_{512} + R_{531})$	Hernández-Clemente *et al*. (2011)
Photochemical Refl. Index (600)	$PRI_{m2} = (R_{600} - R_{531})/(R_{600} + R_{531})$	Gamon *et al*. (1992)
Photochemical Refl. Index (670)	$PRI_{m3} = (R_{670} - R_{531})/(R_{670} + R_{531})$	Gamon *et al*. (1992)
Photochemical Refl. Index (670 and 570)	$PRI_{m4} = (R_{570} - R_{531} - R_{670})/(R_{570} + R_{531} + R_{670})$	Hernández-Clemente *et al*. (2011)
Normalized Photoch. Refl. Index	$PRI_n = PRI_{570}/[RDVI \cdot (R_{700}/R_{670})$	Zarco-Tejada *et al*. (2013)
Carotenoid/Chlorophyll Ratio Index	$PRI \cdot CI = (R_{570} - R_{530})/(R_{570} + R_{530}) \cdot ((R_{760}/R_{700}) - 1)$	Garrity *et al*. (2011)
R/G/B indices		
Redness Index	$R = R_{700}/R_{670}$	Gitelson *et al*. (2000)
Greenness Index	$G = R_{570}/R_{670}$	Calderon *et al*. (2013)
Blue Index	$B = R_{450}/R_{490}$	Calderon *et al*. (2013)
Blue/green indices	$BGI1 = R_{400}/R_{550}$	Zarco-Tejada *et al*. (2005)
	$BGI2 = R_{450}/R_{550}$	Zarco-Tejada *et al*. (2005)
Blue/red indices	$BRI1 = R_{400}/R_{690}$	Zarco-Tejada *et al*. (2012)
	$BRI2 = R_{450}/R_{690}$	Zarco-Tejada *et al*. (2012)
BF1	$BF1 = R_{400}/R_{410}$	This study
BF2	$BF2 = R_{400}/R_{420}$	This study
BF3	$BF3 = R_{400}/R_{430}$	This study
BF4	$BF4 = R_{400}/R_{440}$	This study
BF5	$BF5 = R_{400}/R_{450}$	This study
Red/green indices	$RGI = R_{690}/R_{550}$	Zarco-Tejada *et al*. (2005)
Ratio Analysis of Reflectance Spectra	$RARS = R_{746}/R_{513}$	Chappelle *et al*. (1992)
Lichtenthaler Index	$LIC1 = (R_{800} - R_{680})/(R_{800} + R_{680})]$	Lichtenhaler *et al*. (1996)
	$LIC2 = R_{440}/R_{690}$	Lichtenhaler *et al*. (1996)
	$LIC3 = R_{440}/R_{740}$	Lichtenhaler *et al*. (1996)
Chlorophyll fluorescence		
Reflectance Curvature Index	$CUR = (R_{675} \cdot R_{690})/R_{683}^2$	Zarco-Tejada *et al*. (2000)
SIF	$FLD2(750; 762)$	Plascyk (1975)
Plant disease index		
Healthy-index	$HI = \frac{(R_{534} - R_{698})/}{R_{534} + R_{698}} - \frac{1}{2} \cdot R_{704}$	Mahlein *et al*. (2013)
Canopy temperature		
Tc / CWSI		Jackson *et al.* (1981)

Supplementary Table 2. Values and ranges used for the model inversion and look-up-table (LUT) generation.

Parameter	Abbreviation	Value / range
Chlorophyll content [μg/cm²]	C_{a+b}	5–70
Carotenoid content [μg/cm²]	C_{x+c}	3–15
Anthocyanin content [μg/cm²]	A_{nth}	0.1–6.0
Dry matter content [g/cm²]	C_m	0.0022
Water content [g/cm²]	C_w	0.005
Mesophyll struct. coef.	N	1.7–2.4
Leaf Area Index [m²/m²]	LAI	1–5
Average leaf angle [deg.]	$Lidf_a$	30–70
Hot spot parameter	Hot	0.1
Soil reflectance	Rsoil	PROSAIL dry soil spectra
Observer angle [deg.]	Tto	0
Sun zenith angle [deg.]	Tts	66.9
Relative azimuth angle [deg.]	Psi	0

Supplementary Table 3. Nominal values and range of variation used in FluorFLIGHT simulation analysis based on field data measurements.

Parameter	Abbreviation	Nominal values	Range
FLUSPECT			
Mesophyll structure	N	2.9	-
Chlorophyll content	C_{a+b} (μg/cm^2)	35	5–80
Carotenoid content	C_{x+c} (μg/cm^2)	8	5–12
Water content	C_w (mg/cm^2)	0.013	-
Dry matter	C_{dm} (mg/cm^2)	0.024	-
Senescent material	C_s	0	0
Fluor. quantum efficiency	F_i	0.04	0–0.1
FLIGHT			
Solar zenith, view zenith (º)	θ_s, θ_v	31.3, 0.0	-
Solar and view azimuth (º)	Φ_s, Φ_v	30.44, 0.0	-
Total LAI		3.15	0–3
Leaf angle distribution	LAD[1-9]	0.015, 0.045, 0.074, 0.1, 0.123, 0.143, 0.158, 0.168, 0.174	
Fractional cover (%)	FC	20	
Crowns shape	CSh	ellipsoid	
Crown radius and centre to top distance	E_{xy}, E_z (m)	2.0, 1.5	
Tree height	Hmin, Hmax	4, 5	
Soil reflectance	$\rho_{\lambda soil}$	ASD measurements	
Soil roughness	Θ_{soil}	0	
Solar irradiance	$\rho_{\lambda s}$	ASD measurements	

Supplementary Table 4. Accuracy of the support vector machine (SVM), neural network (NN) and linear discriminant analysis (LDA) to distinguish among disease severity (DS) classes of olive quick decline syndrome caused by *Xylella fastidiosa* for assessing the separation of asymptomatic (AS) vs. symptomatic trees (AF; affected) using flux-based traits fluorescence and temperature (PSFT), pigment- and structure-based Functional Traits (PS) and RGB-NIR indices (SVI) plant trait pools.

Asympt. vs. *Xf*-sympt.		**Pigment-, Structure-, Fluorescence and Temperature-based Functional Traits (PSFT)**						**Pigment- and Structure-based Functional Traits (PS)**						**Standard RGB-NIR bandset (SVI)**					
		PRECISION		**RECALL**		**OVERALL**		**PRECISION**		**RECALL**		**OVERALL**		**PRECISION**		**RECALL**		**OVERALL**	
		P (%) (AS)	**P (%) (AF)**	**R (%) (AS)**	**R (%) (AF)**	**OA (%)**	**κ**	**P (%) (AS)**	**P (%) (AF)**	**R (%) (AS)**	**R (%) (AF)**	**OA (%)**	**κ**	**P (%) (AS)**	**P (%) (AF)**	**R (%) (AS)**	**R (%) (AF)**	**OA (%)**	**κ**
SVM	**TR**	90.19	72.58	80.35	85.62	82.34	0.64	87.7	68.88	77.79	81.83	79.31	0.57	75.23	56.69	68.34	64.81	66.96	0.32
	TS	91.36	68.35	77.73	86.75	80.95	0.61	87.74	67.34	76.46	81.97	78.51	0.56	75.77	52.86	66.02	64.34	65.4	0.29
NN	**TR**	79	65.14	73.8	71.39	72.82	0.45	80.16	56.21	69.47	69.51	69.48	0.37	74.36	52.34	65.98	62.16	64.54	0.27
	TS	78.55	62.96	71.94	70.83	71.49	0.42	79.67	55.22	68.26	69.2	68.6	0.36	72.7	49.49	63.5	60	62.2	0.23
LDA	**TR**	81.36	56.18	69.77	70.8	70.13	0.38	77.48	52.91	67.16	65.4	66.53	0.31	73.66	49.68	64.53	60.28	62.97	0.24
	TS	81.62	51.18	66.89	69.72	67.84	0.34	75.49	46.13	62.88	60.89	62.2	0.22	71.59	47.14	62.08	57.85	60.52	0.19

SVM: Support vector machine; NN: Neural network, Models: LDA: Linear discriminant analysis.
P(AS): Precision asymptomatic (0); P(AF): Precision all affected (AF; DS=1,2,3,4); R(AS): Recall asymptomatic (0); R(AF): Recall all affected (AF; DS=1,2,3,4); OA: Overall accuracy; κ=kappa coefficient; TR: Training (80% dataset); TS: Test (20% dataset).
Number of trees for each sample: Case A: AS=4049, AF=3266.

Supplementary Table 5. Accuracy of the support vector machine (SVM), neural network (NN) and linear discriminant analysis (LDA) to distinguish among disease severity (DS) classes of olive quick decline syndrome caused by *Xylella fastidiosa* for assessing the separation of Initial *Xf*-symptoms (IN) vs. advanced *Xf*-symptoms trees (AD; advanced symptoms) using flux-based traits fluorescence and temperature (PSFT), pigment- and structure-based Functional Traits (PS) and RGB-NIR indices (SVI) plant trait pools.

Initial vs. advanced *Xf*-sympt.		**Pigment-, Structure-, Fluorescence and Temperature-based Functional Traits (PSFT)**						**Pigment- and Structure-based Functional Traits (PS)**						**Standard RGB-NIR bandset (SVI)**					
		PRECISION		**RECALL**		**OVERALL**		**PRECISION**		**RECALL**		**OVERALL**		**PRECISION**		**RECALL**		**OVERALL**	
		P (%) (IN)	**P (%) (AD)**	**R (%) (IN)**	**R (%) (AD)**	**OA (%)**	**κ**	**P (%) (IN)**	**P (%) (AD)**	**R (%) (IN)**	**R (%) (AD)**	**OA (%)**	**κ**	**P (%) (IN)**	**P (%) (AD)**	**R (%) (IN)**	**R (%) (AD)**	**OA (%)**	**κ**
SVM	**TR**	71.45	76.79	70.86	77.31	74.44	0.48	71.07	75.83	69.89	76.85	73.73	0.47	46.18	77.82	62.18	64.68	63.86	0.25
	TS	69.78	75.95	71.85	74.07	73.06	0.46	71.22	72.78	69.72	74.19	72.05	0.44	46.04	75.95	62.75	61.54	61.95	0.22
NN	**TR**	64.66	74.26	66.48	72.68	70.02	0.39	58.09	75.59	65.27	69.55	67.87	0.34	46.26	72.75	57.28	63.16	61.06	0.19
	TS	65.47	72.78	67.91	70.55	69.36	0.38	56.12	72.78	64.46	65.34	64.98	0.29	44.6	70.89	57.41	59.26	58.59	0.16
LDA	**TR**	70	67.63	63.07	74.06	68.68	0.37	66.11	65.28	60.06	70.92	65.64	0.31	58.85	62.87	55.59	65.93	61.1	0.22
	TS	70.5	68.99	66.67	72.67	69.7	0.39	67.63	63.92	62.25	69.18	65.66	0.31	55.4	63.29	57.04	61.73	59.6	0.19

SVM: Support vector machine; NN: Neural network, Models: LDA: Linear discriminant analysis.
P(IN): Precision Initial *Xf*-symptoms (1); P(AD): Precision advanced *Xf*-symptoms (DS=2,3,4); R(IN): Recall Initial *Xf*-symptoms (1); R(AD): Recall advanced *Xf*-symptoms (DS=2,3,4);
OA: Overall accuracy; κ=kappa coefficient; TR: Training (80% dataset); TS: Test (20% dataset).
Number of trees for each sample: Case A: IN=1449, AD=1817.

Supplementary Table 6. Results of the field assessment (Visual) and the remote sensing physiological-traits model (SVM-PSFT) for the detection of non-infected (qPCR=0) and *Xylella fastidiosa*-infected trees (qPCR=1). The table reports the number and percentage of trees correctly classified against the infection status determined by qPCR. The *Xf*-infected trees were split between infected visually asymptomatic (qPCR=1; Disease Severity, DS=0) and infected visually symptomatic trees (qPCR=1; DS≥1). The qPCR dataset was collected from samples across eight orchards thorough the study sites (n=100).

	***Xf*-non-infected trees (qPCR=0) n=42**	***Xf*-infected trees (qPCR=1) n=58**		
		All (DS≥0) n=58	**Asymptomatic (DS=0) n=14**	**Symptomatic (DS≥1) n=44**
Visual assessment	33 (78.6%)	44 (75.9%)	0 (0%)	44 (100%)
Remote Sensing SVM-PSFT model	39 (92.9%)	57 (98.3%)	13 (92.9%)	44 (100%)

Supplementary Table 7. Revisit study comparing the classification accuracy of true negative (TN) and false positive (FP) trees affected by olive quick decline syndrome caused by *Xylella fastidiosa* based on remote sensing physiological traits on four visual assessment dates using the Support vector machine (SVM) model.

TEMPORAL REVISIT ANALYSIS									
	June (flight-based classification)	**October 2016 (field revisit)**		**Feb 2017 (field revisit)**		**June 2017 (field revisit)**		**July 2017 (field revisit)**	
	Asymptomatic	**Asymptomatic**	**Symptomatic**	**Asymptomatic**	**Symptomatic**	**Asymptomatic**	**Symptomatic**	**Asymptomatic**	**Symptomatic**
TRUE NEGATIVES (TN)	818 82.13%	501 61.25%	317 38.75%	422 84.23%	79 15.77%	314 74.41%	108 25.59%	179 57.01%	135 42.99%
FALSE POSITIVES (FP)	178 17.87%	70 39.33%	108 60.67%	36 51.43%	34 48.57%	21 58.33%	15 41.67%	7 33.33%	14 66.67%