Hélio SPIR 20 ans

CANOP

Determining the leaf biochemical and phytosanitary status of orchard trees using spectroscopy from visible to long-wave infrared range

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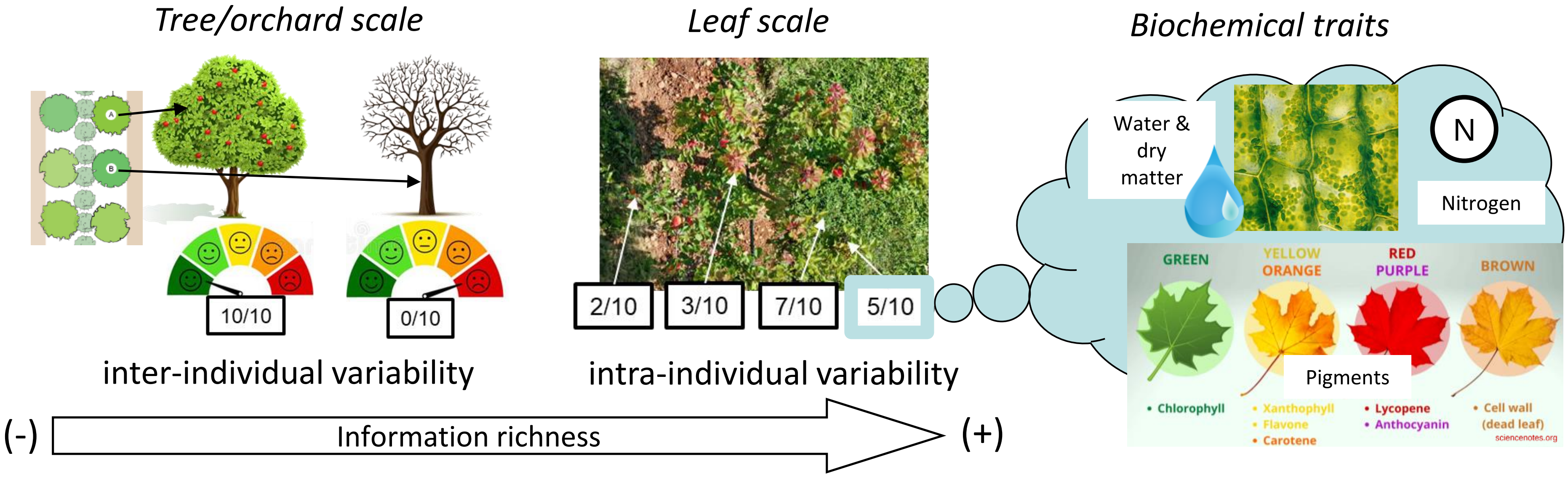
Context

Exploring the gain of remote sensing data collections at (sub)centimetric scale for a better determination of biotic and abiotic stress symptoms in contrasting agro-ecological practices

→ Use of non-destructive and high-throughput optical spectroscopic measurements giving access to biochemical traits highlighting photosynthetic status, water resources, nutrient and biomass allocation



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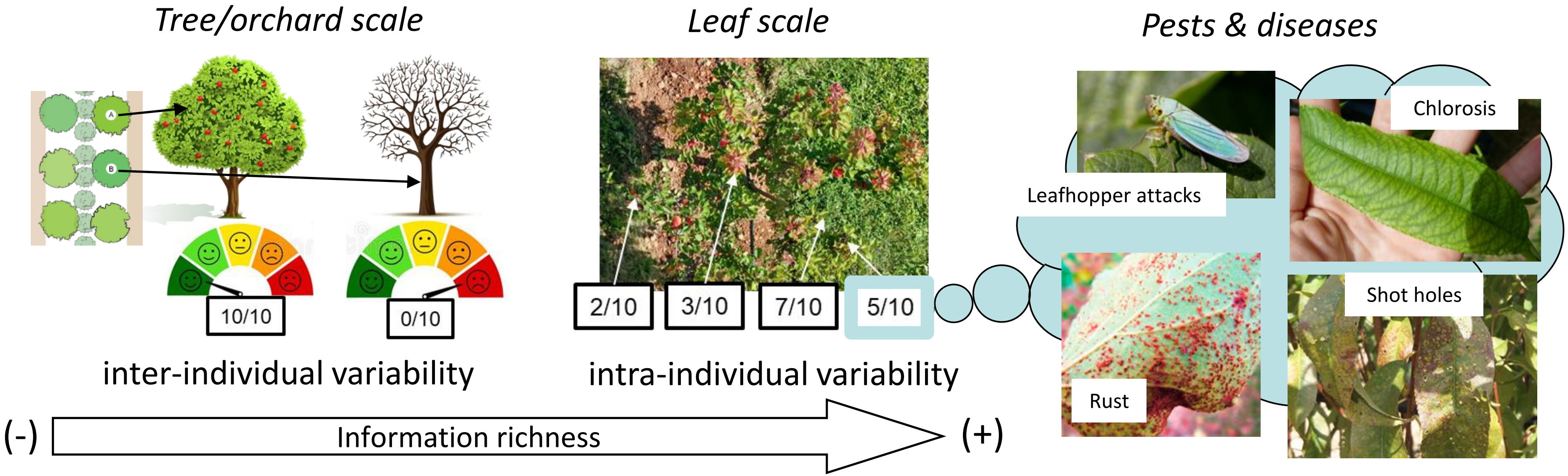
Context

Exploring the gain of remote sensing data collections at (sub)centimetric scale for a better determination of biotic and abiotic stress symptoms in contrasting agro-ecological practices

→ Goal to further determine the type and intensity of pests and diseases from leaf discoloration, water stress, nutrient loss and biomass change



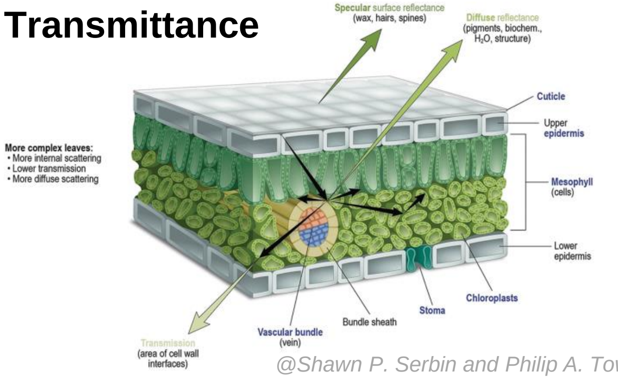
Objectives

Explore relationships between optical data, biochemical traits and pest/disease scores to derive the phytosanitary status at leaf scale

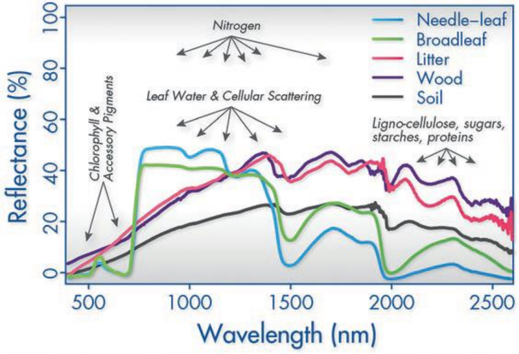
Our study targets peach and apricot tree orchards for two agro-ecological applications: inputs management and variety breeding.

Spectrocopic data in the visible to short-wave infrared range (VSWIR: 0.4-2.5 µm) is efficient to quantify biochemical traits from statistical and physical methods for different vegetation physiological conditions (Wang et al., 2023 ; Gaubert et al., 2023).

Reflectance
Absorbance
Transmittance

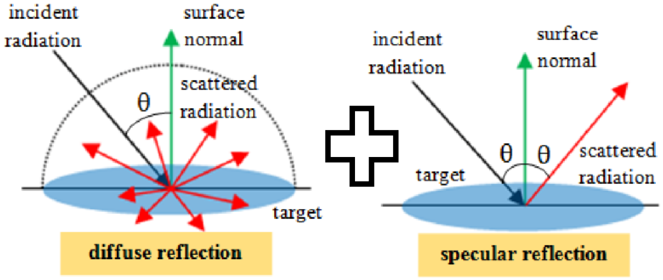


@Shawn P. Serbin and Philip A. Townsend



Spectral absorptions of leaf biochemical traits

Directional-hemispherical reflectance



@Tan et al. 2016

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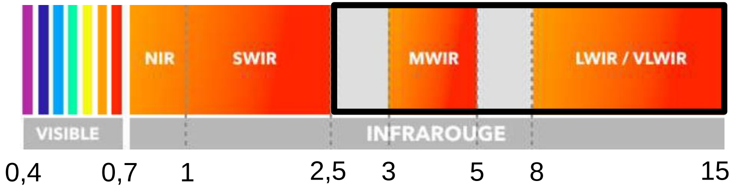
→ Interest for the mid- to long-wave infrared spectral domain (MWIR/LWIR: 2.5-15 µm) ?



Little available data because tough requirements in the measurement protocol :

- cooling the detector with liquid nitrogen
- purging the integrating sphere of water vapor and carbon dioxide with nitrogen gas

Choice of the substitution method to measure optical properties

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→ From statistical to physical methods, which are the most effective ?
→ Is it possible to estimate pest and disease scores ?

Statistical (data-driven):
- fast
- datasets

Physical (model-driven):
- generalizable
- parameterization

Biotic and abiotic factors can be unmixed from the spectral features ?

Objectives

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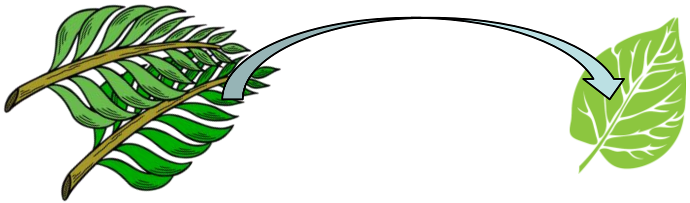
For statistical methods, building relevant datasets is very demanding in terms of human and instrumental resources and is costly for laboratory analysis because a large number of samples is needed.

→ Can we find a compromise by working at shoot scale instead of leaf scale ?



The first work presented relies on raw spectra and a diversified set of leaf observations.

Sites

<u>Two INRAE experimental stations:</u>

INRAE Domaine Saint Paul (Avignon)
- Peach orchard, one variety (Nectarlove cv),
- Conventional treatment with fertilization trials since 3 years and irrigation trials (ECOPECHE network)

INRAE Domaine Amarine (Bellegarde)
- Apricot orchard, 150 varieties replicated in 5 blocks (CORE COLLECTION network),
- Low phytosanitary inputs

Materials

Samplings:

- 5 dates (from June to October 2023), top and bottom tree crown part, 4 leaves from one shoot,
- For apricot: 5 varieties (including 1 monitored),
- For peach: 50%/100% irrigation (1 date) & 0N/180N fertilization trials (all dates)

Optical properties:

- **Leaf scale:** directional-hemispherical reflectance and transmittance of leaf adaxial side in the range 0.4-15µm (Perkin and Bruker spectroradiometers with integrating spheres)

Biochemical traits:

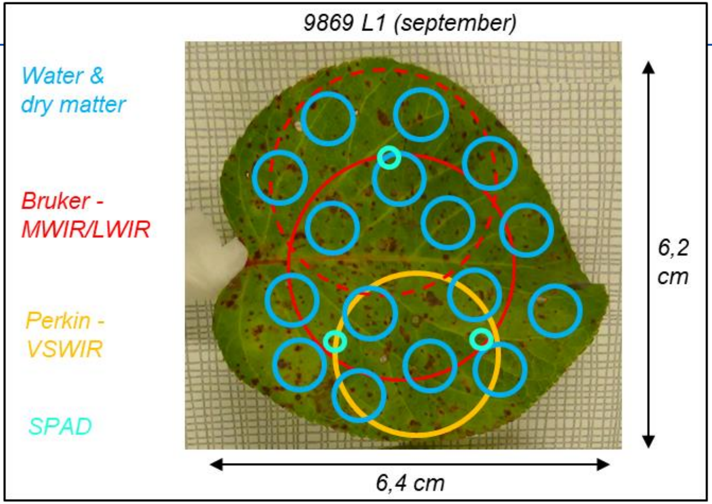
- **Leaf scale:** chlorophyll meter SPAD leaf-clip measurements, water and dry matter content,
- **Shoot scale:** pigments (phenolics compounds, chlorophylls and carotenoids) and total nitrogen contents

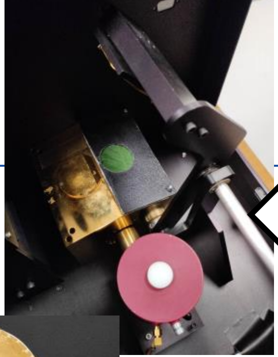
Pest/disease scores:

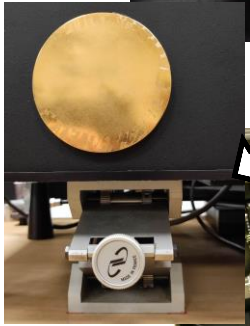
- **Leaf scale:** chlorosis, leafhopper attacks, shot hole and rust diseases

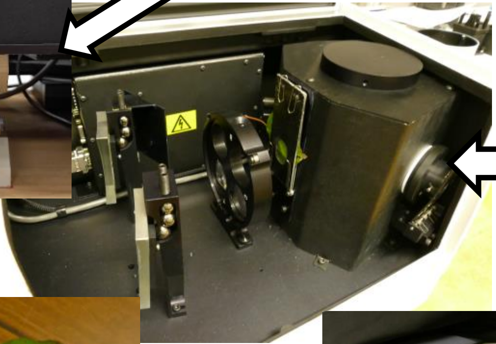
155 samples at leaf scale and 31 samples at shoot scale

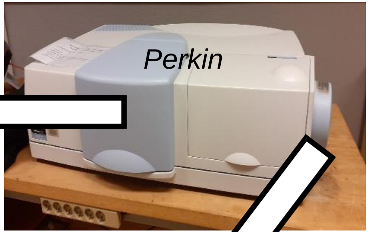
Leaf observation scales

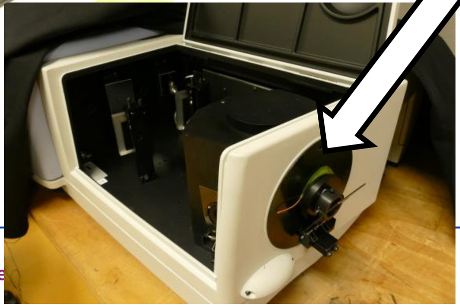




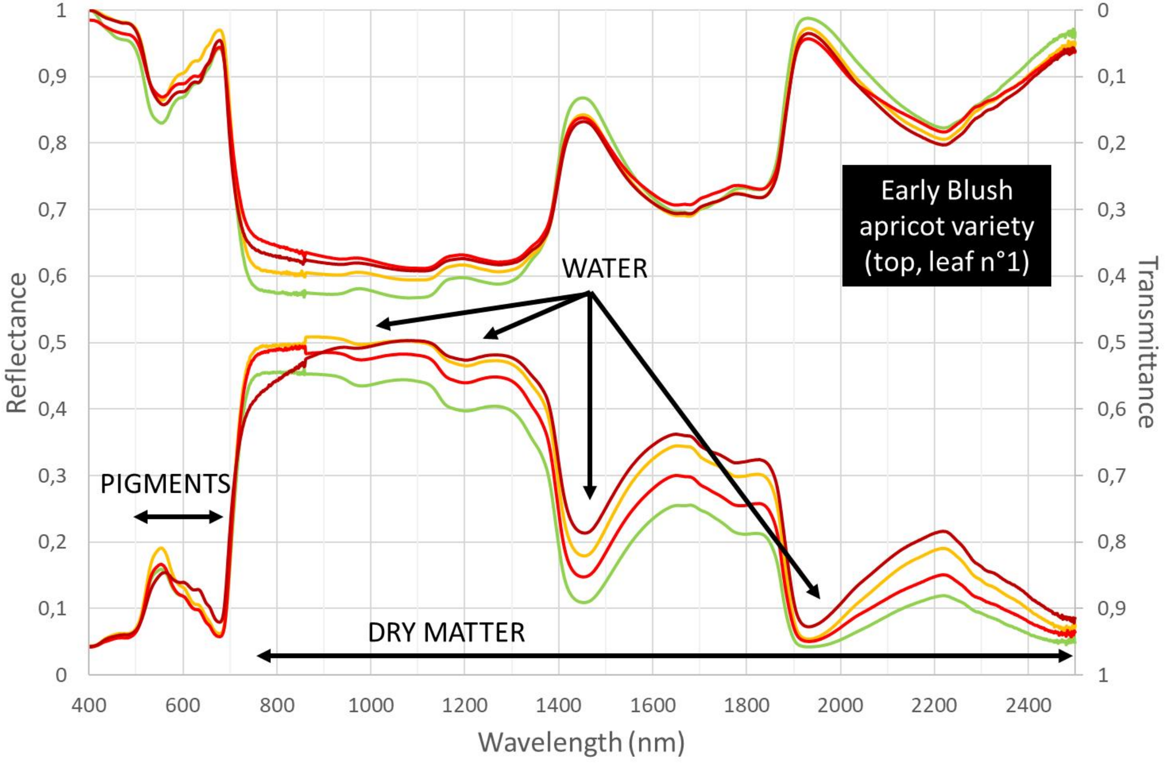


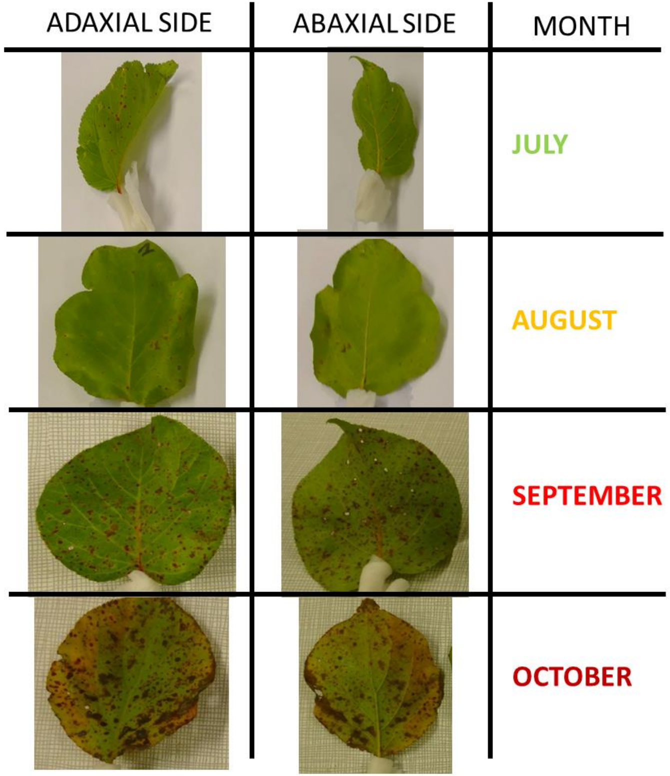






Raw data





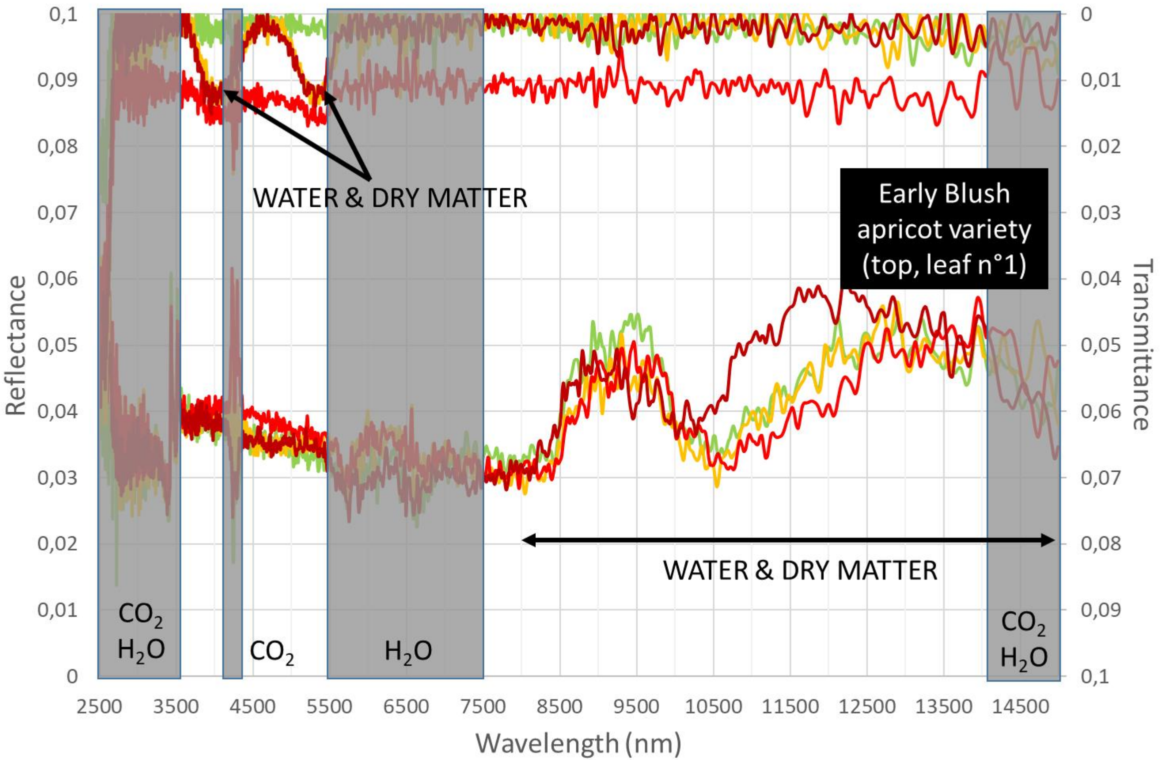
BIOCHEMICAL TRAITS

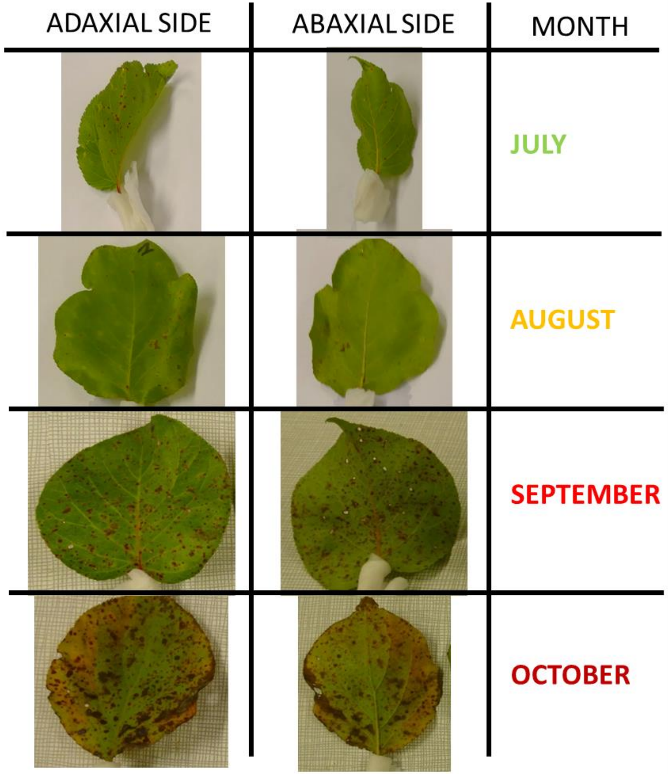
Water content (g.cm-2)	Dry matter content (g.cm-2)	Total chlorophylls content (µg.cm-2)	Total nitrogen content (%)
0.0165	0.0096	46.0	1.5
0.0088	0.0093	22.3	1.8
0.0825	0.0118	17.8	1.5
0.0076	0.0082	20.8	1.6

PEST AND DISEASE SCORES

Frequency chlorosis (%)	Leafhopper attack	Shot hole intensity (%)	Rust intensity (%)
0	no	40	0
0	probable	40	5
60	probable	90	20
70	probable	95	30

Raw data, scale has been enlarged compared to 0.4-2.5µm range, parasitic gas effects due to the substitution method error





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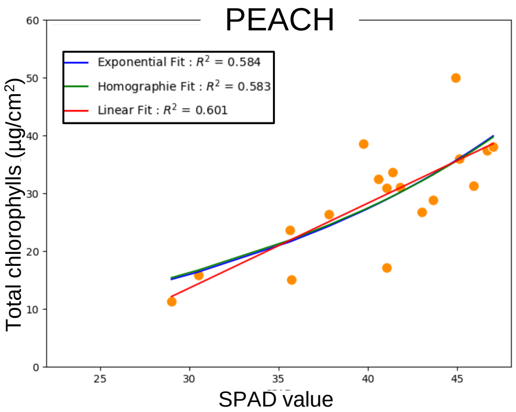
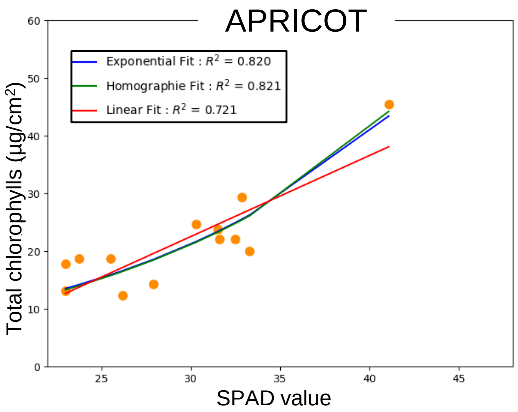
SPAD calibration to upscale shoot scale data to leaf scale

→ Average of 12 SPAD measurements to get a value at shoot scale (4 leaves/shoot, 3 measurements/leaf)

SPAD – total chlorophylls content

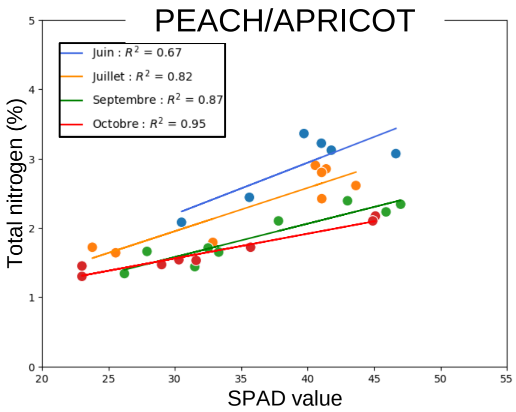
Choice of a homographic regression per species (in green)





SPAD – total nitrogen content

Choice of a linear regression per month



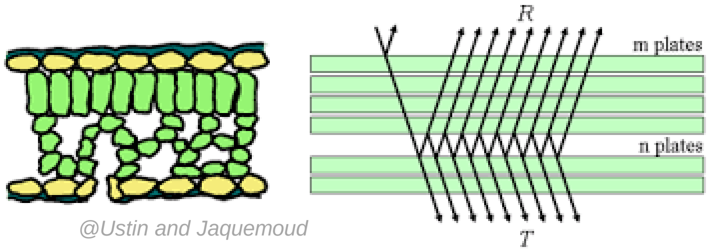
→ Application of the regression for each SPAD value to get total chlorophylls and nitrogen at leaf scale

Estimation methods

Approach	Method and parameterization	Spectral range	Data
Statistical	PLSR (scikit-learn, train/test: 70/30%, 5 cross-validation, averaged metrics over 10 repetitions, relevant spectral bands from Variable Importance in the Projection)	0.4 – 2.5 µm 2.5 – 15 µm 0.4 – 15 µm	All biochemical traits and pest/disease scores
Physical	Iterative inversion of the leaf radiative transfer PROSPECT-D (Powell optimization algorithm, optimized selection of spectral sub-ranges per trait)	0.4 – 2.5 µm	Pigments, water and dry matter content

PROSPECT model

Biochemical traits + one structural trait (N)



@Ustin and Jaquemoud

Directional-hemispherical optical properties

Results with the statistical approach

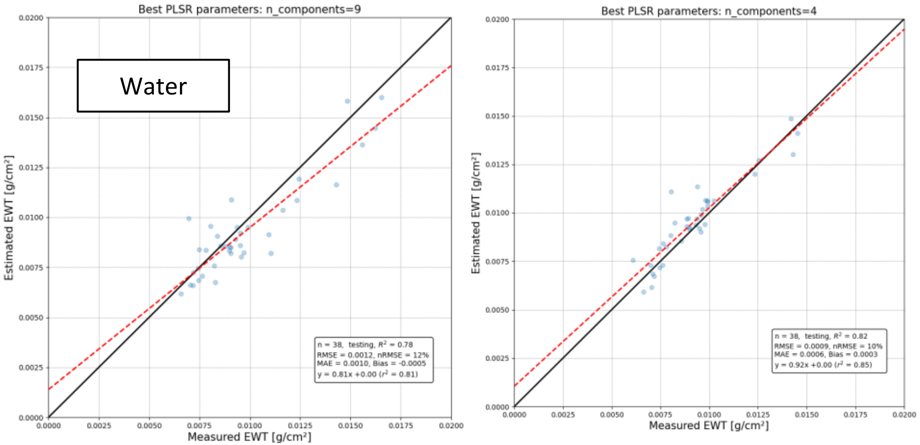
	Spectral range	0,4 - 2,5 µm (VSWIR)				2,5 - 15 µm (MWIR/LWIR)				0,4 - 15 µm (FULL RANGE)			
Original scale	Data	R2	RMSE	nRMSE (%)	LV	R2	RMSE	nRMSE (%)	LV	R2	RMSE	nRMSE (%)	LV
LEAF	Water (g/cm2)	0.75	0.0012	11	6	0.6	0.0015	14	7	0.76	0.0011	11	7
LEAF	Dry matter (g/cm2)	0.78	0.0009	11	7	0.63	0.0012	14	3	0.72	0.001	11	3
SHOOT	Chlorophylls (µg/cm2)	0.59	5.6	16	11	0.2	7.9	22	5	0.54	6	17	7
SHOOT	Nitrogen (%)	0.75	0.22	13	13	0.4	0.32	20	6	0.65	0.26	15	10
LEAF	Chlorosis frequency (%)	0.53	16	24	5	0.22	17	26	4	0.38	15	24	6
LEAF	Rust intensity (%)	0.25	10	29	4	0.19	10	29	5	0.17	10	28	5
LEAF	Shot hole intensity (%)	0.36	18	23	8	0.34	18	23	2	0.3	19	24	2

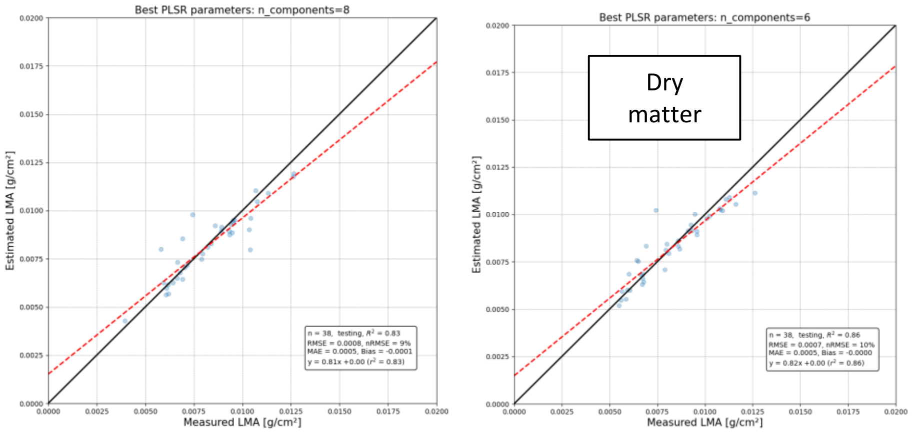
Biochemical traits: VSWIR > FULL RANGE > MWIR/LWIR (cf. all metrics, water: VSWIR ~ FULL RANGE), water/dry matter > nitrogen > chlorophylls (cf. nRMSE), excellent results in VSWIR for leaf scale traits and also nitrogen from shoot scale, slightly less better for chlorophylls from shoot scale but still acceptable

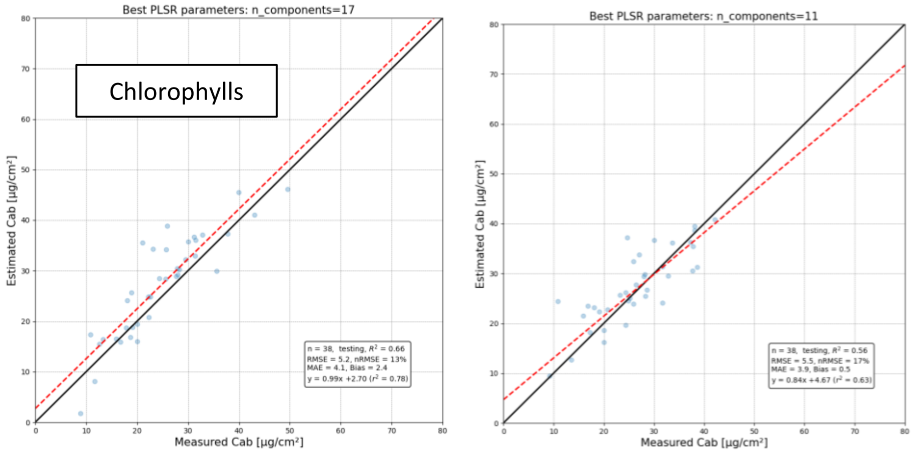
Pest/disease scores: no convincing results (RMSE > 10%, nRMSE values around twice those of biochemical traits), no particular spectral sensitivity, chlorosis & shot holes > rust (cf. nRMSE)

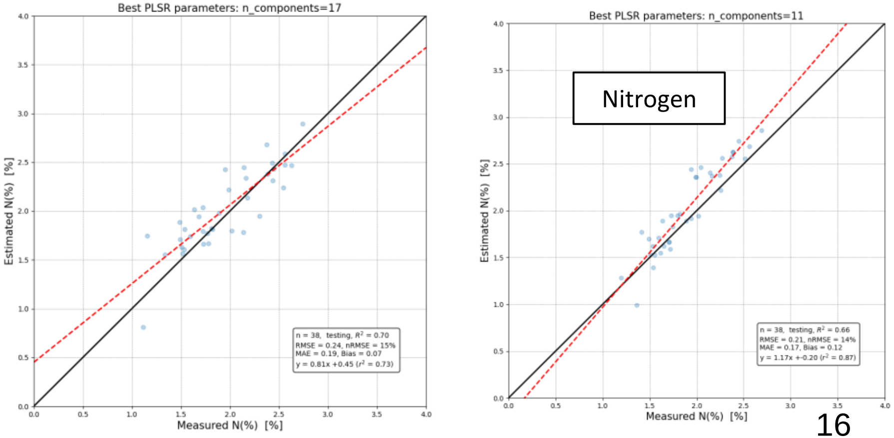
R2: coefficient of determination, RMSE: Root Mean Square Error, NRMSE: normalized RMSE, LV: optimal number of latent variables

VSWIR, results for 1rst/2nd iteration with test dataset

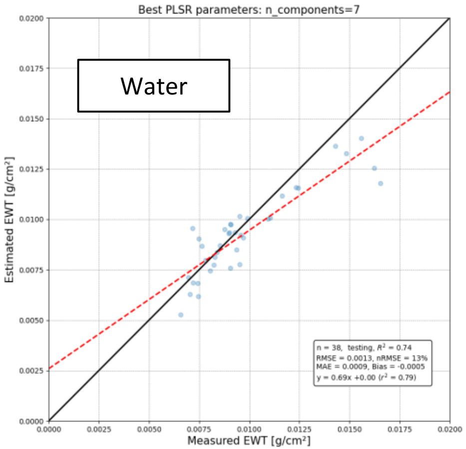


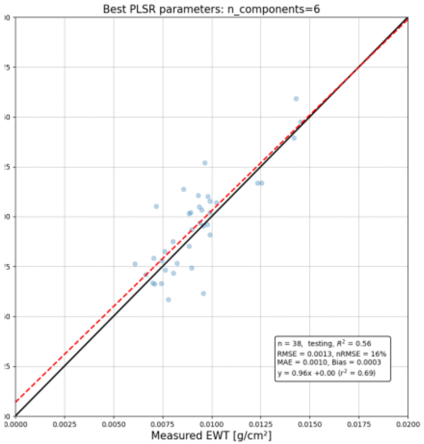


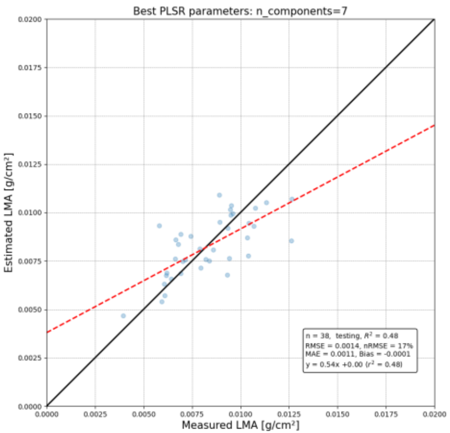


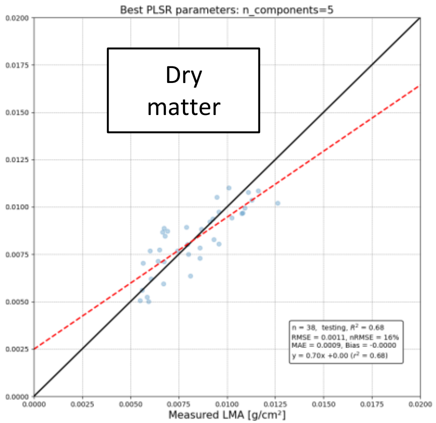


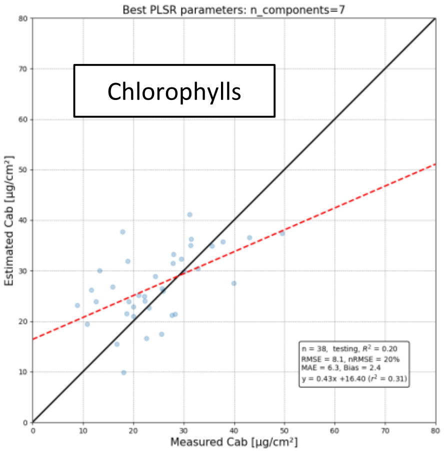
MWIR/LWIR, results for 1rst/2nd iteration with test dataset

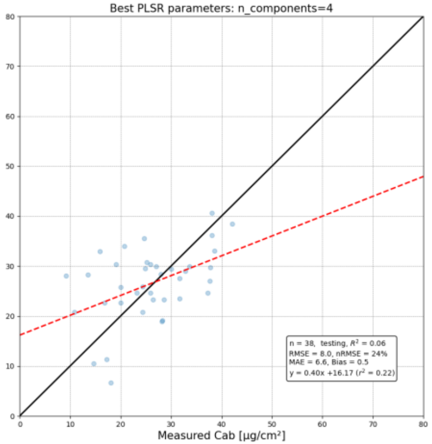


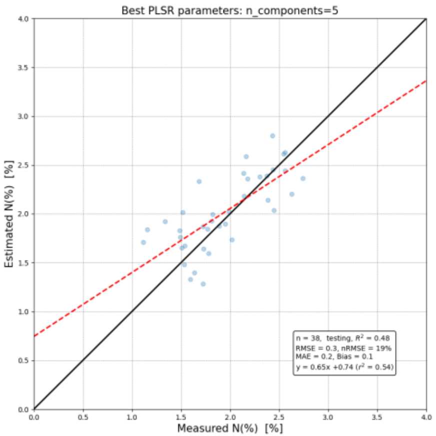


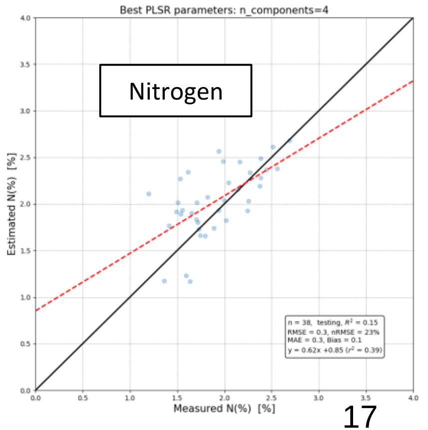




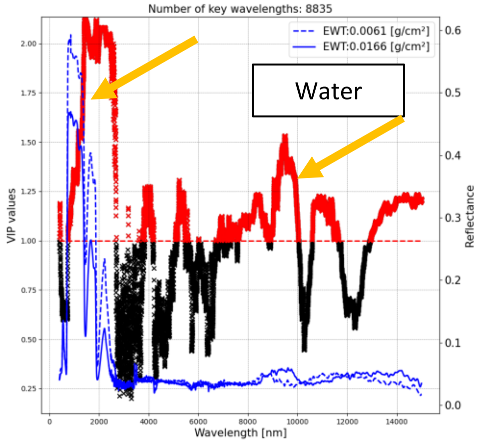


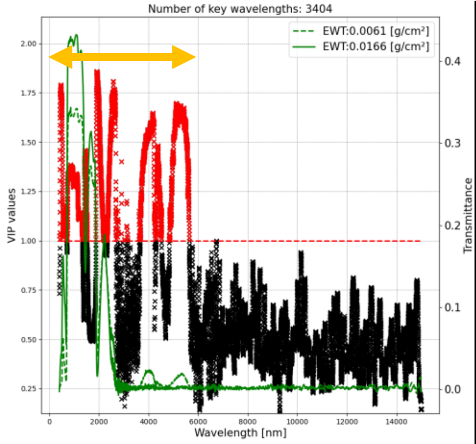


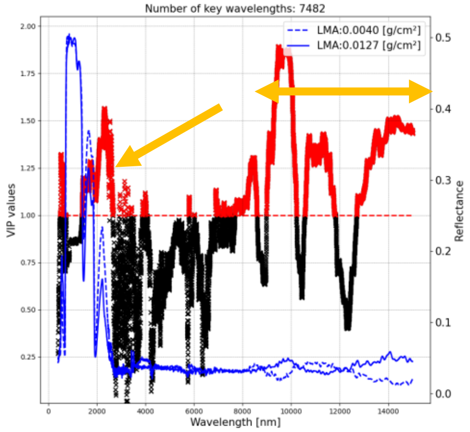


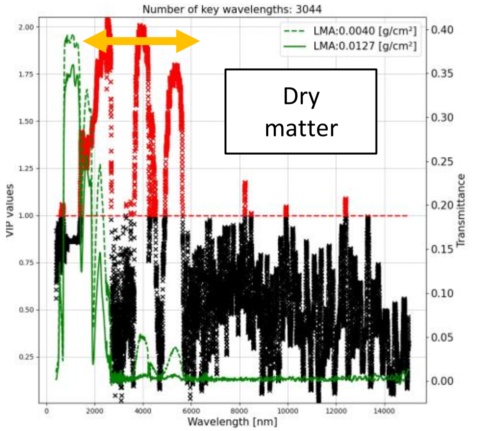


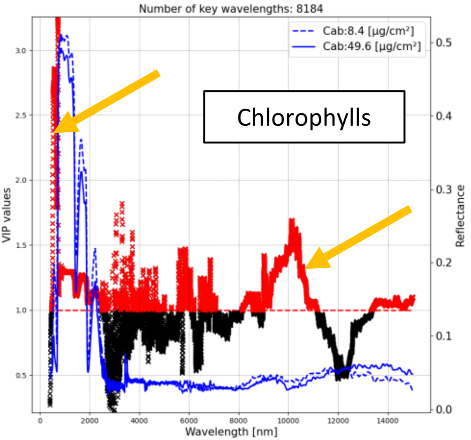
PLSR Variable Importance in the Projection (VIP)

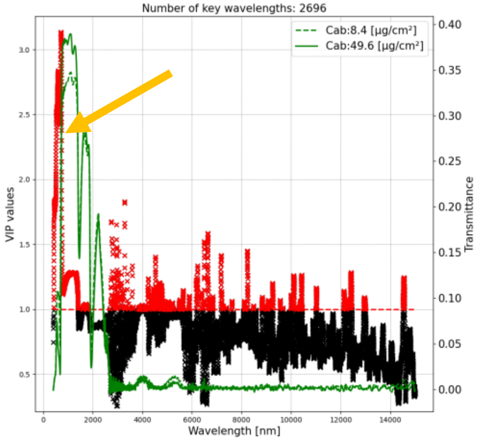


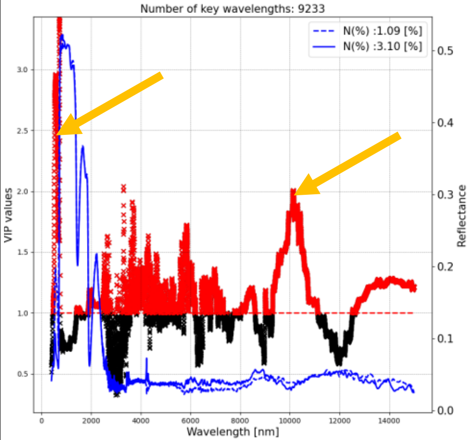


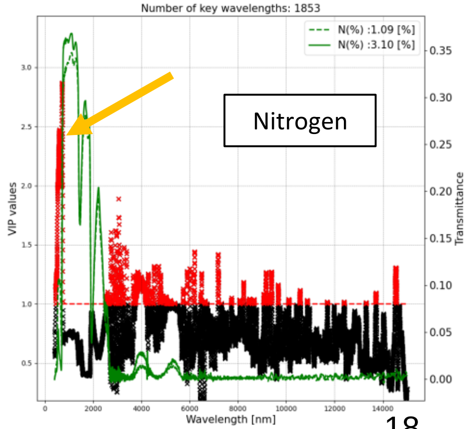












Results with the physical approach

	Spectral range	0,4 - 2,5 µm (VSWIR)			
Original scale	**Data**	**R2**	**RMSE**	**nRMSE (%)**	**Spectral range in nm (R: reflectance, T: transmittance)**
LEAF	Water (g/cm2)	0.85	0.001	10	1100 – 1800 (T)
LEAF	Dry matter (g/cm2)	0.71	0.002	17	1800 – 2400 (R + T)
SHOOT	Chlorophylls (µg/cm2)	0.75	6.29	15	580 – 720 (R)

Biochemical traits: water > chlorophylls > dry matter (cf. nRMSE), excellent results at leaf scale, slightly less better for chlorophylls from shoot scale but still acceptable (cf. RMSE)

Comparison with statistical approach in the VSWIR range: physical > statistical for water and the opposite for dry matter, more or less equivalent for chlorophylls (cf. all metrics)

R2: coefficient of determination, RMSE: Root Mean Square Error, NRMSE: normalized RMSE, LV: optimal number of latent variables

Conclusions and perspectives

- → From raw spectra, good results are globally obtained to derive biochemical traits, but not for pest/disease scores.
- → Using the VSWIR domain leads to better performances than MWIR/LWIR domains alone, the later being mostly useful only for water and dry matter content estimations (as shown in literature for other species).
- → Results are mitigated in terms of performances between physical and statistical approach depending on the biochemical trait.
- → The use of SPAD measurements at shoot scale is promising to get estimations of chlorophylls and nitrogen at leaf scale relying on built-up regressions.

Prospects:

- → Use spectral preprocessing (SNV, CR, CWT, derivatives, etc.), select more specific spectral intervals,
- → Study variable correlations (PCA) and estimate pest/disease scores from biochemical traits,
- → Test variable joint estimations with multi-output PLSR,
- → Test hybrid approaches relying on the training of machine learning algorithms on simulated datasets from physical models,
- → Building of a new dataset in 2024 in agreement with future UAV-borne acquisitions over the orchards

Thanks you

- Projet ANR CANOP “Remotely sensed leaf biochemistry intra-individual variability in orchard tree CANOPies for agroecology” (2023-2026, grant: ANR-22-CE04-0002)
- Website of the project and future data access: https://remotetree.sedoo.fr/canop

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