A spectral analysis of multiple scattering effects In close range hyperspectral imagery of vegetation scenes: application to nitrogen content assessment

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Objective:

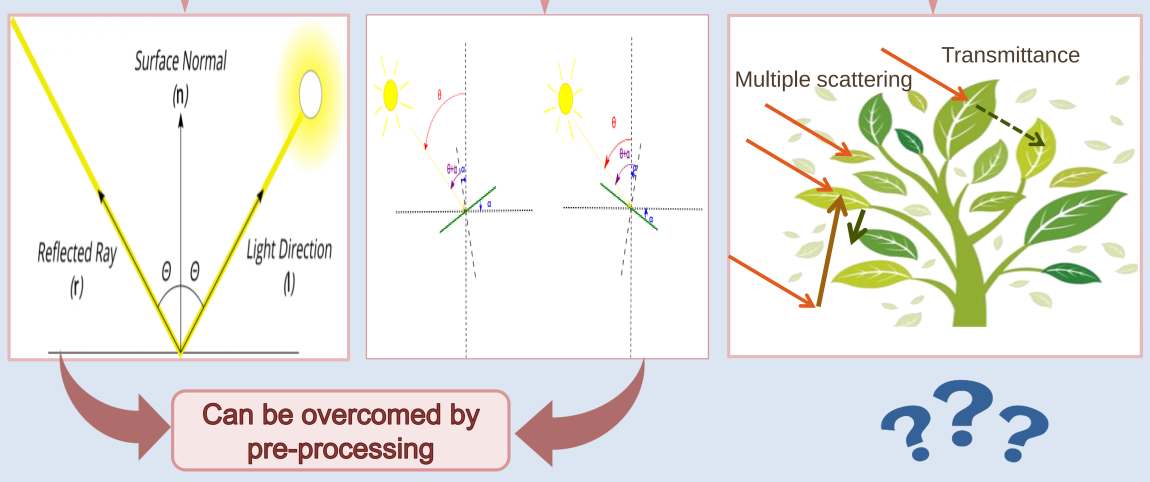
To analyze multiple scattering effects in the context of hyperspectral imaging for plant phenotyping purposes and to propose chemometrical methods to overcome them.

Introduction:

Close range hyperspectral imagery is a promising tool for phenotyping or crop monitoring. In association with Partial Least Square Regression, it allows to build high spatial resolution maps of chemical content at the canopy level.

Several optical phenomena must be taken into account when applying this approach to vegetation scenes in natural conditions:

Additive factors due to specular reflection | Multiplicative factors due to leaf inclination | Multiple Scattering Phenomena



Can be overcomed by pre-processing

Multiple scattering is produced when a leaf is illuminated partly by direct light from the sky, and partly by light reflection or transmission from neighboring leaves

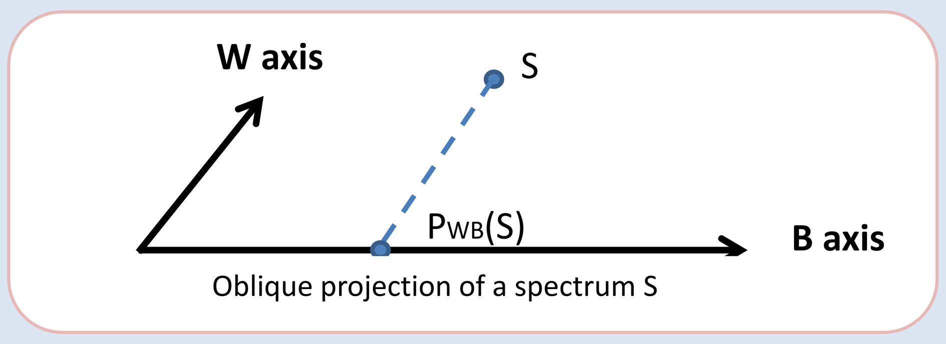
→ Strong non-linear effects on its reflectance spectrum are produced
→ Possible bias in regression results.

Theory of operation

Removing Multiple Scattering by Oblique projection :

An oblique projection matrix following the W direction on B is applied on every spectra.

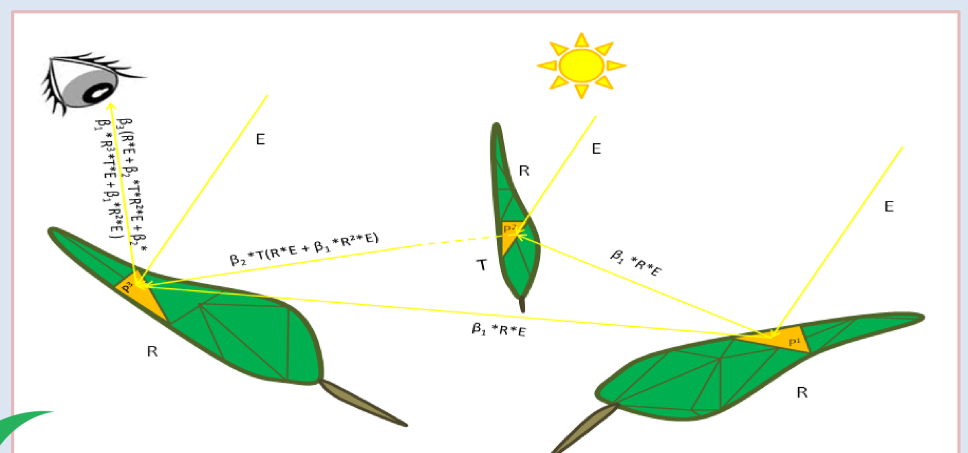
The two subspaces W and B are generated respectively by the scattering effect and the variable of interest (LNC: Leaf Nitrogen Content) in the spectral space.



Determination of B:

B is determined as the total inertia matrix of the loadings obtained by the calibration of the PLS-R on the basic spectra.

Determination of W: *Physical interpretation and formalization of multiple scattering*



Some cases of leaf illumination in its natural environment. E: lighting source radiance. R: leaf reflectance. L: observed radiance. β1, β2, β3 are scalar factors related to leaf inclination.

W is calculated by combining additive terms $R_i^u T_i^v$ generated by the multiple scattering.

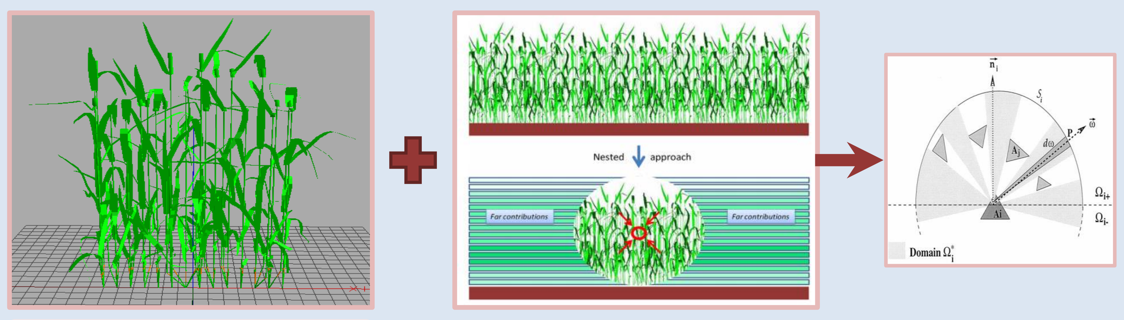
Some parameters must be adjusted: Maximum values of u and v, Maximum dimension of W, etc. → Various combinations of parameters were tested and the best combination was used.

Material and methods:

Method development by simulation

In order to simulate spectra impacted by multiple scattering, a wheat canopy model has been built using simulation models included in the open source software platform Open-Alea:

Adel-Wheat | Caribu



Wheat canopy scene modeled using Adel-Wheat model

Near contributions and far contributions in Caribu simulation scheme.

Reflectance + Transmittance (Same for all leaves) → Adel + Caribu → simulates the apparent reflectance of every visible leaves in the canopy

Method assessment in real conditions:

10 pots of durum wheat were imaged using a hyperspectral camera. For each pot:

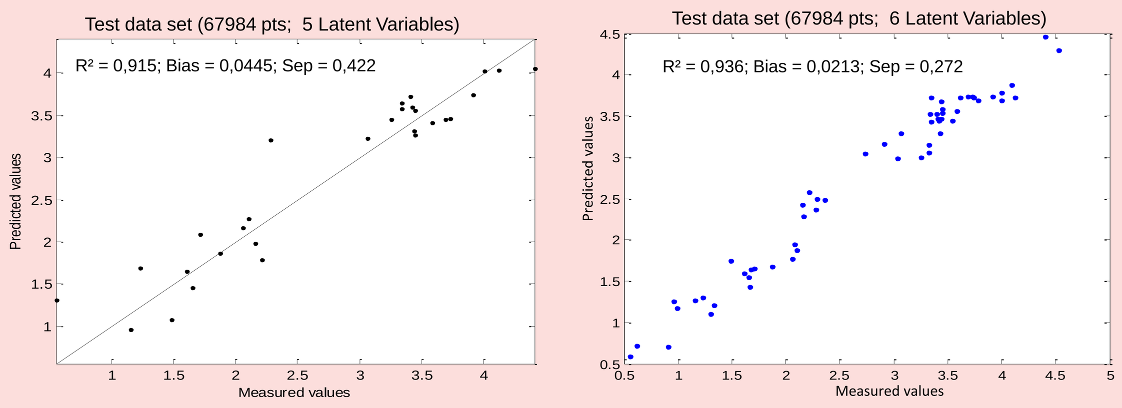
Focal pot surrounded by 6 pots, in order to reproduce as much as possible the conditions of multiple reflections.

Three individual leaves removed from the focal pot and placed on black paper to be imaged without multiple reflections.

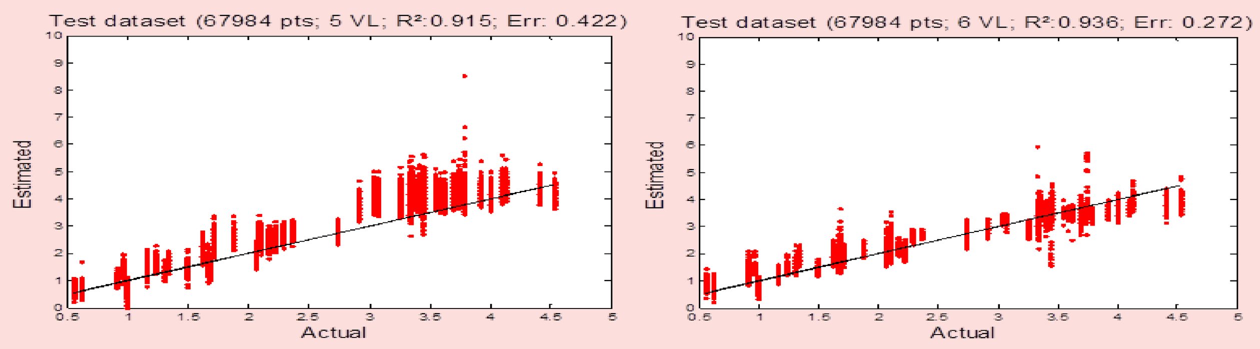
Nitrogen measurement at 4 different points along each leaf, using an ASD field spectrometer reflections.

Simulation Results:

Two PLS-R models were calibrated on the set of basic spectra: Without and with oblique projection



The two models were applied to the simulated spectra issued from Caribu



LNC prediction plots on simulated spectra (%DM).
Left: standard PLS-R model. Right: PLS-R model after oblique projection

The standard error is substantially reduced by this projection (0.272% DM instead of 0.422% DM).

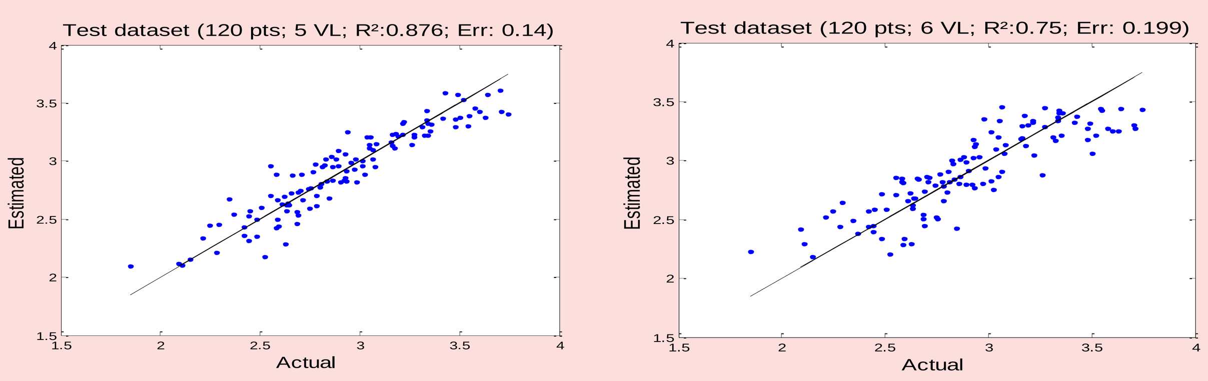
Experimentation Results:

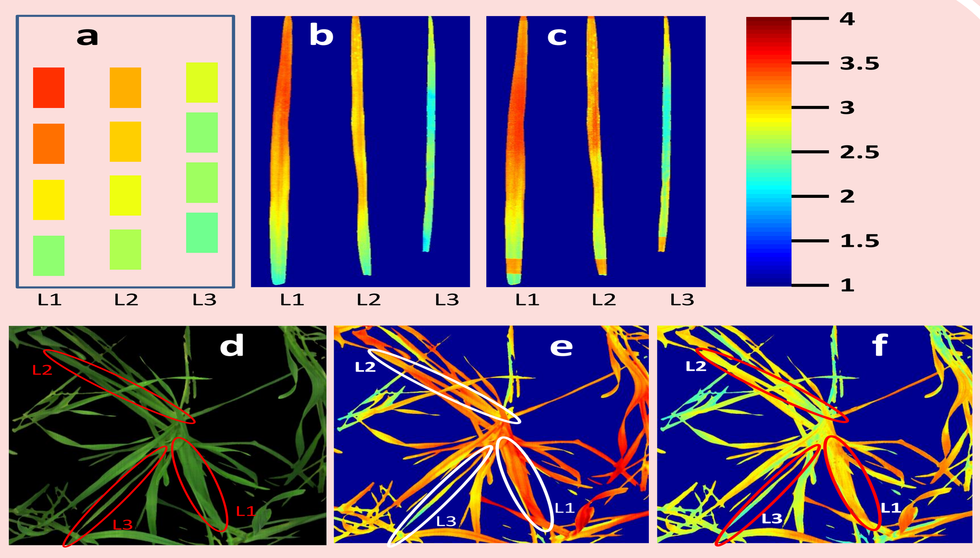
Evaluation of the method in real conditions:

Tests on real plants

According to ASD measurements, a LNC range from about 2 to 3.5 % of dry matter (DM) was obtained from isolated leaves.

Two PLS-R models were built without and with oblique projection, with a cross-validation error below 0.2% DM for both of them.

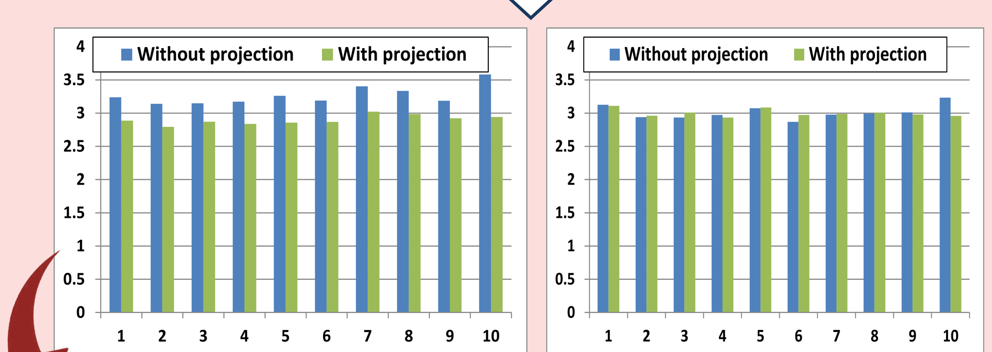




LNC prediction results (%DM) on hyperspectral images at the leaf level.
a: ASD measurement positions and values.
b, c: Prediction on isolated leaves without (b) and with (c) oblique projection.
d, e, f: Prediction on the same leaves before cutting (natural image (d), image processed without (e) and with (f) oblique projection

Both models give nearly the same results on isolated leaves, but very different ones on plant images: PLS-R with no projection seems to generate an over prediction of LNC.

In order to confirm: the ten images combining both pot plants and isolated leaves have been processed with both PLS-R models, and the LNC values have been averaged separately for the two kinds of leaves



A systematic overestimation is obtained with the PLS-R model without projection for standing leaves

Conclusions

A new method has been proposed to overcome the impact of multiple scattering in the processing of hyperspectral images of crop plants by PLS-R :

- **It is based on the physical interpretation and formalization of scattering phenomenon**
- **Very promising results have been obtained on real durum wheat plants,**
- **The considerable impact of plant environment on the prediction of standard PLS-R has been confirmed as well.**

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Reference

AL MAKDESSI N., JEAN, P.-A., ECARNOT, M., GORRETTA, N., RABATEL, G. & ROUMET, P. 2017. *How plant structure impacts the biochemical leaf traits assessment from in-field hyperspectral images: A simulation study based on light propagation modeling in 3D virtual wheat scenes.* Field Crops Research, 205, 95-105.