ESTIMATION OF BIOPHYSICAL VARIABLES BY MODEL INVERSION IN THE FRAME OF PRECISION FARMING: PRELIMINARY RESULTS

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RESUME – La méthode proposée consiste à utiliser des modèles simulant le transfert radiatif dans la feuille et dans le couvert pour estimer gLAI et CHL à partir de mesures de réflectances dans le spectre des courtes longueurs d'onde (420 à 920 nm). L'étude a été réalisée sur un couvert de blé où 6 sites-test correspondaient à 6 états azotés différents. La performance de l'inversion a été évaluée en comparant les estimations de LAI avec des mesures.

***ABSTRACT** – The proposed method consists in using models simulating the radiative transfer within the leaf and within the canopy to estimate gLAI and CHL from hyper-spectral reflectance measurements in the short-wave part of the spectrum (420 to 960 nm). The study was performed on a wheat cover, where 6 test-sites corresponded to crop in 6 different nitrogen status. The performance of the inversion was evaluated by comparing LAI estimations with measurements.*

1 – INTRODUCTION

Existing decision support system could be improved in terms of N fertilizer recommendations by taking into account the spatial and temporal variability in the soil and crop, especially at the within field scale. Remote sensing represents a great opportunity to consider the within field heterogeneity. One of the aspects is the characterization of the spatial heterogeneity in terms of soil and plant characteristics or state variables. In the frame of an experiment devoted to precision farming and more specifically to N fertilization, a methodology to estimate some crop biophysical variables from remote sensing information is proposed. We are especially interested in estimating the green leaf area index (gLAI), which characterizes the crop growth, and the chlorophyll content of the green foliage (CHL), which characterizes the crop nitrogen status. The method consists in estimating these biophysical variables from spectral radiometric measurements, by inverting a radiative transfer model. The methodology was developed at local scale, for 6 levels of nitrogen fertilization, and upscaled at the field scale.

2 – MATERIAL AND METHODS

The study was conducted on a winter wheat field (10 ha). Six test-sites (20 m x 10 m) were supplied with different fertilizer N rates : 0 (P1), 60 (P2), 120 (P3), 180 (P4), 240 (P5) and 300 (P6) kg/ha (Figure 1). The rest of the field (10 ha) received 240 kg N/ha, in 4 applications.

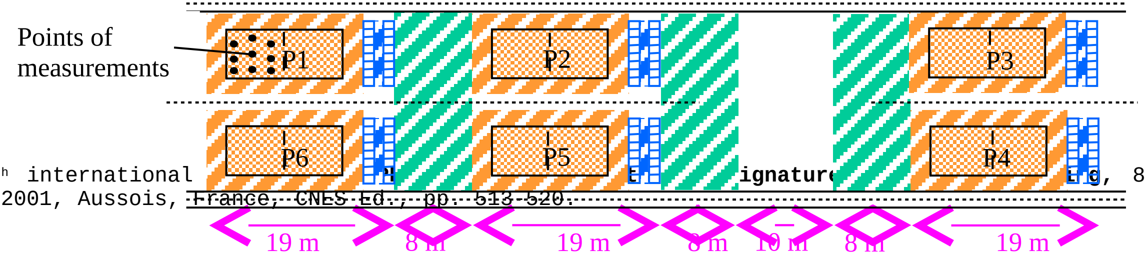

Fig. 1: Description
of the test-sites

2.1 - Measurements

Biological and radiometric measurements were performed both over the test-sites and the whole field. An airborne spectro-radiometer (CASI) was used to measure spectral reflectances of the whole field with a 2 m spatial resolution and a 3 nm spectral resolution, in optical domain (350-1050 nm). A hand-held radiometer (FieldSpec) having the same technical characteristics than the airborne sensor was used to measure ground-based canopy spectral reflectances in the 6 test sites.

Test-sites

Biological measurements used here consisted in leaf chlorophyll obtained from chemical extraction and green leaf area index measured using a surface-meter, those measurements were performed at 7 dates. For each samples, spectral reflectance measurements were performed on 10 upper-leaves with 2 repetitions using FieldSpec device. Those measurements were performed using an halogen source, on fresh leaves. An example is given on Figure 2a, showing that the N stress has a strong impact on the chlorophyll absorption region, on the red-edge position and on the NIR signal level.

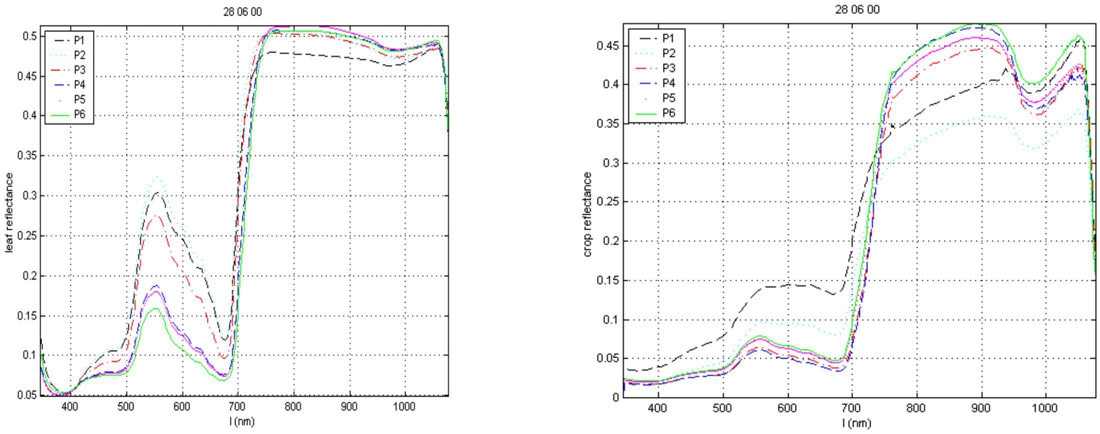

Fig. 2: Hyper-spectral reflectances spectra measured on wheat leaves (a) and crops (b), 28 06 00.

Spectral FieldSpec measurements were also performed in-situ to catch the cover spectral signature at 6 dates. The signal is measured in 512 narrow bands (resolution of 3nm at 700 nm) in the 350-1050 nm range. For each test-site, 9 repetitions were performed on a 6mx6m surface using the following device (Figure 3). To allow a comparison with CASI measurements, equivalent spectral bands were used (32 bands). All the tests were performed using surface averaged spectra.

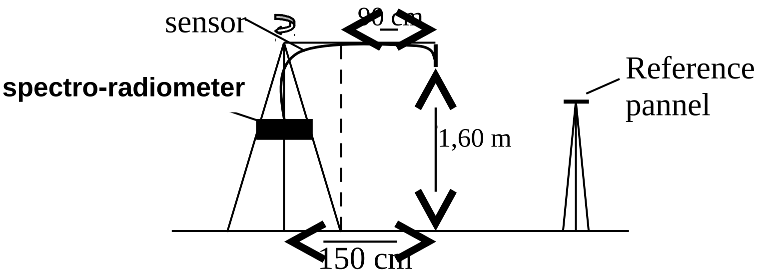

Fig. 3 : Cover spectral reflectance measurement device

We notice, on the example shown on figure 2b, that the N stress influences the signal, however, unlike for the leaf spectra, the response of the cover is also depending on the crop structure.

Field scale

The airborne spectral reflectances were acquired on 4 dates and in 32 bands with a 10nm spectral resolution. Those data were calibrated and corrected for atmospheric effects. After correction, 23 wave-bands were usable. We extracted the spectra corresponding to 22 points spatially distributed over the whole field. For that points, the gLAI was estimated using a LAI 2000.

2.2 – Models Inversion

A canopy radiative transfer model (SAIL, Verhoef, 1984) was coupled to a within-leaf radiative transfer model (PROSPECT, Jacquemoud, 1990) to retrieve gLAI and CHL from spectral reflectances. The SAIL model predicts the cover spectral reflectances. The input parameters are leaf area index, mean leaf inclination Tetal (default value : 56°), hot spot parameter (default value : 0.01), the sun and view geometry, the diffuse fraction of solar radiation (default value : 20%), the spectral soil reflectance parameterized versus measured surface soil moisture, and spectral leaf reflectances and transmittances as predicted by the PROSPECT model. The PROSPECT model input parameters are the leaf thickness N (default value : 1.4), pigment concentrations (chlorophyll CHL, carotenoide Car, brown pigment Cpb), the water content (default value : 0.014 $g.cm^{-2}$), the spectral refraction index and pigment absorption coefficients (F. Baret, personal communication).
In the model, chlorophyll and carotenoïde concentrations are described by a single variable and a single absorption coefficient. Since we were interested in chlorophyll concentration, we computed a relation allowing the estimation of carotenoid versus chlorophyll content using the destructive measurements performed on the test-sites (29 configurations). We obtained the following relation :

$$CHL + Car = 1.3024\ CHL.$$

For each test site, the SAIL/PROSPECT coupled models were used through an inversion procedure to estimate the unknown model input parameters as well as the variables of interest, from leaf and cover reflectance measurements (FieldSpec sensor). The approach was utilized on the 22 points-grid using CASI data. The optimization was performed by minimizing the difference between observed and simulated radiometric signal on a relative root mean square criteria.

3 – ADJUSTMENT OF THE RADIATIVE TRANSFER MODELS PARAMETERS

The tests presented in this section were performed for 4 dates corresponding to 20 configurations. For those configurations, both destructive measurements, FieldSpec fresh leaves measurements, and FieldSpec in-situ cover measurements were available. However, due to unstable illumination conditions, the radiometric data acquired *in-situ* on DoY 116 are not reliable.

3.1 – Adjustment of PROSPECT model parameter

The following test consisted in estimating the capability to adjust PROSPECT model parameters from FieldSpec leaf spectral reflectance measurements. The measured chlorophyll content was used as PROSPECT input. Default values were used for other parameters, except for N and Cpb that were adjusted. The results of the adjustment are presented in Table 1.

Day of Year	Test-site number	N	Cpb	Residual rmse	Day of Year	Test-site number	N	Cpb	Residual rmse
116.	1.	1.57	0.0102	0.0607	154.	3.	1.27	0.2592	0.1290
116.	2.	1.45	0.0107	0.0601	154.	4.	1.41	0.2006	0.1035
116.	3.	1.44	0	0.0593	154.	5.	1.39	0.2712	0.1185
116.	6.	1.89	0.2908	0.1104	154.	6.	1.51	0.1820	0.0799
127.	1.	1.54	0.2161	0.0994	180.	1.	1.44	0.3207	0.1248
127.	2.	1.57	0.0610	0.0657	180.	2.	1.51	0.4222	0.1602

127.	3.	1.62	0.1821	0.0800
127.	6.	1.72	0.2332	0.0811
154.	1.	1.18	0.1966	0.1360
154.	2.	1.18	0.2714	0.1435
180.	3.	1.44	0.3595	0.1370
180.	4.	2.16	0.4214	0.0956
180.	5.	2.15	0.4834	0.0889
180.	6.	1.80	0.6542	0.0993

Table 1: Results of N and Cpb adjustment using FieldSpec fresh leaf measurements.

We notice that the residual error is about 10% and generally smaller for the 2 first dates. The Cp values looks consistent : concentration is increasing with the age of the plant, whereas the thickness of the leaves appears to be quite invariant.

3.2 – Adjustment of SAIL/PROSPECT model parameters

Test-sites scale

The test presented here consists in adjusting the main unknown input parameters and variables of the coupled PROSPECT/SAIL model using FieldSpec *in-situ* cover measurements. In this case, both parameters (N, Cpb, Tetal) and interest variables (gLAI, CHL) were adjusted. The idea was to evaluate whether if reflectance measurements in 32 bands allows to estimate biophysical variables when no other information is available. Other parameters were set to default values. The results of the adjustment are presented in Table 2.

Day of Year	Test-site number	N	Cpb	Cos(tetal)	gLAI	CHL	Residual rmse
127.	1.	1.6286	0.1010	0.2798	1.4052	0.3892	0.0321
127.	2.	1.6723	0	0.2441	3.0634	0.4998	0.0735
127.	3.	1.1836	0	0.2511	6.8537	0.5473	0.0814
127.	6.	0.5242	0.0000	0.3381	6.0305	0.7465	0.1221
154.	1.	1.5064	0.1948	0.3981	1.5938	0.3376	0.0374
154.	2.	1.8694	0.1235	0.3863	2.0825	0.5343	0.0476
154.	3.	2.2017	0	0.4118	3.8236	0.8000	0.0690
154.	4.	2.0730	0	0.3946	3.8050	0.7587	0.0546
154.	5.	1.5039	0.0485	0.3886	3.8728	0.5922	0.0500
154.	6.	2.0631	0	0.4116	3.1986	0.7287	0.0620
180.	1.	1.8668	0.7414	0.9895	1.0897	0.0669	0.0571
180.	2.	2.1410	0.7894	0.8219	0.9805	0.2058	0.0965
180.	3.	2.9574	0.0924	0.4911	1.7908	0.8000	0.0634
180.	4.	1.9661	0.4969	1.0000	1.3166	0.8000	0.1049
180.	5.	2.3804	0.5241	1.0000	1.1362	0.7574	0.0705
180.	6.	2.9710	0.2734	0.8150	1.0965	0.8000	0.0566

Table 1: Results of SAIL/PROSPECT parameters adjustment using FieldSpec in-situ measurements.

Due to acquisition conditions, results obtained for DoY 116 are not presented here. We notice that the results obtained for DoY 180 correspond to unrealistic mean leaf angles. If we consider the adjustment obtained for the 10 first configurations, the mean residual rmse is about 6% when adjusting 5 parameters.

Field scale

A last test of inversion consisted in using CASI spectra extracted from the 4 images to adjust the SAIL/PROSPECT parameters. The spectra used for the inversion were surface reflectances. The rmse obtained is very variable depending on the point and on the flight considered. One specific problem was to evaluate the reliability of the surface reflectance data. Indeed, on the test-sites, we found a big discrepancy between measurements acquired with FiedSpec and CASI. Depending on the flight considered, the dynamics or the level of the signals of the 2 sensors appear to be different.

4- ESTIMATION OF BIOPHYSICAL VARIABLES

To evaluate the performance of the model inversion, estimated and measured biophysical variables were compared.

4.1 – Test-sites scale

At the test-sites scale, the gLAI and CHL observed values are provided by destructive measurements. The result obtained for chlorophyll content estimation was very poor (correlation coefficient = 0.5). Estimated versus measured gLAI are plotted on Figure 4. The correlation coefficient is about 0.75.

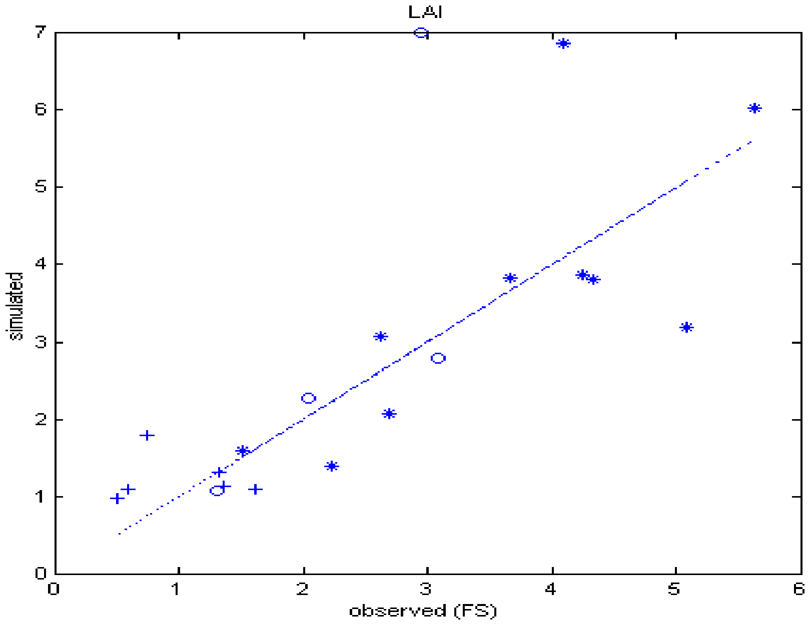

Figure 4 : Estimates versus measured gLAI on the test-sites: Date 116 (o), dates 127 and 154 (*) and date 180 (+).

4.2 – Field scale

On the 22 grid points, the LAI measured with LAI2000 was compared with the inversion results (Figure 5).

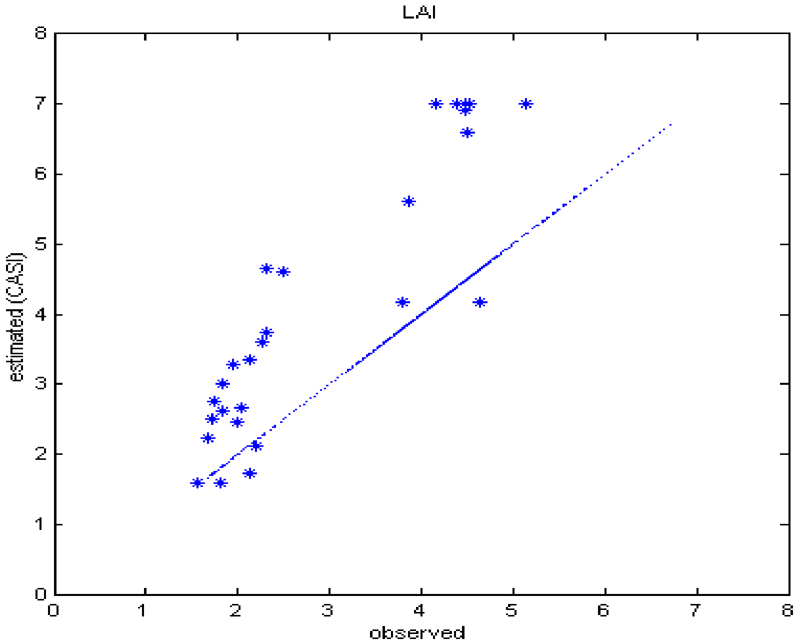

Figure 5 : Estimates versus measured gLAI on the 22 grid points (for 2 dates)

The correlation coefficient is about 0.9, however, we notice a bias in the estimation.

4 – CONCLUSION

This study consisted in evaluating the ability to retrieve biophysical variables from remote sensing signal in the frame of a precision farming program.

Leaf and cover radiative transfer models simulated reflectances. Those predictions were combined with hyper-spectral measurements acquired with a hand-held and an airborne radiometers in order to estimate biophysical variables.

The work was conducted in two steps. The first step consisted in using the radiometric signal to invert radiative transfer model parameters. A first test was performed using fresh leaves reflectance hyper-spectral measurements to estimate PROPECT parameters. A second one consisted in estimating the SAIL/PROSPECT input with *in-situ* reflectance measurements performed on the test-sites. The third test was the estimation of model parameters using an airborne spectro-radiometer for 22 pixels scattered on the whole field.

In the second step, the performance of the inversion was evaluated in terms of gLAI prediction. We compared the LAI estimations with measurements. On the test sites, the measurement came from destructive data, whereas at field scale we used LAI2000 measurements.

This study is a preliminary step towards the estimation of biophysical variable at field scale. The inversion could be performed for every pixel of the field, provided that the remote sensing data are reliable enough. In particular, the consistency between the ground based reflectances and the airborne reflectances has to be analyzed. This points out the importance of the calibration and of atmospheric corrections when using airborne data.

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