ASSESSING THE WITHIN FIELD SPATIAL VARIABILITY OF CROP GROWTH STATUS BY REMOTE SENSING FOR SITE SPECIFIC N FERTILIZATION MANAGEMENT

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ABSTRACT

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. 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. The study was performed on a wheat field, 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

In the frame of an experiment devoted to precision farming and more specifically to the definition of a site specific N application strategy (see Guérif *et al*., same issue), a methodology to estimate pertinent crop biophysical variables from remote sensing information is proposed (from Moulin *et al*, 2001). The originality of the approach consists in estimating the biophysical variables by taking into account their spatial variability into a field. 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 (N) nutrition status.

The method consists in estimating these biophysical variables from spectral radiometric measurements in the short-wave part of the spectrum, 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. The study was conducted on a winter wheat field. On the test-sites, LAI, CHL and N status were estimated using both destructive and non-destructive methods, allowing the calibration of nondestructive methods. A hand-held spectro-radiometer was used to characterize the radiometric response of leaves, soil and crop cover. Those measurements allowed a crop-specific calibration of both the leaf and canopy radiative transfer models. Thanks to the airborne radiometer, the spectral response of the whole field was available, with a 2m spatial resolution. Those data were used to upscale the inversion method at the field level taking into account the within field spatial variability. The output consists in a mapping of gLAI and CHL. The gLAI and CHL estimations were therefore compared to the non-destructive measurements of CHL and LAI performed on 22 points spatially distributed on a grid covering the whole field.

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2 – MATERIAL AND METHODS

The field (10 ha) received 240 kg N/ha, in 4 applications. Six test-sites (20 m x 10 m) were supplied with different N fertilizer rates : from 0 (test-site P1) to 300 kg/ha (test-site P6) with an increment of 60kg/ha (Fig.1).

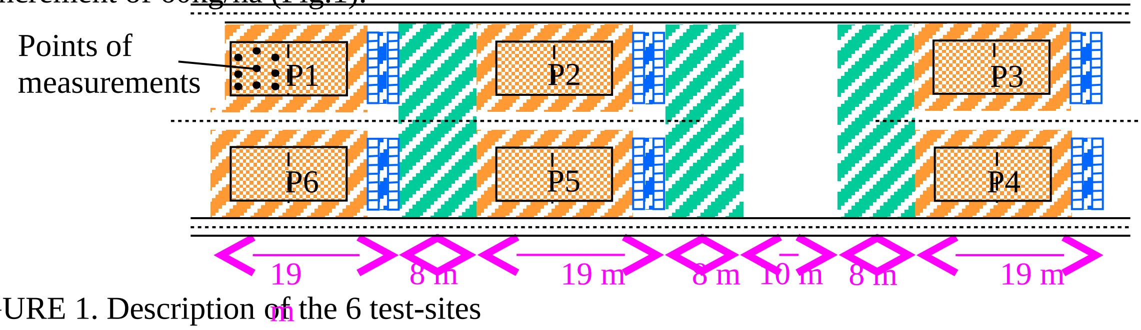

FIGURE 1. Description of the 6 test-sites

2.1 - Measurements

In order to characterize the crop, biological and radiometric measurements were performed both over the test-sites and the whole field. On the test-sites, a hand-held radiometer (FieldSpec) was used to measure ground-based canopy spectral reflectances, aswell as leaf optical properties. The signal was acquired in 512 narrow bands (resolution of 3nm at 700 nm) in the 350-1050 nm range. An airborne spectro-radiometer (CASI), having the same spectral characteristics than the ground-based sensor, was used to measure spectral reflectances of the whole field with a 2 m spatial resolution.

Test-sites

Biological measurements were performed at 7 dates and consisted in green leaf area index (Fig. 2a) measured using a surface-meter and leaf chlorophyll content (Fig. 2b) obtained from chemical extraction.

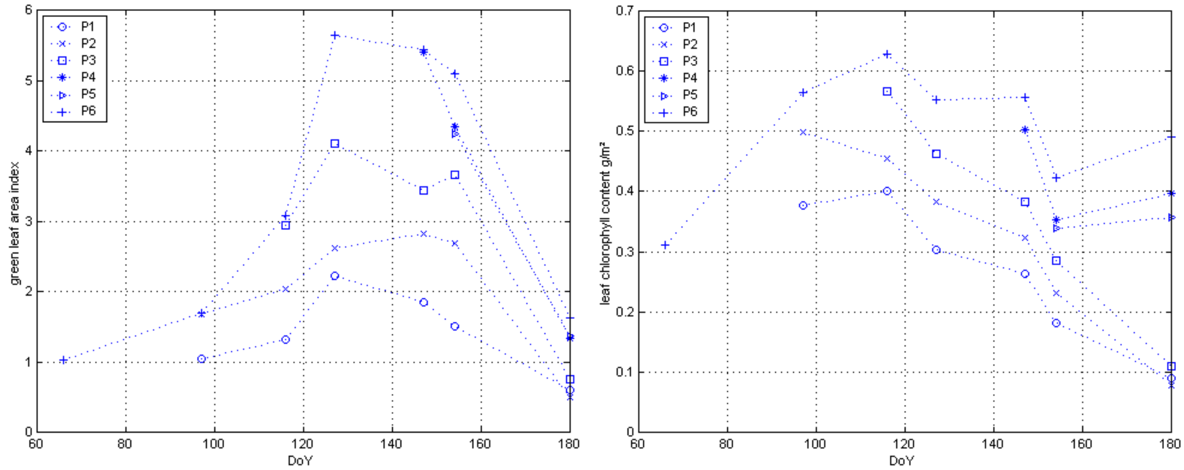

FIGURE 2. (a) Green leaf are index and (b) leaf chlorophyll content, for the 6 test-sites.

In order to characterize the leaf optical properties, we performed spectral reflectance measurements, using FieldSpec device and an halogen source. Measurements were acquired on fresh leaves corresponding to 10 upper-leaves of each vegetation sample. The example presented on Figure 3a, shows the impact of the N stress on the chlorophyll absorption peak, the red-edge position and the NIR signal level.

In-situ radiometric measurements were also performed to catch the cover spectral signature at 6 dates. For each test-site, 9 repetitions were performed on a target of 6mx6m large, using the FieldSpec device as presented on Figure 4a.

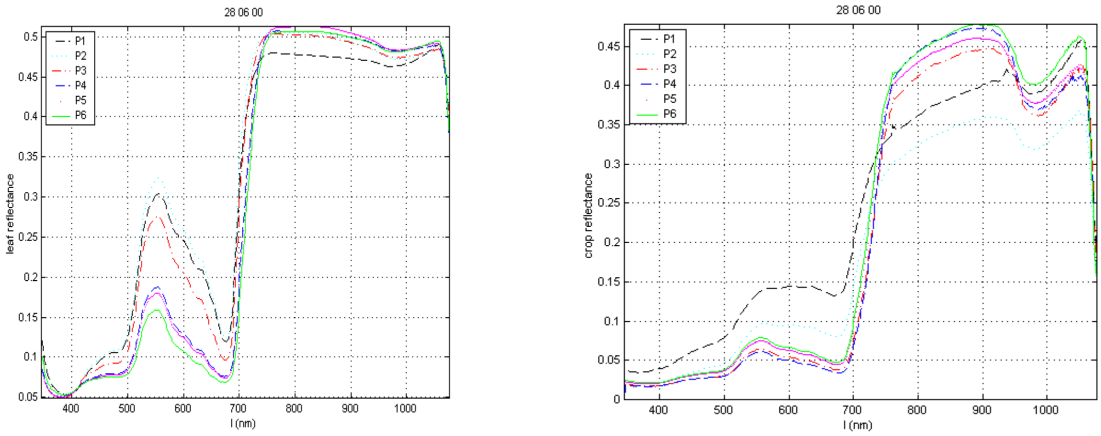

FIGURE 3. Hyper-spectral reflectances spectra measured on wheat leaves (a) and crops (b), 28 06 00.

As shown through the example of Figure 3b, the N stress influences the radiometric signal, however, unlike for the leaf spectra, the response of the cover is also depending on the crop structure.

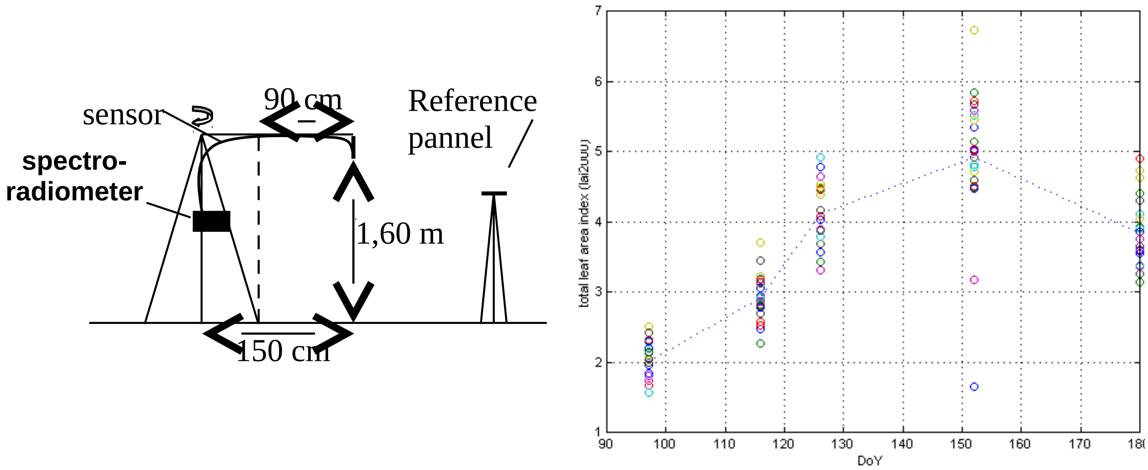

FIGURE 4. (a) Cover spectral reflectance measurement device, (b) LAI2000 measurements on the 22 points grid.

Field scale

The airborne spectro-radiometer CASI gave 4 field images (from April to June) acquired in 32 bands with a 10nm spectral resolution. The airborne reflectances were calibrated and corrected for atmospheric effects. After this process, surface reflectances were available in 23 wave-bands. In order to test the inversion algorithm, the spectra corresponding to 22 points spatially distributed over the whole field were extracted. The results of the inversion was compared to total LAI measurements performed on the 22 points using a LAI 2000 (Fig. 4b).

2.2 – <u>Models Inversion</u>

SAIL (Verhoef, 1984) canopy radiative transfer model coupled to PROSPECT within-leaf radiative transfer model (Jacquemoud, 1990) allow the estimation of gLAI and CHL from spectral reflectances. In PROSPECT, 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. Finally, the contribution of the brown pigments was added to the original PROSPECT version in the absorption coefficient computation.

SAIL input parameters are the leaf area index, the 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. PROSPECT 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).

The inversion of the SAIL/PROSPECT coupled models was performed from leaf and cover reflectance measurements, to estimate the unknown model input parameters as well as the variables of interest, on the 6 test-sites and on the 22 grid points. The optimization was performed by minimizing the difference between observed and simulated radiometric signals, on a relative root mean square error criteria.

3 – ADJUSTMENT OF THE RADIATIVE TRANSFER MODELS PARAMETERS

The adjustment of the radiative transfer models parameters was obtained through the inversion technique. The tests presented in this section were performed for 4 data acquisition dates corresponding to 20 soil/crop configurations. For those configurations, destructive measurements, fresh leaves reflectance measurements, and *in-situ* canopy reflectance measurements were available. All the tests were performed using target averaged surface spectra.

3.1 – Adjustment of PROSPECT model parameter

Here we tested the ability to adjust PROSPECT model parameters using leaf spectral reflectance measurements (acquired with FieldSpec). The measured chlorophyll content was used as PROSPECT input and 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
116.	1.	1.57	0.0102	0.0607
116.	2.	1.45	0.0107	0.0601
116.	3.	1.44	0	0.0593
116.	6.	1.89	0.2908	0.1104
127.	1.	1.54	0.2161	0.0994
127.	2.	1.57	0.0610	0.0657
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

Day of Year	Test-site number	N	Cpb	Residual rmse
154.	3.	1.27	0.2592	0.1290
154.	4.	1.41	0.2006	0.1035
154.	5.	1.39	0.2712	0.1185
154.	6.	1.51	0.1820	0.0799
180.	1.	1.44	0.3207	0.1248
180.	2.	1.51	0.4222	0.1602
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.

The mean residual error is about 10% and generally smaller for the 2 first dates. The Cp values look 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 idea here was to evaluate whether if canopy reflectance measurements in 23 bands allow to estimate biophysical variables when no other information is available. So the performed test 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. 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 2. Results of SAIL/PROSPECT parameters adjustment using FieldSpec *in-situ* measurements.

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

Field scale

Finally, we were interested in testing our ability to retrieve biophysical variables from airborne measurements. So a last test of inversion consisted in using CASI spectra extracted from the 4 images to adjust the SAIL/PROSPECT parameters. Surface reflectances spectra were used. The quality of the results, in terms of rmse, 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, a big discrepancy between measurements acquired with FiedSpec and CASI was found. Depending on the flight considered, the dynamics or the level of the 2 sensor signals appear to be different.

4- ESTIMATION OF BIOPHYSICAL VARIABLES

Using the adjusted parameters as model inputs, the performance of the model inversion was evaluated by comparing the estimated and measured biophysical variables.

4.1 – <u>Test-sites scale</u>

For the 6 test-sites, the estimated gLAI and CHL were compared with biophysical variables obtained from 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.

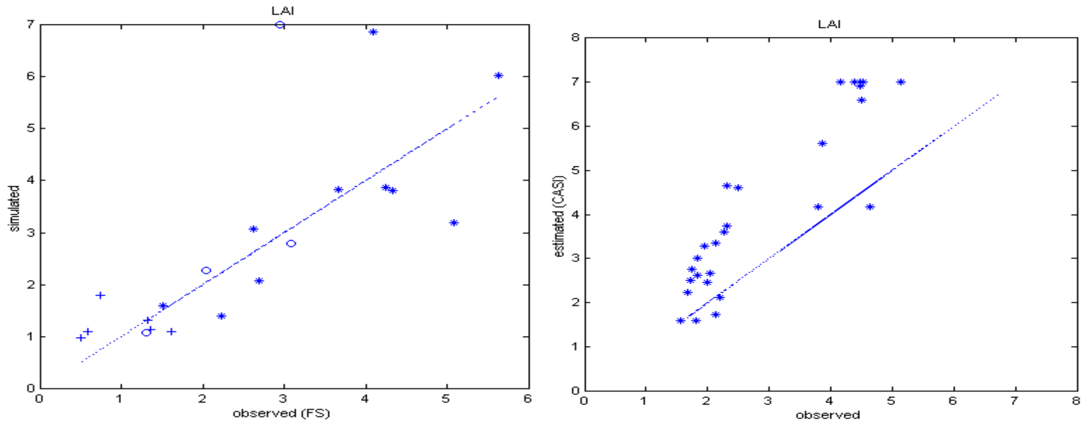

FIGURE 5. (a) Estimates versus measured gLAI on the test-sites: Date 116 (o), dates 127 and 154 (*) and date 180 (+). (b) gLAI estimates versus measured LAI on the 22 grid points (for 2 dates) [from Moulin *et al*, 2001].

4.2 – <u>Field scale</u>

At that scale, no destructive measurements were available, however, a LAI2000 device gave an estimation of the total LAI. The ground measured LAI was compared with the inversion results (Fig. 5b). The correlation coefficient is about 0.9, despite a bias in the estimation.

4 – CONCLUSION

In the frame of a precision farming program, this study consisted in evaluating the ability to retrieve biophysical variables from remote sensing signal. Two coupled leaf and canopy radiative transfer models simulated spectral 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 spectral radiometric signal to adjust the radiative transfer model parameters and estimate the biophysical variables though an inversion technique. We successively used leaves spectral reflectances, ground based canopy reflectances and airborne canopy reflectances to estimate PROSPECT and SAIL parameters and variables. Those tests were performed on the test-sites and on the 22 grid points. In the second step, the performance of the inversion was evaluated in terms of gLAI prediction. We compared the LAI estimations with measurements.

This work is a preliminary step towards the estimation of biophysical variables at field scale. In theory, 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. However, remote sensing appears as an interesting tool for estimating the field heterogeneity of crop growth status and therefore making diagnosis (see Houlès et al in the same issue) and decision for variable N application rate.

REFERENCES

Guérif M., N. Beaudoin, C. Durr, J.M. Machet, B. Mary, D. Michot, S. Moulin, B. Nicoullaud, G.Richard, Designing a field experiment for assessing soil and crop spatial variability and defining site specific management strategies. **Third European Conference on Precision Farming,** 18-20 June 2001 – Montpellier, France, *abstract*.

Houlès V., Guérif M., Mary B., Machet JM and S. Moulin, Do crop characteristics available from remote sensing allow to determine crop nitrogen status?, ***Third European Conference on Precision Farming,*** 18-20 June 2001 – Montpellier, France, *abstract*.

Jacquemoud, S., and Baret, F., 1990, PROSPECT: a model of leaf optical properties spectra, *Remote Sens. Environ*., 34:75-91.

Moulin, S., Guérif, M., Baret, F., and Machet J.M., 2001, Estimation of biophysical variables by model inversion in the frame of precision farming, *8th international congress on* ***Physical measurements and signatures in remote sensing,*** 8-12 janvier 2001, Aussois, France, CNES Ed., pp. 513-520.

Verhoef, W., 1984: Light scattering by leaf layers with application to canopy reflectance modeling: The SAIL model. *Remote Sens. Environ*., 16, 125-141.

2001, **Third European Conference on Precision Farming,** 18-20 June 2001 – Montpellier, France, (non publié).