Preliminary pigment retrieval results from a sparse-canopy poplar plantation in northern Italy using hyperspectral data

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ABSTRACT - *Successful retrieval of leaf pigment content in closed forest canopies is only recently being reported. Nevertheless, forestry continues to pose significant challenges to quantitative biochemical variable retrieval due to problems associated with the structural complexity in common open canopies, conifer canopies or sparse canopies. This research was focused on a poplar plantation in the northern Italy where hyperspectral data were acquired in summer 2001 by different airborne hyperspectral sensors: DAIS (Digital Airborne Imaging Spectrometer) and ROSIS (Reflective Optics System Imaging Spectrometer). The approach investigated for the prediction of chlorophyll content from the airborne hyperspectral data is the numerical inversion of coupled canopy and leaf reflectance models. The ecological properties of the poplar plantation, characterised by low LAI values, open and sparse canopy and an accompanying presence of a thick layer of understory vegetation, represented a challenging issue to the application of simple canopy modelling for interpretation. In this study we have evaluated the influence of understory vegetation on biochemical constituent estimation by inversion of a red edge slope optical index through a comparison of the overstory leaf pigment retrieval results from a poplar stand area in which understory was harvested, before the sensor overpass, relative to the non-tilled part of the poplar stand.*

1.0 INTRODUCTION

The spatial distribution of leaf pigments in forest ecosystems is useful information for vegetation monitoring. In fact, canopy chlorophyll concentration is considered a bio-indicator of forest health status providing guidelines for natural forest and agro-forestry ecosystems management (Mohammed *et al.*, 1997).

Leaf pigment estimation from hyperspectral images through numerical inversion of coupled leaf canopy radiative transfer modelling has been studied (Demarez *et al.*, 2000) and recently demonstrated successfully in forests (Zarco-Tejada *et al*., 2001a). In particular, inversion based on narrow-band vegetation indices (VI) has shown promising results both in forestry and agricultural applications (Dawson, 2000, Zarco-Tejada, 2001a , Haboudane, 2001, Haboudane, 2002).

This paper investigates leaf pigment retrieval in a poplar plantation characterised by structural complexity: sparse, open and thin canopy and an accompanying presence of dense vegetated background. The influence of vegetated understory on chlorophyll (a+b) estimation has been evaluated through an experiment conducted in two poplar stands in which understory was partially harvested, before the sensor overpass. The approach used was scaling up and the numerical inversion of models coupled PROSPECT (Jacquemoud, 1990, Jacquemoud, 1993) and SAILH (Verhoef, 1984, Kuusk, 1991) using a simple ratio vegetation (VI) as a merit function to investigate its performance in minimising effects like shadows, resulting from the complex structure of the plantation canopy. Results from the tilled understory area relative to the non-tilled area were compared

2.0 STUDY AREA

The study area is a poplar (*populus nigra*) plantation located north-west of Pavia in Lombardia region, Italy; it is a CARBOEUROFLUX investigation site managed by the Joint Research Centre (J.R.C.) at Ispra, Italy. The poplar plantation (*Kyoto forest or fast growing forest*) is composed of hybrid poplar trees planted in rows 6 meters apart, in order to maximise the plant growth. This plantation scheme defines an open and sparse canopy situation in juvenile or stressed stands.

3.0 DATA COLLECTION

3.1 AIRBORNE DATA

Hyperspectral images were acquired on July 2001 by DLR (German Aerospace Centre) with the ROSIS (*Reflective Optics System Imaging Spectrometer*) sensor, in the frame of the DARFEM (DAIS and ROSIS for Forest Ecosystem Monitoring) experiment (Brivio *et al.,* 2001). ROSIS images were collected in the principal plane in 115 channels, ranging from 430nm to 850nm (FWHM=7.5nm) and a spatial resolution of about 1m*1m. The processing of the remotely sensed data, including atmospheric and geometric corrections, were performed by the *Imaging Spectroscopy Team* of the DLR centre.

3.2 FIELD DATA AND TEST AREA

The ecological and forestry properties of the study area were characterised, in order to evaluate the variability of the poplar stands, by aerial photo interpretation and forestry measurements: tree height, diameter and crown radius. Additional SPAD 502 *Chlorophyll Meter* (Minolta, Osaka - Japan) measurements were conducted to define plots characterised by homogeneous health *status*, represented by similar leaf pigment content. Four different stands were defined and five leaves for each plot were sampled from the top of poplar tree crowns for laboratory analysis (leaf radiometric measurements and pigment extraction).

Ground measurements included: (i) optical depth for atmospheric corrections using a MS-120 Eko sunphotometer, (ii) LAI measurements of overstory and understory, using the Li-Cor plant canopy analyser LAI-2000, (iii) understory optical reflectance characterisation using a Fieldspec FR^{TM} spectrometer, (iv) leaf reflectance and transmittance measurements using an integrating sphere (Li-Cor 1800-12S) coupled to the Fieldspec FR^{TM}. Leaf samples were stored in plastic bags and kept frozen for the biochemistry analysis: leaf chlorophyll-a and -b content was extracted in the laboratory by the Ontario Forestry Research Institute (OFRI, Sault St. Marie, Canada) team.

Two test areas (test site A and test site B) were selected from different homogeneous stands to evaluate the influence of different understory typology on sensor reflectance. For this purpose, in each test site a 24m*24m area was tilled before the sensor overpass. Stands properties are shown in Table 1.

TEST SITE	***LAIo*** *(m2/m2)*	***LAIu*** *(m2/m2)*	***Fco*** *(%)*	***Fcu*** *(%)*	***Cd*** *(m)*
A	2.33	2.88	90	99	3.94
B	1.50	2.57	60	97	2.95

Table 1 - Test site ecological characteristics (LAIo and LAIu = LAI overstory and understory, fco and fcu= fractional cover overstory and understory, Cd = crown diameter).

4.0 ANALYSIS

4.1 RED EDGE INDICES INVESTIGATION

Recent research in pigment retrieval at canopy level has shown promising results through scaling up techniques and numerical inversion of physically-based coupled leaf and canopy radiative transfer models. Simple turbid-medium canopy models like SAILH have been successfully applied in closed canopy forests (with LAI>3) minimising the effects of canopy structure, in particular effects of shadows, by using a simple ratio vegetation index defining the red edge slope in the inversion procedure (Zarco-Tejada, 2001a).

In contrast, the poplar plantation study area in this experiment is characterised by an open and sparse canopy structure in addition to low LAI values (LAI<3) and the presence of dense vegetated background. Variation in spectral signatures between visible and NIR wavelengths, observed in test areas A and B associated with tilled and non-tilled crowns pixels (Fig.1, Fig.2), demonstrate the understory contribution on canopy reflectance.

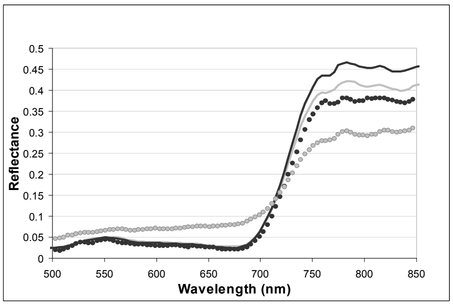

Fig. 1 - ROSIS poplar crown spectra extracted from tilled (black full line) and non tilled (grey full line) test area A and relative background spectra (dotted lines).

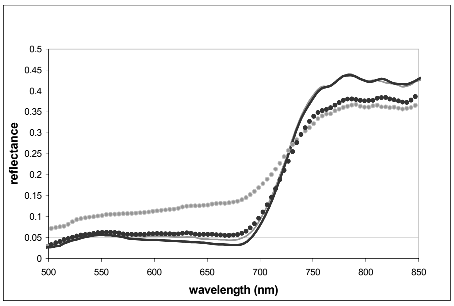

Fig. 2 - ROSIS poplar crown spectra extracted from tilled (black full line) and non tilled (grey full line) test area B and relative background spectra (dotted lines).

Red edge indices, in particular the ratio (R_{740}/R_{720}) relatively unresponsive to shadows (Zarco-Tejada *et al,* 2001), were investigated with respect to its dependency on background optical properties. With this goal, two profiles were defined on ROSIS imagery across tilled and non-tilled test areas A and B. Ratio (R_{740}/R_{720}) variations were observed between crown pixels in tilled and non tilled areas (Fig.2). Therefore, we expect that pigment retrievals using the R_{740}/R_{720}) ratio as a merit function will be also be affected if nominal background spectra are used in the inversion procedure.

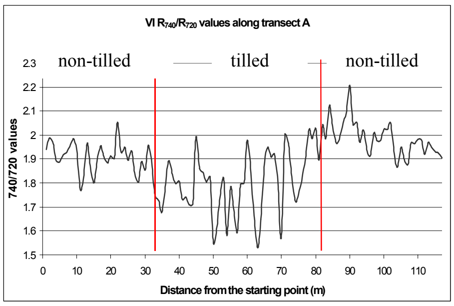

Fig. 3 - Ratio R_{740}/R_{720} values along profile A.

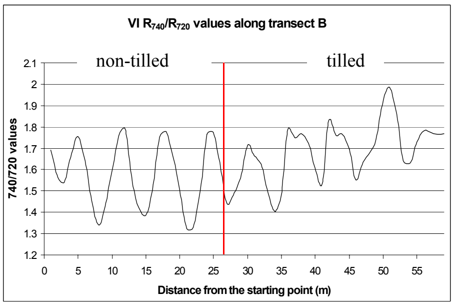

Fig. 4 - Ratio R_{740}/R_{720} values along profile B.

4.2 LEAF AND CANOPY REFLECTANCE SIMULATION

Relationships between chlorophyll (a+b) and the ratio $R_{740}/R_{720,}$ derived from canopy reflectance simulated through PROSPECT and SAILH (PROSAILH), were used to estimate pigment content along the two profiles A and B for varying LAI values.

Leaf biochemical input parameters were assigned average nominal values estimated by PROSPECT inversion on reflectance and transmittance spectra of poplar leaves sampled in the study area (N =1.35, Cw = 0.009 cm, Cm = 0.006 g/cm^2). The hotspot and Mean Tilt Angle (MTA), were assigned nominal values, an average of the available field measurements (hotspot = 0.05, MTA = 45°). Spectra were simulated for various LAI (test area A - LAI range: 2.2 - 3.8; test area B - LAI range: 1.4 - 3.0 with a step increment of 0.4), and leaf chlorophyll content ranging from 10 μg/cm^2 to 55 μg/cm^2 with an increasing step of 5 μg/cm^2. Finally, local understory spectra, measured in the field by a Fieldspec FR spectrometer, were used in simulations to reproduce canopy reflectance properties of test areas A and B in natural ecological condition (non-tilled).

It is observed that chlorophyll retrieved along Profile B strongly depends on LAI for low values (LAI<2.6), therefore precluding the simple use of nominal values in the PROSAILH numerical inversion procedure in presence of thin canopy. Moreover, influence of understory optical properties are evident along the profile: chlorophyll estimated tend to decrease in correspondence to the tilled area compared to the non-tilled area. The chlorophyll trend estimated along Profile A shows that dense vegetated understory influences the pigment retrievals even for higher LAI values and more closed canopy.

4.3 UNDERSTORY INFLUENCE

Pigment retrieval through numerical inversion of the PROSAILH model was attempted in order to quantify the understory influence on overstory pigment estimation when LAI is low. High resolution ROSIS data allowed separation of the problem concerned with low LAI values from complexity associated to sparse canopy structure, since it was possible to target crown pixels in ROSIS imagery.
In particular, spectra were extracted from nine crowns, four pixels each, defined in test areas A and B. The experiment hypothesis was that overstory poplars from tilled and non-tilled area have same biophysical characteristics, therefore differences in pigment retrievals are a response to local understory influence.

Leaf biochemical parameters, canopy structure parameters and sensor-target geometry, previously used in the direct simulations, were assigned nominal values in the inversion procedure. LAI poplar crown were calculated, taking into account the relative overstory Fc of the two test areas (Table 2), from local LAI values estimated by numerical inversion of PROSAILH model on multi-angular DAIS (Digital Airborne Imaging Spectrometer) observations (Meroni *et al.*, 2002).

TEST SITE	***LAI**** *(m2/m2)*	***Fco*** *(%)*	***LAIc*** *(m2/m2)*
A	2.45	90	2.7
B	1.2	60	1.8

Table 2 - LAI*= LAI retrieved from DAIS, Fc= fractional cover, LAIc = calculated crown LAI.

Inversion results using a nominal soil spectra for tilled and non-tilled area are compared with results obtained using local understory optical information (Table 3).

Chlorophyll values retrieved from poplar crowns in tilled and non-tilled areas show an average difference of 6.2 μg/cm^2 when a nominal background is used in the inversion procedure, while no significant differences are observed when local background optical properties are used.

TEST PLOT		**Average Cab Values (ug/cm^2)**			
		Nominal background		Known local background	
		Mean	*Std*	*Mean*	*Std*
A	Tilled	39.0	3.16	39.0	3.16
	Non-tilled	45.2	2.12	39.6	1.94
B	Tilled	35.4	3.67	35.4	3.67
	Non-tilled	41.7	3.68	36.0	3.23

Table 3 - Pigment retrieval in test areas A and B using nominal soil background spectra and local background spectra in the inversion procedure.

4.0 COARSER RESOLUTION RESULTS

Implications for coarser spatial resolution that would not allow targeting crowns were investigated averaging spectra of 20*20 m^2 defined in the tilled and non-tilled test areas.
PROSAILH numerical inversions were performed setting model input variables as before. Chlorophyll (a+b) concentration estimated are shown in Table 4 comparing the results using a nominal soil and local understory optical properties in the inversion procedure.

TEST PLOT		**Average Cab values (ug/cm^2)**	
		Nominal background	Known local background
A	Tilled	34.5	34.5
	Non-tilled	46.7	39.5
B	Tilled	37.7	37.7
	Non-tilled	64.2	38.7

Table 4 - Pigment retrievals in test areas A and B simulating a low spatial resolution sensor.

Chlorophyll values retrieved from poplar crowns in tilled and non-tilled areas, when nominal background is used, show an average difference of 20 μg/cm^2, in contrast to results by Zarco-Tejada (2001b), presumably due to the lower LAI canopies. Significantly less evident differences in pigment estimation (3.6 μg/cm^2) are observed when local background optical properties are used in the inversion procedure.

Even though effects like shadows, that affect the canopy reflectance, have been successfully overcome by using simple ratio VI as merit function in closed canopies, results here show that problems concerning open and sparse canopy still represent a challenging issue for accurate pigment retrievals at coarser spatial resolution.

5.0 CONCLUSION

This research has shown that vegetated understory has a clearly observable contribution on the canopy reflectance, in turn affecting the overstory pigment retrieval when the LAI has low values and the canopy is sparse and open. These ecological characteristics are typical of poplar plantations (*Kyoto forest or fast growing forest*) where stands are juvenile or stressed, therefore compromising the use of estimates of absolute chlorophyll content as bio-indicator in vegetation monitoring in these situations. However, the complete harvesting of the understory may be viewed as a rather extreme unknown in an operational programme of monitoring of these plantations.

The use of red edge slope as a merit function in the inversion procedure can improve the pigment estimation in canopy with complex structure by overcoming effects like shadows, but still show sensitivity to background optical properties and LAI values, affecting the accuracy of chlorophyll estimation. Nevertheless, the estimated relative pigment content appears to correctly identify test areas with relatively different leaf pigment content, and stand condition. In addition, the errors in pigment estimates in the overstory canopy introduced by such issues must be considered relative to the accuracies of pigment retrieval (~ 5 $\mu g/cm^2$) under more ideal condition (Zarco-Tejada *et al.* 2001a).

Problems associated with the challenges to accurate overstory leaf pigment retrievals can be overcome by high spatial resolution data used in radiative transfer models when numerical inversion procedures are performed with known LAI values and local understory optical properties .Field campaigns can give the necessary understory characterisation and LAI values. Accurate LAI maps can also be achieved by multi-angular data analysis, if available.

Simulations of coarser spatial resolution suggest that pigment retrievals in open and sparse canopies, through numerical inversion of radiative transfer models, cannot be performed with results consistent with typical RMSE ranges in recent retrievals for closed canopy forests.

ACKNOWLEDGEMENTS

This study was supported by the EU-funded project HySens coordinate by DLR-Germany. The authors gratefully acknowledge G. Seufert (JRC-IES, Ispra, Italy) and his unit, P. Zarco-Tejada (Universidad de Valladolid), S. Jacquemoud, C. Bacour (Université Paris 7 - Laboratoire Environnement et Développement), the optical laboratory staff (York University, Toronto) and the Remote Sensing Unit of DISAT (Università di Milano Bicocca).

REFERENCES

Brivio P. A., M. Meroni, and C. Giardino, 2001, Monitoring forest ecosystems using hyperspectral and directional observations, *ESA Workshop on "SPECTRA", Nordwijk (The Netherlands) 12-13 June 2001, ESA-ESTEC (in press).*

Dawson T.P., 2000, The potential for estimating chlorophyll content from a vegetation canopy using MERIS, *Int. J. of Remote Sensing* 21: 2043 – 2051.

Demarez, V., Gastellu-Etchegorry, J.P., 2000, A modeling approach for studying forest chlorophyll content, *Remote Sens. Environ.71: 226-238.*

Meroni, M., Colombo, R., Boschetti M., Panigada, C., Rossini, M., Brivio, P.A., Miller, J.R., 2002, LAI retrieval from multi-angle and hyperspectral observations in an intensive poplar plantation, *these conference proceedings.*

Mohammed, G.H., Sampson, P.H., Colombo, S.J., Noland, T.L., Miller, J.R., 1997-. Bio-indicators of forest health and sustainability: development of a forest condition rating system for Ontario, Forest research information paper No. 137, Ontario Forest Research Institute, Sault St. Marie, Ontario-Canada

Haboudane, D., Miller, J.R., Tremblay, N., Zarco-Tejada, P., Dextraze, L., Viau, A. 2001, Heterogeneity of CASI-estimated leaf chlorophyll in corn: assessment and comparison with ground truth from L'Acadie GEOIDE experimental site, *Proceedings of the 23rd Canadian Symposium on Remote Sensing and 10th Congress of the Quebec Remote Sensing Association, Universitè Laval, University Sainte-Foy, Quebec Canada, 21-24 August 2001.*

Haboudane, D., Miller, J.R., Tremblay, N., Zarco-Tejada, P., Dextraze, L., 2002, Integrated narrow-band vegetation indeces for predictionof crop chlorophyll content for application to precise agriculture. *Remote Sens. Environ.*, 81:416-426.

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

Jacquemoud S., 1993, Inversion of the PROSPECT + SAIL canopy reflectance model from AVIRIS equivalent spectra: Theoretical study, *Remote Sens. Environ.* 44: 281 – 292.

Kuusk A., 1991, The hot-spot effect in plant canopy reflectance, in Photon-Vegetation Interactions; *Application in Optical Remote Sensing and Plant Ecology (R. Mynemi and J. Ross, Eds.). Springer-Verlag, New York, 139 – 159.*

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

Zarco-Tejada P., Miller, J.R., Noland, T.L., Mohammed, G.H., Sampson, P.H., 2001a, Scaling-up and model inversion methods with narrow band optical indices for chlorophyll content estimation in closed forest canopies with hyperspectral data. *IEEE Transactions on Geoscience and Remote Sensing*, 39, 1491-1507.

Zarco-Tejada P., Miller, J.R, 2001b Minimisation of shadow effects in forest canopies for chlorophyll content estimation using red edge optical indices through radiative transfer: implication for MERIS. *Proceedings of the IEEEInternational Geoscience and Remote Sensing Symposium (IGARSS'01), July 9 - 13th, 2001, in Sydney, Australia*