

ASSESSMENT OF FOREST CANOPY CHEMISTRY WITH ISM

Gastellu-Etchegorry J.P., Zagolski F., Pinel V., Giordano G., Romier J., Marty G., Mougin E.
Centre d'Etude Spatiale Des Rayonnements
C.N.R.S. - U.P.S., BP 4346, 31029 - Toulouse cdx. - France
Tel.: (33) 61-55-61-30 ; Fax: (33) 61-55-67-01 ; E-mail: gastellu@cnesta.span.cnes.fr

Abstract: An ISM (Imaging SpectroMeter) airborne campaign was organised in 1993 over a pine plantation (Les Landes, SW France). ISM is a spectrometer that operates in the near and mid infrared portions of the spectrum [800-3200nm]. The study was aimed to assess the capability of this airborne spectrometer for obtaining information about the chemical composition (nitrogen, lignin, cellulose) of a tree canopy.

Samples (needles) were collected in the field at the time of the ISM survey: 21 parcels were sampled with 5 samples per parcel. Once these samples were dried and reduced in powder, they were analysed for determining their chemical concentrations. Some relationships appeared between the age of the trees and the needle chemical concentrations.

Spectral analyses of samples was conducted with an InfraAlyser 450 that operates with 19 spectral bands centred on the absorption bands of chemicals. Stepwise analyses of reflectances were conducted for determining statistical relations that relate chemical concentrations to reflectances (lignin $r=71%$; nitrogen $r=78%$; cellulose $r=75%$).

ISM data were geometrically corrected for obtaining spectra of parcels where samples were collected. The objective was to determine if most efficient wavelengths for predicting chemical concentrations are the same at the laboratory and remote sensing level. This comparative analysis was conducted through regression analyses (lignin $r=78%$; nitrogen $r=78%$; cellulose $r=84%$).

Keywords: ISM, spectrometry, chemistry, lignin, cellulose, nitrogen, forest.

I. INTRODUCTION

Modélisation of ecosystem processes such as net primary productivity, photosynthesis, rate of litter decomposition,... requires a sound-knowledge of canopy chemistry; e.g. lignin, cellulose, nitrogen (Birk and Matson, 1987). Commonly, this information is obtained through chemical analyses. It may be also assessed with laboratory spectrometric measurements. The presence of infrared absorption bands in target compounds is at the basis of this high spectral resolution technology.

An airborne campaign was organised in May 1993 for assessing the capability of the airborne ISM spectrometer for studying the canopy chemistry (lignin, nitrogen, cellulose,...). More specifically, the objectives were two fold: (1) computation, with stepwise regression, of relationships between spectrometric information and concentrations of chemical compounds, and (2) analysing the "stability" of these relationships, when one goes from laboratory to remotely acquired information.

II. EXPERIMENTAL DATA

II.1 Study area

"Les Landes" (South West, France) is a large, flat and homogeneous forest. It covers about one million hectares and produces 20% of French timber, mainly maritime pine (*Pinus pinaster*). The test site (Nezer), is a forest plantation area. It consists of a mosaic of homogeneous parcels of pines, clear cuts and numerous fire protection tracks. Biophysical characteristics (*i.e.* row spacing and width, tree density, dbh, canopy depth, understory vegetation,...) of the parcels of maritime pine are well documented. They were checked and up-dated at the time of ISM data acquisition. The different stands of the plantation offer a wide variety of maritime pine ages from clear cuts up to 50 years.

II.2 Spectrometric airborne measurements

** ISM Instrument:

ISM (Imaging SpectroMeter) is an airborne spectrometer (Zagolski *et al.*, 1992) that operates in the near and mid-infrared portions of the spectrum [800-3200nm]: 64 contiguous 12.5nm spectral bands in the [800-1500nm] region and 64 contiguous 25nm wide spectral bands in the [1500-3200nm] region. The instantaneous field of view is 1'. A moving mirror scans across track areas. The scanning speeds unfortunately too slow (<3Hz) for obtaining a real imaging spectrometer. Signal to noise is about 100 ($\lambda < 2700\text{nm}$).

The flight altitude over the test site was 3000m.

** Radiometric corrections:

Due to technical problems, calibration coefficients could not be available. This drawback was minimised with the use of spectral bands ratios.

A correction (Fast Fourier Transform method) was applied to the data for removing a low frequency modulation that was caused by mechanical vibration at the time of acquisition. This did not significantly modified the ISM spectra.

** Geometric corrections:

These were conducted with the help of informations from the on board inertial platform:

- *position of the plane:* latitude, longitude, altitude

- *navigation parameters:* roll, pitch, drift, ground speed, geographic cape and true heading.

II.3. Field Sampling

During the airborne campaign, 21 parcels were sampled (5 samples/parcel). Each sample consisted of several needles from different canopy positions from up to bottom. The samples were refrigerated in the field prior to laboratory spectral and chemical analyses of lignin, nitrogen and cellulose content. Because all pine trees within one parcel had the same age and had grown under the same conditions, it was assumed that the average values of 5 samples collected from a parcel were representative for this parcel. Chemical analyses validated this hypothesis with a 95% significance level.

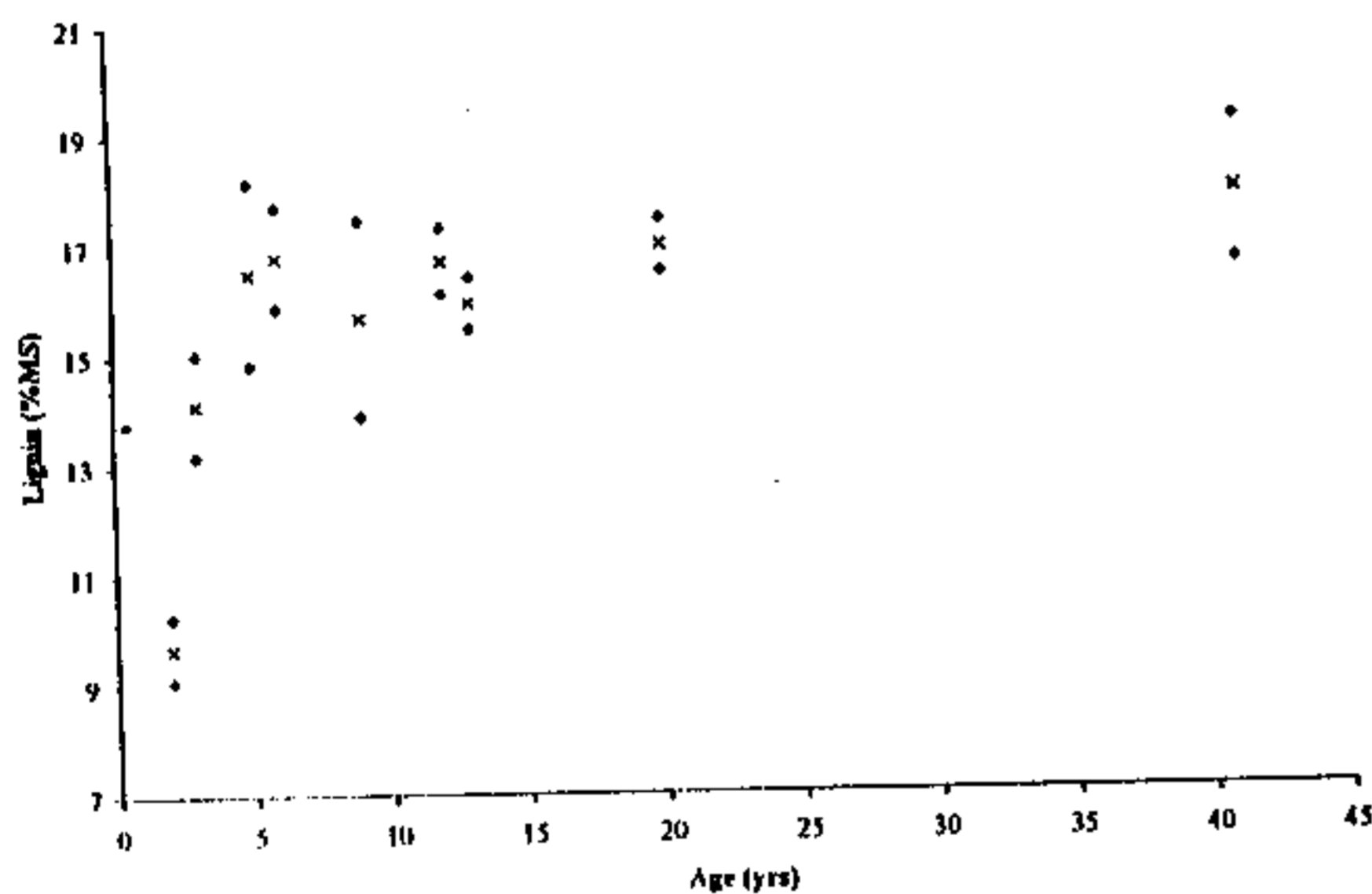
II.4. Laboratory analyses

** Chemical measurements

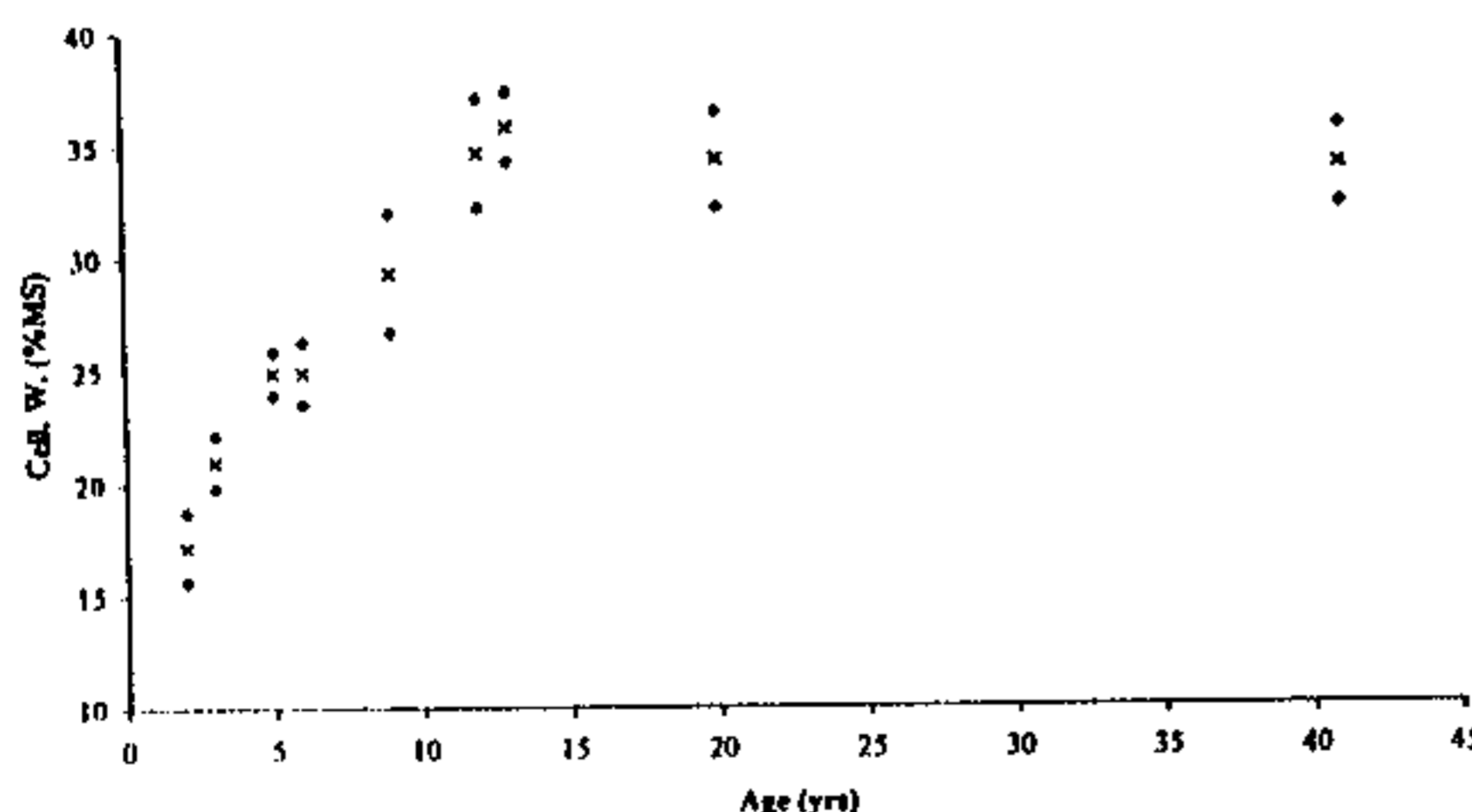
Chemical analyses of total nitrogen, lignin and cellulose were conducted by Europe Sol*. Total nitrogen was calculated as 6.25 times the Kjeldahl nitrogen content (A.O.A.C., 1970), after digesting samples in a block digester using sulphuric acid. Lignin was determined using a modified Van Soest and Wine (1970) method. Cellulose (Cell. W), often referred as "crude fibre", was also determined using the method of Weende. Chemical concentrations were partially inter-correlated (Table 1). Moreover, some relationships were observed between the age of the tree and the chemical concentrations of needles (Fig 1).

	N	L	CellW
N	100	36	-63
L	36	100	-61
CellW	-63	-61	100

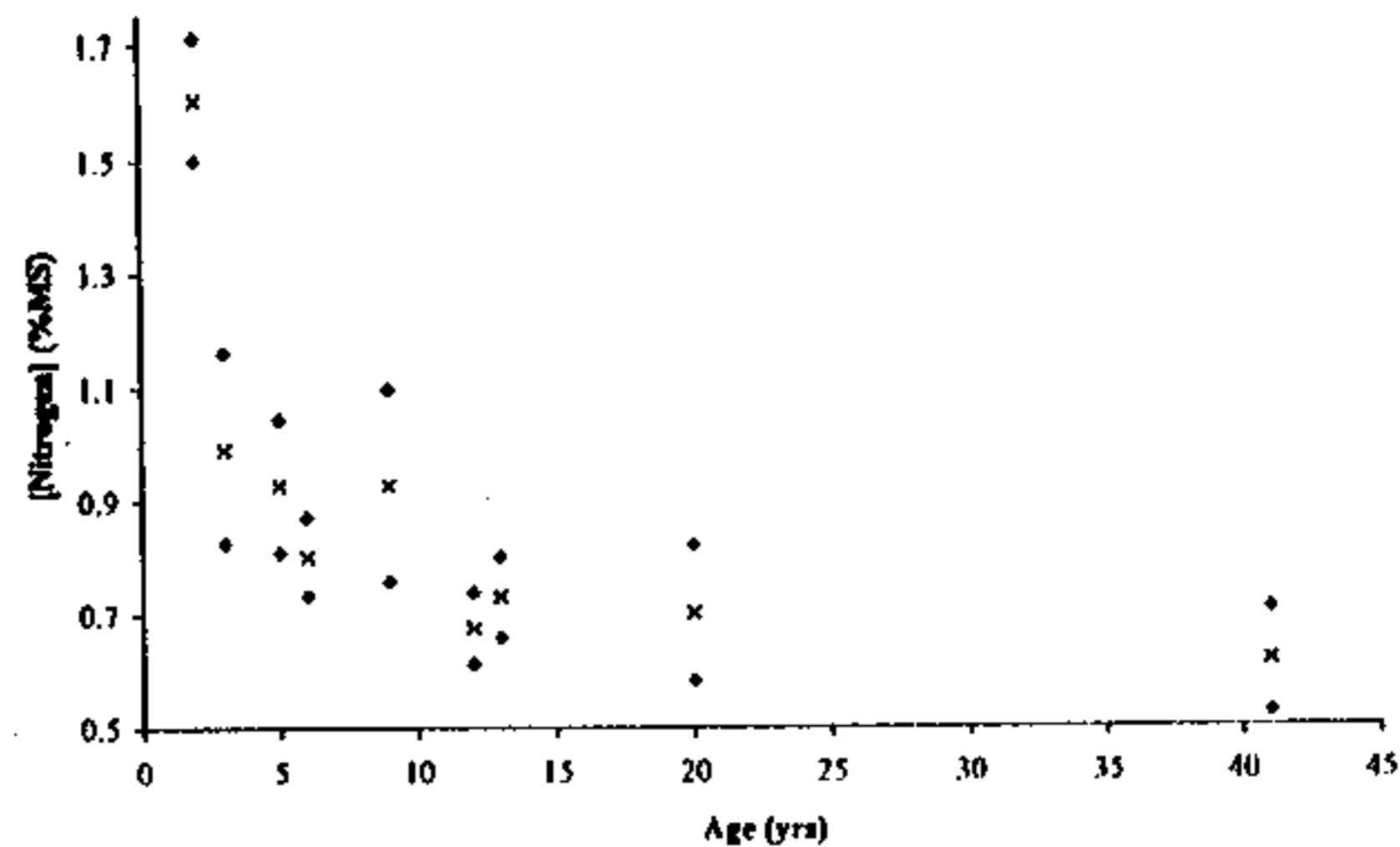
Table 1: Correlations between pine needle lignin, cellulose and nitrogen concentrations.



(a)



(b)



(c)

Fig 1: Chemical concentrations of pine needle vs age of the tree: (a) lignin, (b) nitrogen, (c) cellulose.

** Spectral measurements

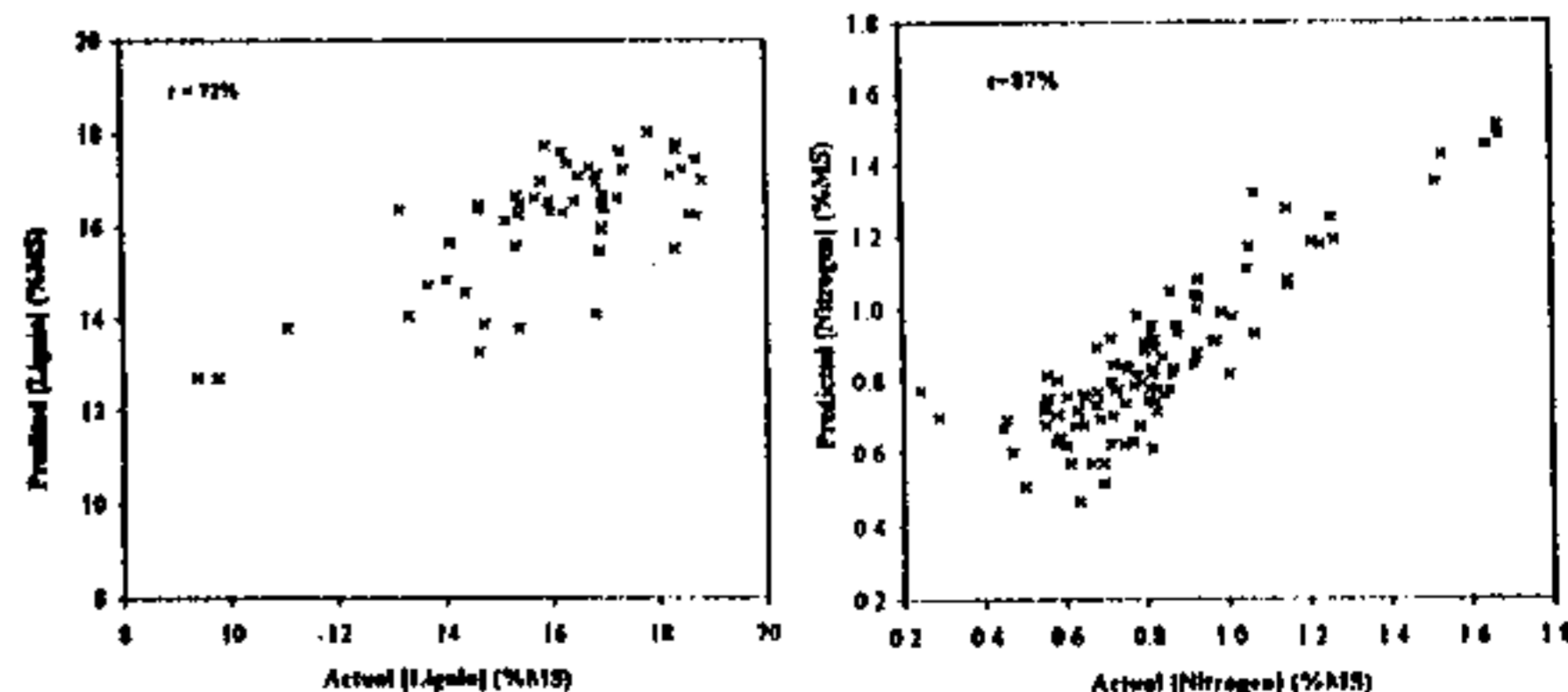
All vegetation samples collected in the field were dried and ground down to similar particle sizes for further spectral analysis. The objective was to determine the most significant wavelengths for assessing chemical compounds. Total hemispherical spectral reflectances were recorded with a computerised spectrophotometer (Technicon InfraAnalyser 450) operated in a single-beam mode. This instrument measures spectral reflectances at 19 different wavelengths with the help of filters. Associated target compounds are indicated between brackets: 1445nm (wetness), 1680nm (reference), 1722nm (starch, cellulose, lignin), 1734nm (protein, cellulose), 1759nm (oil), 1778nm (cellulose, starch, fibres), 1818nm (cellulose), 1940nm (wetness), 1982nm (protein), 2100nm (starch, cellulose), 2139nm (protein, starch), 2180nm (protein), 2190nm (protein, starch), 2208nm (urea), 2230nm (reference), 2270nm (starch, cellulose, lignin), 2310nm (oil), 2336nm (fibres, cellulose, lignin), 2348nm (cellulose, nitrogen).

Two ratios $\log\left(\frac{\rho}{\rho_{1680}}\right)$ and $\log\left(\frac{\rho}{\rho_{2230}}\right)$ were computed with 2 reference reflectances. These ratios were meant for further comparison between laboratory and remotely acquired results. Consequently, spectral bands within atmospheric absorption bands (*i.e.* 1445nm, 1818nm and 1940nm) were discarded.

III. LABORATORY-DERIVED PREDICTIVE EQUATIONS

Stepwise regression analysis was applied to laboratory-derived reflectance spectra for determining those spectral bands, and associated linear relations, that are predictive of chemical concentrations. Regression analysis was applied on the ratios

$\log\left(\frac{\rho}{\rho_{1680}}\right)$ and $\log\left(\frac{\rho}{\rho_{2230}}\right)$. Only wavelengths with a 95% significance level were selected (Fig 2).



(a)

(b)

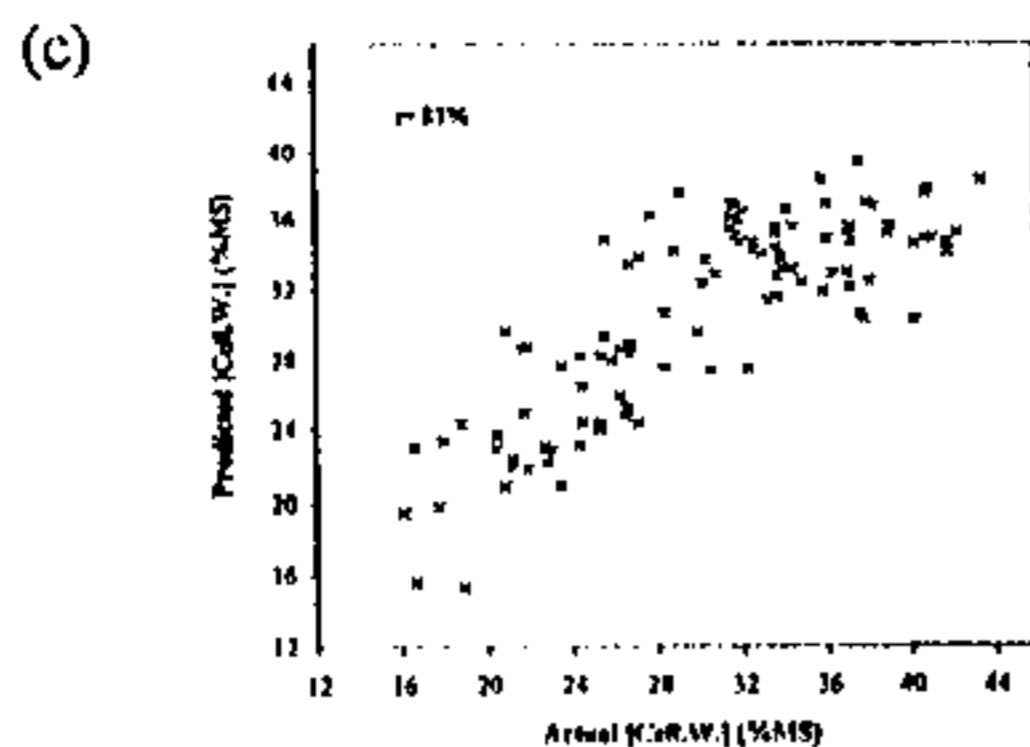


Fig 2: Actual and predicted chemical concentrations of pine needle Laboratory measurements : (a) lignin, (b) nitrogen, (c) cellulose.

Table 2 displays the most successful wavelengths and associated correlations between the predicted and actual chemical concentrations. It should be noted that:

- two to three wavelengths were sufficient for predicting nitrogen and cellulose concentrations with correlations larger than 81%. Results for lignin are much poorer than for the other compounds.

- selected predictive wavelengths could not be always attributed to absorption bands of compounds. This could partly be explained by some intercorrelation between chemicals (Table 1). This was especially the case for lignin.

	$\log(\rho/\rho_{1680})$	$\log(\rho/\rho_{2230})$
CellW	1982/2270*: 82% 1722*/1982/2270*: 86% 1759/1778*/1982: 84% 1759/1778*: 83% 1759/1778*/2190: 85%	1759/1982/2348*: 81% 1759/1982: 81% 1759/1982/2190: 82% 1778*/2310: 75% 1759/1778*/2310: 83%
Nitrogen	1734*/2336/2348*: 87% 1734*/2336: 82% 1734*/1778/2336: 84%	1734*/2336/2348*: 84% 1778/2336/2348*: 81%
Lignin	1982/2336*: 61% 1982/2336*/2348: 69%	1734/2348: 63% 1734/2336*/2348: 71%

Table 2: Laboratory derived optimal wavelengths with associated correlations. Wavelengths that can be attributed to chemicals are indexed with the symbol *.

The best relationships predictive of lignin, cellulose and nitrogen concentrations are mentioned below. They are represented in percentage of dry matter. Wavelengths that can be attributed to chemicals are indexed with the symbol *.

$$\text{- lignin: } 6-609.\log\left(\frac{\rho_{2348}}{\rho_{2230}}\right)+654.\log\left(\frac{\rho_{1734}}{\rho_{2230}}\right)-64.\log\left(\frac{\rho_{2336}}{\rho_{2230}}\right) \quad r=71\%$$

$$\text{- cell W: } 94.84-518.\log\left(\frac{\rho_{2310}}{\rho_{2230}}\right)+451.\log\left(\frac{\rho_{1778}}{\rho_{2230}}\right) \quad r=75\%$$

$$\text{- nitrogen: } 14-529.\log\left(\frac{\rho_{1734}}{\rho_{2230}}\right)+214.\log\left(\frac{\rho_{2336}}{\rho_{2230}}\right)-147.\log\left(\frac{\rho_{2348}}{\rho_{2230}}\right) \quad r=87\%$$

IV. APPLICATION OF PREDICTIVE EQUATIONS

Reflectance ratios $\log\left(\frac{\rho}{\rho_{1680}}\right)$ and $\log\left(\frac{\rho}{\rho_{2230}}\right)$ means per parcel were calculated with ISM data and for all the parcels where samples were collected. For statistical purposes the small number of sampled parcels is undoubtedly a limiting factor.

Laboratory-derived predictive relationships were applied to ISM derived reflectance ratios. Five parcels could not be used because too few ISM data were acquired on this site. The results found for

validated parcels were too small for applying regression analyses directly with ISM data. This explains why the above mentioned laboratory-derived predictive equations were used at the level of ISM data. This approach led to relatively weak correlation between predictive and actual concentrations (Fig 3), i.e. lignin $r=78\%$, nitrogen $r=78\%$, cellulose $r=84\%$. Best results were obtained with predictive equations that relied on wavelengths that could be attributable to chemical compounds. Surprisingly, the extrapolation of laboratory predictive equations to airborne data led better correlations. This can be partly explained by the few sampled parcels.

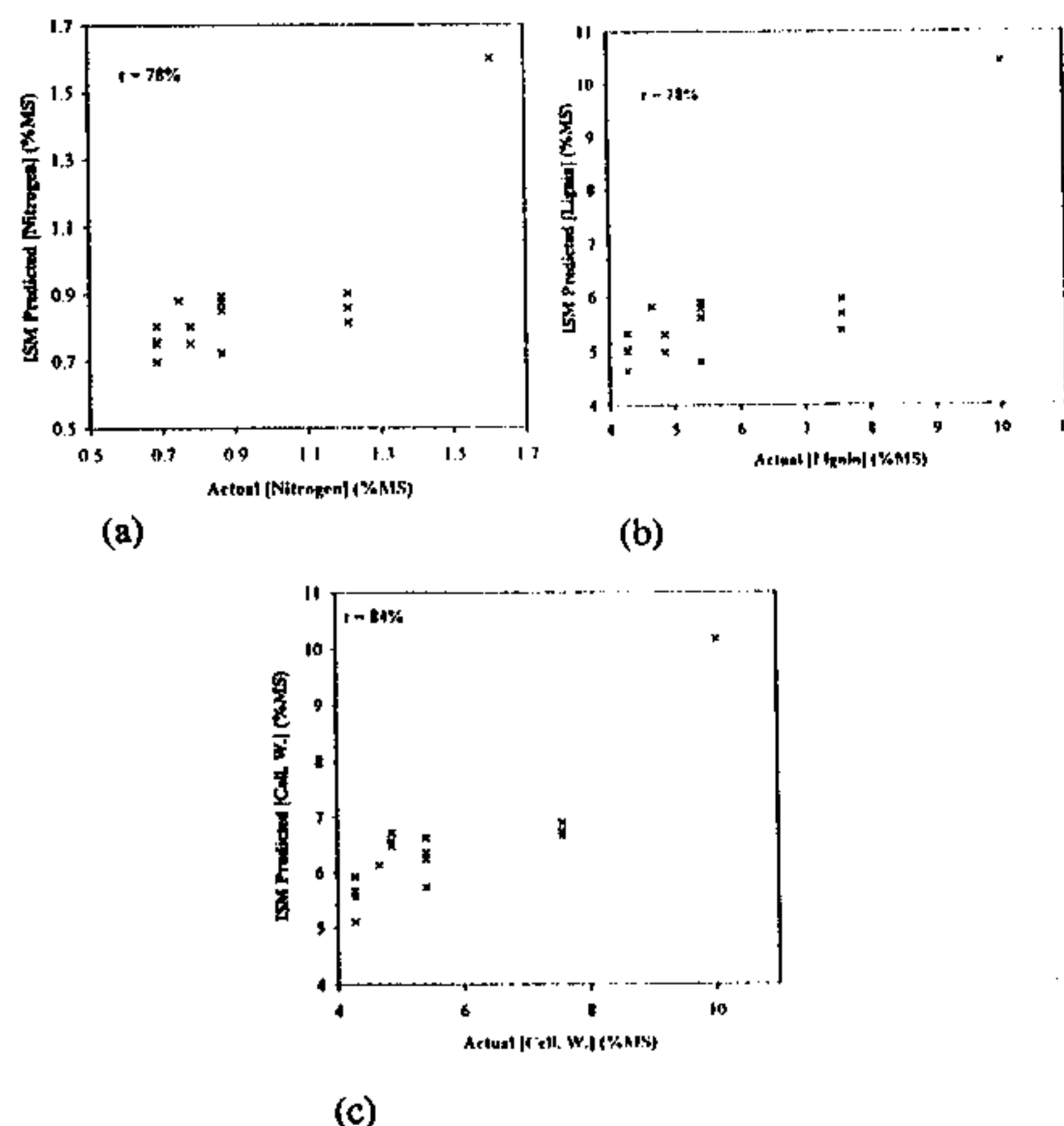


Fig 3: Actual and ISM predicted chemical concentrations: (a) lignin, (b) nitrogen, (c) cellulose.

V. CONCLUDING REMARKS

Laboratory and spectral chemical analyses of samples of pine needles allowed us to determine relationships that are predictive of lignin, nitrogen and cellulose concentrations. These equations were extrapolated to ISM data. The non imaging capability of the instrument was a very serious constraint of data analyses. Encouraging results were obtained: lignin $r=78\%$, nitrogen $r=78\%$ and cellulose $r=84\%$. It is expected that better results could be obtained if both the structure of the overstory and the understory are considered through the use of radiative transfer model.

VI. REFERENCES

- A.O.A.C., 1970, Official methods of analysis (11th Ed.) Association of Official Analytical Chemists, Washington D.C.
- Birk E. and Matson P.A., 1987, Site fertility affects seasonal carbon reserves in loblolly pine, *Tree Physiol.* 2:17-27.
- Gastellu-Etchegorry J.P. *et al.*, 1993, An assessment of canopy chemistry with AVIRIS - A case study of The Landes forest, S.W. France -, *I.J.R.S.*, Sept. 93, accepted.
- Zagolski *et al.*, 1992, Preliminary results of the ISM campaign - The Landes, South West France -, *Proc. IGARSS'92*, Houston, Texas.