The European Imaging Spectrometry Airborne Campaign - EISAC Selected Examples of Application Oriented Data Evaluation

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ABSTRACT

The paper summarizes the activities and the interim results of the European Imaging Spectroscopy Airborne Campaign (EISAC), that has been initiated jointly by the European Space Agency (ESA) and the Joint Research Centre (JRC) of the Commission of the European Communities. In the framework of the campaign, flights over 7 European test sites have been performed in May/June 1989.

The EISAC data evaluation programme comprises a wide range of applications in agriculture, forestry, geology/soil science and oceanography/marine biology. In a first phase, data evaluation was concentrated on quality assessment, radiometric and atmospheric correction of the airborne data. The second phase deals with spectral signature modelling and with the definition and evaluation of relevant surface parameters, aiming towards optimized approaches for the exploitation of the data of future spaceborne imaging spectrometers with medium (MERIS) and high spatial resolution (HRIS). Examples of spectral evaluation of GER data reveal the high potential of imaging spectrometry for the application of remote sensing in Europe.

I. INTRODUCTION

In the framework of the joint ESA/JRC EISAC campaign, between May 15th and the end of June 1989, imaging spectrometer flights over seven European test sites have been performed successfully as follows:

<u>A. Test Sites (see Fig. 1)</u>

<u>1. Oceanographic test sites.</u>

Test site	Applications
1. Skagerrak	- Monitoring of chlorophyll distribution and pollution of coastal waters (Norway).
2. North Sea, Waddensea, Helgoland	- Coastal Ecology, monitoring of sea water quality and algae blooms (W-Germany).
3. Northern Adria, Venice Lagoon, Sacca di Gorò	- Monitoring of coastal ecology and sea water quality (Italy.)

2. Land applications test sites.

Test site Applications

4. Upper Rhine Valley - Forestry, Agriculture (W-Germany).
5. Somerset Levels - Agriculture (United Kingdom).
6. Almaden - Soil Science, Vegetation (Spain).
7. Ardeche - Soil Science, Land Use (France, JRC experiment).

B. Airborne Data

Moniteq's Fluorescence Line Imager (FLI/PMI) and the 63 band multispectral scanner of Geophysical Environmental Research Corporation (GER) were the core sensors of the campaign. In addition the ITRES Compact Airborne Spectrographic Imager (CASI) was flown over two test sites.
The sensor deployment was technically supported by the German Air and Space Research Organization (DLR). The airborne operations were managed by GDTA (France).
The following airborne data has been acquired:

1. FLI/PMI data. The FLI instrument was flown, in spatial as well as in spectral mode, over all test sites, except the Ardeche.
Spectral range: 400 - 805 nm
Spectral sampling: spatial mode 8 selectable bands $\geq$ 2.6 nm bandwidth
spectral mode 288 bands each 2.6 nm wide
Number of acquired CCTs: 77 (1650 BPI)

2. GER data. Except the Helgoland and Somerset site, the GER instrument acquired data from all test sites.
Spectral range: 450 - 2500 nm
Spectral sampling: VIS/NIR: 450 - 843 nm, 31 bands each 12.3 nm (nominal)
SWIR I: 1440 - 1.80 nm, 4 bands each 120 nm
SWIR II: 2005 - 2500 nm, 28 bands each 16.2 nm
Number of acquired CCTs: 24 (6250 BPI)

3. Metric camera (RMK 15/23). 683 IR false colour photographs have been taken over all test sites, except the Ardeche.

4. CASI data. The two EISAC lines over the Skagerrak test site were covered also with CASI, which was deployed in the framework of the coincident Norwegian NORSMAP campaign. In 1990 the Freiburg test site was covered with CASI, in order to test its capabilities for land applications.
Spectral range: 400 - 900 nm
Spectral sampling: spatial mode 8 selectable bands $\geq$ 1.8 nm
spectral mode 288 bands each 1.8 nm wide

C. Radiometric Ground Truth

Parallel to the overflights on each test site an extensive ground measurement programme has been executed by local Coordinating Investigators (CI) supported by JRC. The following principal radiometric ground measurements have been performed:
- atmospheric measurements performed in coincidence with the overflights.

- continuous incoming irradiance measurements.
- measurements of spectral reflectance of selected sea surfaces, characteristic tidal (sandbars, algae and mud flats etc.) and land surfaces (bare soils, rocks, agricultural crops, natural vegetation etc.)
- continuous monitoring of selected reference targets during overflights and measurements for evaluation of view angle effects.

For the radiometric measurements a suite of instruments was available, including 2 GER D-IRIS, 1 GER S-IRIS, 3 Spectron Engineering SE 590 spectroradiometers. In addition bandpass radiometers and ratioing radiometers were deployed.
Principally atmospheric measurements were performed as in the follwing example of JRC measurements in Ardeche and the Upper Rhine Valley. At both test sites, measurements of the atmospheric beam transmittance were performed using a bandpass radiometer (EXOTECH) and a spectroradiometer (SE 590). The method used is that of Langley /5/. Some results of these measurements are shown in Fig.2 for the Upper Rhine Valley test site. A satisfactory agreement has been obtained between the two types of instruments although further measurements of this kind under stable atmospheric conditions are required in order to establish a fast and reliable procedure for the measurement of atmospheric beam transmittance in a continuous spectrum. In the case of the SE 590 measurements, a best fit of direct irradiance values and air mass has been established for the 252 channels of the spectroradiometer. This kind of data is directly applicable to the airborne data obtained during the overflights of the two test sites concerned and thus atmospheric corrections can be performed in order to have a better correlation between ground and airborne data.

II. EVALUATION PROGRAMME

The EISAC data sets comprising airborne and groundtruth data were distributed to more than 30 research institutes all over Europe.
The coordination of the EISAC data evaluation was entrusted to JRC Ispra. The evaluation programme is scheduled to last until late 1991. In this context JRC lays its main emphasis on the following topics:
- Radiometric correction of data
- Atmospheric correction of data
- Spectral signature modelling
- Definition and evaluation of relevant surface parameters to be received by future spaceborne instruments regarding especially the modelling of a combined vegetation and ocean band set (i.e. midband frequency, bandwidth, number of bands?) of the Medium Resolution Imaging Spectrometer (MERIS) on the first ESA Polar Platform Mission.
- Data analysis in terms of applications in agriculture, forestry, soilscience and oceanography.

A campaign analysis workshop with 40 participants was held in April 1991 at JRC-Ispra to review the results of the campaign and to discuss the conclusions. 20 presentations gave an excellent impression of the results and also of the problems related to the use of imaging spectrometer data. The discussions revealed an excellent overview on the requirements of European users to future imaging spectrometers and airborne campaigns.

A. Assessment of Data Quality

The first phase of the evaluation programme was dedicated to the assessment of the data quality of the core sensors FLI/PMI and GER. The data has been investigated independently by JRC and the CIs, aiming mainly at the validation of noise level, effective spectral resolution and radiometric calibration /2,4/.

1. GER Data

The investigations of the different groups led to corresponding results for the GER instrument:

a) Signal/Noise ratio (SNR). Assuming that for a homogeneous target sample

SNR = Average Signal/Standard Deviation

the following SNRs have been estimated:

- VIS/NIR module:
  low reflectance targets (4-8% at 500 - 600 nm): SNR = 5-10
  high reflectance targets (20-50% at 750 - 850 nm): SNR =20-50
- SWIR II module:
  In the SWIR II spectrometer the SNR deteriorates with decreasing radiance levels due to atmospheric absorption. The best SNR (25-40) is found in GER bands 40-50, whereas SNRs decrease to about 5-10 in bands 36 - 38 and 55 - 63 /2/.

b) Effective spectral bandwidth. A comparison of Lowtran standard atmosphere absorption bands with GER spectra at band positions, potentially sensitive to gaseous absorptions, led to the conclusion that the nominal bandwidth of 12.3 nm in the VIS/NIR was not kept. An effective bandwidth of 50 nm has been estimated by modelling the appearance of the narrow oxygen absorption band at 760 nm for different band positions and bandwidths. First assuming that mechanical vibrations had caused the exceeded bandwidths, in the meantime investigations of DLR, Oberpfaffenhofen led to the conclusion that the VIS/NIR spectrometer was defocused (F. Lehmann, DLR, pers. communication 1990).
A slight overcompensation of atmospheric CO_2 absorption can be observed in band 39 (2054 nm), which might indicate that the given bandwidth of the SWIR II module (2000 - 2500 nm) is slightly exceeded /2/.

c) Radiometric calibration. The observation of considerable differences between GER spectra with applied preflight radiance factors and field spectra, measured during the overflights, required increased efforts to achieve reliable calibration factors on the basis of inflight data. DLR and JRC have been working independently on the development of above mentioned calibration files to be applied to the GER data of all EISAC test sites. In both cases the investigations led to new tables of radiance factors and offsets for all channels, which have been obtained by fitting the achieved GER radiances to radiances modeled on the basis of radiometric field measurements and radiative transfer calculations /2,4/.
Differences occurring between DLR and JRC calibrations may result from the

use of different atmospheric models (e.g. DLR, Lowtran 7 /4/; JRC, derivates of models developed by Tanrè et al. and Guzzi et al. /1,2,6,7/).

2. FLI/PMI data

SNRs over dark targets have been estimated in the range from 20 to 30 (GER 5-10). Generally the geometric characteristics of the roll corrected data are considered sufficient, whereas the radiometric quality suffers from the moderate SNR and the deficiencies listed below /3/:

a) Inter-camera calibration.
- strong differences between the four cameras, only gross errors removeable.
- no absolute, only cosmetic calibration possible.

b) Detector normalisation.
- dropped detector elements.
- great differences between the responses of the single detector elements.
- only cosmetic calibration working.
- residual noise apparent as a result of data processing.
- the absolute radiance level of the EISAC Somerset data is reduced by a factor of approx. 4 compared to 1988 data of the same site, possibly due to increasing, non-linear degradation of the detector elements (pers. communication S. Briggs & A. Jones, BNSC-NERC, 1989).

c) Geometric characteristics.
- the data appears compressed due to strong undersampling.
- residual high frequency jitter.

B. Atmospheric Correction of the Airborne Data

The comparison of airborne data with spectral field and laboratory measurements requires a conversion of the airborne data to reflectance factors. Different atmospheric models such as the LOWTRAN 7 code were used by the participating institutes.
The atmospheric correction model which was used by the JRC throughout the Ardeche study is based upon the formulation of radiative transfer as developed from Tanré et al. /6,7/ and it provides corrections for atmospheric absorption, scattering and pixel adjacency effects. Diffusion and absorption processes are assumed to be independent. Upward and downward transmission coefficients are therefore easily derived by introducing the auxiliary quantity of optical thickness τ which measures the total extinction of a light beam due to molecular and aerosol scattering passing through an airmass. The method was modified in order to account for atmospheric extinction processes as a function of altitude.

C. Recent Thematic Data Evaluation and Future Activities

Upon the basis of clarified data quality and of reliable in-flight calibration, the second phase of the EISAC programme, dedicated to thematic data evaluation, was started.
First attempts concentrated on the mapping of chlorophyll distribution and

pollution of coastal waters and on the spectral differentiation of various land surfaces and ground covers.

Encouraging results could be achieved in the discrimination of different soils and rocks by using their characteristic spectral features in the short wave infrared (SWIR) between 2.0 and 2.5 µm. The evaluation of GER data, obtained from bare rock and soil surfaces in the Ardeche test site (F), revealed identical absorption features in airborne as well as radiometric field and laboratory measurements, which correspond to the varying contents of Al-OH and CO_3 bearing minerals /2/. But also combined lignin and cellulose absorptions appear in spectra from the second GER SWIR spectrometer module, once the amount of green leaves in the observed vegetation is significantly reduced. This becomes clearly evident in spectral signatures derived from mature wheat and barley crops. Corresponding cellulose-lignin absorptions, though weaker, can also be identified in spectra from mediterranean shrublands (see Fig.3).

The Institute of Physical Geography at Freiburg concentrated on the modelling of the reflectance red edge and on the detection of irrigated fields in the Freiburg Upper Rhine Valley test site using the SWIR bands of GER. The combined set of image-truth and groundtruth data enabled the calculation of averaged spectra for selected soil and plant parameter combinations. This procedure considerably reduced system noise in the spectra.
Separate correlations between the parameters describing the Gauss function and the measured plant parameters were calculated for each soil type. The analysis showed highly significant correlations ($r > 0.93$) between both, the "minimum reflectance" and the "inflection wavelength of the red edge and the plant height of corn (Fig.4). The resulting regression functions for the correlation "minimum reflectance/plant height" vary strongly depending on the soil type of the considered field. In the opposite the "inflection wavelength" ($r = 0.997$) is not influenced by the signal of the underlaying soil. It is only determined by the plant parameters. Furthermore the suitability of the SWIR channels for the discrimination of dark clay soils from irrigated soils was shown. The water content of the top soil proofed to be well parameterized through a ratio between the reflectance at 2.16 and 2.04 micron ($r = 0.91$). A transfer of this relation to non-vegetated pixels in the GER data allowed a classification of the irrigated bare soils independent of the soil type.

With respect to the development of the Medium Resolution Imaging Spectrometer (MERIS), to be launched in the framework of the first ESA Polar Platform Mission, EISAC data furthermore will be used to investigate the:
- quantification of nature and physical status of vegetation communities.
- boundaries for the detection of plant spectral features in mixed soil-plant spectra.
- influence of different soil properties on the mixture of spectra.

Supplementary CASI data of the Freiburg test site, that has been flown on July 20th 1990, will be included into this part of the research programme. In the near future the European remote sensing community is looking forward to the deployment of JPL's AVIRIS in Europe in the period from June 13 to July 20, 1991.

III. CONCLUSIONS

The EISAC campaign provided high radiometric resolution airborne data and groundtruth of manifold European sea and land surfaces, covering a wide range of oceanographic and land applications. Upon this basis important experiences in the field of radiometric and atmospheric correction of imaging spectrometer data, obtained under European conditions, were gained. This new know how enables an improved application oriented evaluation of the EISAC data and a better definition of the requirements for future airborne imaging spectrometry campaigns in Europe.
The main problems of EISAC data evaluation are related to the following facts:

- the FLI/PMI as well as the GER sensor didn't provide the data quality that was expected according to the given pre-flight specifications.
- due to the latter fact and due to the lack of reliable informations about the pre-flight calibration, the data of both sensors had to be calibrated on the basis of in-flight radiometric and atmospheric measurements.
- the moderate SNR levels make it difficult to find reliable reference targets (i.e. large and homogeneous enough) for in-flight calibration. In addition pixel-by-pixel evaluations require the application of noise reduction algorithm, that may affect the information content of the data.

The above mentioned experiences demand a strict control of preflight specifications and calibration of the sensors in the preparation phase of future campaigns. At the given level of data quality increased emphasis has to be put on detailed atmospheric and meteorological measurements and on the careful selection of large and homogeneous in-flight calibration targets. For the future application of imaging spectrometry, an increased availability of imaging spectrometers covering the entire spectral region from 0.4 to 2.5 µm is needed, not only for remote sensing of soils and rocks but also in order to derive important plant biochemical/-physical parameters (e.g. Lignin, Protein features) in the the SWIR region for vegetation studies.

REFERENCES

1. GUZZI R., RIZZI R. & ZIBORDI G., 1987: Atmospheric correction of data measured by a flying platform over sea: elements of a model and its experimental validation. *Applied Optics*, 26, p. 3043-3051.

2. HILL J., 1990: Analysis of GER Imaging Spectrometer Data Acquired During the European Imaging Spectrometry Aircraft Campaign (EISAC)'89, Quality Assessments and First Results. Proceedings of the 10th EARSeL Symposium 1990, Toulouse, in press.

3. JONES A.R., WYATT B.K., WILSON A.K., PLUMMER S.E., BRIGGS S.A. & DRAKE N.A., 1990: Discrimination of nitrogen fertilizer levels on permanent graslands from ground- and aircraft-based imaging spectrometers. Proceedings of the 10th EARSeL Symposium 1990, Toulouse, in press.

4. LEHMANN F., MACKIN S., RICHTER R., ROTHFUSS H. & WALBRODT A., 1989: The European Imaging Spectroscopy Campaign 1989 (EISAC) - pre-processing, processing and data evaluation of the GER airborne imaging spectrometer data. Progress report to the JRC Ispra Establishment of the European

Communities. Institute for Opto-electronics, DLR - German Aerospace Research Establishment, Oberpfaffenhofen.

5. SHAW G., REAGAN A. & HERMAN B., 1973: Investigations of Atmospheric Extinction using direct solar radiation measurements made with a multiple wavelength radiometer. *Journal of Applied Meteorology* 12, 374-380.

6. TANRE D., HERMAN M. & DESCHAMPS P.Y., 1981: Influence of the background contribution upon space measurements of ground reflectance. *Applied Optics*, 20, 3676-3684.

7. TANRE D., DESCHAMPS P.Y., DUHAUT P. & HERMAN M.,1987: Adjacency effects produced by the atmospheric scattering in Thematic Mapper data. *Journal of Geophysical Research*, 92, D10, 12000-12006.

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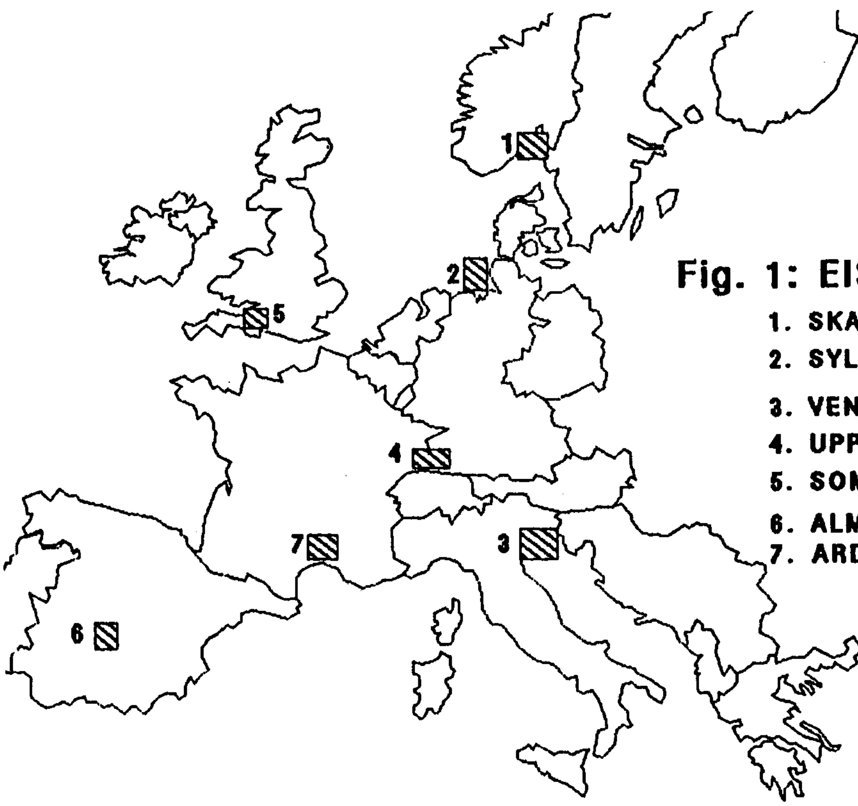

Fig. 1: EISAC TEST SITES

1. SKAGERRAK
2. SYLT AND HELGOLAND
3. VENICE AND SACCA DI GORO
4. UPPER RHINE VALLEY
5. SOMERSET LEVELS
6. ALMADEN
7. ARDECHE

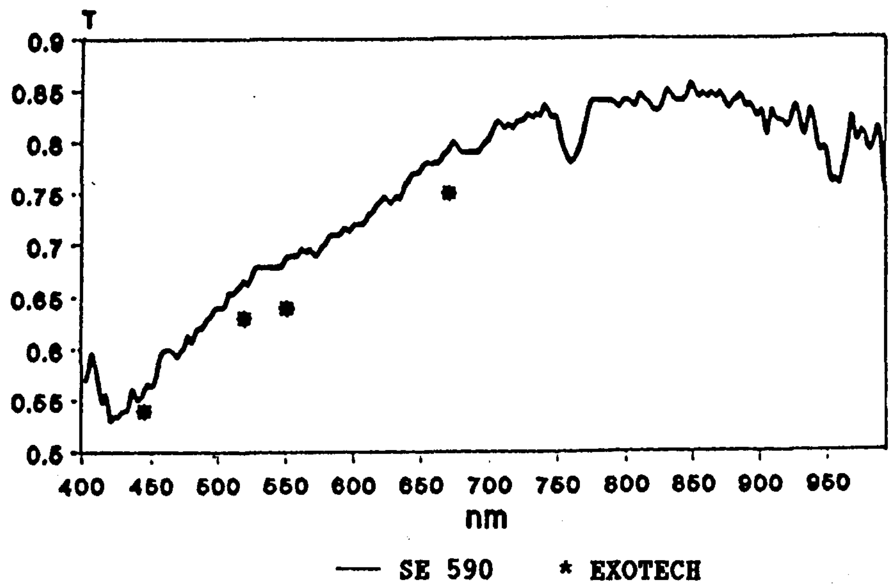

Fig.2: Atmospheric beam transmittance Upper Rhine Valley 13 June 1989

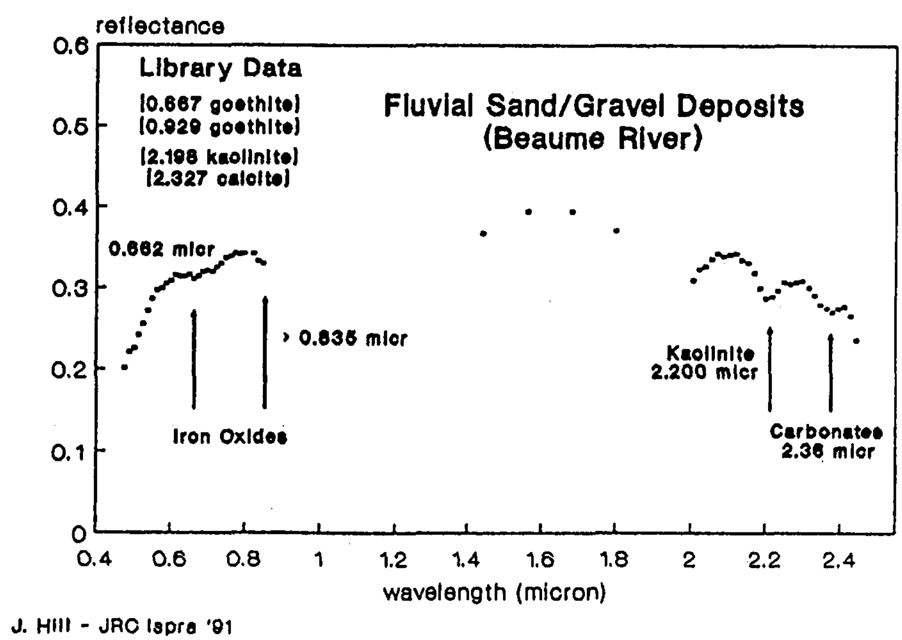

Fig.3a: GER reflectance spectrum of fluvial deposits from the Ardeche test site

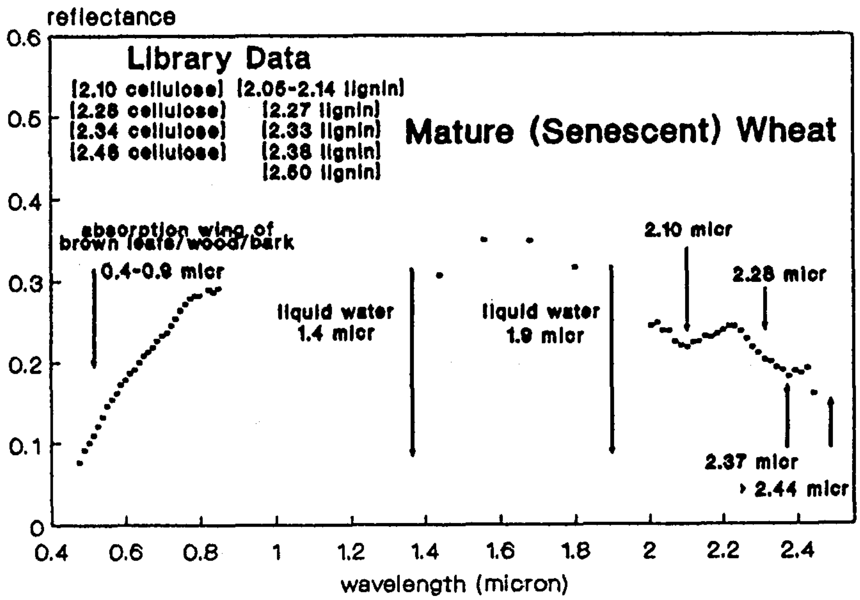

Fig.3b: GER reflectance spectrum of mature wheat in the Ardeche test site

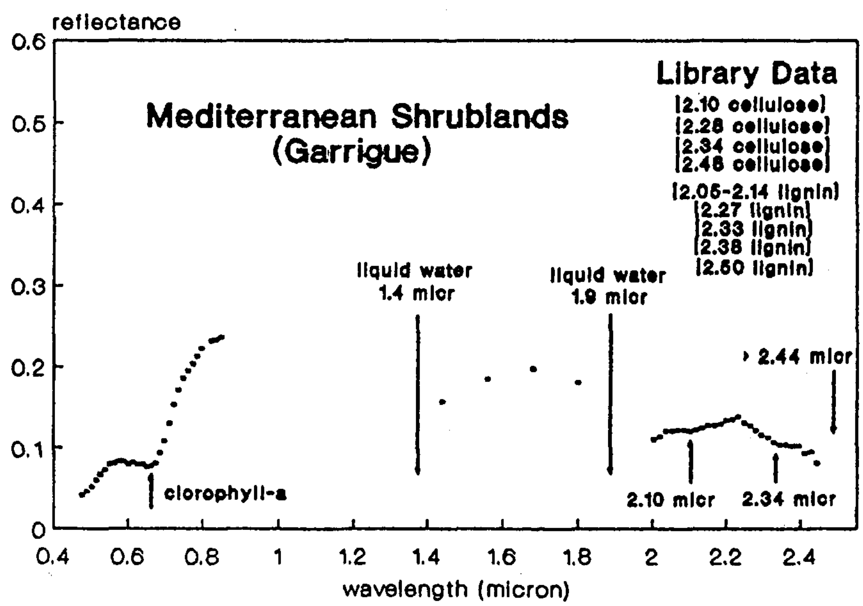

Fig.3c: GER reflectance spectrum of mediterranean shrublands in the Ardeche test site

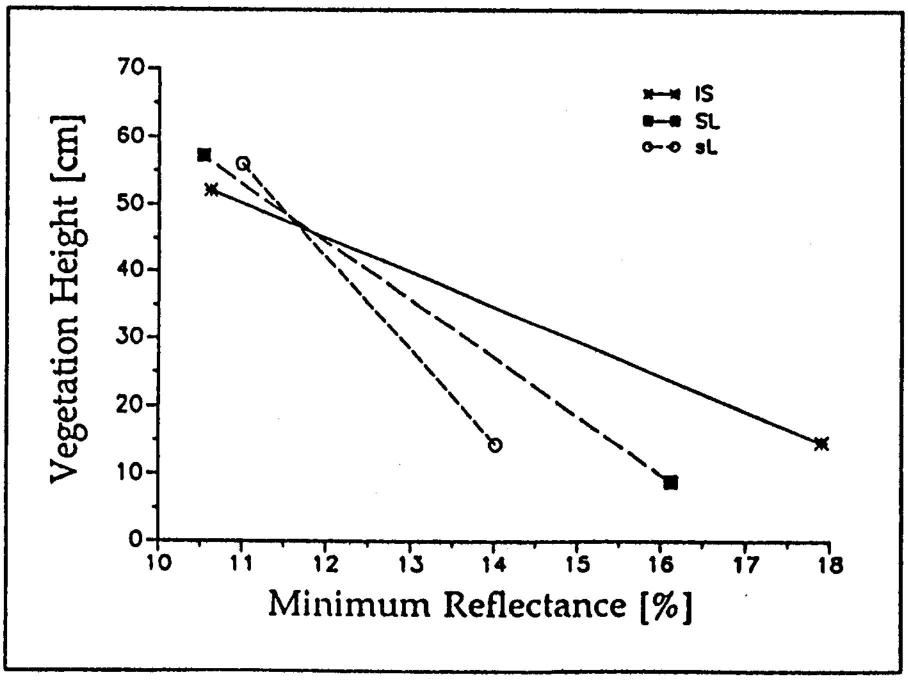

Fig.4a: Regression between "minimum reflectance" and vegetation height of corn on different soil types in the Upper Rhine Valley

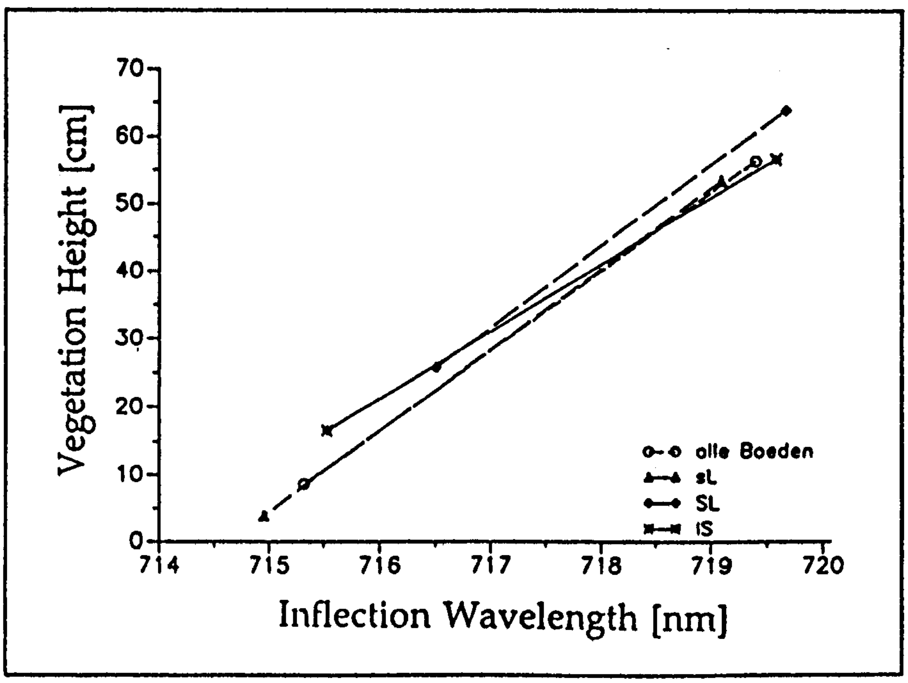

Fig.4b: Regression between "inflection wavelength" and vegetation height of corn on different soil types in the Upper Rhine Valley