Hyperspectral-based characterization of grassland for the control of agri-environmental measures

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ABSTRACT

Agri-environmental measures (AEM) are now compulsory and consolidated in many rural development plans in EU. Due to the diversity of farming systems and their importance in agricultural landscape, grasslands and headlands management represent an important part of the AEM. Currently available techniques for non-destructive herbage measurements have a limited accuracy. In the absence of fast and automatic means to monitor grassland, the quality of grassland management strongly depends on visual judgments. With the recently imaging spectroscopy development, a new and quick method for non-destructive grassland characterization can be explored. The main objectives of this research are to (a) determine best hyperspectral wavebands for the study of grasslands over the spectral range of 400-1300 nm, and (b) to assess grasslands classification accuracies achievable using various combinations of hyperspectral narrow wavebands. Thirty-three grasslands were studied and monitored from end of May to the flight day for a total of eleven consecutive dates of observation where ground cover was scored visually. These parcels were divided into management classes (MCo) reflecting ground observations. Hyperspectral images and ground measurements were recorded simultaneously in the end of June 2004. Grass height (GH), fresh-matter yield (FMY) and dry-matter yield (DMY) were determined and grassland management classes were spectrally identified (MCi) by their canopy variation (texture, vegetation indices, productivity...). Due to the bad meteorological conditions, images were corrected and the spectral analysis was performed on 24 test sites within the CASI image unaffected by poor quality due to the bad weather conditions. The results indicated that 83% of the MCo were correctly estimated through hyperspectral images.

Keywords: Grassland management, Agri-environment, Imaging Spectroscopy, CASI.

1 INTRODUCTION

With the CAP reform, the European agriculture should become more competitive and at the same time will have to face more environmental constraints. Agri-environmental measures are now compulsory and consolidated in many rural development plans in EU. Due to the diversity of farming systems and their importance in the agricultural landscape, grasslands and headlands management represent an important part of the agri-environmental measures.

The control of the agri-environmental measures is closely linked to the knowledge of grasslands management system combined with their physico-chemical and environmental characteristics at the regional level. This information is generally collected over the region of interest by systematic ground observation campaigns. Unfortunately, this approach can be expensive and time consuming.

An alternative solution could be the use of remote sensing as a consistent verification tool in the management and the control of parcel-based agricultural activities. Nowadays, remote sensing is mainly used to control the land-use (e.g. IACS[1] systems), but due to their spectral resolution, the actual panchromatic or multispectral sensors are limited for ecological studies and for monitoring semi-natural grasslands. The excellent spatial and spectral resolution of hyperspectral sensors would significantly improve remote sensing capacities.

The overall objective of this CASI-ATM 2003 project is to analyse airborne imaging spectrometer data in order to realise spectral separation of grasslands based on management practices.

On the one hand, this CASI-ATM 2003 project is a continuum and a possible validation of the first flight campaign using CASI-2 (VIS/NIR) and SWIR sensors, which was performed in August 2002 on an other Belgian site(Lorraine test site). This previous study was undertaken to analyse meadows quality characteristics and had

Presented at the Airborne Imaging Spectroscopy Workshop, Bruges, 8 October 2004

[1] Integrated Administration Control System

determined that the good spectral resolution of the CASI and SASI sensors allows to estimate the quantity (e.g. wet matter, biomass, grass height) and the quality (e.g. protein, VEM, DVE) of grass canopy and so to establish regional inventories on grass production potentials [1]. These first results were very promising and this new campaign were an opportunity to validate these results in different conditions (different places, different moments).

On the other hand, this study is innovative and tries to enlighten how remote sensing technologies in hyperspectral domain are capable to facilitate monitoring and assessment of policies and agri-environmental measures.

In the Walloon Region, AEMs are the subject to specific regulations (11th March 1999 and 15th December 2000). Amongst the applied agri-environmental measures, the main ones that could be advantageously controlled by means of remote sensing, focalized on the hyperspectral mode in the frame of this project, are:

- late mowing or grazing;
- very late mowing with input limitation;
- grassy headland;
- extensive headland;
- strips of extensive meadows.

For each of these measures or production methods, constraints have been defined which could be controlled by means of analyses of hyperspectral imagery:

Temporal constraints: periods of mowing, grazing, sowing or harvesting are generally fixed. In some cases, the measures must be applied during several years to be subsidized.

Spatial constraints: areas concerned by the agri-environmental measures inside of the agricultural parcels must meet some requirements in terms of minimal dimensions, surface area (minimal and maximal) or distance.

Technical constraints: technical constraints are for example generally applied on phytosanitary and fertilizing treatments, most of time prohibited or limited. In case of grazing, the carrying capacity is often limited.

This study is focused on the temporal constraints and evaluates the opportunity of using of airborne hyperspectral data to calculate different indices in order to trace the recent history of grasslands and headlands in terms of management. Cutting or grazing actions can be considered as major stresses, which have an impact on the spectral signature of grass canopy. Changes of spectral signature depend not only on the nature and the intensity of the action, but also on the time spent between the action and the remote sensing data acquisition.

2 MATERIALS & METHODS

2.1 Study Area and Ground Measurements

The study area of this project is the municipality of Attert, located in the southeast part of Belgium (with center coordinates of 5°45'22.79''E and 49°44'48.55''N). Attert is a representative grassland region where environmental aspects are important, as it is located in a Natura 2000 area. In the year 2002, three quarters of the declared parcels (about 600 parcels) are grasslands and the total acreage of temporal and permanent meadows represents two thirds of the total agricultural area (approximately 1700 ha). This site was chosen for the important part of agricultural area covered by grassland and its large panel of grasslands management practices including grassland with agri-environmental measures.

A subset of 33 parcels was followed before the flight for a total of 11 consecutive dates of observation where ground cover was scored visually. Table 1 provides management practices observed for each date (13/05, 22/05, 25/05, 28/05, 01/06, 03/06, 09/06, 12/06, 16/06, 20/06 and 24/06/04) that allow to identify a management class (MCo) for each parcel. In total 3 parcels (MCo =NPNF) with agri-environmental measures were present on the study area with no cut and no grazing authorized before 30/06.

These parcels are characterized with a high biomass and grass height and a good homogeneity in terms of texture. Twelve parcels (MCo = P) were grazing land. Grazing defoliates vegetation, alters nutrient cycles and delays plant development through trampling [2] increasing in this way the biological diversity and heterogeneity. Finally, 18 haying grasslands were identified (MCo = F). Haying of grassland involves the cutting of the grass just above the ground and then removing the vegetation, which is used as livestock fodder. Frank and Hofmann [3] determined that haying stimulated stem development, resulting in greater stem density and biomass production.

Table 1. Management practices observed on the thirty-three monitored parcels and their respective management class (MCo). R = Restoration, F = Haying, P = grazing, NP NF = No Grazing and No Haying

PARCEL	OBS1	OBS2	OBS3	OBS4	OBS5	OBS6	OBS7	OBS8	OBS9	OBS10	OBS11	MCo	LAST CUT
1	*	P	RP	P	P	P	RP	RP	P	RP	F	P	22/06/2004
2	P	P	P	P	P	P	P	P	P	P	F	P	22/06/2004
3	*	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	F	18/06/2004
4	*	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	RF	F	14/06/2004
5	*	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	F	18/06/2004
6	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	RF	F	15/06/2004
7	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	
8	*	P	P	P	P	P	P	P	P	P	P	P	
9	NP NF	NP NF	NP NF	F	RF	RF	RF	RF	RF	RF	RF	F	28/05/2004
10	P	P	R	R	R	P	P	P	P	P	RP	P	
11	RF	RF	RF	P	P	P	RP	P	P	P	P	P	
12	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	RF	RF	RF	F	09/06/2004
13	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	F	22/06/2004
14	NP NF	NP NF	NP NF	F	RF	RF	RF	RF	RF	RF	RF	F	27/05/2004
15	NP NF	NP NF	NP NF	F	RF	RF	RF	RF	RF	P	RP	F	28/05/2004
16	*	P	P	P	P	P	P	P	P	P	P	PP	
17	*	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	RF	F	14/06/2004
18	*	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	RF	RF	RF	F	07/06/2004
19	*	P	P	P	PR	P	P	RP	RP	RP	RP	PP	
20	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	
21	*	P	P	P	PR	P	P	P	P	P	RP	PP	
22	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	
23	P	P	RP	P	P	P	P	P	P	P	P	PP	
24	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	RF	F	14/06/2004
25	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	RF	RF	RF	F	07/06/2004
26	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	RF	F	14/06/2004
27	*	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	RF	F	14/06/2004
28	*	NP NF	P	P	P	P	P	P	P	P	P	P	
29	*	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	RF	RF	F	10/06/2004
30	*	P	P	P	P	P	P	P	P	P	P	PP	
31	*	P	P	P	P	P	P	P	P	RP	RP	PP	
32	*	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	RF	RF	RF	F	09/06/2004
33	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	NP NF	F	RF	F	18/06/2004

In addition to these observations, ground measurements were realized simultaneously with the hyperspectral airborne flight. For each of the parcels, 4 sampling units were defined and georeferenced with GPS. Ground observations included a measure of grass height, grass biomass and floristic composition. Samples from each elementary sampling unit were also analyzed in laboratory to determine the dry matter content.

Due to the bad meteorological conditions, images were corrected and the spectral analysis was only performed on 24 test sites within the CASI images unaffected by poor quality due to the bad meteorological conditions.

2.2 Hyperspectral data acquisition

The flight has been scheduled during the last two weeks of June and the beginning of July. This period coincides with the cutting and grazing periods and the control of the agri-environmental constraints. Data were collected on 26th June 2004 from two spectro-radiometric imagers, CASI (400-950nm) and ATM sensors, mounted on an aircraft.

Priority was given to the use of spectral bands from the CASI sensor. However, the project required high spatial resolution therefore data were acquired with a minimum of 2.4m by 2.4m spatial resolution along the nadir line. This resolution can indeed be considered as adequate to spectrally identify homogeneity and/or heterogeneity per pixel and per parcel.

A total of 96 spectral bands with approximately 6 nm spectral sampling interval in the region from 400 to 900 nm and the ATM thermal radiation emitted by the earth surface in one spectral TIR band were recorded.

The study area was covered by 10 flight lines with an overlap of 30-40 %. The table below gives some details of the flight campaign.

Table 2. Details of the flight CASI-ATM 2003 campaign.

Location	Attert municipality
Sensor	CASI & ATM
Altitude	3940 ft
Ground speed	115 knots
Spatial resolution	2.4m x 2.4m for CASI
Swath width	303 pixels
Track length	7.5 km
Number of track	10 flight lines

2.3 Methods

The selection of the biophysical and biochemical variables to investigate in this study has been driven by their ability to track the status of grass vegetation. On the one hand, this implies detectable gradients of the observed pixels between and within parcels. The grassland/headland spatial variability has been used to characterise the management system (e.g. old and young grassland could be respectively characterised by pixel homogeneity or pixel heterogeneity). On the other hand, depending on the management system, the spectro-biophysical relationships could be improved by using indices calculated from hyperspectral data. For this reason, the project has used all the wavelengths area covered by the airborne hyper-spectrometers, from visible to near infrared (CASI sensor) and the thermal infrared band (ATM sensor).

Due to the large spectrum measured by the CASI sensor in the spectral mode (400 to 950 nm), the project has adopted two strategies. In the first one, different indices based on spectral reflectance patterns like in a classical multispectral approach have been computed. On the other hand, the full spectral resolution has been exploited through hyperspectral analyses.

- **Indices strategy**: The most pertinent wavelengths for each index calculated from the CASI sensor and the most pertinent combination of these different indices (calculated from CASI and ATM sensors) have been evaluated with traditional statistical methods.
- **Hyperspectral data analyses strategy**: the possible relationships between spectral data for specific wavelengths and grassland status have also been studied for all CASI data. Spectral transformation techniques are used to reduce the redundant information content. These analyses are based on statistical methods or other image-processing techniques commonly applied to hyperspectral imagery.

3 RESULTS

3.1 Spectral Analysis at Pixel Level (intra-parcel)

This spectral analysis at pixel level is used to investigate and validate CASI/SASI-2002 results, with regards to the characterisation of grass canopy with quantitative information regarding biophysical parameters like biomass, grass height, fresh-matter yield (FMY) and dry-matter yield (DMY). These parameters are directly linked to the age and the management practices supported by grasslands.

In this project the study of reflectance spectroscopy of visible-NIR wavelengths was focused on the characterization of grassland canopy chlorophyll content through characteristics of the positive gradient region within the 677 to 780 nm spectral range. However, ranges 530 to 570 nm and 830-970 nm were also used to produce vegetations indices.which are described below:

Photochemical Reflectance Index:

$$PRI = \frac{R_{529} - R_{569}}{R_{529} + R_{569}}$$

This index is related to the efficiency of light utilisation by the photosynthetic apparatus.

Red-edge slope, Red-edge step and Red-edge maximum slope wavelenght:

$$RESL = \max\left(\frac{dR}{d\lambda}\right)_{\lambda} \text{ in the range 677 to 780 nm} \qquad REST = R_{780} - R_{677} \qquad REMS = \lambda_{RESL}$$

Normalized Difference Vegetation Index:

$$NDVI = \frac{R_{780} - R_{677}}{R_{780} + R_{677}}$$

Water Band Indexes

$$WBI_1 = \frac{R_{902} + (R_{902} - R_{832})}{R_{971}} \quad [2] \qquad\qquad WBI_2 = \frac{R_{902} - R_{785}}{\lambda_{902} - \lambda_{785}}$$

To obtain representative spectral response for each sampling unit, the CASI-ATM pixel responses were averaged within 3x3 pixel subset, centred around the sampling unit location where reflectance spectra is a finely quantified. The different vegetation indices were calculated on these sets of data.

Inspection of the regression results (Table 3) indicates that NDVI and WBI1 and WBI2 are the best indicators to estimate biophysics characteristics. These results confirm the previous ones obtain during the CASI/SASI 2002 campaign realised on a different test-site [1].

Table 3. Observed correlation coefficients between the different indices and grassland characteristics

	Leaf water content	FMY	DMY	Grass Height	Biomass
λRESL	0.297	0.078	0.023	0.19	0.087
NDVI	**0.814**	**0.753**	**0.303**	**0.417**	**0.585**
PRI	0.716	0.567	-0.016	0.243	0.029
RESL	0.579	0.637	0.215	0.149	0.172
REST	0.55	0.595	0.195	0.127	0.152
WBI1	**-0.688**	**-0.587**	**-0.163**	**-0.641**	**-0.335**
WBI2	**-0.722**	**-0.504**	**-0.074**	**-0.534**	**-0.123**

Even if these correlation coefficients are less important (this difference is probably the consequence of the poor quality resulting of bad meteorological conditions during the flight), these results confirm the possible use of spectroscopy imagery for grassland characterisation.

Results in table 3 (see also Compton conclusions [4]) also show that ground truth data collection or canopy sampling for remote sensing studies of grass canopies should measure the total wet biomass and the total dry biomass. This will allow for the calculation of the leaf water content which is more highly correlated with spectral reflectance than either total wet biomass or total dry biomass.

3.2 Spectral Analysis at Parcel Level (inter-parcel)

In a second step, the project has analysed the possibility to classify grassland in three management classes, haying grasslands, grazing grasslands or neither haying nor grazing grasslands. This last class represents the parcels with agri-environmental measures.

The grassland classification is based on the hypothesis that management practices can be identified by the combination of textural indices (qualitative parameters) with vegetation indices (quantitative parameters) selected at the pixel level which are highly correlated with biophysical characteristics (productivity, grass height).

Different textural indices were calculated depending on the type of approach considered. In a global approach, all the pixels of a parcel are analysed simultaneously while in a local one the analysis is made with a moving windows of 3x3 pixels. In the first case, the texture parameter is simply the variance of all the pixels reflectances for each narrow band and in the second case, this parameter is calculated from moving windows determining the variance of the 3x3 pixels windows which are then aggregated over all the parcel to produce a local variance (intra window variability) which is used in complement of the total or global variance.

As the number of bands available for analysis is important with hyperspectral data, many of them are highly correlated and provide redundant information. Band selection refers here to the use of a subset of the most important wavelengths for identification of grassland management practices. In a first step, we used a discriminant analysis to identify regions of interest in the reflectance spectra and to choose the relevant vegetation indices.

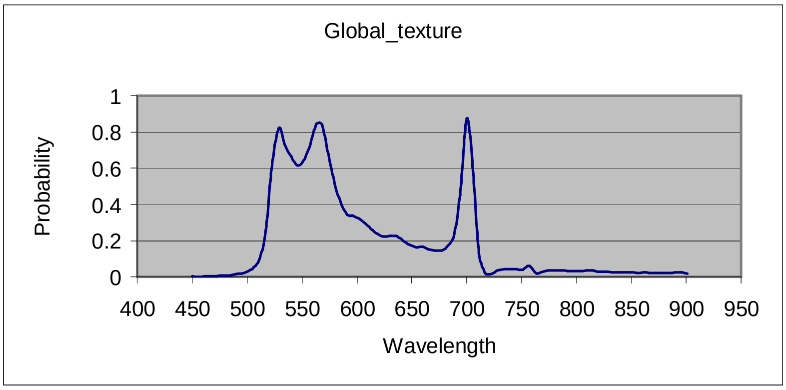

Figure 1. Probability level of the differences between grassland classes: discrimination analysis using global texture parameter calculated for each waveband.

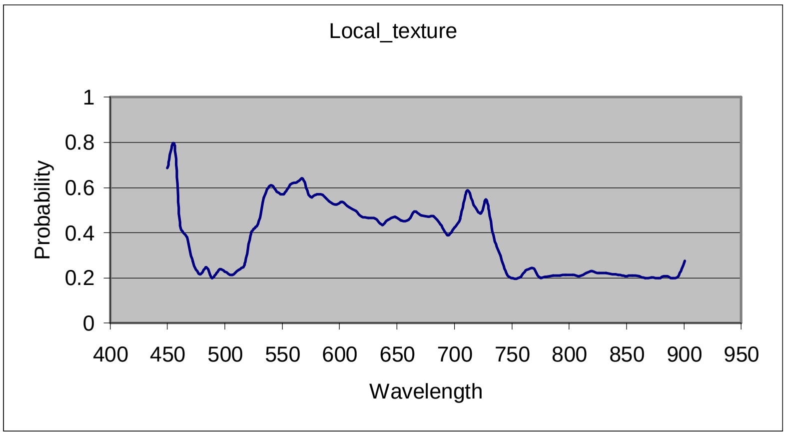

Figure 2. Probability level of the differences between grassland classes: discrimination analysis using local texture parameter calculated for each waveband.

For the global texture parameter, two regions of interest in the reflectance spectra are clearly identified. The first one is located below 500 nm and the second one above 725 nm. The response obtained for the local texture is quite different and presents a minimum value of the probability around 500 nm and above 750 nm but the observed level is not significant ($P<0.05$). Based on these results, two wave bands from the global texture analysis have been selected (450 nm and 725 nm) together with previously defined indices to proceed in a second step to a discriminant analysis with all the selected dependent variables. This second analysis was performed on the 24 parcels situated in the flight lines having a good quality.

The stepwise discriminant analysis identified 3 vegetation indices, (PRI, NDVI and WBI1) and one textural global index (450nm) as significant. The results presented in table 4 using a cross validation procedure show that about 83% of correct classifications may be obtained.

Table 4. Cross classification results.

Classification results	**Observed management classes**		
	F	**NP NF**	**P**
F	13	0	1
NP NF	2	3	1
P	0	0	4
N total	15	3	6
N correct	13	3	4
Proportion	86,70%	100%	66,70%

Even with hyperspectral images characterised by a poor quality, these results are very good and promising.

Only 4 parcels have been classified in a bad management class: two parcels with MCo = F, one parcel with MCo = P were classified as MCo = NPNF while one parcel with MCo = P was classified in F. These misclassifications can easily be explained by a regrowth of grass after a long period without pasture or after haying. As the initial idea is to control if MAE are applied, these results also show that if the 21 parcels with MCo = P or F had been declared in MAE, and therefore identified as MCo = NPNF, 18 of them would have been declared as irregular parcels and only 3 parcels would not have been identified as irregular. It is satisfactory for a first screening and identification of the parcels which have to be controlled in the field, minimising by this way the cost of the field campaign.

4 CONCLUSION

The aim of this study was to assess the ability of near-infrared reflectance spectroscopy (CASI sensor) to be a rapid and reliable method for estimating the grassland management practices and to control if agri-environmental measures are correctly applied (fixed cutting dates, etc). Thirty-three grasslands including all the management practices (grazing, haying, grassland restoration and MAE) were monitored and a wide range of cutting dates were recorded allowing a study over a wide range of field conditions. The results indicate that spectral variations of vegetation within parcels of the same management categories may be related to cutting dates or pasture duration and that spectral mapping of grassland heterogeneity related to management practices may be performed with hyperspectral data, the only limiting factor being the date of the flight with regards to cutting date constraints related to MAE.

ACKNOWLEDGMENTS

This study was suported by the Belgian science policy through the Belgian STEREO programme for remote sensing in the framework of the PRODEX programme of the European Space Agency (ESA). This work was being conducted in cooperation with the Agricultural Systems Unit of the CRA-W (Libramont) and the Vlaamse Instelling voor Technologisch Onderzoek (Vito).

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