SEASONAL VARIABILITY IN SPECTRAL REFLECTANCE FOR DISCRIMINATING GRASSLANDS ALONG A DRY-MESIC GRADIENT IN SWITZERLAND

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ABSTRACT

Dry grasslands in Switzerland are species-rich habitats resulting from a traditional agricultural land use. Almost 40% of plant and in some cases over 50% of the animal species present on dry grasslands are included in the red lists, and are classified as endangered or threatened. Furthermore, it is estimated that about 90% of dry grassland in Switzerland have been transformed to other land cover types over the past 60 years. Existing grasslands are managed differently depending on the region and the lower-altitude communities range from very dry and nutrient-poor to mesic and nutrient-rich conditions. There is a need to better understand the seasonal variation of the reflectance properties of these grassland ecosystems in order to develop efficient and reliable tools for mapping, evaluating and monitoring within the framework of a national inventory. In this study, we examined the potential use of remote sensing for monitoring the development of these grasslands during their growing season. In addition, we investigated the optimal points in time during the growing season for discriminating the different grassland types spectrally. For this purpose a field spectrometer, the Analytical Spectral Devices (ASD) FieldSpec Pro FR, was used to collect reflectance data from 12 sample fields (4 grassland types) in 12 time steps at the Cantons of Aargau and Chur. The measurements examined were from the beginning of March until the beginning of October 2004. The 4 grassland types cover the wetness / nutrient gradient. The revisiting period of the sample areas was approximately 10-14 days depending on the weather conditions. Analysis for statistically significant differences in reflectance was performed between the vegetation types during the growing season. Continuum removal analysis was used as a spectral transformation method in addition to the original reflectance spectra. After the statistical significant bands between the grassland types were found, Classification and Regression Trees (CART) were used to select the bands that could optimally be used to discriminate the different types. Finally, using the bands selected from the CART analysis, the separability of the grassland types during the season was estimated using the Jeffries-Matusita (JM) distance. Our results demonstrate that there is seasonal variation in the spectral reflectance of the grasslands. Furthermore, the potential of using spectral information for discriminating different grassland types changes during the growing period.

Keywords: field spectrometer measurements, species richness, grasslands, continuum removal, seasonal variability, CART, spectral reflectance

1 INTRODUCTION

Dry grasslands are amongst the most species rich habitats of Switzerland. They are the result of centuries of sustainable land use by man and are a characteristic component of the cultural landscape and traditional agriculture of Switzerland. Dry grasslands are very important for nature conservation since more than 350 species (13.1%) present in the red list of higher plants and pteridophytes, depend on these habitats [1]. Species richness can reach up to 100 plant species per $100m^2$ with the fauna richness being equally impressive [2]. A number of studies refer to these habitats and their importance for nature conservation [1-5].

However, these species-rich grasslands are endangered. Since 1945 their area has decreased by 90% mainly due to intensification of agricultural use and the fact that meadows grow wild and decline, unless they are mown [1]. As a result of this change 40% of the plant species growing on dry grasslands are on the red list and many of the animals are rare, endangered or threatened with extinction. Based on the Federal Law on the protection of Nature and Environment a Swiss federal inventory was initiated in 1995 to map sites of significant conservation interest so they can eventually be given protection status by law [1]. Nevertheless, the mapping procedure is carried out through extensive field work making it time consuming and expensive. Furthermore questions if there are habitats that merit (additional) evaluation or if the already protected dry grasslands still protect the species richness, arise. It is becoming evident that a system for monitoring the development of these habitats is required in order to evaluate their ecological status in time.

Remote sensing is a major source of information required for the study of landscape and vegetation development [6]. Price [7] emphasizes the importance of remote sensing towards monitoring and better management of grasslands to ensure their productivity and sustainability. Colour-infrared aerial photographs have been used for pre-interpretation of potential dry grasslands [1] and multispectral sensors like Landsat TM for discrimination of grasslands types under different management practices [8-10]. However, technological advancements have produced new and innovative remote sensing sensors, like hyperspectral sensors [11], creating new challenges. Hyperspectral sensors record with very high spectral resolution of individual bands of less that 10nm over a continuous spectrum covering the 400-2500nm region. Since band widths are narrow local variations in absorption features can be detected contrary to multispectral scanners.

Spectral characteristics of vegetation are determined by many factors influencing the absorption, transmission and reflectance of incoming solar radiation [6, 12]. Chlorophyll, carotene and xanthopyll, influence the visible part of the spectrum (400-700nm) whereas spectral characteristics in the mid and near infrared part of the spectrum (700-1300nm and 1300-2500nm) mainly depend on cell structure, water absorption and foliar biochemical contents [6, 12]. Furthermore vegetation species composition, vegetation stress, canopy cover, and the phenological stage of the vegetation have a major influence on spectral response [13] .

Making use of the unique spectral characteristics of vegetation and the ability of hyperspectral remote sensing to detect detailed narrow spectral features, scientists have studied the spectral differences of forest [14] and grass [15, 16] species. The use of airborne hyperspectral sensors for mapping grass quality [17] and for monitoring of coastal vegetation [18], and of the AVIRIS sensor for mapping vegetation [19] and floristic gradients in grasslands [20] showed promising results. In addition, more than one hyperspectral recording during the growing season improved separability of dune vegetation types [21].

The main objective of this study was to evaluate the potential of using the seasonal variability in spectral reflectance, derived from hyperspectral recordings, for discriminating dry grasslands in Switzerland. There was an interest to identify the best statistically significant spectral wavelength for discriminating grasslands of different types. Furthermore, since recordings were done during the season, the optimal time or times for separability and best discrimination of the different types of grasslands was investigated.

2 MATERIALS AND METHODS

2.1 Study area

The data used in this study were collected from two sampling areas in Switzerland. The first was near the village of Kuttigen at the Canton of Aargau in the eastern part of the Swiss Plateu region. The main grassland types of that area are mesic, species-rich with high nutrients. The stands are mostly tall and dense with many layer of vegetation, with tall and short grasses and herbs of various heights. The majority of the grasslands in the area of Kuttigen are used for the production of hay and only a few are used as pastures. The second sampling area was situated close to the village of Bonaduz at the Canton of Graubunden in the eastern part of the Central Alps region. True semi-dry and some subatlantic dry grasslands are the main types present in the area. Most important characteristics of these types are low level of high-nutrient species and richness in herbs. They are generally dominated by *Bromus erectus* or *Brachypodium pinnatum* with stems standing well above the surrounding shorter vegetation. Subatlantic dry grassland occurs in hot and dry conditions, on rocky or gravelly sites. In addition to *Bromus erectus*, small submediterranean dwarf shrubs can be found, such as *Teucrium chamaedrys, Teucrium montanum* and *Fumana procumbens* [1, 5]. Most grasslands in this area are used as pastures for cows and a smaller part as meadows.

2.2 Field data collection and processing

Spectral reflectance of 4 grassland types was measured and a total of 12 fields were sampled. The grassland types examined in this study (Tab.1) are part of the classification scheme used for the “Dry Grasslands in Switzerland” (DGS) project [1].These types were formed based on the phytosociological composition of the vegetation species with an additional effort to create a vegetation key that was valid for the whole of Switzerland up to the tree-line.

The 4 grassland types (AE, AEMB, MB, XB) investigated in this study come from the lower-altitude communities and cover part of the dry-mesic gradient. The 12 sample fields were selected in order to have an area greater than 5 Landsat TM pixels so they could be used in other studies as well. Furthermore they were characteristic of their type with a purity of more that 75% of the type they belonged to.

Table 1: The grassland types sampled with their codes used in this paper and their description [1].

Type code	Phytosociology	Description
AE	Arrhenatherion	Mesic, species-rich, high-nutrient grassland
AEMB	Transition Arrhenatherion to Mesobromion	High-nutrient, semi-dry grassland
MB	Mesobromion	True semi-dry grassland
XB	Xerobromion	Subatlantic dry grassland

Spectral profiles of the vegetation were collected under sunny and cloudless conditions between 10:00 and 16:00 h using a field spectrometer. The measurements were taken during the growing season of 2004 in 12 time steps from March to October. The sampling was done while walking along 2-3 diagonal transects across the length of every grassland field. This ensured that the spectral measurements would cover the range of variance within each field. Every field was sampled using the same transects though the growing season. Approximately 100-140 spectrometer measurements per field were taken from nadir about 1.5 m over the vegetation and a detailed field protocol was kept. A white reference Spectralon calibration panel was used between every 15-20 measurements to account for the changing atmospheric conditions and irradiance of the sun, removing the effects of the solar illumination [22].The spectral reflectance of the vegetation was calculated as fraction of the approximately 100% reflectance of the white panel.

The Analytical Spectral Devices (ASD) FieldSpec Pro FR spectrometer was used to measure the in situ reflectance. This spectrometer has a 350-2500 nm spectral range and 10 nm spectral resolution with a 25° field-of-view [23]. The reflectance values recorded were at every nm giving a total of 2150 bands. However, the reflectance spectra were too noisy where the atmospheric water absorbed most incoming radiation. Therefore, a number of bands around 1450nm and 1940nm had to be excluded leaving 1935 bands for further analysis.

Apart from the changing atmospheric conditions during the sampling, the possibility of an unforced human error or a malfunction of the spectrometer was also present. Something like that could lead to the registration of a false spectral recording. To ensure that no erroneous files were incorporated in subsequent analyses all the spectral recordings collected during the growing season were checked for errors. This was done by developing a code in the statistical package R [24] to identify potentially false recordings within the 120-140 that existed for each field. First the mean spectral response of a field was calculated and then a 4 standard deviation threshold (+2STD,-2STD) around the mean was applied. Then the wavelengths at every spectral band of each recording were checked for deviation from this threshold. Finally, for every recording, the sum of wavelenghts deviating from the threshold was calculated. An example is given in Figure 1 where from the 129 recordings for the specific field, recordings 45 and 109 have all their wavelength recordings outside the 4 standard deviation threshold. Using this method in conjunction to the detailed field protocol comments, false recordings were identified and excluded from further analysis.

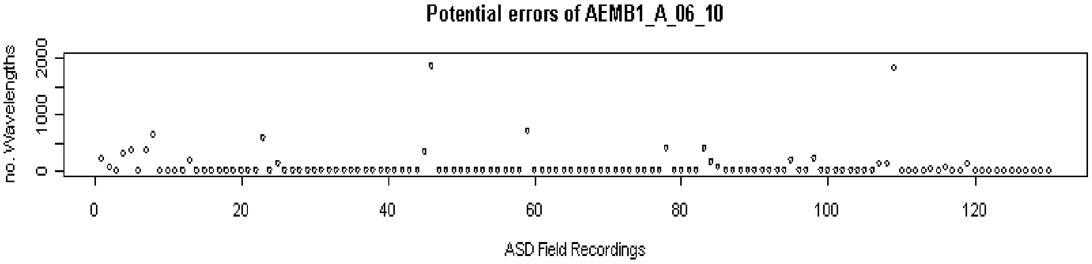

Figure 1: Identification of potential false recording at Aarau field AEMB1 on the 10th June 2004.

2.3 Data transformation

In this study continuum removal analysis was used as a spectral transformation method. Continuum removal is a normalisation technique that enhances the location and depth of individual absorption features [25] putting the isolated spectral features on a level field, thus enabling inter-comparison [26]. The continuum is formed by fitting a convex hull over the top of a spectral curve and using the straight line segments between the local maxima. The convex hull was forced to go through the wavelengths where most of the vegetation reflectance spectra had reflectance maxima, specifically in the regions of 555, 919, 1095, 1275, 1673 and 2209nm. This was done to normalise absorption features of the chlorophyll in the visible and the water absorption in the shortwave infrared part of the spectrum [15]. Once the continuum lines are formed between the defined wavelengths the continuum removed spectra are calculated by dividing the original reflectance values by the corresponding values of the continuum line [27]. The continuum removal transformation method was applied to all the recordings thought the growing season. Both the continuum removed and the original reflectance spectra were incorporated in the subsequent analysis.

2.4 Statistical analysis

Comparison between the spectral signatures of the grassland types was done by applying the Mann-Whitney U-Test (Wilcox test) [28]. The Mann-Whitney U-Test examines whether the differences between two sets of sample data are truly significant or whether these differences could have occurred by chance.

The reflectance of the grassland types was statistically tested to investigate whether there is significant difference between every pair of grassland types per spectral band. The null hypothesis was tested that amongst the pairs of grassland types there is no significant difference between the median reflectance at each spectral band. The significance level was $p<0.01$.If the hypothesis was rejected, it meant that the variance within the two grassland types was smaller that the variance between them [29] for the specific spectral band. The number of statistically different grassland type pairs per spectral bands was counted for every recording day during the growing season. This method provided a basis for identifying the most important spectral bands for discriminating between the grassland types and how they change in time.

The Mann-Whitney test was applied to the reflectance and to the continuum removed spectra. Analysis was also performed between individual fields of the same grassland type to get a better insight of the spectral variability within the same class. Results from that analysis are not presented in this paper.

2.5 Classification and Regression Tree analysis

While hyperspectral imagery is very rich in information, band dimensionality reduction is required before applying any standard statistical classification techniques [30]. In this study Classification and Regression Trees (CART; [31]), were chosen to identify which spectral bands in particular could be used for the optimal discrimination and classification of the grassland types. Optimal hyperspectral band selection using CART has been used in a few studies in literature and has shown to have promising results [32, 33].

CART are statistical models that allow the relation between a dependent variable (grassland type) to a set of independent variables (spectral bands). The result of the CART modelling is a statistically optimised dichotomous tree explaining the presence or absence of the ordinal response of a depended variable as a function of decision rules for independent variables. Some advantages of the CART analysis [34, 35] are: a) they are flexible in handling different dependent variable data types and a big number of independent variables, b) their results are easily summarised and interpreted, c) they give an insight of the interactions between variables and finally d) are methods nonparametric and nonlinear.

CART analysis was performed for every recording day in the growing season. For a given day, an initial spectral band pre-selection was done. Only the spectral bands that were statistically different for all grassland types combination were used. The spectral information was analysed and a decision tree was generated using only the bands that assisted the most in the separation of the grassland types. The selected spectral bands were the ones that explained the greatest amount of deviance [35]. To prevent overfitting of the constructed decision tree on the given data and to ensure its ability to generalise on independent data, “pruning” was applied. This process reduces the tree to the optimal size of nodes to balance between precision and generality [35]. The optimal size of each tree was calculated after a 10-fold cross-validation, that was repeated 15 times, was performed.

The CART analysis was applied to the reflectance as well to the continuum removed spectra. All analysis was implemented using the freely available statistical software *R* [24] and the extension package *tree* [36].

2.6 Distance analysis

The separability between the grassland types and how it changed during the growing season was also investigated. For every recording day, using the optimal spectral bands selected from the CART analysis, the feature space was created. The separability between the grassland types in that feature space was calculated using the Jeffries-Matusita (JM) distance. The JM distance between a pair of probability distributions is seen as the measure of the average distance between the two class density functions [37]. The JM distance is asymptotic to the value of 2 for increasing class separability.

3 RESULTS

The results presented in this paper are from a smaller part of the acquired dataset. In particular, three grassland types are examined (AE, AEMB, MB) at 9 time steps of the growing season. The spectral recordings are from the study area close to the village Kuttigen at the Kanton of Aargau. The recording dates are 25th May, 10th June, 25th June, 21st July, 28th July, 15th August, 23rd August and 18th September 2004.

3.1 Statistically significant spectral bands

The ability to discriminate between the grassland types during the growing season is illustrated by the sum of statistically significant bands. The Mann-Whitney test was applied for all possible combination of individual fields and grassland types for each recording day. The histograms in Figure 2 summarise the results from the 15th August 2004 where 8 fields were sampled, having 27 possible field combinations. The higher the frequency of a spectral band, the more field combinations is significantly different for, and can subsequently be used to discriminate them. Going into detail of that recording date, continuum removed spectra (Fig.2a) when compared to the original spectra (Fig.2b), have less significantly different spectral bands in the near-infrared (800-950nm and around 1100nm) and mid-infrared (around 1600nm) regions and more at the green reflectance peak (570nm).

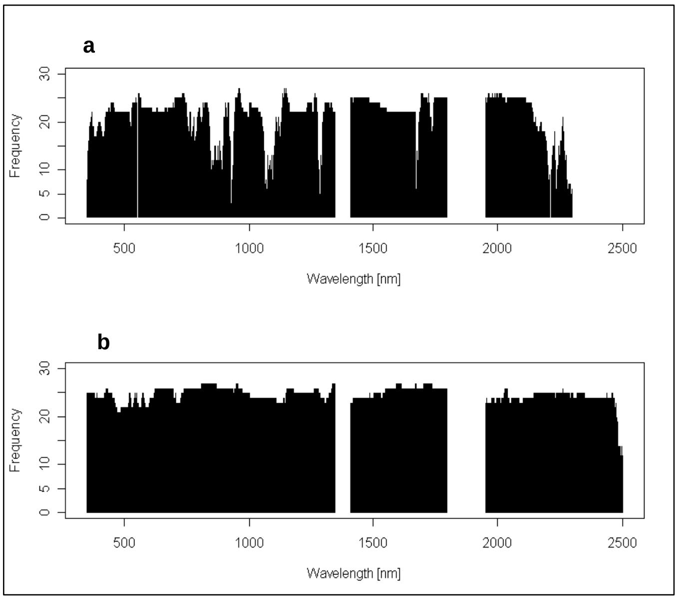

Figure 2. Frequency plot of significantly different spectral bands using the Mann-Whitney U-test for $p<0.01$ for (a) continuum removed and (b) reflectance spectra. Results are taken from the recordings of the 15th August 2004 when 8 fields of 3 grassland types (AE, AEMB, MB) were tested.

The low frequency of significantly different spectral bands in the near-infrared region, when continuum removed spectra were analysed, was probably due to the normalisation for absolute differences of reflectance peaks that continuum removal performs. Differences in that part of the spectrum are caused by canopy structure [6] that are normalised and removed with the continuum removal technique. Higher frequency in the green reflectance region was due to the enhancement of absorption features as a result of the continuum removal technique.

An overview of the total number of significantly different spectral bands during the growing season is shown in Figure 3. When examining the original reflectance spectra, the number of spectral bands, is higher through the whole season, except for June 10th, when compared to the continuum removed spectra. However, for continuum removed spectra, the number is more stable through the season. It is interesting to observe the sudden drop on July 28th. For that date there are much less spectral bands that can discriminate the grassland types. This was probably due to the cutting of the grasslands around that period that made them very similar spectrally removing phenological, structural and biophysical differences.

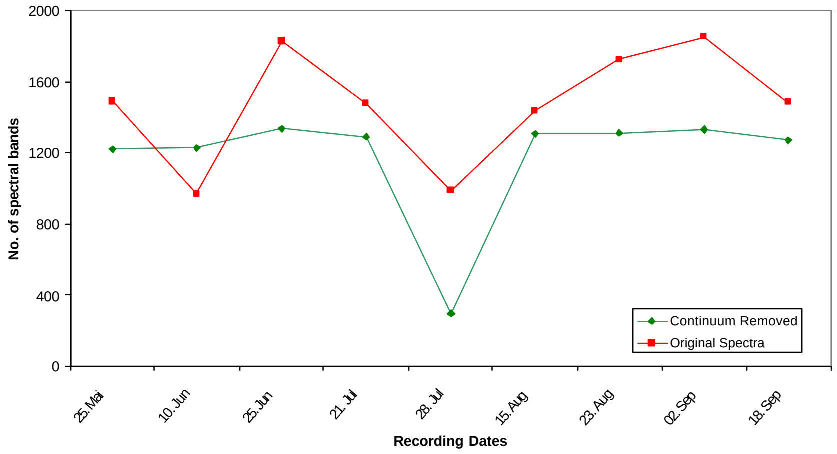

Figure 3. Total number of significantly different spectral bands (Mann-Whitney U-test; p<.0.01) between AE, AEMB and MB grassland types during the growing season for reflectance and continuum removed spectra.

Analysis on the number of significantly different spectral bands between the individual grassland types (Figure 4) showed that types AE and MB, the two sides of the dry-mesic gradient, have a higher number of spectral bands that can be used to discriminate them when using continuum removed spectra (Fig.4a). At the sudden drop of July 28th the AEMB-MB grassland discrimination is less affected compared to the other combinations both for continuum removed (Fig.4a) and original spectra (Fig.4b). Grassland types AE-AEMB have a higher number of spectral bands that discriminate them through the season when compared to MB-AEMB types, both for continuum removed and the original spectra.

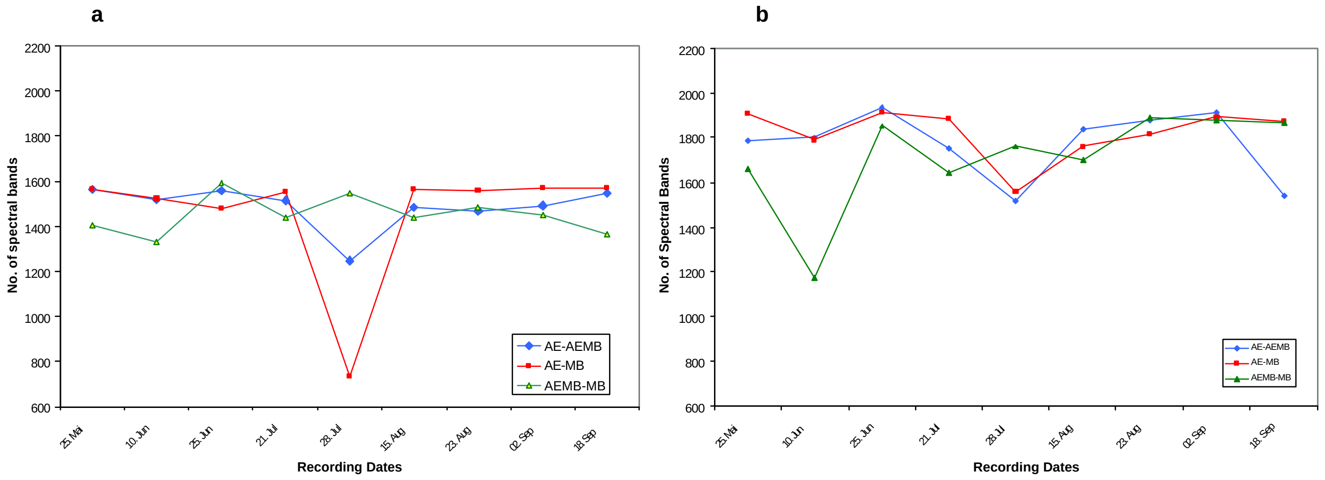

Figure 4. Number of significantly different spectral bands (Mann-Whitney U-test; p<.0.01) for AE-MB, AE-AEMB, AEMB-MB grassland types combinations for (a) continuum removed and (b) reflectance spectra during the growing season.

3.2 Classification and Regression Trees analysis

The results from the CART analysis are the specific spectral bands that can discriminate optimally the grassland types and provide the best separability between them. An example of a CART tree result is shown in Figure 5. The overall graphical representation of these results during the growing season is illustrated in Figure 6.

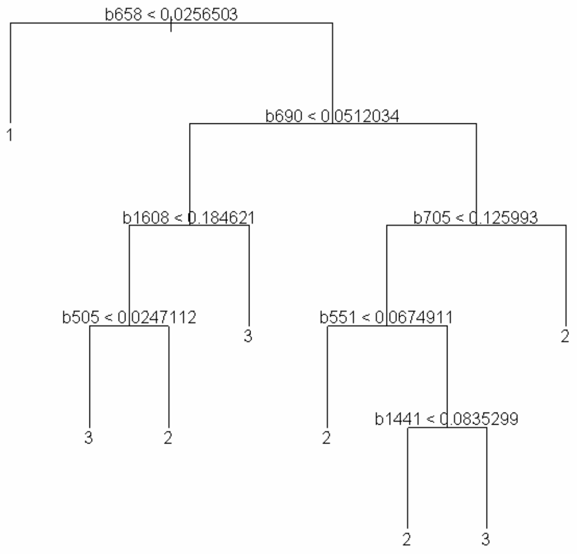

Figure 5. Example of CART analysis for June 10th using reflectance spectra for grassland types AE=1, AEMB=2, MB=3.Spectral bands selected: 658, 690, 160, 505, 705, 551 and 1441nm. Misclassification error rate: 7.7%

Spectral bands selected from the CART analysis when continuum removed spectra were analysed are shown in red and spectral bands selected when the reflectance spectra were analysed are shown in black. Preliminary analysis on these results showed that the short-wave infrared (SWIR) part of the spectrum is not as useful in discriminating the grassland types at the beginning of the season as it becomes after July 28th. After that date we observed constant selection of spectral bands form that part of the spectrum. Furthermore, when continuum removed spectra were analysed we noticed a selection of spectral bands in the visible part of the spectrum, around the green reflectance peak and chlorophyll absorption features through the growing season. When reflectance spectra were analysed we noted a selection of wavelengths in the near-infrared ridge region of the spectrum during the season. In addition, we could see that selection of wavelengths for July 28th is significantly different from all other recording dates. This is due to the cutting of most of the fields around that date. After the cutting of the fields and their gradual development the region around 1300nm becomes important for the discrimination of the grassland types when continuum removed spectra are analysed.

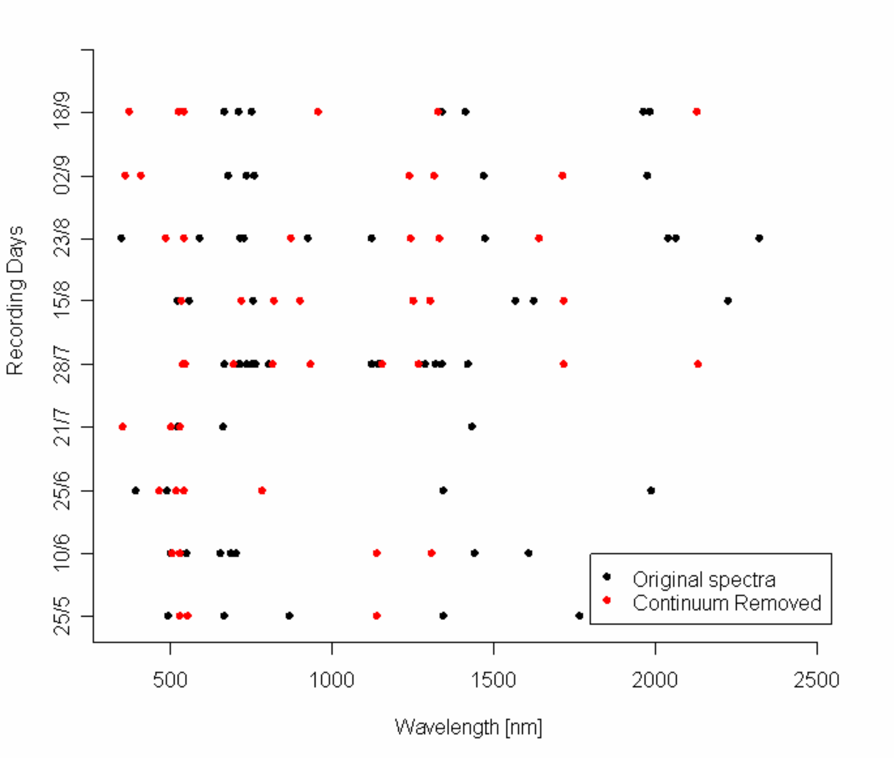

Figure 6. Selected spectral bands from the CART analysis for optimal discrimination of the grassland types for continuum removed and reflectance spectra during the growing season.

Looking at the misclassification performance of the CART trees (Figure 7) we can conclude that when the continuum removed spectra were used in the analysis we could achieve better grassland types classification results. Excluding the 28th of July, the other recordings through the growing season had a smaller error rate.

The misclassification error rate followed the same trend when reflectance or continuum removed spectra were analysed. There was a continuous drop until almost minimum from the beginning of the season (May 25th) until the recording before the cutting of the fields (July 21st).Then we observed an increase for the next two recordings (July 28th, August 15th) that was much higher for the original spectra especially for the second date.

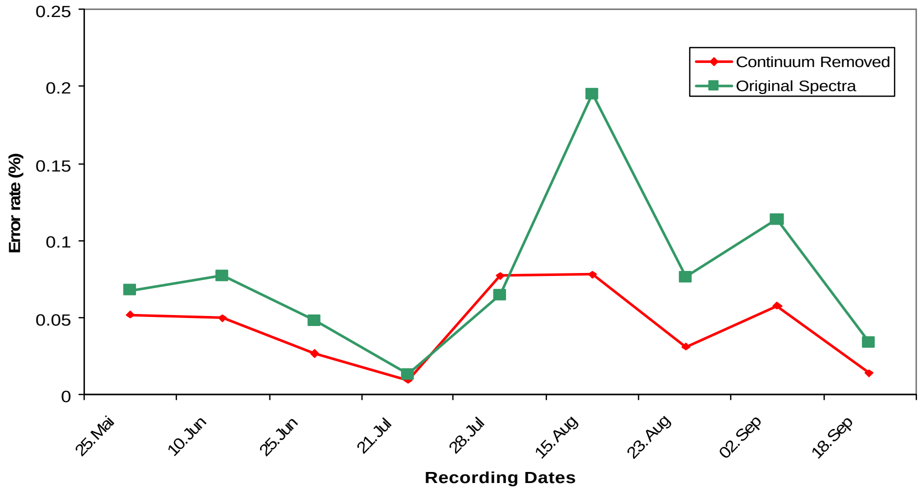

Figure 7. Misclassification error rate of CART analysis for continuum removed and reflectance spectra of the grassland types during the growing season.

In general the misclassification rate was very good. Apart from August 15th, when reflectance spectra were analysed and it reached 19.5%, for all the other recording dates and spectra analysed it was below 10%.

3.3 Feature space distance analysis

Using the selected wavelengths of the CART analysis the separability between grassland types using the Jeffries-Matusita (JM) distance was calculated during the growing season (Fig.8). Grassland types AE and MB, the two sides of the dry-mesic gradient, could be separated very well both when reflectance or continuum removed spectra were used for the analysis. The Jeffries-Matusita distance, except for July 25th, was close to 2, along the growing season. Separability between grassland types AE and AEMB was very good when their spectra were transformed using continuum removal (Fig.8a). When the reflectance spectra were analysed certain days gave worse separability results (July 21st, August 15th, and September 2nd) (Fig.8b). Grassland types AEMB and MB were not as well separated as the other field combinations. However, their JM distance through the season was above 1.2, being relatively good. In addition, we could see that when reflectance spectra (Fig.8b) were analysed the above grasslands types were better separable between June 25th and July 28th whereas when continuum removed spectra was used it added one more date to the above period (August 15th).

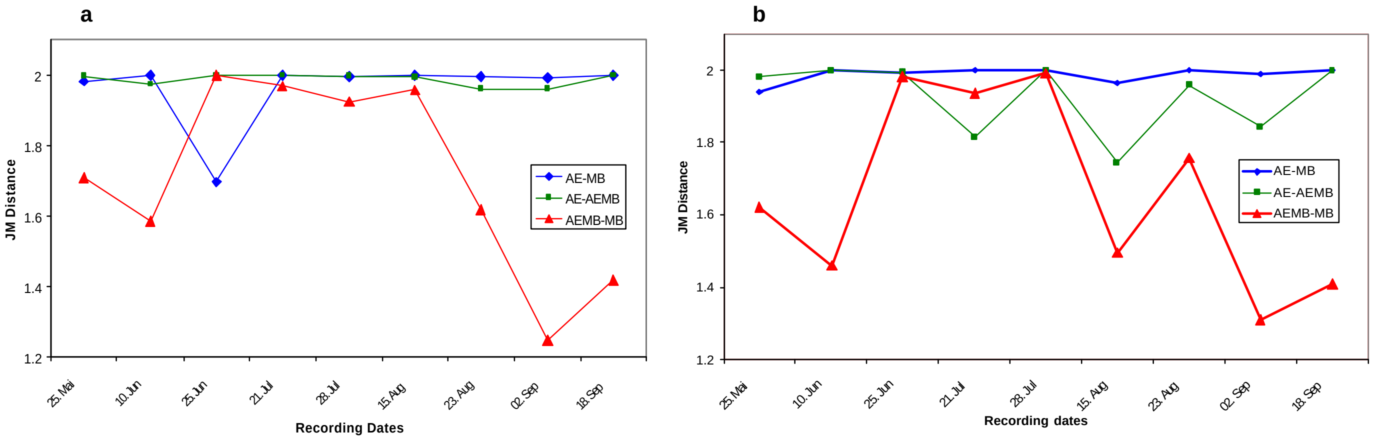

Figure 8. Jeffries-Matusita distances for AE-MB, AE-AEMB and AEMB-MB grassland types combinations during for (a) continuum removed and (b) reflectance spectra during the growing season.

4 CONCLUSIONS

Preliminary results from this study demonstrated that the increased spectral resolution of hyperspectral sensors provides big opportunities for discriminating dry grassland types in Switzerland. This study showed the importance of multiple recordings during the growing season. Many recordings (when feasible) offer a much better understanding of the spectral differences between grassland types and increase the possibilities for successful discrimination and classification. Certain grassland type combinations showed better separability earlier in the growing season than others. Important knowledge was gained on the specific parts of the electromagnetic spectrum that present the best possibilities for discrimination of the grassland types and how these change during the growing season. In addition, this study showed that spectral transformation using continuum removal analysis gave useful results. Continuum removal improved separability in certain parts of the spectrum by enhancing absorption features but also normalised differences in other parts, reducing the significantly different spectral bands there. That led to a smaller number of statistically significant bands that could discriminate the grassland types when compared to reflectance spectra. Nevertheless, continuum removed spectra gave an overall better class-separability throughout the season for the grassland type combinations examined. Finally, Classification and Regression trees proved to be a powerful statistical approach for reducing the dimensionality of hyperspectral data and for optimising the selection of spectral bands that would optimise grassland type separability.

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