MONITORING WHEAT FIELDS AND GRASSLANDS USING SPECTRAL REFLECTANCE DATA

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ABSTRACT

Monitoring of open land including both agricultural areas and natural vegetation types is important e.g. for land utilization mapping and endangerous species habitat analysis. Mapping using satellite or airborne high resolution spectral scanners is becomming increasingly important within agriculture and nature management in order to monitor vegetation parameters such as biomass and leaf area index (LAI) or to detect and classify small scale natural habitats by spectral discrimination. Ground truth nadir measurements of high resolution spectral signatures are not affected by atmospheric attenuation and have hence proven useful as a supplement to remotely sensed data. In this study, a GER mini-IRIS spectroradiometer was used to collect spectral samples over 5 different wheat cultivars and 4 types of natural grassland at the peak of the growing season. Further, LAI was measured over the wheat cultivars in order to evaluate the performance of 8 selected vegetation indices. Discrimination analysis show that 3 wheat cultivars can be separated from Hussar, which is the predominant wheat cultivar in Denmark, and that grasslands can be separated on an age and plant specie diversity level. The use of narrow and broad band imaging scanners with different spatial resolutions is discussed, based on the results of the discrimination analysis. It is concluded, that utilization of a high resolution hyperspectral scanner such as the DAIS-3715 will improve discrimination of both wheat cultivars and grasslands.

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INTRODUCTION

Study areas

The wheat fields are located nearby Research Center Foulum and around Tjele Estate in the township of Tjele near Viborg (fig. 1). This region is a typical Danish rural area, where the majority of the land is cultivated and relatively flat (slopes less than 6 degrees). The soils in the region consist of coarse sandy loam, caracterized by FAO as Orthic Acrisols. Five different cultivars of wheat were chosen for spectral signature analysis: Terra, Hussar, Hunter, Hereward and Marabu. They were all at the same phenological development stage when the measurements were carried out (growth stage: Zadoks 61-63). Hussar has proven to be well suited for the climatic conditions prevalent in Denmark. This cultivar has a relatively short stem and produces big ears resulting in a high yield potential. Hussar accounted for 38% of the total yield of wheat in Denmark in 1995. This number is expected to exceed 50% in 1996.

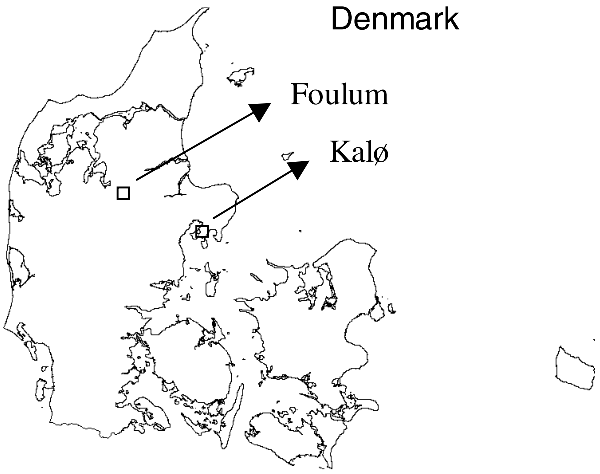

Figure 1: Map of Denmark showing the two study areas: Foulum and Mols Bjerge (Kalø).

Mols Bjerge, Kaloe, (fig. 1) is one of the most hilly regions in Denmark with a relief up to 137 m.a.sl.. For the last 250 years cultivation has been gradually abandoned in favour of e.g. domestic livestock grazing and arable land have been replaced by grassland. To cover a range of management histories 180-250 years old, unfertilized grasslands and young, resown grasslands, fertilized until the early 1980s have been chosen for the study. The 4 different localities differ also with respect to plant specie diversity covering moderate/high plant specie diversity (HD) and low plant specie diversity (LD). The abbreviations Old(HD), Old(LD) and Young(HD), Young(LD) are used in the following.

Old(HD) can be characterized as a dry, heathlike grassland with dominance of Agrostis capillaris and Deschampsia flexuosa with A. vinealis, Poa pratensis, Holcus mollis and Hieracium pilosella abundant and occasionally dominant. Old(LD) has likewise heathlike vegetation but with overall dominance of D. flexuosa. Young(HD) has dry vegetation, which has a low productivity and is relatively species rich, with large patches of bare ground. H. pilosella, Aira praecox, Trifolium arvense, Vicia hirsuta and V. lathyroides are the dominant species. Young(LD) is a species poor, productive, and uniform grassland dominated by Lolium perenne, A. tenius, H. mollis and Rumes acetosella.

THEORY

The cells in plants are very effective scatterers of light because of the high contrast in the index of refraction between the water-rich cell contents and the intercellular air spaces (Ray, 1994). Thus vegetated surfaces are often assumed to be isotropic reflectors, allthough this may not allways be the case. However this assumption is adopted in this study, where all spectral measurements were performed around solar noon. The advantage of measuring the spectral reflection from a canopy lies especially in the prospect of obtaining fast and accurate non-destructive information about the photosynthetic activity (Christensen, 1991) or the magnitude of evapotranspiration used for hydrological modelling (Soegaard, 1991). The leaf area index (LAI) is a key parameter in this respect, which can be estimated by the measured reflectance in a given combination of spectral bands in the visible and near-infrared range (Thomsen, 1991), generally referred to as vegetation indices (VI).

METHODOLOGY

The GER mini-IRIS operates in the region from 400-2500 nm with a spectral resolution of 10 nm from 400-1000 nm and 24 nm from 1000-2500 nm. The measurements in each plot were collected along a transect of 6 samples with a 10 m interval. Each sample consists of 10 scans covering a sampling area of appr. ½m². The measurements were performed from the 25th-28th of June 1995 around solar noon covering five plots at Foulum and 4 plots in Mols Bjerge. At Foulum leaf area index was measured for each cultivar. In 3 plots LAI-measurements were performed with a LAI2000 instrument excactly where the spectroradiometer samples were made. Additional spectroradiometer measurements were made over the Terra and Hussar cultivars followed up by destructive sampling for estimation of LAI in the laboratory. Hereward were measured both with LAI2000 and by destructive sampling.

Measurements

Vegetation is dark in the visible spectrum from 400nm - 700nm because of the high absorption of pigments which occur in leaves. There is a slight increase in reflectivity around 550nm (visible green) because the pigments are least absorptive there. In the spectral range between 700nm and 1300nm plant cover has a high reflectance, increasing with LAI and biomass. From 1300nm to 1800nm vegetation has a relatively low reflectance due to absorption primarily by leaf water. From 2100nm - 2500nm leaf water content may be dominated by soil moisture when plant cover is low. Spectral measurements were averaged by transect to give the mean spectral reflectance pattern for each wheat cultivar (fig. 2) and grassland type (fig. 3).

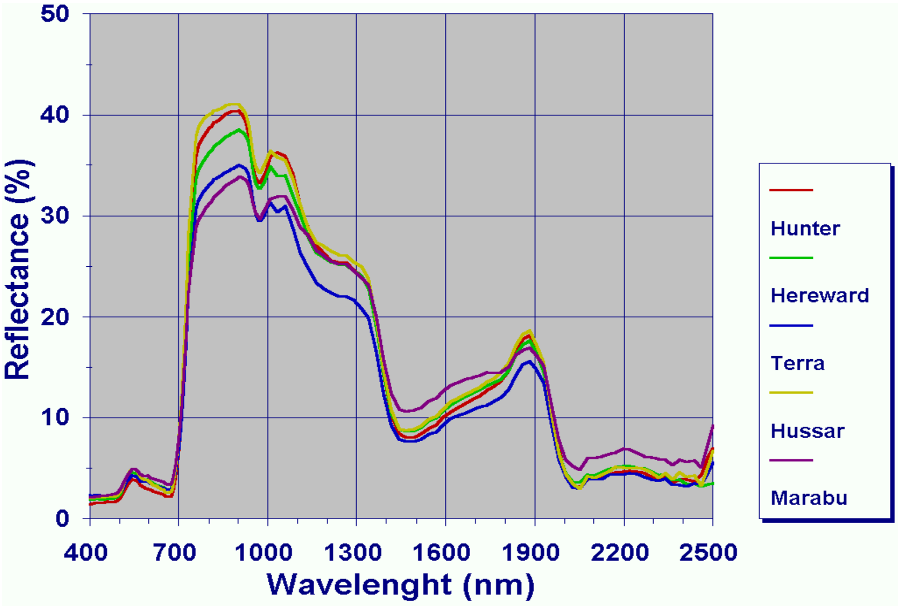

Figure 2: The reflectance curves for the different wheat cultivars showed identical reflectance patterns. Premature senescence of Marabu caused, however, a cross-over around 1000nm, as well as a slightly higher level in the near- and mid-infrared range.

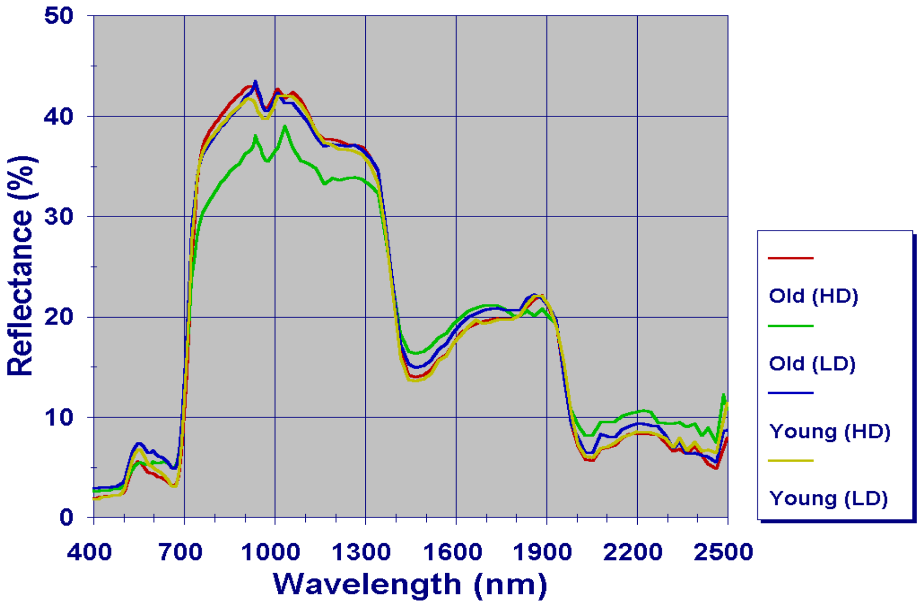

Figure 3: Old and young grasslands with different plant diversities have a different reflectance in VIS, especially in blue and red. In NIR, old grasslands show very different reflectance patterns due to heterogenity differences. Young grasslands are not distinguishable at the plot level in NIR.

ANALYSIS

Vegetation indices

A number of different vegetation indices (VI) were calculated based on spectral reflectance patterns of the 5 wheat cultivars, all at the same phenological development stage and the derived vegetation indices of 3 wheat fields were compared with the LAI2000 measurements (table 1). Since most of the prevalent vegetation indices are designed for use with broad-band satellite sensors, the Landsat TM configuration was simulated.The 1DL_DGVI is, however, a narrow band index based on the first-order derivative of the spectral reflectance curve across the chlorophyl red-edge from 626nm to 795nm and so the full resolution of the spectral measurements were utilized.

Linear regression analysis proved the MSAVI2 index to give the best correlation with LAI. It is evident that the MSAVI2 value for Hussar is rather low, compared with the regression line (fig. 4). This is probably an effect of the more erectophile appearance of Hussar and the fact that the leaves of Hussar displayed small brown spots due to climatically induced leaf-tissue reactions.

The vegetation indices calculated for grasslands are also listed in table 1. For old grasslands, VI seemed to be increasing with plant species diversity whereas VI for young grasslands seemed to be decreasing with plant species diversity. This is due to the fact that young, low diversity grasslands dominated by very productive, sown species have a higher VI than old, low diversity grasslands dominated by indigenous species with low productivity.

Table 1 (next page): RVI: Ratio Vegetation Index (Jordan, 1969), NDVI: Normalized Difference Vegetation Index (Rouse et al., 1973), SAVI: Soil Adjusted Vegetation Index (Huete, 1988), MSAVI2: Second Modified Soil Adjusted Vegetation Index (Qi et al., 1994), GEMI: Global Environmental Monitoring Index (Pinty and Verstraete, 1991), ARVI: Atmospherically Resistant Vegetation Index (Kaufman and Tanre, 1992), GVI: Green Vegetation Index (Crist and Cicone, 1984), 1DL_DGVI: First-order derivative green vegetation index using local baseline (Elvidge and Chen, 1995).

Table 1: Derived vegetation indeces

		Wheat, statistical parameters					Grasslands, derived VI			
		α	β	R^2	Std.err. Y-est	N	Old (HD)	Old (LD)	Young (HD)	Young (LD)
RVI	$\frac{NIR}{R}$	4.77	-7.58	0.75	1.82	19	12.51	6.68	7.03	10.16
NDVI	$\frac{NIR - R}{NIR + R}$	0.07	0.55	0.76	0.03	19	0.84	0.72	0.74	0.81
SAVI	$\frac{NIR - R}{NIR + R + L}(1 + L), L = 0.5$	0.08	0.20	0.78	0.03	19	0.59	0.47	0.52	0.56
MSAVI2	$\frac{1}{2} * \left(2(NIR) - \sqrt{(2 * NIR + 1)^2 - 8(NIR)}\right)$	0.12	0.59	0.79	0.04	19	1.13	0.96	1.03	1.08
GEMI	$\eta * (1 - 0.25 * \eta) - \frac{red - 0.125}{1 - red}$, where $\eta = \frac{2 * (NIR^2 - red^2) + 1.5 * NIR + 0.5 * red}{NIR + red + 0.5}$	0.09	0.43	0.74	0.03	19	0.85	0.73	0.80	0.82
ARVI	$\frac{NIR - rb}{NIR + rb}$, where $rb = red - \gamma * (red - blue), \gamma = 1.0$	0.03	0.83	0.52	0.02	19	0.95	0.87	0.90	0.94
GVI	$-0.2848 * TM1 - 0.2435 * TM2 - 0.5436 * TM3 + 0.7243 * TM4 + 0.0840 * TM5 - 0.1800 * TM7$	0.05	0.02	0.77	0.02	19	0.40	0.34	0.38	0.38
1DL_DGVI	$\sum_{\lambda_1}^{\lambda_n} \mid \rho'(\lambda_i) - \rho'(\lambda_1) \mid \Delta \lambda_i$ λ_i = center wavelenght at the i′th band $\lambda_1 = 626\,nm$ ρ' = first derivative reflectance	6.88	5.28	0.74	2.74	19	-	-	-	-

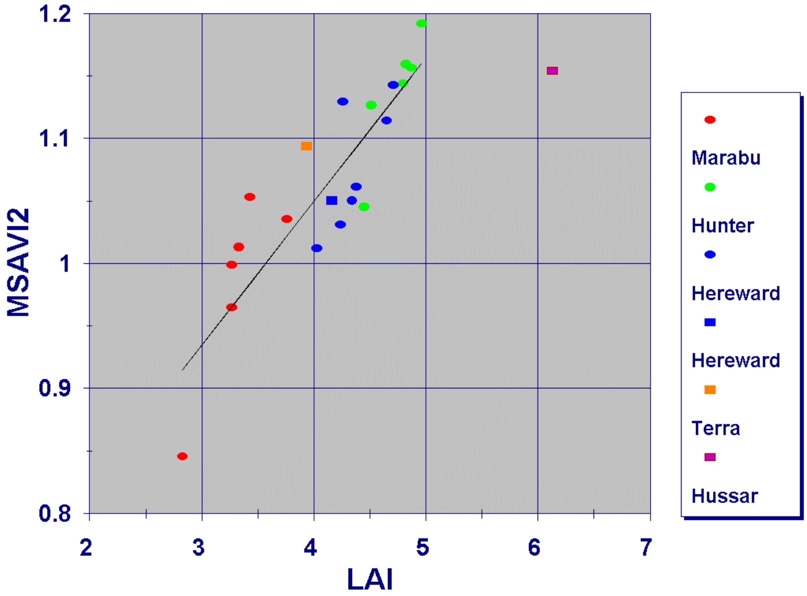

Figure 4: MSAVI2 as a function of LAI.

Discrimination

A discrimination method combining t-tests and F-tests was used. The analyses established the likelihood that a given sample could be a member of a population with specified characteristics or tested the hypothesis of equivilancy between two samples. A 5% significance level was used for the tests. All samples from one plot were individually tested against all samples from another plot and the discrimination possibility for each channel were found.

RESULTS

At Foulum the discrimination analysis tested every wheat cultivar against Hussar (fig. 5) and at Mols Bjerge grasslands were tested to achieve discrimination on either age or plant diversity (fig. 6).The discrimination axis show the sum of both t- and F-tests discriminant at $p < 5\%$, t-test discriminant at $p < 5\%$ and F-test discriminant at $p < 5\%$. If every sample of a plot can be discrimnated from every sample in the test plot, the sum ads up to 100%. Landsat TM configuration is indicated in the graphs.

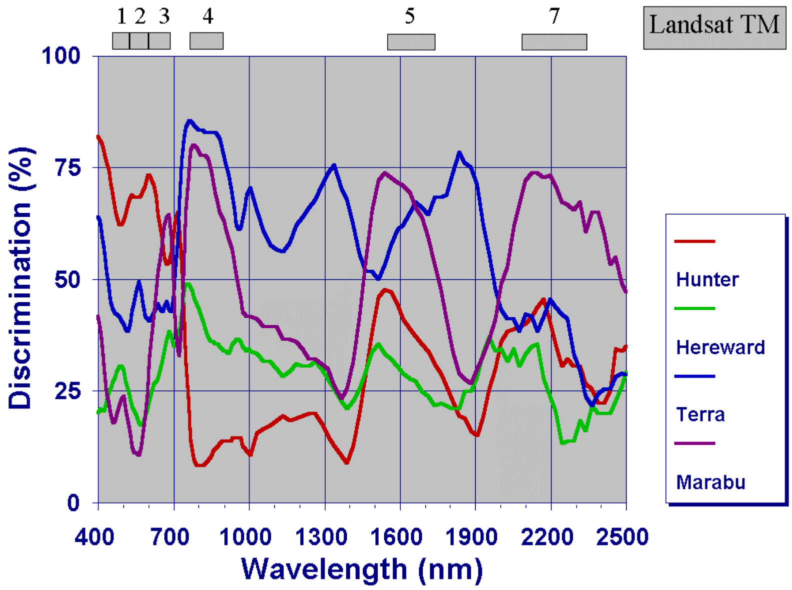

Figure 5: Spectral discrimination of wheat cultivars.

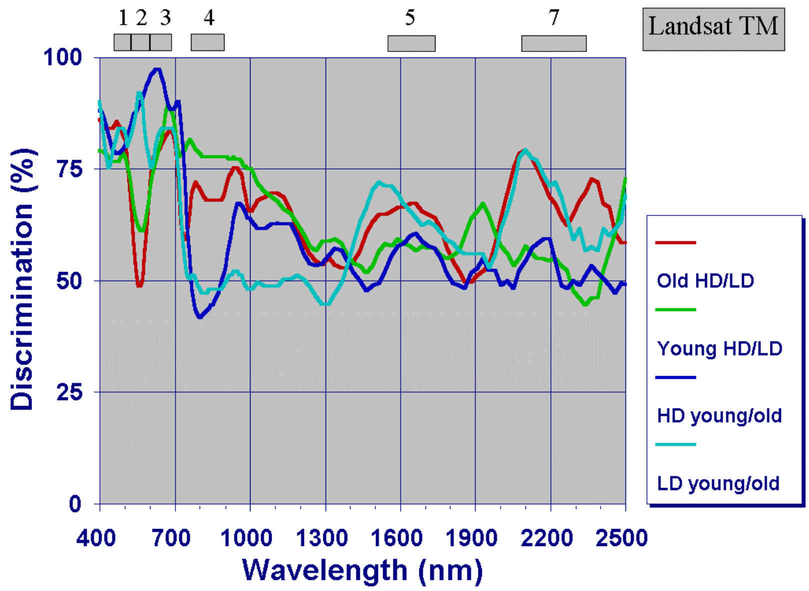

Figure 6: Spectral discrimniation of grasslands

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Fig. 5 shows that Hunter proves to be separable from Hussar in VIS as Hunter has a low reflectance in this spectral range due to a higher photosynthetic activity. Terra and Marabu prove to be separable in the NIR- and mid-IR range. The plateau centered around 850nm is caused by the differences in canopy density as Hussar is more lush and dense than Marabu and Terra. The Marabu cultivar followed barley in rotation, which has caused an accumulation of pathogenic bacteria to accumulate in the soil leading to a premature senescence of the crop. The result is an early withering, reflected in the peak around 670nm (yellow light) and the maximum from 1500-1700nm (differences in water content). Further, the maximum around 2150nm can be related to the withering of the plants, which causes soil reflectance properties to become increasingly important. The separability of Hereward is less than 50% throughout the entire spectral range.

Erectophile canopies generally scatter more radiation into the lower leaf layers than planophile canopies. The 5 wheat cultivars varied considerably in this respect, with Marabu representing the most planophile canopy and Hussar representing the most erectophile canopy. Further, the 5 canopies had very different leaf sizes. These general canopy specific features are probably the most significant parameters influencing the spectral discrimination of wheat cultivars.

Fig. 6 shows that discrimination on grassland diversity (green and red curve) on sample level is promising. In VIS (blue and red) discrimination is above 80% with a local minimum of 50-60% in green around 550 nm. Discrimination on age (dark and light blue) has a discrimination above 80% from 400-700 nm with a local maximum around 90% around 550 nm. After a small decrease, discrimination on diversity increases to 70-75% from appr. 750-900 nm . In the same interval, discrimination on age decreases drastically to below 50%. The reversed curve pattern suggests discrimination is possible within both age and diversity. A general increase in discrimination from 1500-1700 nm is seen. Comparison with fig.3 shows that grassland that can be discriminated at the sample level may not be discriminated at the plot level. This fact stresses that texture is an important parameter when it comes to the classification of natural vegetation.

Classification possibilities of wheat cultivars and grasslands from satellite data are introduced in fig. 5 and fig. 6. Grassland discrimination in VIS and NIR could be achieved from broad band satellite sensors. However, spatial resolution may turn out to be a delimiting factor, as discrimination on texture is evident and an airborne scanner with high spatial resolution would be preferable. Wheat cultivar discrimination is likely to be less sensitive to textural variation and hence to spatial resolution. The separability potential is, however, restricted to relatively narrow bands especially in the visible and a smaller sensor configuration than Landsat TM would be desirable.

CONCLUSION

Discrimination analysis of ground truth, high resolution spectral reflectance measurements over grasslands and wheat cultivars show that discrimination is possible in the VIS, NIR or mid-IR part of the solar spectrum. This implies that high resolution hyperspectral data from the DAIS-3715 scanner will provide a superior classification both within grasslands, primarily due to the high spatial resolution, and within wheat cultivars, primarily due to the high spectral resolution. Hyperspectral airborne data are generally very expensive, but they provide a means of obtaining data of high quality at the optimal time of the growth cycle. The low frequency classification demand of grasslands partly compensates for the high costs. In an agricultural aspect a higher frequency of monitoring is desirable, and as agricultural fields are relatively homogenious, satellite imagery can, when available, be used as a supplement for deriving biophysical parameters, such as leaf area index. Upscaling from ground truth data with a very fine spatial resolution via airborne hyperspectral scanner data to satellite data with a relatively coarse resolution will be investigated in the future.

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