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Temporal variation of the winter rape crop spectral characteristics

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A b s t r a c t. Application of remote sensing techniques in agriculture can be succesfull only if it is based on the knowledge of spectral-temporal properties of different crops and bare soils. The main goal of this study was to follow changes in the reflectance of a winter rape (*Brassica napus*) cultivar throughout a growing season. Variation in the spectral characteristics related to solar position was investigated as well. Radiation reflectance in the following wavelengths: 540, 555, 640, 740, 860 and 960 nm, was measured with a ground-based spectrophotometer at nine growing stages between planting and maturity of winter rape. Multi-temporal reflectance data characterize well morphological and biochemical changes as winter rape developes throughout the growing season. Specific elements of this plant, e.g., young leaves, pods and yellow flowers cause differences in the seasonal reflectance patterns when compared to those of wheat or corn.

K e y w o r d s: crop growth, winter rape, field spectroscopy, vegetation indices, remote sensing

INTRODUCTION

A lot of research has been dedicated to the agricultural land cover, acreage estimation and yield forecasting using remote sensing techniques in the past decades (Moulin *et al.*, 1995; Bouman, 1992; Jacquemoud *et al.*, 1995; Benedetti *et al.,* 1994; Nieuwenhuis and Kramer, 1995). To improve our ability to measure and monitor changes in the important landscape parameters from the distance, radiance data obtained from ground measurements are needed.

Vegetation canopy can be characterized by a set of parameters. They include reflectance and transmittance as optical parameters which bear wavelength and temporal dependencies. Geometrical shapes and inclination of leaves, stalks, stems etc. as structural parameters bear temporal and spatial dependencies (Goel, 1988). They change in consecutive phenological stages during a growing season. Spectral data for a particular agricultural surface may be true only for a short time since architectural changes of vegetation canopies occur regularly during the normal growth cycle. Moreover, spectral behaviour of vegetation canopies with the canopy composition, architectural differences, growth stage, canopy closure and leaf optical properties depends upon solar zenith angle (Kollenkark *et al*., 1982; Pinter *et al.,* 1985). Temporal variation of vegetative surfaces can reduce applicability of the multispectral satellite data, thus remote sensing classification procedures of the agricultural scenes should be based on the temporal characteristics of the crops over the entire season.

Knowledge of spectral characteristics of an individual crop growing stage is necessary in detecting any deviations in plant development. Stresses caused by plant disease, drought and nutrient deficiences may change optical properties of leaves, and then, can significantly influence canopy reflectance in the way that is specific for a given growing stage.

A number of important efforts over the last few years of dealing with radiation modelling and field measurements have led to a greatly improved understanding of the biophysical, atmospheric and other factors which cause variability in the spectral reflectance over time. However, relatively few measurements have been published on the present temporal variation of a given arable crop during its whole growing season. Seasonal changes in the reflectance were shown from the ground measurements of wheat or barley (Leamer *et al.,* 1978; Giovacchini, 1984; Kuusk, 1991) and corn (O'Neil, 1984). Such data on the winter rape crop are not available in literature. Winter rape is the most important oil plant in Poland and the main source of vegetable oil. This crop is sown in Poland at the end of August and harvested in June the following year. Total area of winter rape amounted to 500 000 ha. Increasing mean size of fields makes us look

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for a possibility to use remote sensing techniques for yield forecasting, condition monitoring, overwintering assessment, and stress detection in this crop.

The objective of the present work was to define winter rape spectral reflectance and to follow changes in the crop reflectance through a growing season within visible and near infra-red wavelengths, both individually and combined to form a vegetation index. Since the spectral characteristics were investigated at a set of solar zenith angles, the results should show the influence of the time-of-day on the spectral signatures.

METHODS

The measurement were taken in Poznań, Poland (52°40' N, 16°84' E). Winter rape (var. Bolko) was sown in rows 25 cm apart, in four containers (40 x 30 cm) which could be moved. Thus, the row orientation was always perpendicular to the solar direction. Spectral data were taken from the soil and then, at nine growing stages during winter rape crop development (Table 1). In autumn at plant development stages 4, 5 and 8, leaves were measured at three solar zenith angles (SZA) and at the stage of 12 leaves only at two SZA. In each growing stage, spectral response of plants was measured four times at the nadir direction at each SZA.

Spectral radiance measurements were taken with a SPZ-03 spectrophotometer in the visible (540, 555, 640 and 740 nm) and near-infrared (860 and 960 nm) range of the electromagnetic spectrum. The spectrophotometer field of view (FOV) is 15° at nadir. The sensor was mounted on frame at a distance of 1.7 m from the center of the plot and in its FOV there were two rows of plants. Readings from a calibrated $BaSO_4$ plate were recorded instantly before and after each measurement sequence. Normalized reflectance (NR) factors were calculated by calculating rations of spectral responses of the rape canopy to those obtained over the barium sulfate plate with known reflectance properties as a function of the solar zenith angle. The measurements were taken before the solar noon, from the early morning at 2 to 4 solar zenith angles (40, 50, 60 and 70°).

Photographs of the measured scene were taken through an optical path of the spectrometer. The pictures were used to assess the canopy cover at each growing stage.

RESULTS AND DISCUSSION

As a result of the winter rape plant development throughout the growing season, substantial changes in their shape and morphology are observed. These changes are not only caused by the enlargement of leaves but also due to the presence of different, plant elements, specific to given stage, e.g., young leaves, flowers, buds etc. Changes of winter rape plant architecture throughout the growing season decide on the spectral properties of this crop.

Seasonal changes in reflectance from winter rape crop in green, red and near-infrared wavebands recorded at different SZA are shown in Fig. 1. Seasonal reflectance patterns for winter rape were, in general, similar to those observed for other arable crops like corn (Baush, 1993), or wheat and barley (Giovacchini *et al.,* 1984), however, some significant differences could be noticed. At early growing stages of winter rape, till the stage of 4 leaves, spectral characteristics of the crop was strongly influenced by the soil. In the stage of 2-3 leaves, vertically oriented leaves appear on plants. In this stage, reflectance is higher than in the case of bare soil, especially at higher solar position since the soil surface is smoother after 20 days from the sowing date and soil there is less self-shadowing.

Changes of the spectral signatures of winter rape stages were greater for the reflectance in the NIR wavelengths during the whole vegetation season. At SZA=50°, at stem formation stage the reflectance in the NIR wavelengths is 3 times greater than from bare soil compared to the reflectance in red wavelengths which was 2.1 times lower in the budding stage than that of bare soil.

Table 1. Agronomic parameters of winter rape crop during the growing season

Growing stage	Date	Solar Zenith Angles	Dominant plant part	Soil cover (%)	Leave inclination (°)	Plant height (cm)
Soil	4 September	40° - 70°	-	-	-	-
2-3 leaves	5 September	40° - 70°	green leaves	15	75	4
4 leaves	10 September	50° - 70°	green leaves	34	60	7
5 leaves	20 September	50° - 70°	green leaves	44	45	9
8 leaves	1 October	60° - 70°	green leaves forming a rossette	52	40	12
12 leaves	11 October	60° - 70°	green, wilted leaves	30	-	15
Stem formation	10 April	40° - 70°	stem with small green leaves	90	30	15
Budding	25 April	40° - 70°	stem with green leaves and buds	90	30	30
Flowering	15 May	40° - 70°	yellow flowers	85	30	60
Full ripening	2 July	40° - 70°	brownish pods on stems	80	-	60

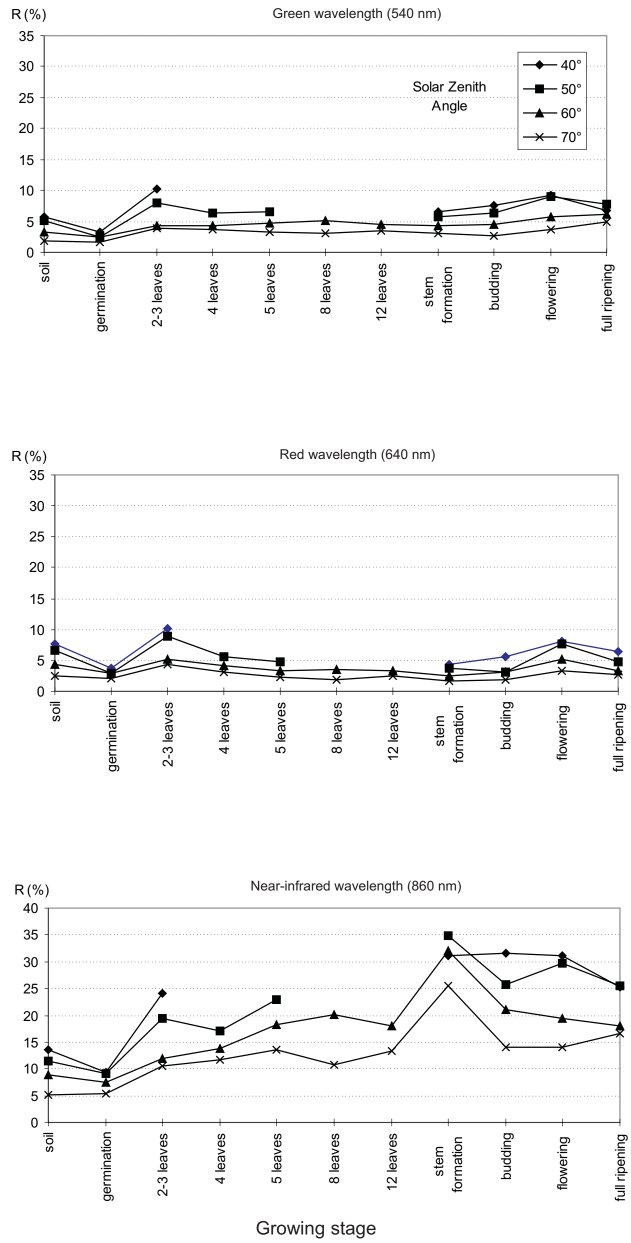

Fig. 1. Multitemporal plots of reflectance factors for three wavelengths as derived from spectral measurements acquired during the growing season at four Solar Zenith Angles.

After the stage of 2-3 leaves, the percentage canopy cover rises slowly with development and reflectance in the visible waveband decreases. In the 4 leave-stage, for the first time in the winter rape crop development, reflectance in the red wavelengths was lower than the reflectance in the green wavelengths at all SZAs (Fig. 2d). Photosynthetic pigments accumulate gradually as the rape leaves mature and plant biomass increases and the maximum absorption in the visible wavelengths occurs in the stem formation stage. In the budding stage, first yellow flowers appear in the crop and reflectance, in both green and red wavelengths, begins to rise. After the maximum in the flowering stage, reflectance in the visible wavelengths decreases because green pods, which developed from flowers, are capable of absorbing visible irradiation. However, replacing yellow flowers with green pods that occurs in the last stage, resulted in decreasing reflectance in the red wavelengths at all SZAs while reflectance in the green wavelengths only at high solar position (SZA=40°).

Reflectance in the NIR wavelengths increases with the vegetative growth and reaches its maximum around the stem formation stage when plant biomass is the greatest. After the stem formation stage, reflectance in the NIR wavelengths start to decrease since plant leaves begin to senesce and the amount of cell-wall/air interface, which is mainly responsible for the internal scattering of radiation in the near-infrared wavelengths, is reduced.

Winter rape plant development in the growing season was disturbed by a dry period at the stage of 12 leaves. Spectrally measured plants in this stage had wilted leaves which caused a considerable decrease of reflectance in the NIR wavelengths, particularly at high solar zenith position. In the visible wavelengths, dry period did not affect the reflectance.

During the whole winter rape growing season, variation of reflectance in the VIS wavelengths with changes in the solar zenith angle, were greater than reflectance in the NIR wavelengths which is consistent with the Huete's (1987) results for wheat. At the stage of stem formation, reflectance in the red wavelengths at SZA=40° is nearly twice and half of that at SZA=70°, compared to a factor of 1.2 for the reflectance in the near-infrared. Relation between reflectance in both VIS and NIR wavelengths on SZA was greater at the later stages, i.e., budding and flowering than at the beginning of plant development.

A linear regression analysis was performed on the time series for reflectance and percentage canopy cover, using a 95% confidence limit. This indicated that reflectance in the visible wavelengths, especially in the red wavelengths, has much weaker relationship to the canopy cover than reflectance in the near-infrared wavelengths. Low correlation coefficients for the reflectance in the red wavelength results from great differences in canopy architecture at the beginning of plant development, which caused rapid changes in the reflectance. Reflectance in the visible wavelengths has stronger relationship to the canopy cover at greater SZAs, while for the reflectance in the near-infrared wavelengths this relationship is stronger at higher solar positions.

A sum, difference, ratio or other linear combination of the reflectance factor from two or more wavelength intervals produce various spectral vegetation indices (Wiegand *et al.,* 1991). Vegetation indices are commonly used in remote

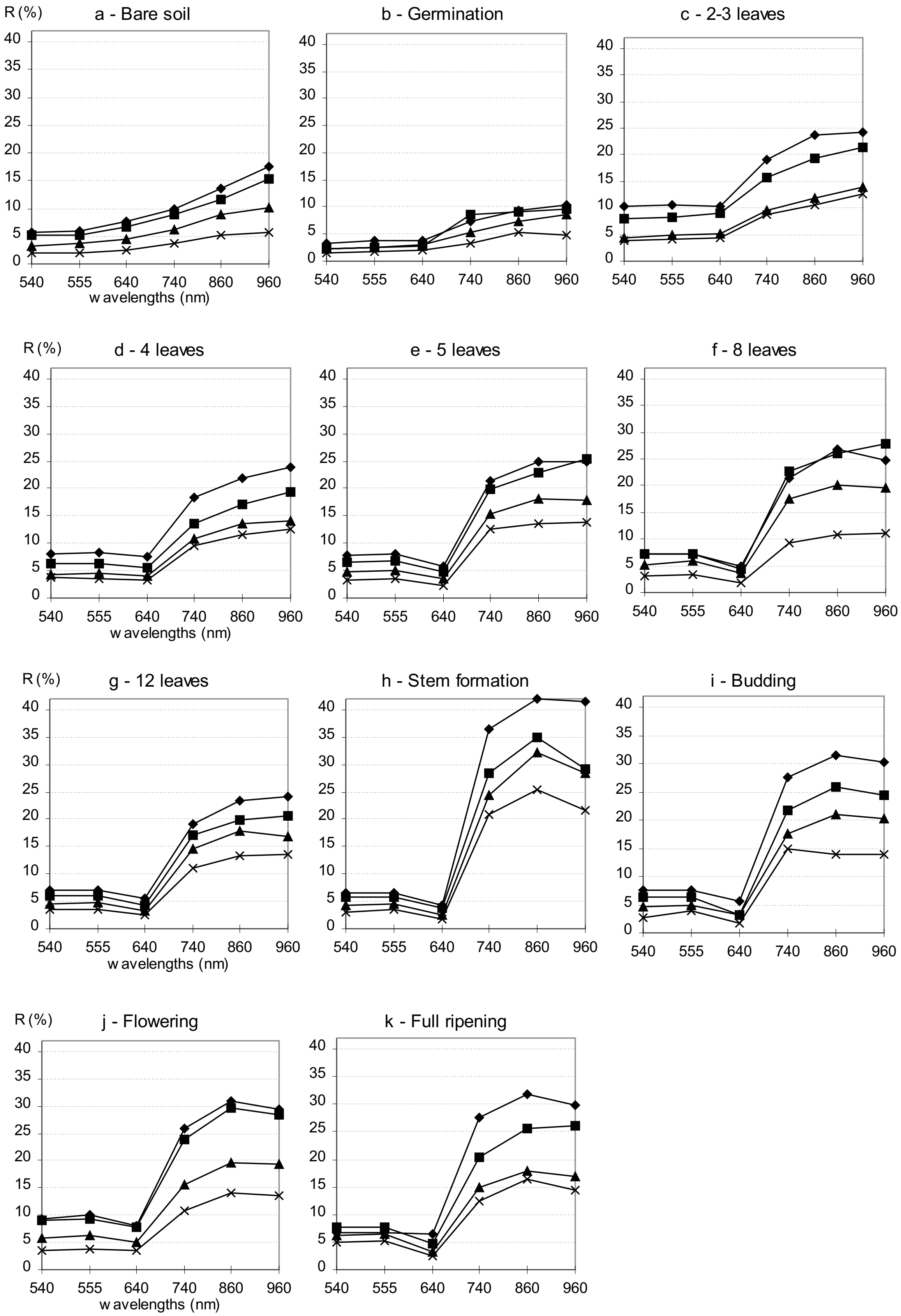

Fig. 2. Spectral reflectance signatures of the winter rape crop in eleven growing stages at four Solar Zenith Angles. For explanations see Fig. 1.

sensing since they are relatively independent of illumination intensity and reduce errors introduced by the non-Lambertian response of $BaSO_4$ reference panels at low sun angels (Pinter *et al.*, 1983). In this study experimental results from the previous chapter were used for the calculation of four nonlinear vegetation indices:

$$\mathrm{NDVI} = \frac{R_{740} + \left(R_{860} + R_{960}\right)/2 - R_{640}}{R_{740} + \left(R_{860} + R_{960}\right)/2 + R_{640}},$$

$$\mathrm{GREEN/RED} = \frac{\left(R_{540} + R_{555}\right)/2}{R_{640}},$$

$$\mathrm{NIR/RED} = \frac{R_{860}}{R_{640}},$$

$$\mathrm{Comp2} = \frac{R_{740} + \left(R_{860} + R_{960}\right)/2 + R_{640}}{2},$$

and three linear indices:

Brightness $= 0.522\,(0.4433\,(R_{540}+R_{555})/2)+0.632\,R_{640}+0.586\,R_{740}+0.264\,(R_{860}+R_{960})/2$,

Yellowness $= -0.829\,(R_{540}+R_{555})/2+0.522\,R_{640}-0.039\,R_{740}+0.1850\,(R_{860}+R_{960})/2$,

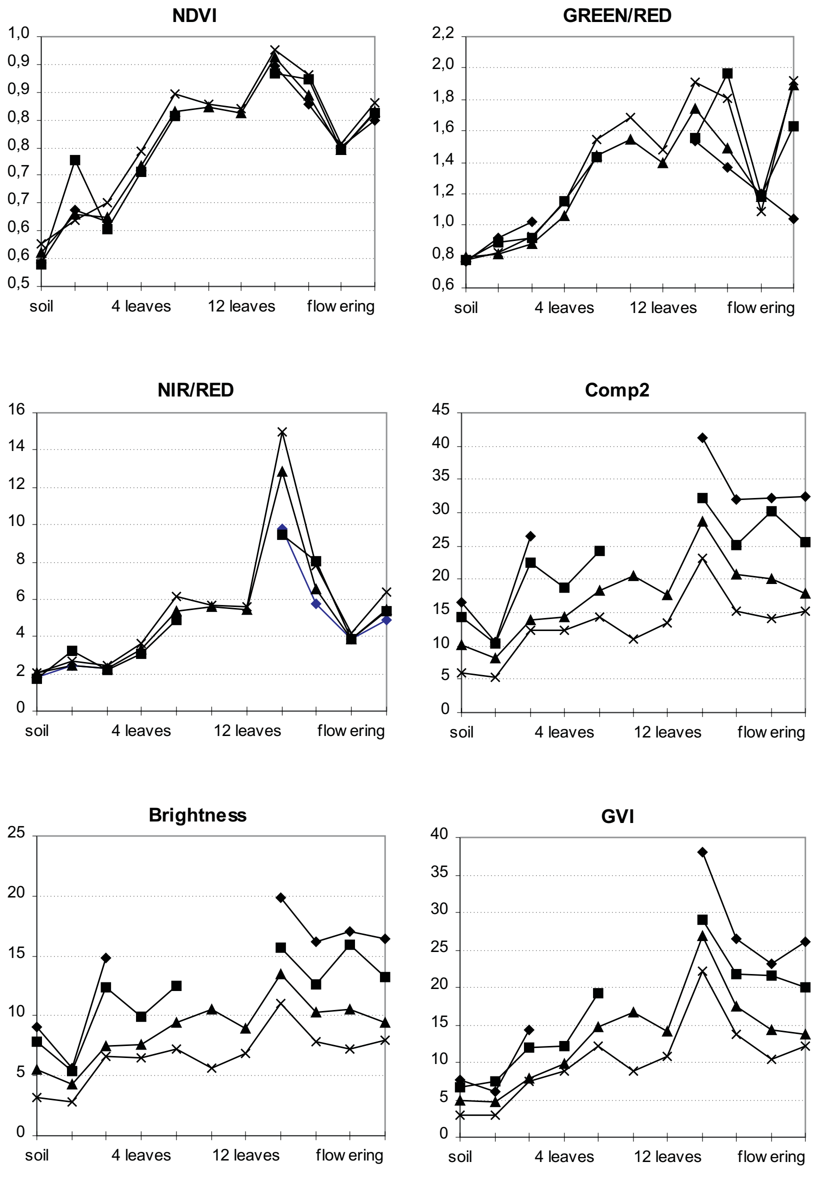

Fig. 3. Seasonal variation in four nonlinear and two linear vegetation indices of the winter rape crop at four Solar Zenith Angles. For explanations see Fig. 1.

GVI = 0.29 $(R_{540}+R_{555})/2-0.562\ R_{640}+0.6\ R_{740}+$ $0.491(R_{860}+R_{960})/2$,
(Jensen, 1996; Nilsson, 1985).

Values of all the analyzed vegetation indices were increasing from the germination stage to the stem formation stage and then decreased at the end of the growing season (Fig. 3). This trend is well known from several studies concerning spectral-temporal characteristics of different crops. Linear regression between percentage canopy cover, reflectance and vegetation indices produced similar correlation coefficients for the NIR reflectance and for all the analyzed vegetation indices.

The nonlinear vegetation indices can exaggerate the effects of the SZA on the spectral wheat characteristics (Jackson, 1990). In this study, these indices, particularly NDVI, minimize the influence of the sun position. NDVI was less dependent on the solar position than reflectance in the NIR wavelengths and all the linear indices. In all vegetation stages of the winter rape crop daily variation of individual wavelengths and linear indices (due to the changing solar position) was greater than variation of the nonlinear indices. For example, reflectance in the IR wavelengths for SZA=70° was 1.7 times higher than at SZA=40° compared to the factor of 1.06 for the NDVI. The NIR/RED ratio variation was greater than the NDVI which is in agreement with Jackson's *et al.* (1990) results for wheat. In most stages, the value of the former index at SZA=70° is nearly twice higher than at 40° SZA. Only in the 12-leave stage, when the plants were wilted, NDVI was less dependent on the SZA.

CONCLUDING REMARKS

The results indicate that winter rape spectral characteristics change considerably during the normal growing season. These changes have been affected by the morphological changes of plants, mainly in the mezophyll tissue. The conclusion of this experiment is that multi-temporal reflectance data characterize morphological and biochemical changes well as the winter rape develops throughout the growing season. Specific elements of this plant, e.g. yellow flowers, cause differences in the seasonal reflectance patterns when compared to wheat or corn. These dissimilarities can be used for better crop identification in the remote sensing for agricultural applications. For the discrimination of growing stages of winter rape nonlinear vegetation indices are the best. These indices may be difficult only when rape plants are in the middle of their development: between the stage of 4 leaves and 12 leaves.

Spectral reflectance factors varied with the sun angle, an effect largely due to the surface features that create shadows. The greatest effect was observed for the individual wavelengths and linear vegetation indices. These results demonstrate that the use of nonlinear vegetation indices in temporal studies could lead to less serious misinterpretations of the data collected at different times of the day.

Spectral signatures of the main winter rape phenological stages proposed in this study can be used to identify aberrations in the development from the normal growth pattern. These deviations may be caused by drought, disease or insect infestation etc., and their detection may be possible only when the "standard"spectral profiles of winter rape crop will be known.

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