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DISCRIMINATION BETWEEN FALLOW AND ARABLE FIELDS BY MULTITEMPORAL REFLECTANCE MEASUREMENTS

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ABSTRACT

After 1989, when structural transformation of Polish agriculture began, the land use structure has been changing significantly and a big part of formerly ploughed fields lies fallow. Airborne and satellite images can provide quantitative and temporal information for monitoring changes of fallow fields acreage. Over the last few years several studies have been dedicated to the spectral characteristics of the arable crops, while spectral data concerning fallow fields are needed as well. The objective of the present study is to find out whether it is possible to distinguish fallow fields from crop fields on the basis of spectral data and determine when the differences between them are the greatest in the growing season. Spectral measurements were taken from two fallow fields of different age, as well as from winter and spring barley, winter wheat, winter rape and potato fields. Field spectral reflectance measurements were made with a CIMEL CE-313 luminancemeter. Four vegetation indices NDVI, STVI, GRVI and MSI, were calculated. The results show that the best time for spectral separation of fallow fields from arable crops was in the second half of May when the cereal crops were in the stem elongation stage, and winter rape crops in the budding stage. In this time, the spectral properties of potato crop are dominated by the soil background, thus the spectral response of this crop and fallow fields are considerably different. The STVI vegetation index provided maximum discrimination between the fallow fields and arable crops as well as among the fallow fields of different age.

INTRODUCTION

Remote sensing is a very useful tool for acquisition of accurate and timely information on the acreage and spatial distribution of crops in a local and landscape level. The accuracy of this information depends on the significance of differences in the spectral response among the various crops. The difference in crop percent canopy, closure or biomass might cause one crop to have significantly different reflectance properties from others at the same time in the growing season. However it , can be difficult to discriminate arable crops with the similar growth and canopy morphology using remote sensing techniques. In this case multitemporal data are required. Multitemporal remote sensing involves data colection from the same area, from more than one date or year. Agricultural crops have individual phenological growth cycles and they emerge, mature and senesce at near the same time each year. Information about the developmental stages of each crop in a given region throughout the year are collected in a „crop calendar” (1). Crops develope at different rates and their spectral properties change accordingly throughout the vegetation season thus, their multitemporal reflectance profiles are often different. Remotely sensed data of agricultural areas used for classification purposes should be obtained at times of the year that maximize the spectral contrast between crops. According to (2) the best results of vegetation classification can be attained when data are collected early in the growing season. At this time, the differences in vegetation developement dynamics result in various percentage ground cover by plants of each crop.

Multitemporal reflectance characteristics of arable crops can be collected during field campaign, when reflectance factors are measured. Reflectance factor is defined as the ratio of the flux reflected by a sample surface to that which would be reflected by a perfectly diffuse Lambertian surface (3). Calibrated reference panels can be used to develop reflectance factors for comparisons of spectra from various dates and sites (4). Reflectance factors of plant canopies can be used as ground truth in airborne and spaceborne remote sensing for vegetation. A lot of research has been dedicated to the spectral characteristics of the arable crops and their temporal variation (5, 6, 7).

Multitemporal reflectance characteristics of fallow fields as agricultural lndscape component should be recognized as well.

In Poland, after 1989, when structural transformation of the agriculture began, the land use structure has been changing significantly and a big part of formerly ploughed fields lies fallow. The acreage of abandoned grounds in agriculture landscapes in Poland amounts to 1.8 millions hectares (almost 14% of the total ploughed area). In some parts of the country the share of abandoned fields in the total ploughed area is up to 30%. Accurate monitoring of fallow fields extent is important in agricultural planning and policy making. Airborne and spaceborne images would provide reliable information about acreage of fallow fields if their spectral characteristics are well recgonized.

The objective of the present study is to characterize the reflectance characteristics of two fallow fields of different age and three arable crops, find out whether it is possible to distinguish fallow fields from crop fields on the basis of spectral data and determine when the differences between them are the greatest in the growing season.

METHODS

The study was conducted on a farm and fallow fields located near Poznań, Poland (52 40' N, 16 84') in Wielkopolska region where cereals, oilseed rape and potatoes cover respectively 76%, 8% and 5% respectively of the total ploughed area. The field spectral measurements were taken on twelve dates throughout the 2002 growing season. The spectral data were collected only on clear, sunny days during the midday hours. Five representative sites were chosen for measurements within each of the three arable crops: winter wheat, winter oilseed rape and potatoes and two fallow fields. Table 1 gives the species composition of the two fallow fields representing different age (two and six years old).

All fields were situated on soils lessives formed with loamy sand texture (8). On the Munsell soil color chart, soil was classified as a dull yellow orange (10 YR 7/3). It was assumed that soils on all fields had similar spectral response. Observations were made on the crop growth stage (Table 2) and they were determined according to BBCH-Identification keys (Biologishe Bundesanstalt, Bundessortenamt und Chemical Industry) (9). A digital photograph was taken at each site to further supplement quantitative and qualitative observations.

Field spectral reflectance measurements were made with a CIMEL CE313 luminancemeter, which head was mounted on a hand-held boom, elevated approximately 2.5 meters above the canopy. The luminancemeter's sensor with a field-of-view (FOV) of 10° covers an area of 0.15 m^2. Three spectra were obtained for each measurement point at the nadir direction and were then averaged. Reference panel (Spectralon) measurements were collected immediately before the luminance measurements. Reflectance factors (R) were calculated as a ratio of the reflected radiance from crop and fallow fields to that reflected from a reference panel in five wavebands: 450, 550, 650, 850 and 1650 nm.

Five vegetation indices were calculated by combining the reflectance factors:

$$NDVI=(R_{850}-R_{650})/(R_{850}+R_{650}) \quad (10),$$

$$STVI=(R_{1650}*R_{650})/R_{850} \quad (11),$$

$$MSI=R_{1650}/R_{850} \quad (12),$$

$$GRVI=R_{550}/R_{650} \quad (13),$$

where: R_{450}, R_{550}, R_{650}, R_{850}, R_{1650}: reflectance factors in the 450, 550, 650, 850 and 1650 nm bands respectively.

RESULTS

Figure 1 shows mean decadal temperature and rainfall in 2002 against the many years' means. The weather conditions during the growing season were favourable to vegetation development.

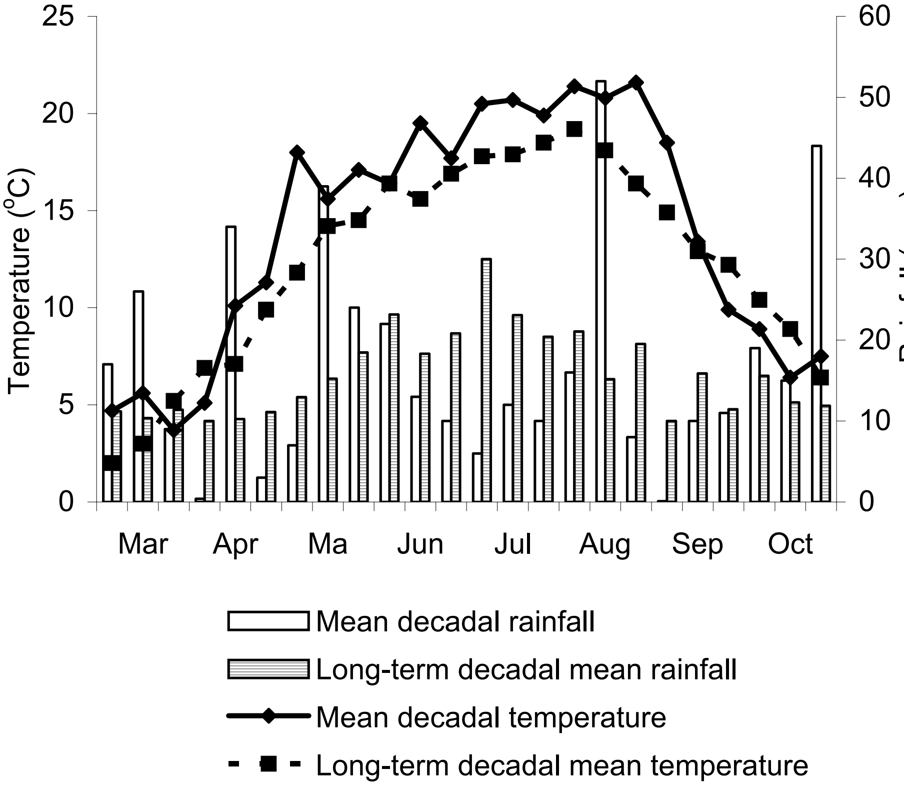

Figure 1. Weather conditions during the 2002 growing season.

The mean decadal temperatures during the 2002 growing season were above the norm except for the last decade of March and the first of April in the spring and the last decade of September and two first decades of October. Mean rainfall in the 2002 growing season was higher than long-term mean, however summer months were dry.

Table 1 presents developmental stages and ground cover of the crops on dates when the spectral measuremets were taken during the growing season.

Table 1. Agronomic characteristics of the three arable crops.

Date	Winter wheat		Winter oilseed rape		Potatoes	
	Crop growth stage*	Ground cover [%]	Crop growth stage	Ground cover [%]	Crop growth stage	Ground cover [%]
18 March	Tillering (2)	44	Leaf develo-pment (19)	96	-	0
29 March	Tillering (2)	49	Stem elongation (3)	99	-	0
23 April	Tillering (2)	97	Inflorescence emer-gence (5)	100	-	0
02 May	Stem elon-gation (3)	100	Flowering (begin-ning) (6)	100	-	0
10 May	Stem elon-gation (3)	100	Flowering (full) (6)	100	Germination (0)	0
22 May	Heading (5)	100	Development of fruit (7)	100	Leaf develo-pment (1)	10
04 June	Flowering (6)	99	Ripening (8)	99	Inflorescence emergence (5)	58
18 June	Development of fruit (71)	95	Ripening (8)	98	Flowering (begin-ning) (6)	89
27 July	Development of fruit (77)	91	stubble	-	Senescence (93)	55
19 August	Stubble	-	stubble	-	Senescence (97)	46
	Winter oilseed rape		Winter wheat		Winter wheat	
02 October	Leaf develo-pment (14)	17	Leaf develo-pment (1)	5	Leaf develo-pment (1)	8
25 October	Leaf develo-pment (16)	69	Tillering (2)	28	Tillering (2)	33

* Principal growth stages according to BBCH-Identification keys

SEASONAL PATTERNS OF REFLECTANCE FACTORS

Because two fallow fields were not cultivated for various periods of time their plant species compositions differ (Table 2). Due to an earlier stage of succesion on the FF1 the vegetation was sparse and plants did not cover the soil entirely. Thus, the total amount of vegetation on this fallow field was greater throughout the growing season than on the FF1. Consequently, the reflectance in the visible (VIS) and shortwave infrared (SWIR) bands from FF2 was higher and in near infrared (NIR) band lower than from FF1 during the whole season.

Table 2. Species composition and age of two fallow fields.

Fallow field	Age [years]	Species composition
FF1	2	Erigereon canadensis L Festuca rubra L.s.s. Aspera spica-venti (L.) P. Beauv. Taraxacum officinale (L.)
FF2	6	Agropyron repens L. *Rumex acetosella L.* Agrostis capiliaris L.

In late March, before the beginning of the growing season, both fallow fields had reflectances in the VIS and NIR bands similar to those of winter wheat (figure 2). At this time, a very high proportion of NPV (near 95%) in the total amount of vegetation on the FF1 and FF2 fallow fields caused relatively high reflectances in the red band (8-10%) and low reflectances in the near-infrared band (20-25%). Reflectance factors from wheat showed similar values since plants of this crop covered the soil only partially (ground cover 44%) and soil background contribution in the spectral response was significant. The winter oilseed rape had a greater canopy closure (ground cover 96-99%) before the start of the vegetation growth, thus the red and SWIR reflectance factors were

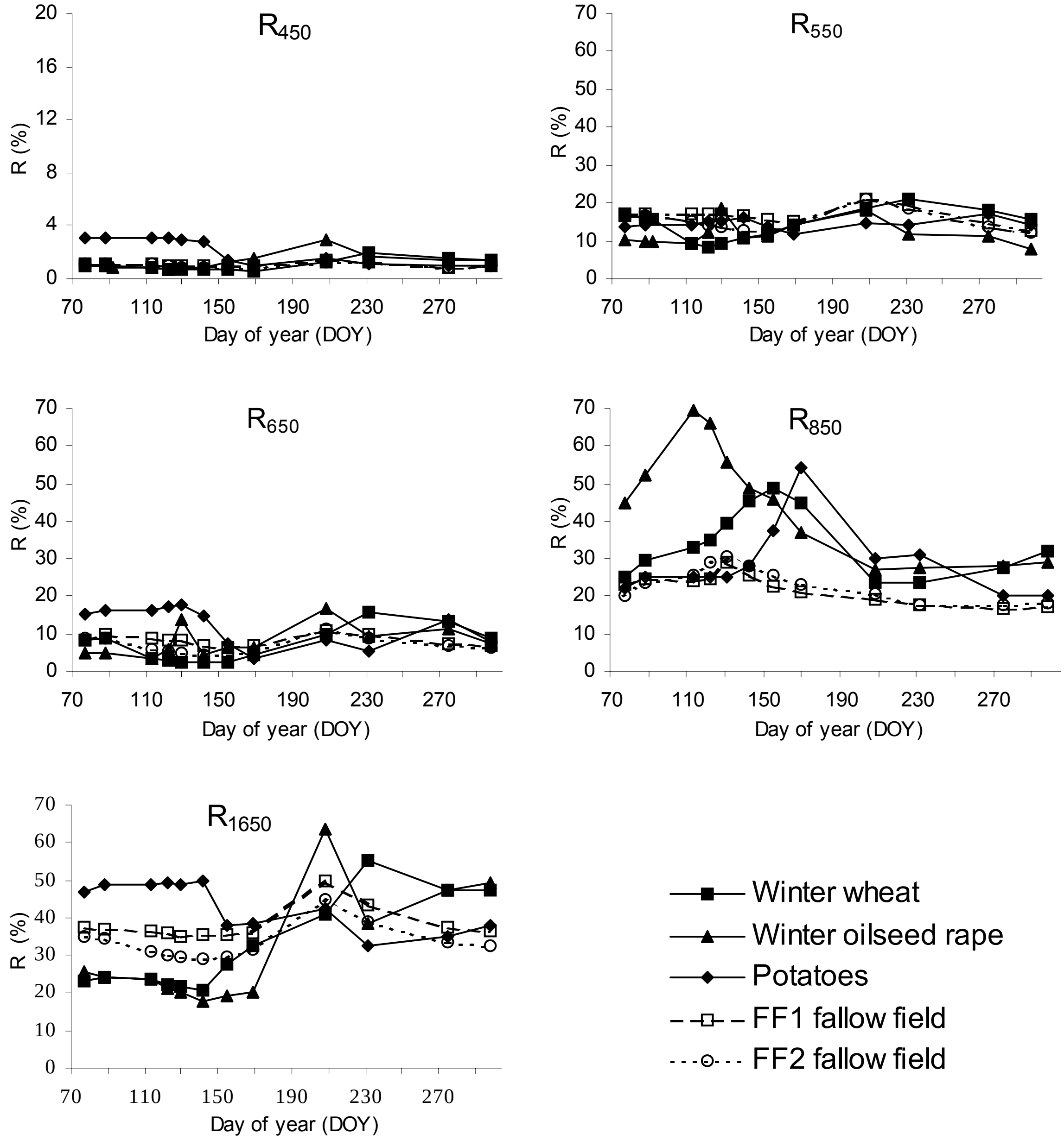

Figure 2. Multitemporal plots of reflectance factors for four wavelengths measured during the growing season form three arable crops and two fallow fields of different age. Dashed lines represent spectral response in periods between the harvest and autumn sowing dates.

significantly lower and the NIR reflectance factors were higher from this crop than that from winter wheat, fallow fields and bare soil in the potatoes field before plant emergence. In late March, the highest reflectances in the red and SWIR wavebands were recorded from the bare soil. The reflectance factors in the NIR band from fallow fields were similar to that of bare soil what is consistent with (14), who found that as NPV content increases in grass canopies spectral reflectance curves of NPV and soils have similar shapes in the NIR wavelength range.

After the onset of vegetation growth, in early April, the reflectance in the red band from the wheat, oilseed rape and fallow fields started to decrease while the reflectance in the NIR band to increase. The decrease of the reflectance in the red band was connected with intensive chlorophyll absorption in rapidly developing green leaves and the increase of response in the NIR band was a result of scattering caused by leaf mesophyl structure (15).

The lowest reflectance in the red band and the highest in the NIR band from the oilseed rape, wheat and both fallow fields was recorded when these crops were in peak biomass in the season. For oilseed rape it happened in late April and later, at the beginning of May, the reflectance in the red band from this crop increased rapidly since yellow flowers appeared on the plants. The reflectance in the red band from the wheat and FF1 decreased steeply in April and early May, reaching lowest values in mid May. The NPV on the fallow fields tended to increase and reached at this time around 25% and 38% of the total amount of the vegetation on FF1 and FF2 respectively. Vegetation on the fallow field FF1 included a lower amount of NPV, thus the reflectance factors from this field in the red band were significantly lower and in the NIR band higher than from FF2. The minimum reflectance factors values in the red band from F2 was observed in early June. In mid-June the reflectance factors in the red band from potatoes reached lowest values in the season and highest values in the NIR band. At this time, potato plants had maximum aboveground biomass and were in the flowering stage. However, sparse flowers did not influence the spectral properties of the crop.

In early June the reflectance factors in the red and SWIR bands from wheat, oilseed rape and fallow fields increased steeply and factors in the NIR band decreased. The reflectance increase in the red band was caused by vegetation senescence, when chlorophyll breakes down and thus absorb less photosynthetically active radiation. The SWIR band is heavily influenced by water in plant tissue (16), and reflectance in this band from senescing plants is higher than from green plants. Plant senecence caused also collapsing cell walls which increases the number of light-scattering air-cell wall interfaces (17) and consequently decreases the reflectance in the NIR band.

Oilseed rape was harvested in early July and wheat in early August. After the harvest the reflectance factors in the red and SWIR bands from wheat and oilseed rape stubbles were very high and significantly higher than reflectances from fallow fields. At this time, the reflectance in the NIR band decreased rapidly from all crops and fallow fields.

Later in the growing season, weeds emerged on the stubble, mostly Agropyron repens, and reflectance factors in red and SWIR bands decreased gradually according to the increase weed plant ground cover while reflectance factors in NIR band increased.

VEGETATION INDICES

Figure 2 shows seasonal profiles of four vegetation indices: NDVI, GRVI, MSI and STVI calculated from reflectance factors. The temporal variation in NDVI is similar to the variation of reflectance factors in the NIR band, because this band dominates the vegetation indices. The vegetation indices for both fallow fields showed two turning points in the course of the growth period. STVI and MSI showed the reversed to NDVI and GRVI seasonal pattern but turning point dates were similar. The first turning point corresponded to maximum green vegetation amount. Plants on the FF1 developed faster than on FF2, thus the first turning date for FF1 occured earlier, on DOY 130 while for F2, about two weeks later, on DOY 142. The second turning point agreed with the onset of summer plant regrowth and occurred on both fallow fields on DOY 208. The first turning dates of arable crops also corresponded to peak greenness of each crop but occured at various dates: for wheat, oilseed rape and potatoes on DOY 142-155, DOY 113 and DOY 169 respectively. The occurence of maximum values of wheat NDVI in the second part of May is consistent with results of (17) who analyzed seasonal variation of NDVI calculated from NOAA AVHRR images. These images covered agricultural regions where wheat crops dominated (near 70%). (18) also showed that the peak NDVI obtained from NOAA AVHRR images covering meadows in Poland occurred in mid-

May. The second turning dates in the profiles of the vegetation indices for wheat and oilseed rape coincided with harvest time, when measurements were taken from the stubble. STVI showed greater differences between the arable crops and the fallow fields than NDVI, GRVI and MSI. STVI is a vegetation index that incorporates, apart from the NIR (850 nm) and red (650 nm) also SWIR (1650 nm) reflectance factors which are sensitive to the presence of NPV in vegetation. The greatest differences between the STVI of fallow fields and wheat and oilseed rape crops occurred at the time when these crops were in peak biomass in the season. On DOY 142 and DOY 113 STVI from wheat and oilseed rape were four and almost seven times lower than from F1 and eight and twelve times lower than from F2. STVI from wheat and oilseed were more similar to F1 which had greater amount of green vegetation than to F2. On DOY 10.05. STVI from potatoes field were seven and three times higher than from F1 and F2 respectively.

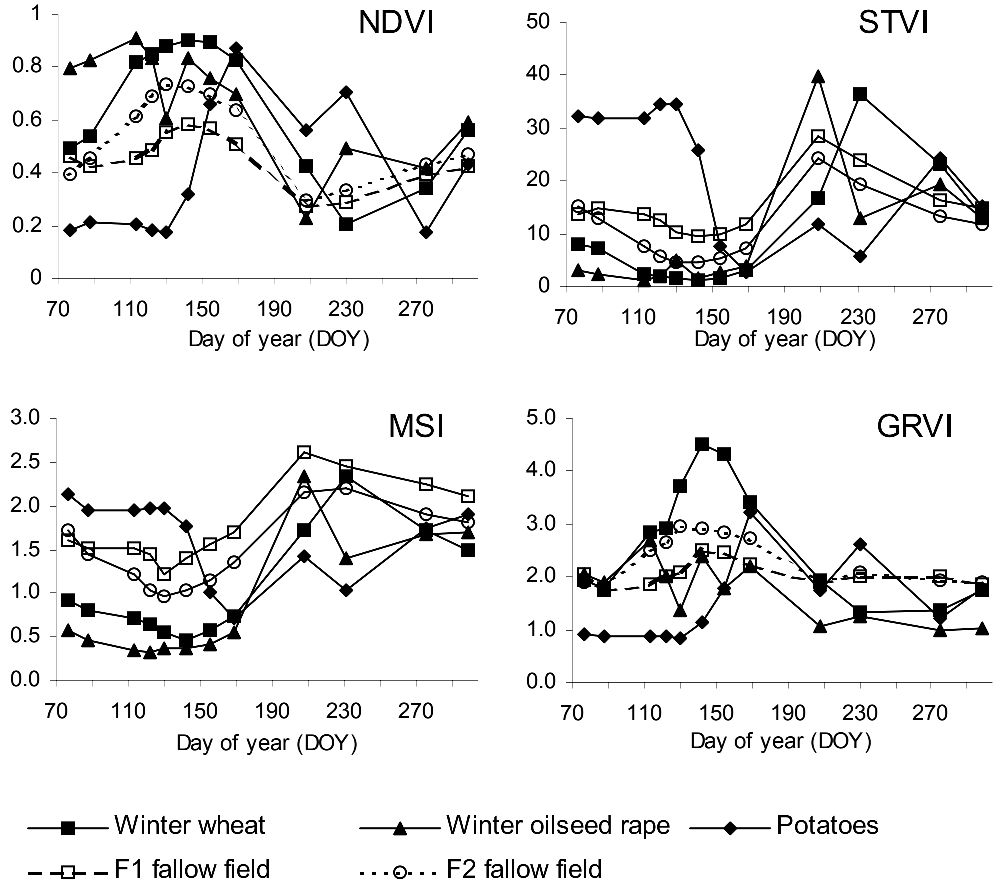

Figure 3. Multitemporal plots of four vegetation indices form three arable crops and two fallow fields of different age. Dashed lines represent spectral response in periods between the harvest and autumn sowing dates.

The greatest differences between potato and fallow fields were observed shortly after the germination of the potatoes. At these time STVI from bare soil were still very high while from the fallow fields, due to the presence of relatively great amount of green vegetation, were low.

CONCLUSIONS

The two fallow fields and three crops have distinguishable phenological cycles that can be detected by spectral ground measurements. During the whole growing season reflectance factors as well as vegetation indices varied significantly with different dynamics. Each of the crop leaf-out, grow to maturity, and senesce at slightly different time and their phenological cycles vary in phase. Discrimination between these crops and fallow fields using data from spectral field measurements was possible because the crops developed more rapidly and produce more biomass (e.g., through fertilization) than vegetation on fallow fields. The greatest spectral differences between fallow fields and winter wheat and oilseed rape occured when arable crops reached their maximum green vegetative development. The best time for distinquishing spectrally between oilseed and fallow fields was in late April and between wheat and fallow fields in late May. The most significant spectral differences between fallow and potato fields occured shortly after the potatoes plant emergence, in early May, when the soil background dominated in the spectral response of the crop.

Presence of NPV in vegetation on fallow fields produced less seasonal variation of the reflectance factors and vegetation indices from fallow fields than from arable crops. The best time for discrimination among fallow fields of different age occured in the first half of May. At this time the proportion of green plants in the total amount of vegetation was highest in the season. STVI index was the most suitable for discriminating fallow fields from arable crops as it combines reflectance factors from the red and NIR bandwidths but also from the SWIR wavelengths. The vegetation indices examined in this study were calculated using only field measurement data. Therefore, further study to provide validation using satellite data is necessary.

Further investigations should be conducted using hyperspectral sensors sampling in very narrow portions of the spectrum. Hyperspectral data may provide new, critical information on plant biophysical variables available in specific narrow bands (19).

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