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MONITORING OF CHANGES IN THE REFLECTANCE OF ELECTROMAGNETIC RADIATION FROM WINTER OILSEED RAPE CANOPY WITH THE USE OF FIELD RADIOMETER CE 313

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A b s t r a c t . The aim of the study was determination of the effect of differentiated nitrogen fertilization and the variety of winter oilseed rape on the results of spectral measurements, and estimation of the opportunities of yield forecasting on the basis of reflectance factors and vegetative indices. Measurements of spectral radiation from the plants were carried out with the use of radiometer CE 313 (Cimel Electronique Co.) and evaluated in the form of three reflectance factors (SWO_{650}, SWO_{850}, SWO_{1650}) and three vegetative indices (NDVI – Normalized Difference Vegetation Index, RVI – Ratio Vegetation Index, ELAI – Estimated Leaf Area Index). The conducted experiments proved significant differences between plots sown with different plant varieties and fertilized with different doses of nitrogen. Differentiation of plant development under the influence of nitrogen fertilization was shown in the phase of full budding of oilseed rape using all analysed reflectance factors and vegetative indices, as well as at the beginning of the phase of silique development. High correlation between the values of spectral measurements carried out in the phase of full budding of oilseed rape and the yield of seeds, and convergence of the differentiation of the spectral characteristics and the yields obtained from experimental combinations indicate the possibility of applying spectral measurements in estimation of the status of crop cultures and in forecasting of winter oilseed rape yield.

K e y w o r d s : varieties of winter oilseed rape, nitrogen fertilization doses, spectral measurements

INTRODUCTION

Adequate estimation of growing crops has an important significance for decision taking connected with agricultural production and commercial as well as charitable activity concerning agricultural products. Reliable information referring to disturbances in regular plant development, available in a time guarantying efficiency of undertaken interventions, permit producers to limit the negative action of stress factors such as pathogens, drought or deficiency of nutritive components. For many years, visual estimation was the basic method of controlling plant development. Since this method has only a limited usefulness resulting from disproportion between the number of the needed specialists and the area requiring monitoring, attempts are made in order to develop better methods permitting objective estimation of plant development. The leading new approach currently used in the estimation of the condition of crops is the search for dependences between stressors and the reflectance of electromagnetic radiation from plants. This thesis is illustrated by results of studies on the spectral properties of the following crops: wheat and barley (Giovacchini *et al.* 1984, Kuusk 1991, Leamer *et al.* 1978), maize (Daughtry *et al.* 2000, O'Neill et al. 1984), bean and pea (Ridao *et al.* 1998), rice (Vaesen *et al.* 2001), oilseed rape (Piekarczyk 2001), and potato (Wójtowicz and Piekarczyk 2001). Spectral characteristics of particular crops depend, among others, on the biomass and the degree in which soil is covered by grown plants. This has been shown in numerous papers (Broge and Leblanc 2000, Davidson and Csillag 2001, Maas 2000, Thenkabail *et al.* 2000, Tucker *et al.* 1979, Vaesen *et al.* 2001). Biophysical parameters of plants analysed in the above mentioned populations depend on the course of meteorological conditions and agrotechnical treatments, as well as on biological properties of varieties grown. Close connection of biophysical parameters with the reflectance of electromagnetic radiation creates the possibility of utilizing spectral measurements in the detection of stress factors differentiating the character of spectral reflectance and in the exact definition of the phases of plant development and thereby in the determination of the timing or intensity of the needed agrotechnical treatment. Spectral measurements find an application also in studies on the possibility of yield forecasting.

Vegetative indices calculated on the basis of coefficients of wave reflectance in the range of red and infrared of the electromagnetic spectrum were used in the estimation of wheat (Asrar *et al.* 1985, Jakson *et al.*1983), barley (Kleman and Fagerlund 1987), soybean and maize (Crist 1984) yields.

The authors of this paper carried out studies on the spectral properties of winter oilseed rape. The objective of this elaboration was determination of the effect of variety and differentiated nitrogen fertilization on the results of spectral measurements, and estimation of opportunities of winter oilseed rape forecasting on the basis of the values of wave reflectance and the vegetative indices. Measurements of spectral radiation from plants were carried out with the use of radiometer CE 313 (Cimel Electronique Co.) and evaluated in the form of three reflectance factors (SWO_{650}, SWO_{850}, SWO_{1650}) and three vegetative indices (NDVI, RVI, ELAI).

MATHERIAL AND METHOD

Experiments were carried out in two vegetative seasons, 2003/2004 and 2004/2005, in Łagiewniki (N 51°46’, E 17°14’). Experimental factors included oilseed rape variety (population variety – Lisek; two complex varieties – Mazur and Kaszub; two restored varieties – BOH 3103; MR 153; line DH W 15) and spring nitrogen fertilization (60, 100, 140, 180, 220 kg N ha^{-1}). The experiment was established in random block design in four replications. The experiment was carried out on a proper brown soil belonging to a good wheat complex and classification IIIa. The following pre-sowing fertilization was applied: 20-25 kg N ha^{-1}, 63-60 kg P_2O_5 ha^{-1}; 96-130 kg K_2O ha^{-1}. Seeds were sown on the 26th of August, on 10.8 m^2 plots. Seeding was done by a mobile seeder Øyorda type, at 30 cm intervals. The sowing norm was 70 seeds per 1 m^2. Throughout the whole vegetative period, the oilseed rape was protected against weeds, pests and diseases using plant protection agents recommended for this purpose. Plants were harvested using a combined-harvester after previous application of Reglone.

Measurements of spectral radiation from the plants were carried out with the use of radiometer CE 313 (Cimel Electronique Co.) with a sensor field of view of 10°. This equipment permits measurement of the absolute value of monochromatic energetic luminance in five spectrum ranges and its maximal sensitivity includes waves of the following lengths: 450, 550, 650, 850 and 1650 nm. Results of the spectral measurements of oilseed rape plots are shown in the form of reflectance factors of visible waves (SWO_{650}), in the range of infrared (SWO_{850}) and middle infrared (SWO_{1650}), and three vegetative indices:

$$\mathrm{NDVI} = \frac{R_{850} - R_{650}}{R_{850} + R_{650}},\ \mathrm{RVI} = \frac{R_{850}}{R_{650}},\ \mathrm{ELAI} = -0{,}441 + 0{,}285 * \frac{R_{850}}{R_{650}} \tag{1}$$

In the formulae R_{850}, R_{650} denote canopy reflectance in the infrared (850 nm) and red (650 nm) wavelength respectively.

Spectral measurements were carried out at midday hours. In the season of 2003/2004, the measurements were performed on the 26th of September when oilseed rape was in the phase of 5-6 leaves - BBCH 15-16; on the 15th of April – in the phase of budding – BBCH 57, and on the 31st of May – at the beginning of the phase of silique development – BBCH 71. In the season of 2004, measurements were made on the 1st of April – in the phase of the beginning of main shoot elongation – BBCH 30, on the 20th of April – in the phase of budding – BBCH 57, and on the 19th of May, in the phase of full flowering – BBCH 65. On each plot, the spectral measurements were carried out in four sites.

The obtained results were evaluated by the analysis of variance, and the significance of differences was determined at the confidence level of $P \leq 0.05$ and by coefficients of linear correlation. Symbol 'ni' indicates the absence of any bases for discarding the zero hypothesis.

RESULTS

Spectral measurements performed in autumn 2003 in the phase of 5-6 leaves – BBCH 15-16, indicated significant differentiation between varieties applied in the experiment (Tab. 1). Line DW W-15 was characterized by the lowest values of the coefficient SWO_{850} and the vegetative indices NDVI, ELAI and RVI, while the highest values were shown by the coefficients SWO_{650} and SWO_{1650}.

Table 1. Values of reflectance factors and vegetative indices from measurements made in the phase of 5-6 oilseed rape leaves – BBCH 15-16 (2003/2004)

Variety	SWO_{650}	SWO_{850}	SWO_{1650}	NDVI	ELAI	RVI
Lisek	0.08 ab	0.65 b	0.25 a	0.79 b	2.02 b	8.63 b
Mazur	0.08 ab	0.65 b	0.25 a	0.79 b	2.06 b	8.77 b
Kaszub	0.08 ab	0.60 ab	0.25 a	0.76 ab	1.75 ab	7.70 ab
BOH 3103	0.08 ab	0.61 ab	0.25 a	0.78 b	1.98 b	8.50 b
MR 153	0.07 a	0.64 ab	0.25 a	0.79 b	2.09 b	8.89 b
DH W-15	0.09 b	0.59 a	0.27 b	0.72 a	1.47 a	6.71 a
$LSD_{0.05}$	0.014	0.055	0.019	0.147	0.467	1.639

SWO_{650} – reflectance factor of visible waves, SWO_{850} – reflectance factor in the range of infrared, SWO_{1650} – reflectance factor in the range of middle infrared. NDVI – Normalized Difference Vegetation Index, ELAI – Estimated Leaf Area Index, RVI – Ratio Vegetation Index.
Means of the same category followed by different letters are significantly different from one another using LSD test at 5% level of probability.

This differentiation was the result of smaller mass of this variety. Also in spring, in the phase of oilseed rape budding – BBCH 57, the values of spectral reflectance of waves and vegetative indices depended on the variety (Tab. 2). Similarly as in the phase of 5-6 leaves – BBCH 15-16, the highest values of SWO_{650} and SWO_{1650} reflectance factors were shown by the line DH W-15. The highest coefficient values in the range of near infrared were shown by the Lisek variety.

Vegetative indices showed significant differentiation between the varieties with the lowest yields: BOH 3103, DH W-15 and the varieties with higher yields: Lisek, MR 153, Mazur and Kaszub. Similar – though not identical – dependences were shown by the analyses of seed yields (Tab. 3). Significant differences for this feature were found between the line DH W-15, showing the lowest yield, and the group of varieties Lisek, MR 153, Mazur and Kaszub, as well as between the variety BOH 3103 and the varieties Lisek, Mazur and MR 153. In the phase of budding – BBCH 57, there was also a differentiation of the size of spectral reflectance depending on the nitrogen fertilization level (Tab. 2).

The reflectance of visible waves was significantly higher on plots fertilized with lower doses of nitrogen (60 and 100 kg N ha^{-1}) than on plots fertilized with the highest dose (220 kg N ha^{-1}). The highest values of near and middle infrared were recorded on plots fertilized with a dose of 140 kg N ha^{-1}. In turn, the vegetative indices showed a significant differentiation between plots fertilized with the lowest nitrogen dose – 60 kg N ha^{-1} – and the plots where the highest dose of nitrogen – 220 kg N ha^{-1} – was applied. Similar dependences referred to seed yield (Tab. 3). Significant differences for this feature were shown between the plots fertilized with 60 kg N ha^{-1} and the plots fertilized with 180 and 220 kg N ha^{-1}.

Table 2. Values of reflectance factors and vegetative indices from measurements done in oilseed rape budding phase – BBCH 57 (2003/2004)

Factor	SWO_{650}	SWO_{850}	SWO_{1650}	NDVI	ELAI	RVI
Variety						
Lisek	3.68 ab	52.7 b	15.2 b	0.87 b	3.67 b	14.4 b
Mazur	3.60 a	48.1 ab	14.1 ab	0.86 b	3.45 b	13.7 b
Kaszub	3.26 a	47.1 a	13.0 a	0.87 b	3.72 b	14.6 b
BOH 3103	4.06 bc	46.0 a	14.7 ab	0.84 a	2.85 a	11.5 a
MR 153	3.41a	48.6 ab	13.3 a	0.87 b	3.68 b	14.5 b
DH W-15	4.36 c	49.7 ab	17.6 c	0.84 a	2.91 a	11.8 a
$NIR_{0.05}$	0.451	4.63	1.70	0.019	0.510	1.789
Nitrogen dose (kg N ha^{-1})						
60	3.90 b	46.0 a	14.7 a	0.84 a	2.99 a	12.1 a
100	4.05 b	48.9 a	15.5 b	0.85 ab	3.11 ab	12.5 ab
140	3.81 ab	52.8 b	15.6 b	0.86 ab	3.58 ab	14.1 ab
180	3.53 ab	47.7 a	13.5 a	0.86 ab	3.51 ab	13.9 ab
220	3.37 a	48.1 a	13.9 ab	0.87 b	3.72 b	14.6 b
$NIR_{0.05}$	0.527	3.72	1.89	0.020	0.625	2.193

Explanation: look at Table 1.

Table 3. Effect of variety and fertilization on winter oilseed rape seed yield (2003/2004)

Yield dt ha^{-1}					
Variety					
Lisek	Mazur	Kaszub	BOH 3103	MR 153	DH W-15
59.3 c	56.2 c	55.5 bc	52.4 ab	58.1 c	47.9 a
Nitrogen fertilization kg N ha^{-1}					
60	100	140	180	220	
51.7 a	54.5 ab	54.9 ab	57.4 b	56.2 b	

Explanation: look at Table 1.

Spectral measurements carried out in the phase of silique development – BBCH 71 – showed an insignificant increase in the visible reflectance and near infrared, as well as a distinct decrease of reflectance in the range of middle infrared in relation to the phase of budding (Tab. 4). In the range of middle infrared, radiation is absorbed by water and, therefore, the decrease of the value of radiation proves that the biomass of plants and of water contained in the biomass were increased. Significant differences between the varieties were shown with the help of spectral wave reflectance from the range of near and middle infrared and the vegetative indices. The highest values of SWO_{1650} coefficient characterized the breeding creations ripening as the latest ones – line DH W-15 and the Lisek variety. Using the SWO_{850} coefficient, significant differences were proven between the variety BOH 3103 and the variety Mazur. On the other hand, all vegetative indices showed significant differences between BOH 3103 and the varieties Mazur and MR 153.

In this phase of plant development, significant differences between plots fertilized with different doses of nitrogen were shown only with the use of vegetative indices. All analysed indices showed significant differentiation between plots fertilized with the doses of 60 and 200 kg N ha$^{-1.}$ Using the indicator NDVI, it was demonstrated that there existed also differences between plots fertilized with doses of 60 and 220 kg N ha^{-1} and plots on which the doses of 100, 140 and 180 kg N ha^{-1} were applied.

Table 4. Values of reflectance factors and vegetative indices from measurements made at the beginning of the phase of oilseed rape silique development, BBCH 71 (2003/2004)

Factor	SWO_{650}	SWO_{850}	SWO_{1650}	NDVI	ELAI	RVI
Variety						
Lisek	4.24 a	54.3 ab	9.60 ab	0.86 b	3.25 ab	13.0 ab
Mazur	4.05 a	54.7 b	9.14 ab	0.86 b	3.43 b	13.6 b
Kaszub	4.38 a	53.5 ab	8.97 a	0.85 a	3.17 ab	12.7 ab
BOH 3103	4.18 a	51.3 a	9.18 ab	0.85 a	3.08 a	12.3 a
MR 153	4.03 a	54.2 ab	9.11 ab	0.86 b	3.44 b	13.6 b
DH W-15	4.00 a	52.7 ab	9.71 b	0.86 b	3.33 ab	13.2 ab
$NIR_{0.05}$	ni	3.23	0.73	0.009	0.284	0.99
Nitrogen dose (kg Nha^{-1})						
60	4.36 a	52.7 a	9.48 a	0.85 a	3.02 a	12.2 a
100	4.13 a	53.0 a	9.32 a	0.86 b	3.24 ab	12.9 ab
140	3.98 a	52.4 a	9.08 a	0.86 b	3.36 bc	13.3 ab
180	4.13 a	53.5 a	9.25 a	0.86 b	3.30 bc	13.1 ab
220	4.06 a	55.7 a	9.29 a	0.87 c	3.49 c	13.8 b
$NIR_{0.05}$	ni	ni	ni	0.008	0.236	1.14

Explanation: look at Table 1; ni – not significant differences.

Spectral measurements permitted to show numerical dependence between the status of oilseed rape cultivation and the yield of seeds. The highest correlation between the yield and the spectral measurements was found when the measurements were made in the phase of oilseed rape budding – BBCH 57, i.e. more than 3 months before harvest (Tab. 5).

Table 5. Correlation coefficients between yield and reflectance factors and vegetative indices (2003/2004)

Reflectance factors and vegetative indices	Phenological growth stages of oilseed rape		
	BBCH 15-16	BBCH 57	BBCH 71
(SWO_{650})	–0.25	–0.50**	0.12
(SWO_{850})	0.49**	0.19	0.41*
(SWO_{1650})	–0.12	–0.46*	–0.17
NDVI	0.36	0.59**	0.11
ELAI	0.31	0.58**	0.14
RVI	0.31	0.58**	0.14

* – significant correlation at $\alpha = 0.05$, ** – significant correlation at $\alpha = 0.01$.

Vegetative indices obtained from that measurement were more strongly correlated with the yield than the spectral wave reflectance. The strongest correlation with the yield was shown by the indicator NDVI and then by the indices RVI and ELAI. Correlation coefficients of these indices with the yield had the following values: 0.59, 0.58 and 0.58, respectively. When the measurements were carried out in the phase of 5-6 oilseed rape leaves – BBCH 15-16, and in the beginning of silique development – BBCH 71, the coefficient SWO_{850} was significantly correlated with the yield.

Spectral measurements performed in spring 2005 in the phase of the beginning of main shoot elongation – BBCH 30, indicated significant differentiation between the varieties grown in the experiment (Tab. 6). The lowest values of coefficient SWO_{850} and the vegetative indices: NDVI, ELAI and RVI and the highest values of the coefficients SWO_{650} and SWO_{1650} characterized the line DH W-15. Therefore, also in spring, this form showed the smallest plant mass.

Also in the phase of oilseed rape budding – BBCH 57, the varieties differed in the values of the spectral wave reflectance (Tab. 7). The highest values of SWO_{650} coefficient was shown by line DH W-15. The highest value of the coefficient in the range of near infrared, similarly as in the year 2004, was shown by Lisek line which was also characterized by the highest values of vegetative indices. Vegetative indices showed significant differentiation between the variety with the lowest yield, DH W-15, and the remaining varieties. With the help of the NDVI indicator, it was shown that there were also significant differences between the group of varieties: Mazur, BOH 3103, MR 153, and the variety Kaszub which yielded better only than DH W-15 and the Lisek variety with the highest yield. The arrangement of the varieties using the NDVI indicator reflects well enough the size of the obtained yields of seeds by the particular varieties. The lowest yields were shown by the varieties DH W-15 and Kaszub, while the Lisek variety was characterized by the highest yield (Tab. 8).

Table 6. Values of reflectance factors and vegetative indices from measurements made in the phase of the beginning of main shoot elongation, BBCH 30 (2004/2005)

Variety	SWO_{650}	SWO_{850}	SWO_{1650}	NDVI	ELAI	RVI
Lisek	9.30 a b	34.42 a	22.20 ab	0.57 bc	0.64 bc	3.72 a
Mazur	8.26 a	35.18 a	20.21 ab	0.62 c	0.79 d	4.33 c
Kaszub	10.00 b c	33.72 a	23.37 bc	0.54 ab	0.57 ab	3.55 ab
BOH 3103	8.94 a b	35.50 a	21.41 ab	0.59 bc	0.73 cd	4.10 bc
MR 153	9.11 a b	33.95 a	21.80 ab	0.57 bc	0.66 cd	3.86 bc
DH W-15	10.94 c	32.15 a	25.54 c	0.49 a	0.43 a	3.04 a
$LSD_{0.05}$	1.339	ni	2.327	0.074	0.204	0.717

Explanation: look at Table 1 and 4.

Table 7. Values of reflectance factors and vegetative indices in the budding phase – BBCH 57 (2004/2005)

Factor	SWO_{650}	SWO_{850}	SWO_{1650}	NDVI	ELAI	RVI
Variety						
Lisek	3.49 ab	53.70 c	14.65 bc	0.88 d	3.99 b	15.56 b
Mazur	3.52 ab	51.79 bc	13.37 ab	0.87 c	3.80 b	14.89 b
Kaszub	3.48 a	47.56 ab	13.03 a	0.86 b	3.53 ab	13.93 ab
BOH 3103	3.60 ab	53.11 c	13.30 ab	0.87 c	3.75 b	14.71 b
MR 153	3.61ab	51.76 bc	14.96 c	0.87 c	3.67 b	14.43 b
DH W-15	4.28 b	46.70 a	14.18 abc	0.83 a	3.02 a	12.17 a
$NIR_{0.05}$	0.735	4.829	1.568	0.029	0.533	1.869
Nitrogen dose (kg N ha^{-1})						
60	3.55 ab	47.52 a	12.70 a	0.86 a	3.37 a	13.38 a
100	3.57 ab	47.52 a	13.48 ab	0.86 a	3.39 a	13.44 a
140	3.85 ab	51.14 ab	14.92 b	0.86 a	3.46 a	13.69 a
180	3.73 ab	52.91 b	14.24 ab	0.87 b	3.63 ab	14.30 ab
220	3.50 a	54.74 b	14.24 ab	0.88 c	4.05 b	15.76 b
$LSD_{0.05}$	0.340	5.163	1.739	0.008	0.431	1.511

Explanation: look at Table 1.

Table 8. Effect of variety and nitrogen fertilization on the yield of winter oilseed rape seeds (2004/2005)

Yield dt ha^{-1}					
Variety					
Lisek	Mazur	Kaszub	BOH 3103	MR 153	DH W-15
56.7 b	54.8 a	52.9 a	53.4 a	54.0 ab	52.6 a
Nitrogen fertilization kg N ha^{-1}					
60	100	140	180	220	
51.1 a	52.4 a	55.0 b	55.1 b	57.0 b	

Explanation: look at Table 1.

In the phase of oilseed rape budding – BBCH 57, it was also observed that the size of spectral reflectance was differentiated depending on the level of nitrogen fertilization (Tab. 7). The lowest values of visible reflectance were recorded in the measurements made on plots fertilized with the highest dose of nitrogen (220 kg N ha^{-1}). The reflectance of waves of near infrared was significantly lower on plots fertilized with lower nitrogen doses (60 and 100 kg N ha^{-1}) than in plots fertilized with higher N doses (180 and 220 kg N ha^{-1}). The highest values of middle infrared, similarly as in the season 2003/2004, were recorded on plots fertilized with the dose of 140 kg N ha^{-1} . Using the NDVI indicator, it was shown that there was a significant difference between the plots fertilized with the doses of 140, 180 and 220 kg N ha^{-1}. The values of indices ELAI and RVI increased with increasing doses of fertilization and significant differences were recorded between plots fertilized with doses of 60, 100 and 140, and 220 kg N ha^{-1} .

Similarly, the yield of seeds increased under the influence of fertilization. Differences significant for this feature were found between the plots fertilized with 60 kg N ha^{-1} and those fertilized with 140, 180 and 220 kg N ha^{-1} and between the plots fertilized with 100 and 220 kg N ha^{-1} (Tab. 8). Spectral measurements carried out in full flowering - BBCH 65, indicated a distinct increase of visible reflectance in relation to the phase of budding (Tab. 9). Significant differences between varieties were shown using spectral wave reflectance and vegetative indices. The highest values of spectral wave reflectance were shown by the variety BOH 3103. Variety Lisek differed significantly in its values of visible reflectance from the remaining varieties. Mazur and Kaszub varieties were characterized by significantly the lowest values of visible reflectance and the highest vegetative indices.

Spectral measurements permitted to show the numerical dependence between the crop status of oilseed rape and the yield of seeds. A significant correlation between the yield and the results of spectral measurements was found when the measurements were made in the budding phase of oilseed rape – BBCH 57 (Tab. 10).

Similarly as in the season of 2003/2004, the strongest correlation with the yield was shown by the indicator NDVI and, in further sequence, by the indices RVI and ELAI. The correlation coefficient of these indices with the yield showed the values of 0.57; 0.47 and 0.47, respectively.

Table 9. Values of reflectance factors and vegetative indices from measurements made in full flowering – BBCH 65 (2004/2005)

Variety	SWO_{650}	SWO_{850}	SWO_{1650}	NDVI	ELAI	RVI
Lisek	13.32 b	52.47 a	14.68 ab	0.60 a	0.70 a	4.01 a
Mazur	10.05 a	53.20 ab	13.04 a	0.68 b	1.10 b	5.42 b
Kaszub	10.29 a	53.86 ab	13.35 a	0.68 b	1.09 b	5.38 b
BOH 3103	15.57 c	57.53 b	16.08 c	0.58 a	0.62 a	3.74 a
MR 153	14.90 bc	55.91 ab	15.92 bc	0.58 a	0.64 a	3.80 a
DH W-15	14.96 bc	54.73 ab	15.81 bc	0.57 a	0.61 a	3.70 a
$LSD_{0.05}$	2.013	5.000	1.688	0.033	0.148	0.519

Explanation: look at Table 1.

Table 10. Correlation coefficients between yield and reflectance factors and vegetative indices (2004/2005)

Reflectance factors and vegetative indices	Phenological growth stages of oilseed rape		
	BBCH 30	BBCH 57	BBCH 65
(SWO_{650})	–0.14	–0.30	–0.04
(SWO_{850})	0.19	0.21	0.15
(SWO_{1650})	–0.11	–0.12	–0.01
NDVI	0.17	0.57**	0.14
ELAI	0.19	0.47*	0.14
RVI	0.19	0.47*	0.14

* – significant correlation at $\alpha = 0.05$, ** – significant correlation at $\alpha = 0.01$.

DISCUSSION

This work shows that spectral measurement can be used in the estimation of winter oilseed rape crop status. Measurements of spectral wave reflectance from oilseed rape plants performed with the use of a field radiometer recorded differences resulting from plant development. Significant differences were found in the phase of 5-6 leaves – BBCH 15-16, and in the phase of the beginning of main shoot elongation – BBCH 30, as well as in the stage of budding – BBCH 57, and in the full flowering stage – BBCH 65, as well as at the beginning of the phase of silique development – BBCH 71, of the grown plant. Results of spectral measurement of oilseed rape plots presented in the form of spectral visible wave reflectance (SWO_{650}) in the range of near infrared (SWO_{850}) and middle infrared (SWO_{1650}), and three vegetative indices: NDVI, ELAI, RVI, permitted to present numerical differences between plots sown with different varieties and fertilized with different doses of nitrogen. At all measurement times, significant differences were found between the varieties grown in the experiment. In the particular phases – of 5-6 leaves – BBCH 15-16, at the beginning of the main shoot elongation – BBCH 30, and also in the phase of oilseed rape budding – BBCH 57, the differentiation between the varieties was primarily the result of the different degrees in which the soil area was covered by the particular varieties. On the other hand, in the phase of full flowering – BBCH 65, and at the beginning of the development of siliques – BBCH 71, when in the field of vision of the luminance-meter there were only parts of the plants, the differences between the varieties resulted from the different colour of plants which in turn was the result of differences in the rate of plant ripening. Significant differentiation of spectral reflectance from oilseed rape varieties were shown by Behrens *et al.* and by Piekarczyk *et al*. Phillips et *al.* demonstrated a differentiation between winter wheat varieties in the phase of earing. On the other hand, Aparicio *et al.* found small differentiation of spectral reflectance from wheat varieties. The latter authors explained this fact by small differentiation of the indicator of leaf area surface.

In the phase of budding – BBCH 57, and at the beginning of the phase of silique development – BBCH 71, a differentiation in the spectral reflectance was observed depending on nitrogen fertilization level. In both phases, using vegetative indices, significant differences were shown between plots fertilized with the lowest nitrogen dose – 60 kg N ha^{-1}, and the plots where the highest dose of 220 kg Nha^{-1} was applied. The effect of nitrogen doses on the values of spectral reflectance was also shown by Lukina *et al.* who carried out experiments on winter wheat.

Among spectral coefficients, visible radiation showed the lowest values of wave reflectance in each measurement time. Low visible reflectance is the result of high absorption of waves from the range of radiation spectrum by plant colours. The highest values were shown by reflectance in the range of near infrared because this radiation, after penetration into the plant, is many times reflected from its internal structures. Spectral measurements made in the phase of 5-6 leaves – BBCH 15-16, in the phase of the beginning of main shoot elongation – BBCH 30, as well as in the phase of budding – BBCH 57, and in the phase of full flowering – BBCH 65, and at the beginning of silique development – BBCH 71 in oilseed rape, showed that the values of spectral wave reflectance were more variable than the vegetative indices.

Furthermore, a dependence was shown between the status of oilseed rape cultivation and the yield of seeds. In both analysed seasons, the highest correlation of the spectral measurement results with the yield was when the measurements were done in the phase of oilseed rape budding – BBCH 57. Also experiments performed on wheat (Ahlirchs and Bauer 1983), rice (Patel et *al.* 1985) and barley (Kleman and Fagerlund 1987) showed that the significance of the correlation between spectral measurement values depended on the developmental phase of plants. Similarly as in our paper, the precision of yield forecasting decreased when the measurements were carried out in the generative phases of plant development. The low connection between the values of the vegetative indices and the oilseed rape seed yield obtained from measurements in the generative phases were explained by Basnyat *et al.* by high reflectance of yellow flowers and by the fall of leaves after plant flowering of that species.

In the phase of oilseed rape budding – BBCH 57, a stronger correlation with the yield was shown by the vegetative indices than by the spectral wave reflectance. A similar dependence was described by Ahlrichs and Bauer (1983) who carried out experiments on spring wheat. Significant correlation between the values of spectral measurements and the yield of seeds, and convergence of the differentiation of spectral characteristics and the yields obtained from experimental combinations, indicate the possibility to apply spectral measurements in the forecasting of winter oilseed rape yield.

CONCLUSIONS

1. Measurements of spectral reflectance from oilseed rape plants permitted numerical presentation of differences between plots sown with different plant varieties and fertilized with different doses of nitrogen.
2. Significant differences between plant varieties were found at all times of spectral measurements.
3. Differentiation of plant development under the influence of nitrogen fertilization was shown in the phase of full budding of oilseed rape using all analysed wave reflectance and vegetative indices, as well as at the beginning of the phase of silique development.
4. High correlation between the values of spectral measurements carried out in the phase of full budding of oilseed rape and the yield of seeds, and convergence of the differentiation of the spectral characteristics and the yields obtained from experimental combinations, indicate the possibility of applying spectral measurements in the estimation of the crop status and in the forecasting of winter oilseed rape yield.

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MONITOROWANIE ZMIAN W ODBICIU PROMIENIOWANIA ELEKTROMAGNETYCZNEGO OD ŁANU RZEPAKU OZIMEGO ZA POMOCĄ RADIOMETRU POLOWEGO CE 313

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Streszczenie. Celem tego opracowania było określenie wpływu zróżnicowanego nawożenia azotem i odmiany na wyniki pomiarów spektralnych oraz ocena możliwości prognozowania plonowania rzepaku ozimego na podstawie wartości współczynników odbicia fal i wskaźników wegetacyjnych. Pomiary odbicia spektralnego od roślin rzepaku wykonano przy użyciu polowego radiometru CE 313 firmy Cimel Electronique. Wyniki pomiarów spektralnych poletek rzepaku przedstawiono w postaci trzech spektralnych współczynników odbicia fal (SWO650, SWO850, SWO1650) oraz trzech wskaźników wegetacyjnych (NDVI, RVI, ELAI). Przeprowadzone doświadczenie wykazało istotne różnice pomiędzy poletkami obsianymi różnymi odmianami i nawiezionymi różnymi dawkami azotu. Zróżnicowanie rozwoju roślin pod wpływem nawożenia azotem wykazano w fazie pełni pąkowania rzepaku przy pomocy wszystkich analizowanych współczynników odbicia fal i wskaźników wegetacyjnych oraz na początku fazy rozwoju łuszczyn. Wysoka korelacja pomiędzy wartościami pomiarów spektralnych przeprowadzonych w fazie pełni pąkowania rzepaku a plonem nasion oraz zbieżność zróżnicowania charakterystyk spektralnych i plonów uzyskanych z kombinacji doświadczalnych wskazują na możliwość zastosowania pomiarów spektralnych do oceny stanu upraw i prognozowania plonu rzepaku ozimego.

Słowa kluczowe: odmiany rzepaku ozimego, dawki nawożenia azotem, pomiary spektralne