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Effect of multi-component fertilizers on seeds yield, yield components and physiological parameters of winter oilseed rape (*Brassica napus* L.)

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Abstract. Subject of the discussed studies was an analysis of the impact of mineral multi-component fertilizers, from Polish and foreign producers, on the yield and yield components of winter oilseed rape (*Brassica napus* var. oleifera). Two field experiments were carried out in 2015–2017 in Lipnik. The experimental crop was winter oilseed rape, hybrid cultivar DK EXPLICIT. Two factors were studied in the experiment A: 4 multi-component mineral fertilizers - two Belarusian (1 i 2), one Russian and one Polish (Polifoska 6) and 4 doses of fertilization (250, 500 and 750 kg ha^{-1}). In the experiment (B) were compared two factors: 3 multi-component mineral fertilizers - Belarusian, Russian and Polish production - Polifoska 8 and 4 doses of fertilization (200, 400 and 600 kg ha^{-1}). The fertilizers applied in the experiments, manufactured in Belarus, Russia and Poland, did not show variations in the amount of yield of winter rape. The number of winter rapeseed plants on the area unit (in autumn and spring) was independent of the type of fertilizers. In the experiment B, higher number of rapeseed siliques was obtained after application of Polifoska 8, than other fertilizers. Rapeseed grown on soil with the fertilizers manufactured in Belarus showed a lower value of greenness index (SPAD) and leaf area index (LAI). As a result of the application of multi-component fertilizers, manufactured in Belarus, Russia and Poland, the recorded differences in the winter rapeseed yield, yield components and physiological parameters did not exceed 10%.

Key words: doses of fertilization, fertilizers NPK(S): Belarusian, Russian, Polish, winter rape yield structure.

INTRODUCTION

Winter oilseed rape (*Brassica napus* L.), in Poland and in other countries of the cold temperate climate zone, is one of the most important oil crop. In European conditions, it is the basic raw material for the production of oil for consumption and industrial purposes. In Poland in 2017, the total yield of rape seeds amounted to 2697.3 thousand tons and was higher by 478.0 thousand tons compared to the previous year (CSO 2017; CSO 2018). Increased oil seed rape yield results from the increase in cultivation area and technological progress expressed, among others, by obtaining more efficient population and hybrid cultivars. The quality of seed yield determines the value of agriculture and use of winter rape cultivars. On the area of Poland, after joining the European Union, cultivars appearing in the list of the Common Catalogue of Varieties of Agricultural Plant Species, may be grown. In 2010, an intensive hybrid cultivar DK EXPLICIT was registered and recommended in all regions of Poland.

Winter rape is classified as crop species with very high nutritional needs (Kowalska & Remlein-Starosta, 2011). The most important element affecting the dynamics of growth and yield of rapeseed is nitrogen used in spring in two parts (Friedt et al., 2003; Szczepaniak et al., 2015). Among fertilizer components, nitrogen has the greatest impact on seed quality (Bartkowiak-Broda, 2005). Winter rape belongs to plants with very high requirements in relation to potassium and strongly responsive to fertilizing this component, (Damon et al., 2007) Oilseed rape as a cruciferous plant, also requires good potassium and phosphorus nutrition. Winter oilseed rape, well supplied with phosphorus and potassium, creates strong leaf rosettes and strongly roots before winter, which promotes good wintering. In the spring, phosphorus and potassium facilitate rapid formation of new leaves and stems, while in the summer they accelerate the maturation of seeds in siliques, increase the yield of seeds and content of fat (Orlovius, 2003; Piekarczyk et al., 1014).

Cruciferous plants, to which oilseed rape belongs, are characterized by the highest demand for sulfur. Sulfur fertilization, especially at appropriately high nitrogen doses, may also favorably affect the maintenance or increase of fat content in rape seeds as a result of yield increase (Podleśna, 2002; Lošák & Richter, 2003). Orlovius (2003) emphasizes that the high probability of sulphur deficit is mainly present on lighter mineral soils.

Commonly, multi-component fertilizers are currently used for oilseed rape, both complex NPK and mixed NP and PK, generally having better physical properties than single components, which should be done in a rational way (Nogalska et al., 2012). Fertilizers used in rapeseed cultivations are, for example, Polifoska 6 or Polifoska 8. Due to granulation and thus uniform composition, they have good physical properties and are comfortable to use. They differ in the fixed proportion of nutrients established by the manufacturer. In the following years, an increase in the production and consumption of multi-component fertilizers is noted. In Poland, in the 2016/2017 marketing year, the use of these fertilizers amounted to 2.0 million tons and increased by 0.2 million tons compared to the previous year (Domańska, 2018). The multi-component fertilizers present on the Polish market are diversified in terms of chemical composition as well as national and foreign producers. So far, there have been no comparative studies effects operations of fertilizers of Polish, Russian and Belarusian production. There are indications that fertilizers of eastern production, despite similar composition, give a much worse effect.

The subject of the discussed studies was an analysis of the impact of mineral multi-component fertilizers, from Polish and foreign producers (Belarusian and Russian), on the yield and yield components of winter rape (*Brassica napus* var. oleifera). The conducted research also analyzed the impact of different doses of multi-component fertilizers.

MATERIALS AND METHODS

Field experiment

Two field experiments were carried out in 2015–2017 in Lipnik (53°41'N, 14°97'E) at the Agricultural Experimental Station belonging to the West Pomeranian University of Technology in Szczecin. The experimental plant was winter oilseed rape, hybrid cultivar DK EXPLICIT. The plot area was 15 m^2. The experiments were laid out as randomized blocks in 4 replications. The soil was loamy sand (Polish Soil Classification 2011). The scope of the research included two experiments.

Experiment A

Two factors were studied the experiment: I. factor: 4 multic-omponent mineral fertilizers (NPK 6-20-30). i.e. two Belarusian (1 i 2), Russian and Polish (Polifoska 6), II. factor: 4 doses of fertilization: 0 - control variant, minimum, optimum, maximum. The dose of multi-component fertilizer was determined for phosphorus, which is the most expensive ingredient. The doses were calculated based on the demand of rape in relation to phosphorus. The minimum dose was 50% lower than the optimal dose of 100 kg P_2O_5 per hectare, and the maximum dose was 50% higher than that. Doses of multi-component fertilizers were 250, 500 and 750 kg per hectare, respectively. Polifoska 6 is a complex granular NPK(S) 6-20-30(7). The producer of the fertilizer is 'POLICE' S.A. This fertilizer is recommended for use on potassium-poor soils, in conditions of low organic fertilization and for potassophilic plants such as: sugar beet, potato, maize and rapeseed (https://nawozy.eu).

Experiment B

The study compared two factors: I. factor: 3 multi-component mineral fertilizers of Belarusian, Russian and Polish production – Polifoska 8. Applied fertilizers were characterized by the following composition of NPK(S): Belarusian 8-24-24, Russian 9-25-25(4) and Polish 8-24-24(9). II. factor: 4 doses of fertilization: 0 - control variant, minimum, optimum, maximum, amounting respectively 200, 400 and 600 kg per hectare. Fertilization levels were calculated based on the soil phosphorus supply. The minimum dose was 50% less than the optimal dose of 100 kg P_2O_5 per hectare, and the maximum dose was 50% higher. Polifoska 8 is a fertilizer NPK(S) 8-24-24-(9). It is the fertilizer with uniform light gray to dark gray granules or light pink, sized 2–5 mm, not less than 92%. Polifoska 8 contains 8% nitrogen (N) in ammonium form, 24% phosphorus (P_2O_5) soluble in neutral ammonium citrate and water, i.e. available in the form of mono- and di-ammonium phosphate, including 21% soluble in water. The fertilizer contains 24% potassium (K_2O) soluble in water, in the form of potassium chloride and 9% sulfur dioxide (SO_3) soluble in water, in the form of sulfate. Chemical composition of Polifoska 8 is to promote good root formation and proper development. The producer of the fertilizer is 'POLICE' S.A. (https://nawozy.eu).

In the successive years of the experiment the cultural practices were applied to oilseed rape. After harvesting the preceding oat crop, the stubble was turned down using a stubble cultivator. Then, after about two weeks, plowing was carried out using medium rotary plow. Just before sowing, after manual application of multi-component fertilizers, the soil was tilled to a depth of about 8 cm with cultivator with a string roller. The sowing was carried out using the ØYORD seed drill on August 26. About a week after sowing, insecticide protection was applied (Alstar Pro 100 EW 0.1 dm^3 ha^{-1}), and after the next 7 days, a supplement herbicidal treatment was carried out to volunteer cereal plants and other monocot weeds (Supero 05 EC). Then, after 14 days from the sowing of rape, when the seedlings developed at least one pair of true leaves, herbicidal spraying was performed (Metazanex 500 SC 2 dm^3 ha^{-1}). The last treatment performed after subsequent 7 days was a fungicide treatment with double action: fungicidal and regulating the crop stand the plants conformation (Toprex 375 EC at dose of 0.4 dm^3 ha^{-1}). In early spring with the start of vegetation (about 3–4 March), the first nitrogen fertilization was carried out in the amount of 80 kg N ha^{-1} as ammonium nitrate. The second dose of nitrogen fertilization was applied in the phase of the third internode elongation (5–7 April) at 80 kg N ha^{-1} as ammonium nitrate. Then, the first fungicide treatment was performed within a few days' interval (Alstar Pro 100 EW 0.1 dm^3 ha^{-1}). In the final stage of flowering, an insecticide-fungicide treatment was performed (Trion 250 EW 0.6 dm^3 ha^{-1} plus Proteus 110 OD 0.6 dm^3 ha^{-1}). The harvest was carried out using a combine harvester after reaching the full maturity of rape seeds.

Methodology of analysis

When carrying out the research, the following traits were determined: seeds yield, number of plants per m^2 (autumn and spring), number of siliques per plant, number of seeds per silique, plant height, SPAD (greenness index) and LAI (leaf area index). During the vegetation in the autumn, after emergence in the phase of 4–6 leaves (BBCH 16) and in spring, the plantation density was determined by counting plants in four places on each plot (4×0.125 m^2) and recalculating the obtained results into 1 m^2. Plant height was determined by measuring 20 plants on each plot at full maturity (BBCH 89). Before harvest, the samples of plants were collected from the same places where plants were counted after emergence in order to assess the yield components – number of siliques on the plant, number of seeds in silique and weight of 1,000 seeds. The harvest was made with a field combine-harvester (Wintersteiger nursery master elite). The weight of 1,000 seeds was determined in accordance with the PN-68/R-74017: 1968 standard. The LAI parameter was measured using a Decagon AccuPar ceptometer with an external PAR LI 190 S.A. sensor by Licor (USA). Five measurements were taken on each plot, making readings from 20 sensors within one measurement. The chlorophyll content was determined by the photo-optical method using the Minolta SPAD-502 analyzer (USA) on randomly selected 10 plants from each variant.

Statistical analysis

The results were statistically processed using the analysis of variance in a 2-factor random blocks design. Confidence sub-intervals (LSD) were calculated using Tukey's multiple test, assuming a significance level of $P \leq 0.05$. In addition, the analysis of variance with regression for the main effect of quantitative factor - the dose of fertilizer - was performed for selected soil features. The significance of regression equations was determined using the ANOVA with regression with F-Fisher-Snedecor test. Regression lines are shown on figures. Statistical analysis of results was carried out using the Statistica 10.0 software.

Soil and weather conditions

Soil from the experiment A was characterized by the following parameters: pH_{KCl} 5.2 ± 0.3 available phosphorus (P_{avail} = 56.5 ± 6.2), available potassium (K_{avail} = 110.9 ± 9.3), exchangeable magnesium (Mg_{exchan} = 64.4 ± 4.5 mg kg^{-1}). It was the soil with an average content of analysed macronutrients (Egner et al., 1960, ISO 13536:2002P).

Soil from the experiment B was characterized by the following parameters: pH_{KCl} 5.3 ± 0.4, P_{avail} = 47.5 ± 5.7, K_{avail} = 97.9 ± 8.5, $Mg_{exchang}$ = 54.4 ± 5.3 mg kg^{-1}. It was the soil with moderate content of available phosphorus and exchangeable magnesium and low of available potassium (Egner et al., 1960; ISO 13536:2002P).

In the years of research, meteorological conditions in Lipnik were very diverse. In autumn 2015, it initially did not deviate from the norm in terms of temperature and rainfall, while the end of the year was very warm: in December, the air temperature exceeded the norm by even 5.1 °C. From October to April, very low rainfall was recorded, hence these months were classified as dry and very dry. During those 7 months, only 143 mm of rain fell, which was only 56% of the average value. In the first quarter of 2016, the temperature fluctuated within the normal range, while May and June were very warm, exceeding the long-term value by respectively 2.9 °C and 2.0 °C. High rainfall in June was somewhat complemented by shortages from the earlier period. The second half of 2016 was in thermal terms within the norm, except from September, which turned out to be anomalously warm – 16.6 °C and very dry – only 13 mm of rainfall. The rainfall shortages lasted until March 2017. Large precipitation appeared in the summer, in June-August there was 310 mm of rain, which constituted 174% of the long-term sum (183 mm). These months were slightly warmer than average. The average air temperature in the season from September 2015 to August 2016 was 10.3 °C and exceeded the norm by 2.1 °C, and the total rainfall was 423 mm, which accounted for only 79% of the average, in the 2016/2017 season; these values were respectively: 9.1 °C – exceeding the standard by 1.1 °C and 604 mm – constituting 113% of the long-term value.

RESULTS AND DISCUSSION

Effect of different multi-component fertilizers on winter rape productivity

In experiments A and B, the average yield of winter rape seeds from two years was respectively in the range from 2.30 to 2.58 and from 2.55 to 2.64 Mg ha^{-1}. Relatively low yield of 2.50 Mg ha^{-1} obtained in the experiment was the result of unfavourable humidity conditions and high temperatures in most of the growing season in 2015 and 2016, which significantly hindered the preparation of the soil for the sowing of winter rape and its subsequent growth. Results of many studies confirm particularly high sensitivity of rape to the weather course during the growing season (Diepenbrock, 2000; Dunker & Tiedemann, 2004; Bartkowiak-Broda, 2005; Szczepaniak, 2014; Weymann et al., 2015; Oleksy, 2018). Polish and imported fertilizers used in the experiments, having the same percentage composition, did not differentiate the yield. The results indicate that macronutrients present in tested fertilizers are characterized by the same availability for cultivated rape (Table 1, 2).

The rapeseed plant density is a trait that significantly affects the size and quality of the crop. In the literature, there are presentations showing justified use of lower sowing density of winter rape seeds, because the yield of seeds and fat did not significantly differ from those obtained in conditions of higher sowing density (Kwiatkowski, 2012). In autumn, before the inhibition of vegetation in both experiments, the number of plants was obtained at a similar level, ranging from 50.3 to 55.7 plants per square meter. After starting the spring vegetation, a plant losses of 38% was found. In research by Czarnik et al. (2015), similar results were obtained for plant density for the hybrid cultivar Primus, i.e. 53.6 plants. Regarding the number of plants per area unit determined in autumn and spring, no statistically significant differences were found under the influence of Polish and imported fertilizers applied (Table 1, 2).

Table 1. Effect of multi component fertilizers on seeds yield, yield components and physiological parameters seeds of winter rape, experiment A, average from 2016–2017

Trait	Fertilizer				$LSD_{0.05}$
	Belarusian 1 NPK 6-20-30	Belarusian 2 NPK 6-20-30	Russian NPK 6-20-30	Polifoska 6 NPK 6-20-30(7)	
Seeds yield [Mg ha^{-1}]	2.30	2.58	2.37	2.38	n.s.
Number of plants per m^2 (autumn)	51.0	55.7	52.0	51.3	n.s.
Number of plants per m^2 (spring)	32.7	32.0	32.7	33.0	n.s.
Number of siliques per plant	114	120	109	106	n.s.
Number of seeds per silique	12.3	13.7	13.4	14.0	n.s.
Plant height [cm]	132	138	138	141	n.s.
Weight of 1,000 seeds [g]	4.66	4.62	4.54	4.74	n.s.
Greenness index (SPAD)	55.0	62.9	63.3	64.1	7.59
Leaf area index (LAI)	1.86	2.22	2.12	2.32	0.206

n.s. – not significant difference.

Table 2. Effect of multi component fertilizers on seeds yield, yield components and physiological parameters of winter rape, experiment B, average from 2016–2017

Trait	Fertilizer			$LSD_{0.05}$
	Belarusian NPK 8-24-24	Russian NPK 9-25-25(4)	Polifoska 8 NPK 8-24-24(9)	
Seeds yield [Mg ha^{-1}]	2.55	2.47	2.64	n.s.
Number of plants per m^2 (autumn)	50.3	52.5	52.3	n.s.
Number of plants per m^2 (spring)	32.7	32.8	32.7	n.s.
Number of siliques per plant	114	124	130	14.2
Number of seeds per silique	14.2	12.1	12.4	n.s.
Plant height [cm]	140	138	142	n.s.
Weight of 1,000 seeds [g]	4.44	4.62	4.69	n.s.
Greenness index (SPAD)	57.0	59.2	55.2	n.s.
Leaf area index (LAI)	2.03	2.10	2.06	n.s.

n.s. – not significant difference.

Plants cultivated in the experiment A established a number of siliques on the plant of 110 pieces. This amount is comparable to that obtained by Jarecki et al. (2013) for Primus F1 and Visby F1 and smaller compared to data provided by Malarz et al. (2006) for Kaszub cv. rape – 162 pieces. Fertilizers used in the experiment A did not differentiate the amount of siliques per plants. Using Polifoska 8 in experiment B, more siliques were produced on rapeseed plants than after using the two other fertilizers and this was confirmed by statistical calculations (Table 2). Fertilizers used in both experiments did not differentiate values of the number of seeds in the rapeseed rape within the range from 12.3 to 14.2.

In experiments carried out in 2015 by the Central Research Center for Cultivated Plants (COBORU 2016), in the West Pomeranian province, the average height of plants of cultivar DK EXPLICIT was 166 cm, the weight of a thousand seeds – 4.6 g. Winter rape plants cultivated in experiment A and B were about 16% lower. The weight of one thousand seeds of winter oilseed rape cultivated in both experiments was analogous to that obtained in the COBORU experiments (Table 1, 2). In relation to the number of seeds in silique and the weight of one thousand seeds, no statistically significant differences were found under the influence of the applied Polish and imported fertilizers (Table 1 and 2). Wielebski & Wójtowicz (1998), on the basis of results obtained in the experiment with five cultivars of winter oilseed rape, concluded that the number of siliques per plant was significantly different in reference to the nitrogen dose, and the remaining elements of the yield structure, such as: number of seeds in silique and weight of 1,000 seeds did not significantly differ.

In the experiment A, significantly higher level of SPAD (greenness index) was obtained by plants growing on soils fertilized with Belarusian 2, Russian and Polifoska 6 fertilizers, taking 62.9, 63.3 and 64.1 values. The physiological index LAI (leaf area to soil surface) was significantly differentiated as a result of the fertilizers used. The use of Belarusian 1 fertilizer was a factor causing the rapeseed plants growing on these objects to have a lower greenness index of 55.0 and LAI index of 1.86. Fertilizers used in experiment B, Belarusian, Russian and Polifoska 8 did not differentiate the SPAD and the LAI index (Table 2).

Effect of different multi-component fertilizers doses on winter rape productivity

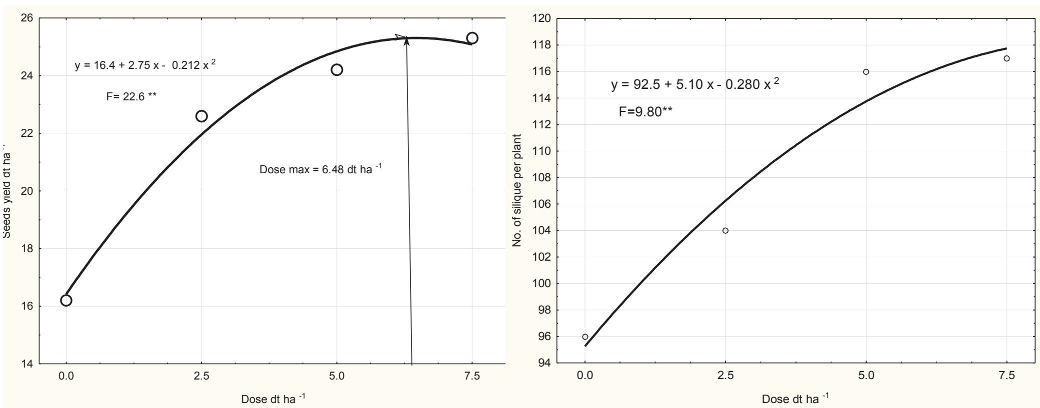

Figure 1. Regression line between dose of fertilizer and seeds yield and number of siliques per plant, experiment A.

The analysis of the effect of varied doses conducted in experiment A showed statistically confirmed differences in the yield of winter rapeseed. The calculations showed that it was possible to obtain the highest yield using fertilizer in the dose of 6.58 Mg ha^{-1}. Further increase of the dose had no rationale (Fig. 1). The results of the experiment B showed an analogous relationship, the highest yield (2.80 Mg ha^{-1}) was obtained using the dose of 4.15 Mg ha^{-1}. Further increase of the applied fertilizer dose resulted in a decrease in yield (Fig. 2). It needs to be highlighted that the application of the minimum dose of the analysed fertilizers resulted in a very high increase in rapeseed yield as compared with variant without fertilization (Table 3 and 4). According to the analysis of the effect of fertilization on the yield of winter rapeseed by Gaj (2010), the object variation was mainly due to the contrast's significance: the absolute control (without NPK fertilization) and other fertilization variants.

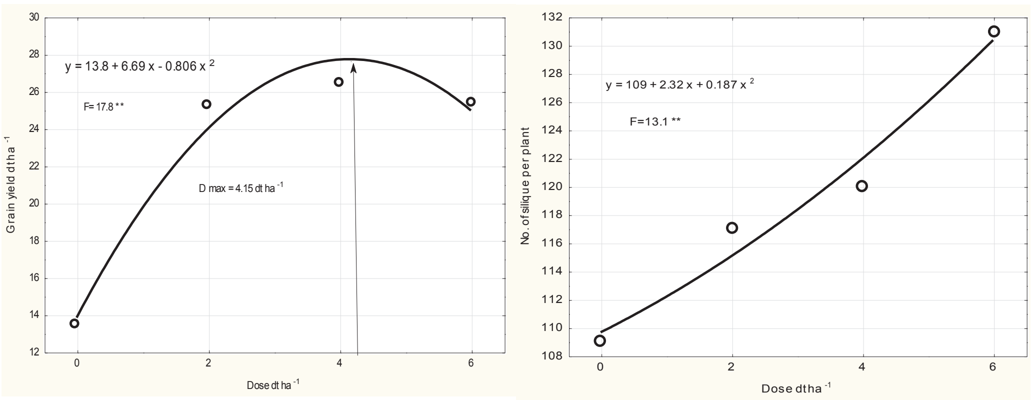

Figure 2. Regression line between dose of fertilizer and seeds yield and number of siliques per plant, experiment B.

In both experiments, the number plants per m^2 of winter rapeseed which was measured in autumn and spring was independent of the applied fertilizers and doses (Table 3, 4).

Table 3. Comparison of the effect of fertilizers on seeds yield, yield components and physiological parameters of winter rape experiment A, average from 2016–2017

Trait	Fertilizer dose [kg ha^{-1}]				$LSD_{0.05}$
	0	250	500	750	
Seeds yield [Mg ha^{-1}]	1.62	2.26	2.42	2.53	0.231
Number of plants per m^2 [autumn]	50.5	52.3	55.9	49.5	n.s.
Number of plants per m^2 [spring]	30.0	32.2	32.6	32.9	n.s.
Number of siliques per plant	96	104	116	117	10.2
Number of seeds per silique	11.1	13.9	13.0	13.2	1.57
Plant height [cm]	125.0	136.9	137.3	137.7	9.92
Weight of 1,000 seeds [g]	4.61	4.60	4.66	4.66	n.s.
Greenness index (SPAD)	43.3	59.6	63.9	65.5	4.86
Leaf area index (LAI)	1.60	2.09	2.20	2.32	0.236

n.s. – not significant difference.

The three parameters determining the yield of winter rapeseed (the number of siliques per a plant, the number of seeds in the siliques and the plant height) showed higher values with an increase of the applied dose. However, the significant difference was found only regarding data for fertilized and unfertilized objects (Table 3, 4, Figs 1, 2).

In A and B experiment, the application of multi-compound fertilizers to the soil had no effect on the weighty of 1,000 seeds values (relatively high, 4.6 g) (Tables 3, 4). Ranjbar et al. (2014) report that the weight of 1,000 seeds was not dependent on different tillage system, which suggesting the stability of this trait.

Table 4. Comparison of the effect of fertilizers on seeds yield, yield components and physiological parameters of winter rape experiment B, average from 2016–2017

Trait	Fertilizer dose [kg ha^{-1}]				$LSD_{0.05}$
	0	200	400	600	
Seeds yield [Mg ha^{-1}]	1.34	2.53	2.60	2.54	0.254
Number of plants per m^2 (autumn)	51.5	52.8	50.6	51.7	n.s.
Number of plants per m^2 (spring)	30.5	32.3	33.5	32.3	n.s.
Number of siliques per plant	109	117	120	131	13.3
Number of seeds per silique	9.0	13.5	13.6	11.9	1.73
Plant height [cm]	126	138	140	142	14.1
Weight of 1,000 seeds [g]	4.45	4.62	4.53	4.60	n.s.
Greenness index (SPAD)	47.3	56.7	55.9	58.9	4.57
Leaf area index (LAI)	1.60	2.09	2.07	2.03	0.215

n.s. – not significant difference.

The physiological SPAD and LAI indices were higher for winter rapeseed plants grown on all objects with fertilization. The three applied doses of fertilizers did not show differences in the analysed indices, values of which were in the same homogenous group (Table 3, 4).

CONCLUSIONS

The fertilizers applied in the experiments, manufactured in Belarus, Russia and Poland, did not show variations in the amount of yield of winter oilseed rape, cultivar DK EXPLICIT. The number of winter rapeseed plants on the area unit (in autumn and spring) was independent of the type of fertilizers. In the experiment B, higher number of rapeseed siliques was obtained after application of Polifoska 8, than other fertilizers. Rapeseed grown on soil with the fertilizers manufactured in Belarus showed a lower value of greenness index (SPAD) and leaf area index (LAI).

The seeds yield obtaind at increasing fertilizer dose was differentiated. The three parameters determining the yield of winter rapeseed (the number of silique per plant, the number of seeds in the siliques and the plant height) showed higher values with an increase of the applied dose. The applied doses of fertilizers did not show differences in greenness index (SPAD) and leaf area index (LAI), values of which were in the same homogenous group. As a result of the application of multi-component fertilizers, manufactured in Belarus, Russia and Poland, the recorded differences in the winter rapeseed yield, yield components and physiological parameters did not exceed 10%.

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