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The response of winter oilseed rape to diverse foliar fertilization

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Abstract: In this experiment, the response of winter oilseed rape cv. SY Alister F1 to diverse foliar fertilization was evaluated. Foliar fertilization with the preparation Insol 5 was applied at the following dates: control (without a foliar fertilizer); autumn; autumn + spring; autumn + twice spring; spring and twice spring. Each variant in which autumn foliar fertilization was carried out contributed to a significant increase in plant density before harvest. In turn, each variant with spring foliar fertilization significantly increased the number of pods per plant compared to the control. Variants with autumn + spring, autumn + twice-spring, and twice-spring foliar fertilization influenced the increase in the soil-plant analysis development index (SPAD), thousand seed weight and protein and fat yield. The leaf area index was the highest after foliar fertilization applied in autumn + in spring or autumn + twice in spring. Foliar fertilization affected a significant increase in seed yield compared to the control. The content of protein and magnesium in seeds was the highest after the fertilizer application in autumn + twice in spring or twice in spring.

Keywords: *Brassica napus* L. (Partim); nutrients; chlorophyll; yield of protein and oil; chemical composition of seeds

Winter oilseed rape is the basic oil crop in the European Union. Vegetable oil is obtained from the seeds and the remains after its extrusion are used for feeding due to the high protein content. The size and quality of yield of winter oilseed rape depend on many factors: cultivar (Wenda-Piesik and Hoppe 2018), weather conditions (Varga et al. 2014) or cultivation practices (Fordoński et al. 2015, Kováčik et al. 2016). Macro- and micro-element fertilization is an important element of winter oilseed rape cultivation. During the growing season, some nutrients can be provided to the plant leaves (Sienkiewicz-Cholewa and Kieloch 2015, Jankowski et al. 2016b). Soil fertilization is applied based on soil analysis (Yang et al. 2009), while foliar fertilization is applied based on visual symptoms on leaves or, more precisely, with the use of non-destructive apparatuses (Fageria et al. 2009, Liu et al. 2018). Studies by many authors regarding foliar fertilization of winter oilseed rape indicate the effectiveness of such practices (Stanisławska-Glubiak 2008, Jankowski et al. 2016a, Száková et al. 2017). As a result, one can obtain an increase in the yield of seeds, and often in their quality (Chwil 2016, Jankowski et al. 2016b).

Yang-Yuen et al. (1999) conclude that foliar fertilization should only be used in justified cases. Hence, the validity of research on the optimization of foliar fertilization in field crops. During plant growth, foliar fertilization can be performed once or several times at different dates. In winter oilseed rape, foliar application two- or three-times during the plant growth is justified, and the first application can be carried out as early as in the autumn (Fageria et al. 2009).

This study aimed at determining the response of winter oilseed rape to autumn and spring foliar fertilization with Insol 5 applied in several variants at selected plant developmental stages.

MATERIAL AND METHODS

Field experiment. Field experiments with winter rape cv. SY Alister F1 were carried out in the seasons 2014/2015–2016/2017, in the fields of the Podkarpackie Agricultural Advisory Center

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Table 1. Foliar fertilization schedule

Treatment	Description	Dose of Insol 5 (L/ha)		
		I	II	III
A	control	–	–	–
B	autumn	1.5	–	–
C	autumn + spring	1.5	1.5	–
D	autumn + twice spring	1.5	1.5	1.5
E	spring	–	1.5	–
F	twice spring	–	1.5	1.5

Developmental stages (I – BBCH 18; II – BBCH 35; III – BBCH 51)

in Boguchwała (49°59'N, 21°57'E), south-eastern Poland. The experiment was established in four replications in the complete randomized block design. The studied factor was the varied dates of foliar fertilization: A – control (without foliar fertilization); B – autumn; C – autumn + spring; D – autumn + twice spring; E – spring; F – twice spring (Table 1). The applied foliar fertilizer Insol 5 (Insol sp. z o.o., Puławy, Poland) contained (% m/m): Mg – 1.38; B – 0.8; Cu – 0.1; Fe – 0.3; Mn – 0.5; Mo – 0.01; Zn – 0.33.

The cv. SY Alister F1 (Syngenta AG, Basel, Switzerland) is a hybrid cultivar with high tolerance to club root of cabbage (*Plasmodiophora brassicae*). The experiment was located in soil originated from silty clay, classified as Haplic Cambisol (WRB 2014). The pH of the soil was slightly acidic. The soil had a high content of P and K, very high content of Mg and average content of microelements (Table 2).

The plot area was 15 m^2. The sowing rate was 60 seeds/m^2, the row spacing was 25 cm and the depth was 1.5 cm. The previous crop was winter wheat. Seed sowing was carried out on August 29, 2014, August 31, 2015, and August 25, 2016. Before sowing, mineral fertilization was applied in doses of 30 N (ammonium nitrate); 40 P (superphosphate) and 90 K (potassium salt) kg/ha. In the spring before the start of rapeseed growth, 100 kg N/ha was applied, and at the stage of full budding (BBCH 59) another 70 kg N/ha was applied. Weeds, diseases and pests were controlled throughout the growing season, and chemical control was used, as recommended by the Institute of Plant Protection-National Research Institute, Poznań, Poland. Rape was harvested at full maturity of the seeds with a plot combine harvester. The seed yield per plot was calculated for the area of 1 ha, with seed moisture of 9% DM (dry matter).

Weather condition. During the winter dormancy period, the lowest air temperature was recorded in January 2017. Low rainfall was recorded in May 2016 and 2017, compared to the long-term mean. In June and July each year, rainfall was below the long-term average. The course of temperatures was less varied. In April 2017, the mean air temperature was below the long-term average. From May to July, the air temperatures did not differ significantly from the long-term average (Figure 1).

Field and laboratory measurements. The measurement of stomatal conductance of leaves (g_s) was performed with a Meter Porometr SC-1 apparatus (Pullman, USA). The soil-plant analysis development index (SPAD) was measured with a Konica Minolta SPAD-502P meter (Tokyo, Japan). g_s and SPAD measurements were made on 30 rapeseed leaves. Leaf area index (LAI) measurement was performed using a Meter LP-80 AccuPAR apparatus (Pullman, USA). g_s, SPAD and LAI measurements were performed at the start of the rape flowering stage (BBCH 61). Before harvest, plants per 1 m^2 were counted. For biometric measurements, 20 plants were collected from each plot to determine: the number of pods per plant, the number of seeds per pod and the thousand seed weight (9% humidity).

Analytical methods. The content of protein, fat, ash and fiber in seeds was determined with the near-infrared spectroscopy (NIRS) method using an FT NIR MPA spectrometer (Bruker, Billerica, USA). The protein and fat yield were calculated from the seed yield and the percentage of the

Table 2. Physicochemical soil properties and content of available nutrients in soil (mg/kg)

	2014/2015	2015/2016	2016/2017
Soil reaction (1 mol/L KCl)	6.45	6.24	5.85
P	76	65	68
K	138	128	148
Mg	83	76	68
Fe	3501	3243	3428
Mn	373	362	440
Zn	16.7	17.4	18.6
B	1.8	1.9	1.6
Cu	7.4	7.9	7.7

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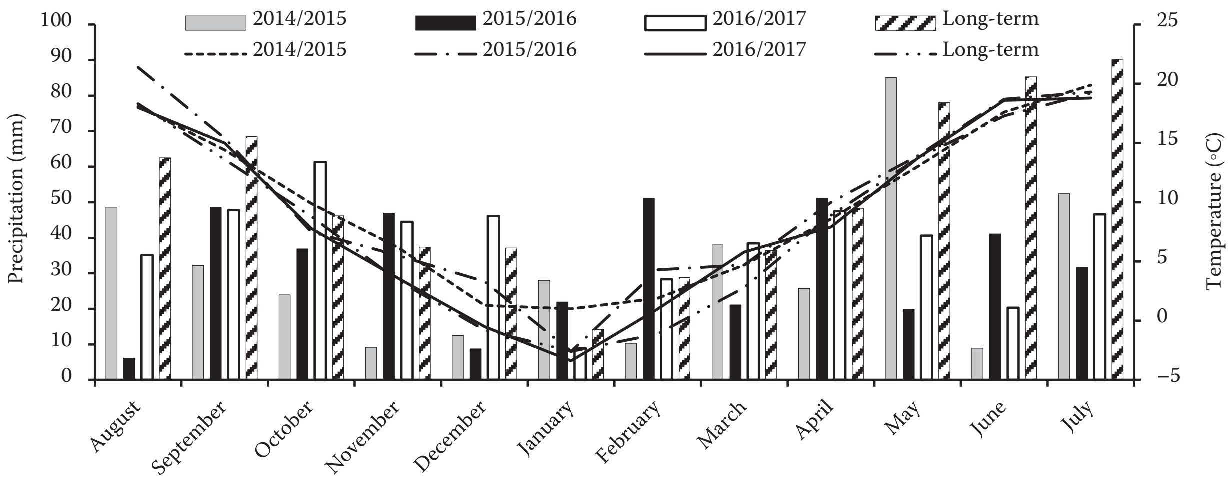

Figure 1. Weather conditions for three growing seasons

given component in the seeds. To determine macroelements and micronutrients, plant samples were mineralized in a mixture of concentrated acids HNO_3:$HClO_4$:H_2SO_4 in the 20:5:1 ratio, in an open system, in a Tecator heating block. The content of K, Ca, Mg, Fe, Mn, Zn, Cu was determined in the obtained samples by atomic absorption spectroscopy (FAAS), using a Hitachi Z-2000 apparatus (Tokyo, Japan). Phosphorus was determined colorimetrically using a Shimadzu UV-VIS spectrophotometer (Kyoto, Japan).

Statistical analyses. The results were subjected to an analysis of variance, and significant differences were analysed with the Tukey's (*LSD* (least significant difference)) test (P = 0.05) using the Statistica 10.0 programme (StatSoft, Tulsa, USA).

RESULTS AND DISCUSSION

Yield components. Foliar fertilization was carried out on the following dates: autumn (B); autumn + spring (C) and autumn + twice spring (D); it affected a significant increase in plant density before harvest compared to the A treatment. On average, plant density before harvesting winter oilseed rape amounted to 43.2 pcs/m^2 (Table 3). The use of the fertilizer Insol 5 only on the autumn date (B) did not have a significant impact on the number of pods per plant, while in other variants, it significantly increased the discussed parameter in comparison to the A treatment. On average, winter oilseed rape plants developed 121.6 pods. The number of seeds per pod was not significantly differentiated by the experimental factor.

The study by Wenda-Piesik and Hoppe (2018) demonstrated a beneficial effect of high-input technology of winter oilseed rape cultivation with autumn foliar fertilization on wintering of plants. Chwil (2016) confirms that foliar fertilizers increase the number of pods set, but they do not differentiate the winter oilseed rape plant density before harvesting. Jankowski et al. (2016b) indicated that

Table 3. Yield components and seed yield (2015–2017)

Treatment	Number of plants before harvest (pcs./m^2)	Number of pods per plant	Number of seeds per pod	1000 seed weight (g)	Seed yield (t/ha)
A	42.2^{b}	116.5^{b}	20.5^{a}	5.07^{b}	4.92^{c}
B	43.5^{a}	118.2^{ab}	20.4^{a}	5.09^{b}	5.12^{b}
C	44.0^{a}	123.9^{a}	20.3^{a}	5.28^{a}	5.63^{a}
D	44.0^{a}	124.5^{a}	20.0^{a}	5.34^{a}	5.64^{a}
E	42.5^{ab}	123.1^{a}	20.1^{a}	5.21^{ab}	5.24^{b}
F	42.7^{ab}	123.5^{a}	20.7^{a}	5.30^{a}	5.58^{a}

Values with different letters (a, b, c) are significantly different (P = 0.05). A – control; B – autumn; C – autumn + spring; D – autumn + twice spring; E – spring; F – twice spring

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the foliar application of B significantly increased the number of seeds per pod by 4%.

In our own studies, autumn + spring (C), autumn + double spring (D) and twice spring (F) foliar fertilization influenced the increase in thousand seed weight (TSW). Less plump seeds were obtained in treatments with autumn (B) foliar fertilization and in the A treatment. In the study by Varga et al. (2014), there was no increase in TSW under the influence of foliar fertilization and the mean TSW ranged from 4.47 g to 4.67 g.

Seed yield. A significant increase in oilseed rape yield was found in treatments with foliar fertilization in comparison to the A treatment (Table 3). The highest yield was provided by autumn + spring (C), autumn + twice spring (D) and twice spring (F) fertilization. Foliar fertilization carried out only in autumn (B) or only in spring (E) resulted in a lower seed yield increase compared to the A treatment. The mean yield of winter oilseed rape in this experiment was 5.35 t/ha.

The studies by Chwil (2016) and Jankowski et al. (2016a) confirm a significant increase (by 10%) of rape seed yield after the application of foliar fertilization compared to the control (without foliar fertilization). Wenda-Piesik and Hoppe (2018) show the validity of using high-input technology in the winter oilseed rape cultivation taking into account autumn and spring foliar fertilization. Ma et al. (2015) showed a higher increase in winter rape seed yield after the foliar application of B compared to soil fertilization with this component.

Measurements of indexes and leaf stomatal conductivity. The SPAD index was the highest after two-time (C or F) or three-time (D) use of the fertilizer Insol 5 (Figure 2). The autumn (B) or only spring (E) date of foliar application did not significantly increase the discussed parameter in comparison to the A treatment. In the study by Koohkan and Maftoun (2016), the soil application of B decreased the chlorophyll content in leaves, which in effect reduced the value of the SPAD index. Pużyńska et al. (2018) showed an increase in the SPAD index, using foliar S and B.

The application of foliar fertilization on the autumn and spring dates (C or D) resulted in an increase of the LAI index. Lower LAI index measurements were obtained after spring (E or F) foliar fertilization, and the lowest after autumn (B) foliar application and in treatment A. Wenda-Piesik and Hoppe (2018) showed that high-input technologies of winter oilseed rape cultivation significantly increase the LAI index compared to the standard cultivation technology, and this is differentiated between the cultivars.

Higher values of the leaf stomatal conductivity measurement were obtained in treatments with foliar fertilization, with the exception of autumn fertilization (B). However, these relationships were not statistically significant. The fertilizer application was the most effective on the autumn + twice spring (D) or twice spring (F) dates. According to Pużyńska et al. (2018), controlling the photosynthetic response of rape to foliar fertilization can

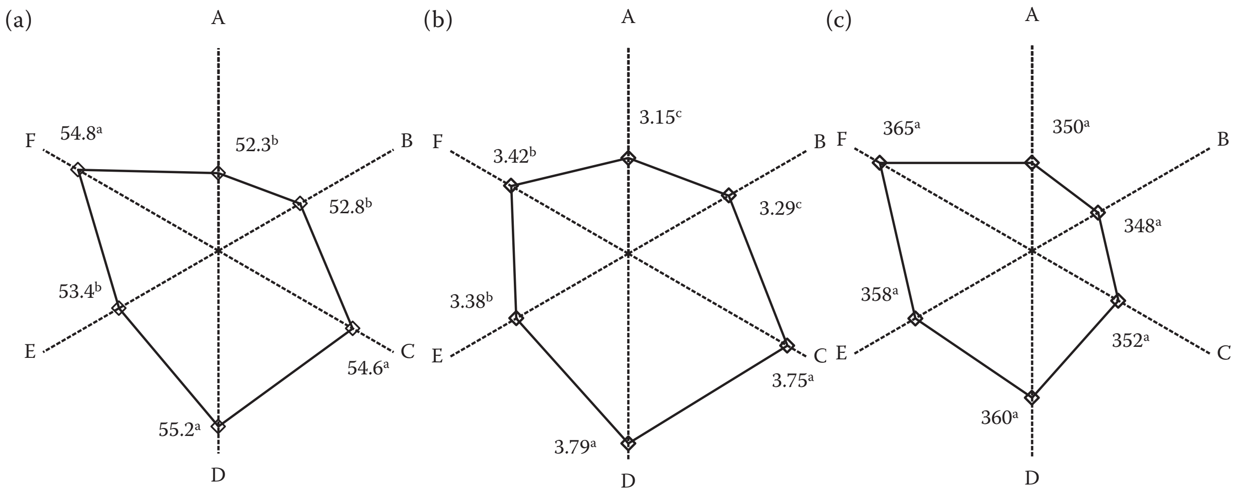

Figure 2. Measurements of (a) soil plant analysis development; (b) leaf area index and (c) stomatal conductance of leaves indicator (2015–2017). Values with different letters (a, b, c) are significantly different (*P* = 0.05). A – control; B – autumn; C – autumn + spring; D – autumn + twice spring; E – spring; F – twice spring

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Table 4. Seed chemical composition and protein and fat yield (2015–2017)

Treatment	Total protein	Fat	Ash	Fiber	Protein yield	Fat yield
	(% DM)				(t/ha)	
A	21.6^{b}	48.2^{a}	7.7^{a}	6.8^{a}	1.06^{b}	2.37^{b}
B	22.1^{ab}	48.3^{a}	7.8^{a}	6.6^{ab}	1.13^{ab}	2.47^{ab}
C	22.7^{ab}	48.1^{a}	8.0^{a}	6.3^{b}	1.28^{a}	2.71^{a}
D	23.1^{a}	47.6^{a}	8.2^{a}	6.2^{b}	1.30^{a}	2.68^{a}
E	22.5^{ab}	48.0^{a}	8.0^{a}	6.4^{ab}	1.18^{ab}	2.52^{ab}
F	22.9^{a}	47.8^{a}	8.1^{a}	6.3^{b}	1.28^{a}	2.67^{a}

Values with different letters (a, b, c) are significantly different (P = 0.05). A – control; B – autumn; C – autumn + spring; D – autumn + twice spring; E – spring; F – twice spring; DM – dry matter

be variable and depends on the weather conditions during the measurement or developmental stage.

Chemical composition of seeds and protein and fat yield. The protein content in seeds was the highest after the application of the fertilizer Insol 5 on autumn + twice spring (D) or twice spring (F) dates. Seeds from the control (A) contained significantly less total protein (Table 4). The content of crude fat and ash was not significantly differentiated. The most fiber was determined in seeds from treatment (A), and significantly less after autumn and spring (C or D) and twice spring (F) foliar fertilization. The protein and fat yield per ha were the lowest in treatment (A), and significantly higher after the autumn and spring (C or D) and twice spring (F) foliar fertilization.

Chwil (2016) using the fertilizer Ekosol U showed a decrease in protein content in seeds, at the same time obtaining the lowest protein and fat yield per hectare in the control. In the study by Lääniste et al. (2004), the foliar application of Mn or Mo increased fat content in seeds by more than 1% compared to the control. In turn, White et al. (2015), under the influence of foliar fertilization with N, obtained an increase in total protein content and a reduction in fat in rape seeds.

The content of macroelements in the grain was not very variable, and the content of microelements was not significantly differentiated by the experimental factor (Table 5). Three-time (D) and two-time spring (F) foliar fertilization significantly increased the Mg content in the seeds as compared to the control (A). Jankowski et al. (2016a) under the influence of foliar fertilization obtained a significant variation in the content of K, S, Cu and Zn (increase) and of P, Mn and Fe (decrease) in seeds. Fordoński et al. (2015) showed higher contents of the micronutrients Fe, Cu, Zn and Mn in rape seeds grown after faba bean, pea, and white lupine than after spring wheat. However, Stępień et al. (2017) obtained a higher level of Zn and Mn in rape seeds grown in the high-input technology and Fe in the medium-input technology.

Table 5. Macroelement and microelement content (2015–2017)

Treatment	P	K	Ca	Mg	Fe	Cu	Mn	Zn
	(g/kg DM)				(mg/kg DM)			
A	6.7^{a}	7.5^{a}	3.8^{a}	4.1^{a}	85.9^{a}	3.3^{a}	36.4^{a}	37.7^{a}
B	6.8^{a}	7.7^{a}	3.7^{a}	4.2^{a}	84.2^{a}	3.1^{a}	37.5^{a}	38.0^{a}
C	6.7^{a}	7.7^{a}	3.8^{a}	4.4^{a}	85.9^{a}	3.6^{a}	37.2^{a}	38.0^{a}
D	6.7^{a}	7.9^{a}	3.8^{a}	4.5^{b}	85.9^{a}	3.6^{a}	37.6^{a}	38.1^{a}
E	6.4^{a}	7.8^{a}	3.8^{a}	4.4^{a}	85.2^{a}	3.4^{a}	36.9^{a}	37.8^{a}
F	6.5^{a}	7.9^{a}	3.8^{a}	4.5^{b}	85.9^{a}	3.6^{a}	37.5^{a}	38.1^{a}

Values with different letters (a, b, c) are significantly different (P = 0.05). A – control; B – autumn; C – autumn + spring; D – autumn + twice spring; E – spring; F – twice spring; DM – dry matter

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In conclusion, it was found that the foliar fertilizer Insol 5 affected a significant increase in yield and a change in the chemical composition of seeds. The SPAD index, the TSW, the seed yield, and the protein and fat yields reached the highest values after autumn + spring, autumn + twice spring, and twice spring foliar fertilization terms. Application of the fertilizer on the autumn + twice spring or twice spring dates resulted in an increase in the LAI index and increased the content of protein and Mg in seeds. Foliar fertilization should, therefore, be used as a permanent element of winter rape cultivation technology.

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