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THE EFFECT OF FOLIAR FEEDING UNDER DIFFERENT SOIL FERTILIZATION CONDITIONS ON THE YIELD STRUCTURE AND QUALITY OF WINTER OILSEED RAPE (*BRASSICA NAPUS* L.)

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ABSTRACT

The present study involved a detailed analysis of foliar feeding of the winter oilseed rape cultivar 'Kana' combined with different regimes of fertilization with calcium and magnesium compounds. Foliar fertilizers, INSOL PK + 5% urea solution and EKOSOL U, were applied three times during the growing period and four different soil fertilization treatments were used: control without fertilization, NPK, NPK + $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, and NPK + $\text{CaO} + \text{MgO}$. This study was carried out based on a three-year field experiment on medium soil with a pH of 4.2 in $1 \text{ mole KCl} \cdot \text{dm}^{-3}$ and with the grain-size distribution of silt loam. The soil was characterized by a low content of available phosphorus and potassium as well as a very low content of sulfur and magnesium. The soil fertilization treatments used and the foliar fertilizers resulted in differences in the yield parameters, the macronutrient content in seed and straw as well as in the protein and oil content in seed. This study found the best production effects and quality parameters in the cultivation of winter oilseed rape in the treatment with the use of magnesium lime in the fertilizer dose. The foliar fertilizers caused greater differences in seed yield as well as in protein and oil content and yield than in the mineral composition.

Key words: foliar fertilization, liming, winter oilseed rape, fat yield, fatty acids, total protein, macronutrients.

INTRODUCTION

Oilseed rape (*Brassica napus* L.) belongs to plants of great economic importance. It provides valuable raw material for the vegetable oil industry and the animal feed industry in the form of extraction meal [9, 29]. The use of rapeseeds as a renewable source of energy in the production of biodiesel is now increasing [2, 36]. In Poland oilseed rape is grown in an area of 900,000 ha, but in order to meet the international commitments to increase the percentage of biocomponents in fuel the rapeseed crop acreage should increase [37].

The technological and nutritional value of rapeseed is determined to the greatest extent by its oil content, the content of protein and its composition as well as the thousand seed weight; these traits are dependent on genetic [11] and environmental factors [42]. Among the agronomic factors, fertilization has the largest share (about 30%) in total rapeseed production costs. The high nutritional requirements of oilseed rape encourage researchers to carry out research on the rationalization of fertilization in order to obtain satisfactory yields both in quantitative and qualitative terms, but also in the economic and environmental aspects [7, 8, 14, 40]. Numerous scientific studies have revealed that only balanced soil fertilization supported by foliar application of nutrients meets the above described expectations [4, 12, 13, 18].

The aim of the present study was to determine the influence of foliar feeding under the conditions of different soil fertilization with calcium and magnesium compounds on yield and the major quality parameters of oilseed rape.

MATERIAL AND METHODS

This study was conducted based on a three-year field experiment established in Rudnik (50°53'23"N 22°57'59.89"E) on silt loam with a pH of 4.2 in $1 \text{ mole KCl} \cdot \text{dm}^{-3}$. The soil was characterized by a low content of available phosphorus and potassium

as well as a very low content of sulfur and magnesium. The climatic conditions during the study period in relation to the long-term values were described in another publication [4]. The experimental design included 3 foliar feeding treatments: 1. control treatment /spraying with water/; 2. INSOL PK + 5% urea solution; 3. EKOSOL U, and 4 soil fertilization treatments: 1. control treatment /without fertilization/; 2. NPK; 3. NPK + MgSO₄ · 7H₂O; 4. NPK + CaO + MgO, in 3 replicates.

Magnesium oxide lime was used in randomly selected plots with an area of 48 m² immediately after the previous crop had been harvested, according to single hydrolytic acidity. Mineral fertilization was used at a rate of 120 kg N · ha⁻¹, 43 kg P · ha⁻¹, 95 kg K · ha⁻¹ in the form of Amofoska 4-16-18 and 4.5S as well as ammonium nitrate; moreover, each year before sowing winter oilseed rape, cv. 'Kana', magnesium sulfate was applied at a rate of 24 kg Mg · ha⁻¹ in randomly selected plots. In the treatments where plants were fed with Insol PK with the addition of urea, the rate of nitrogen was reduced by 20.7 kg N · ha⁻¹, since such an amount of this nutrient was foliar-applied with the spray solution as a 5% urea solution. Foliar application in rape was used in the rosette stage as well as in the stem and bud formation stages. Foliar fertilizers were applied on each of the test treatment of soil fertilization at the following doses: Insol PK – 6 dm³ per 300 dm³ of water per 1 ha and Ekosol U – 2 dm³ per 300 dm³ of water per 1 ha. Insol PK contained (in %): P – 4.4, K – 15.8, and Ekosol U contained (in %): N – 15, P – 2.2, K – 2.7, Na – 0.15, B – 0.01, Cu – 0.012, Fe – 0.012, Mn – 0.017, Mo – 0.002, Zn – 0.1.

The harvest was done at commercial maturity, taking samples from 1 m² in 3 replicates. The samples were used to determine the seed and straw yield as well as the main yield components: 1000 seed weight, number of plants per m², number of pods per plant, and number of first-level branches.

After mineralization in concentrated sulfuric acid with the addition of hydrogen peroxide, total N in seed and straw of winter oilseed rape was determined using the Kjeldahl method, K, Ca and Mg were determined by AAS on a Hitachi Z-8200 polarized Zeeman atomic absorption spectrophotometer, whereas P colorimetrically by the vanadium-molybdate method using a Cecil 2011 colorimeter. Total sulfur was determined according to Butters-Chenery [30]. The uptake of macronutrients was calculated as the sum of a given nutrient in the primary yield and straw based on the nutrient content in these organs. The qualitative evaluation of the yield showed the oil content and yield, the total protein content (N x 6.25), and the protein yield as well as the K/(Ca + Mg) mole ratio and the N/S mass ratio in seed and straw.

The obtained results were evaluated by analysis of variance and presented as means for the 3-year study period (1999–2001). Means were analyzed by T-Tukey's multiple comparisons at a significance level of 0.05.

RESULTS

Yield

The soil fertilization treatments used resulted in differences in the analyzed yield components of winter oilseed rape, except for plant density, and the yield components showed the highest values after application of NPK + CaO + MgO fertilization (Tab. 1). As regards the yield components in question, the foliar fertilizers, likewise soil fertilization, did not affect the plant density, but they increased the other yield components. Among the foliar fertilizers applied, EKOSOL U showed a better effect on the seed and straw yield of winter oilseed rape, whereas INSOL PK had a better effect on the number of siliques per plant and thousand seed weight.

Table 1. Seeds and straw yield as well as the yield structure of foliar fertilized winter rape under different soil fertilization conditions

Foliar fertilizer (A)	Soil fertilization (B)	Seed yield	Straw yield	Thousand seeds weight	Number of plants	Number of siliquas per plant	Number of branches per plant
		[t·ha ⁻¹]	[t·ha ⁻¹]	[g]	[pcs] (per square metre)	[pcs]	[pcs]
WATER	Control	1.49	4.24	4.17	91.58	38.72	1.88
INSOL PK		1.90	5.08	4.64	86.67	45.65	2.51
EKOSOL U		1.76	4.63	4.48	88.58	43.40	2.03
WATER	NPK	2.78	7.28	4.37	88.67	56.87	3.03
INSOL PK		3.01	7.69	4.68	93.58	67.50	3.73
EKOSOL U		3.04	7.88	4.73	89.75	62.74	4.00
WATER	NPK + MgSO ₄	2.88	7.61	4.52	90.00	61.01	3.51
INSOL PK		3.10	7.80	4.95	92.08	72.35	4.15
EKOSOL U		3.23	8.23	4.81	89.67	70.60	4.87
WATER	NPK + CaO + MgO	3.27	8.24	4.69	90.50	72.33	4.54
INSOL PK		3.41	8.53	4.91	91.08	80.27	4.87
EKOSOL U		3.45	8.74	4.85	89.75	80.20	5.17
LSD _{0,05} for (AxB)		n.s.	0.48	n.s.	n.s.	4.56	0.69
	Control	1.72	4.65	4.43	88.94	42.59	2.14

Mean (B)	NPK	2.94	7.62	4.59	90.67	62.37	3.59
	NPK + MgSO ₄	3.07	7.88	4.76	90.58	67.99	4.17
	NPK + CaO + MgO	3.38	8.50	4.81	90.44	77.60	4.86
LSD _{0,05} for B		0.12	0.21	0.16	n.s.	2.06	0.31
WATER	Mean (A)	2.61	6.84	4.44	90.18	57.23	3.24
INSOL PK		2.85	7.28	4.80	90.85	66.44	3.81
EKOSOL U		2.88	7.37	4.72	89.44	64.24	4.02
LSD _{0,05} for A		0.10	0.17	0.13	n.s.	1.63	0.24

The mineral composition of winter oilseed rape

Both soil fertilization and foliar feeding resulted in differences in the content of N, P and S. Moreover, soil fertilization significantly affected the seed content of Ca. Fertilization with the addition of CaO + MgO in the dose significantly increased the P content compared to the treatments with NPK and NPK + MgSO₄ as well as Ca relative to the other soil fertilization treatments. The incorporation of MgSO₄ in fertilization resulted in an increase in the N and S content in relation to the control treatment and NPK, but it did not increase the magnesium content (Tab. 2). The foliar fertilizers did not increase the macronutrient content relative to the control treatment, but after application of EKOSOL U the content of N, P and S was found to be significantly lower.

Table 2. Macronutrient content in seed winter rape after application of foliar feeding under different soil fertilization conditions

Foliar fertilizer (A)	Soil fertilization (B)	N	P	K	Ca	Mg	S
		[g kg ⁻¹ d.m.]					
WATER	Control	25.35	6.07	6.84	2.90	2.65	3.64
INSOL PK		25.91	6.08	7.06	3.62	3.02	4.22
EKOSOL U		25.24	5.14	7.00	3.55	2.98	3.92
WATER	NPK	30.21	5.10	7.07	3.28	2.73	4.01
INSOL PK		28.57	5.65	7.39	3.29	2.82	3.74
EKOSOL U		26.26	4.51	6.99	3.23	2.50	3.62
WATER	NPK + MgSO ₄	30.48	5.80	8.28	3.10	3.04	4.28
INSOL PK		30.43	5.60	7.34	3.18	2.97	4.27
EKOSOL U		28.82	4.87	7.08	3.62	2.60	3.83
WATER	NPK + CaO + MgO	27.80	6.73	6.97	3.97	3.07	3.73
INSOL PK		29.81	5.73	7.68	3.71	3.02	3.93
EKOSOL U		28.24	5.14	7.38	3.73	2.79	3.92
LSD _{0,05} for (AxB)		3.20	0.72	n.s.	n.s.	n.s.	0.70
Mean (B)	Control	25.50	5.76	6.97	3.36	2.89	3.60
	NPK	28.35	5.09	7.15	3.27	2.69	3.79
	NPK + MgSO ₄	29.91	5.42	7.57	3.30	2.87	4.13
	NPK + CaO + MgO	28.61	5.87	7.34	3.80	2.96	3.86
LSD _{0,05} for B		1.43	0.33	n.s	0.42	n.s	0.32
WATER	Mean (A)	28.46	5.93	7.29	3.31	2.87	3.91
INSOL PK		28.68	5.76	7.37	3.45	2.95	4.04
EKOSOL U		27.14	4.91	7.11	3.53	2.72	3.57
LSD _{0,05} for A		1.13	0.25	n.s	n.s	n.s	0.25

Soil fertilization caused differences in the content of all the macronutrients analyzed in winter rape straw, whereas foliar feeding affected the content of N, K, Mg and S (Tab. 3). Their content was closely related to the amount of nutrients incorporated in the individual soil fertilization treatments. Fertilization with the addition of MgSO₄ in the dose significantly increased the sulfur and magnesium content in straw and decreased the calcium content compared to NPK + CaO + MgO. On the other hand, soil deacidification significantly increased the content of nitrogen, phosphorus, potassium, magnesium compared to control or NPK and calcium compared to the other fertilization treatments in winter rape straw (Tab. 3).

Table 3. Macronutrient content in winter rape straw after application of foliar feeding under different soil fertilization conditions

Foliar fertilizer (A)	Soil fertilization (B)	N	P	K	Ca	Mg	S
		[g kg ⁻¹ d.m.]					
WATER	Control	3.77	0.65	9.10	6.60	1.15	3.49
INSOL PK		4.21	0.85	10.17	7.67	0.93	2.67
EKOSOL U		3.74	0.65	8.82	6.87	1.06	2.58
WATER		4.75	0.74	12.21	7.12	1.12	3.53
INSOL PK							
EKOSOL U							

INSOL PK	NPK	5.24	0.68	15.17	7.50	0.97	3.26
EKOSOL U		5.45	0.73	12.42	6.99	1.10	3.26
WATER		NPK + MgSO ₄	4.81	0.74	14.11	6.68	1.23
INSOL PK	5.39		0.73	15.87	6.64	1.06	4.02
EKOSOL U	4.99		0.68	14.72	7.13	1.32	3.81
WATER	NPK + CaO + MgO	5.00	0.86	14.61	7.50	1.38	3.71
INSOL PK		5.09	0.80	14.97	7.81	1.05	2.81
EKOSOL U		5.17	0.82	14.57	7.74	1.35	3.32
LSD _{0,05} for (AxB)		n.s	n.s.	1.85	n.s	n.s.	n.s.
Mean (B)	Control	3.91	0.72	9.36	7.05	1.05	2.91
	NPK	5.15	0.71	13.26	7.20	1.06	3.35
	NPK + MgSO ₄	5.06	0.72	14.90	6.82	1.20	3.95
	NPK + CaO + MgO	5.09	0.83	14.71	7.68	1.26	3.28
LSD _{0,05} for B		0.31	0.10	0.83	0.67	0.12	0.38
WATER	Mean (A)	4.58	0,75	12.51	6.98	1.22	3.69
INSOL PK		4.98	0.76	14.04	7.41	1.00	3.19
EKOSOL U		4.84	0.72	12.63	7.18	1.21	3.24
LSD _{0,05} for A		0.25	n.s.	0.66	n.s.	0.09	0.30

Foliar feeding resulted in much smaller differences in the plant mineral composition than in the case of soil fertilization. The foliar fertilizers significantly increased the nitrogen content compared to the control treatment and decreased the sulfur content. INSOL PK caused a significant increase in the potassium content and a decrease in the magnesium content in relation to the other treatments (Tab. 3).

Nutrient removal was greatly influenced by both soil fertilization and foliar feeding. The lowest values for the uptake of mineral nutrients were found in the control treatments and plots, and only the uptake of sulfur in the control treatment was higher than after application of the foliar fertilizers (Tab. 4). The NPK + CaO + MgO treatment was characterized by the highest uptake of the macronutrients analyzed and only in the case of sulfur the highest uptake was found after application of NPK + MgSO₄. INSOL PK made a greater contribution to the increase in the uptake of N, P, K and Ca than EKOSOL U.

Table 4. Removal of macronutrients after application of foliar feeding of winter rape under different soil fertilization conditions

Foliar fertilizer (A)	Soil fertilization (B)	N	P	K	Ca	Mg	S
		[kg·ha ⁻¹]					
WATER	Control	53.75	11.80	48.78	32.31	8.82	20.22
INSOL PK		70.62	15.87	65.08	45.84	10.46	21.58
EKOSOL U		61.74	12.06	53.16	38.06	10.15	18.84
WATER	NPK	118.56	19.57	108.54	60.95	15.74	36.85
INSOL PK		126.29	22.24	138.90	67.58	15.95	36.33
EKOSOL U		122.78	19.46	119.12	64.90	16.27	36.69
WATER	NPK + MgSO ₄	124.39	22.34	131.22	59.76	18.12	42.84
INSOL PK		136.38	23.05	146.54	61.65	17.48	44.59
EKOSOL U		134.16	21.33	144.01	70.37	19.26	43.73
WATER	NPK + CaO + MgO	132.11	29.09	143.18	74.78	21.41	42.77
INSOL PK		145.07	26.36	153.88	79.27	19.25	37.37
EKOSOL U		142.61	24.90	152.80	80.52	21.42	42.54
LSD _{0,05} for (AxB)		n.s.	2.23	8.85	4.82	1.28	2.39
Mean (B)	Control	62.04	13.24	55.67	38.73	9.81	20.22
	NPK	122.54	20.42	122.19	64.48	15.99	36.62
	NPK + MgSO ₄	131.64	22.24	140.59	63.93	18.28	43.72
	NPK + CaO + MgO	139.94	26.78	149.95	78.19	20.70	40.89
LSD _{0,05} for B		5.13	0.99	3.97	2.17	0.58	1.07
WATER	Mean (A)	107.20	20.70	107.93	56.95	16.02	35.67
INSOL PK		119.59	21.88	126.10	63.58	15.78	34.97
EKOSOL U		115.32	19.44	117.27	63.46	16.78	35.45
LSD _{0,05} for A		4.34	0.79	3.13	1.71	0.45	n.s.

Yield quality parameters

Under the conditions of the present experiment, both soil fertilization and foliar feeding resulted in differences in the seed protein content of winter oilseed rape (Tab. 5). All the soil fertilization treatments had a beneficial effect on the protein content and yield relative to the control and moreover the supply of sulfur through fertilization significantly increased the protein content and yield in

relation to the basic (NPK) soil fertilization treatment. Among the foliar fertilizers used, EKOSOL U significantly decreased the seed protein content compared to the other foliar fertilization treatments, whereas INSOL PK increased the protein content not only in relation to EKOSOL U. However, no significant differences in protein yield were found between the foliar fertilizers applied and only INSOL PK distinctly increased the protein yield compared to the plants sprayed with water.

Table 5. Quality parameters of winter rape after application of foliar feeding under different soil fertilization conditions

Foliar fertilizer (A)	Soil fertilization (B)	Total protein (N × 6.25)	Protein yield	Content of fat [% d.m.]	Fat yield [kg·ha ⁻¹]
		[g·kg ⁻¹ d.m.]	[kg·ha ⁻¹]		
WATER	Control	158.44	236.07	42.05	626.55
INSOL PK		161.94	307.68	43.25	821.75
EKOSOL U		157.75	277.64	44.43	781.97
WATER	NPK	188.81	524.90	41.28	1147.58
INSOL PK		178.56	537.47	42.77	1287.38
EKOSOL U		164.13	498.94	44.87	1364.05
WATER	NPK + MgSO ₄	190.50	548.64	42.24	1216.51
INSOL PK		190.19	589.58	43.89	1360.59
EKOSOL U		180.13	581.80	46.97	1517.13
WATER	NPK + CaO + MgO	173.75	568.16	44.54	1456.46
INSOL PK		186.31	535.33	45.53	1552.57
EKOSOL U		176.50	608.93	48.75	1681.88
LSD _{0,05} for (AxB)		19.95	n.s.	1.71	n.s.
Mean (B)	Control	159.38	273.80	43.24	743.42
	NPK	177.17	520.44	42.97	1266,34
	NPK + MgSO ₄	186.94	573.34	44.36	1364.74
	NPK + CaO + MgO	178.85	604.14	46.27	1563.64
LSD _{0,05} for B		8.96	40.17	0.77	75,99
WATER	Mean (A)	177.88	469.44	42.52	1111.77
INSOL PK		179.25	517.52	43.86	1255.57
EKOSOL U		169.63	491.83	46.26	1336.26
LSD _{0,05} for A		7.05	31.62	0.61	59.82

Among the soil fertilization treatments used, NPK + $MgSO_4$ and NPK + CaO + MgO increased the seed oil content compared to the other fertilization treatments. Foliar feeding increased the oil content, but as far as the fertilizers used are concerned, EKOSOL U showed a much better effect than INSOL PK. Soil fertilization and foliar feeding clearly increased the oil content not only in relation to the control treatment, but also between the individual plots and fertilization treatments. The effect of the experimental factors used on the oil content can be ranked as follows: control < NPK < NPK + $MgSO_4$ < NPK + CaO + MgO, and control < INSOL PK < EKOSOL U (Tab. 5). Neither soil fertilization nor the foliar fertilizers applied affected the fatty acid content in the oil (Tab. 6).

Table 6. Fatty acids composition in winter rape oil in %

Foliar fertilizer (A)	Soil fertilization (B)	14 : 0	14 : 1	16 : 0	16 : 1	18 : 0	18 : 1	18 : 2	18 : 3	20 : 0	22 : 1
		[%]									
WATER	Control	0.05	0.05	5.51	0.38	1.70	66.50	17.26	5.87	0.78	1.91
INSOL PK		0.10	0.03	6.37	0.41	2.04	66.55	16.16	6.80	0.46	1.09
EKOSOL U		0.06	0.05	5.85	0.30	1.83	65.03	17.55	7.02	0.60	1.79
WATER	NPK	0.08	0.03	5.46	0.45	2.47	66.67	17.05	5.24	0.73	1.62
INSOL PK		0.09	0.01	5.68	0.26	1.91	65.53	17.23	7.19	0.53	1.58
EKOSOL U		0.04	0.01	5.83	0.36	2.02	66.32	16.72	6.51	0.52	1.68
WATER	NPK + MgSO ₄	0.03	0.03	5.81	0.43	2.05	66.54	16.26	6.60	0.68	1.55
INSOL PK		0.09	0.01	6.20	0.42	1.97	67.46	15.87	6.27	0.51	1.20
EKOSOL U		0.06	0.01	5.76	0.37	1.84	66.29	16.82	6.76	0.66	1.45
WATER	NPK + CaO + MgO	0.09	0.06	6.72	0.38	1.56	64.42	17.21	7.44	0.75	1.37
INSOL PK		0.10	0.03	6.41	0.39	1.85	63.68	17.83	7.43	0.66	1.60
EKOSOL U		0.07	0.01	5.85	0.27	1.87	67.19	16.38	5.93	0.61	1.79
LSD _{0,05} for (AxB)		n.s.	n.s	n.s	n.s.	0.62	n.s.	n.s	n.s	n.s.	n.s
Mean (B)	Control	0.08	0.04	5.84	0.36	1.86	66.02	16.99	6.56	0.62	1.46
	NPK	0.07	0.02	5.66	0.36	2.14	66.17	17.00	6.37	0.59	1.63
	NPK + MgSO ₄	0.06	0.02	5.92	0.41	1.95	66.77	16.32	6.55	0.32	1.40
	NPK + CaO + MgO	0.09	0.04	6.33	0.35	1.76	65.10	17.14	6.93	0.67	1.59

LSD _{0,05} for B		n.s.	n.s.	0.06	n.s.	0.27	n.s.	n.s.	n.s.	n.s.	n.s.
WATER		0.06	0.04	5.87	0.41	1.95	66.03	16.94	6.33	0.74	1.61
INSOL PK	Mean (A)	0.09	0.02	6.16	0.37	1.94	65.81	16.77	6.92	0.54	1.37
EKOSOL U		0.05	0.02	5.77	0.33	1.89	66.21	16.87	6.70	0.60	1.57
LSD _{0,05} for A		0.03	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.09	n.s.

The experimental factors used resulted in small differences in the K/(Ca+Mg) ratio in seed and straw of winter oilseed rape, with an increasing trend in its value for straw from 0.55 in the control treatment to 0.76–0.87 in the other soil fertilization treatments (Tab. 7). The value of the N/S ratio in rapeseed did not change under the influence of soil fertilization or foliar feeding, whereas its value in winter rape straw narrowed down in the NPK + MgSO₄ treatment and widened after application of INSOL PK (Tab. 7).

Table 7. The relations of elements in grain and straw of winter wheat after application of foliar feeding under different soil fertilization conditions

Foliar fertilizer (A)	Soil fertilization (B)	K/(Ca + Mg) in seeds	K/(Ca + Mg) in straw	N/S in seeds	N/S in straw
WATER	Control	0.48	0.55	6.96	1.08
INSOL PK		0.42	0.57	6.14	1.58
EKOSOL U		0.42	0.52	6.44	1.45
WATER	NPK	0.47	0.70	7.53	1.35
INSOL PK		0.48	0.85	7.64	1.61
EKOSOL U		0.49	0.72	7.25	1.67
WATER	NPK + MgSO ₄	0.52	0.83	7.12	1.20
INSOL PK		0.47	0.97	7.13	1.34
EKOSOL U		0.46	0.81	7.52	1.31
WATER	NPK + CaO + MgO	0.40	0.77	7.45	1.35
INSOL PK		0.45	0.80	7.59	1.81
EKOSOL U		0.45	0.75	7.20	1.56
Mean		0.46	0.74	7.17	1.44
Mean (B)	Control	0.44	0.55	7.08	1.34
	NPK	0.48	0.76	7.48	1.54
	NPK + MgSO ₄	0.48	0.87	7.24	1.28
	NPK + CaO + MgO	0.43	0.77	7.41	1.55
Mean		0.45	0.74	7.30	1.43
WATER	Mean (A)	0.46	0.71	7.28	1.24
INSOL PK		0.45	0.79	7.10	1.56
EKOSOL U		0.46	0.71	7.60	1.49
Mean		0.46	0.74	7.33	1.43

DISCUSSION

Yield

Similarly to wheat [4], winter oilseed rape produced the highest yield in the treatment with the use of CaO + MgO in fertilization, because liming significantly increased the thousand seed weight, the number of branches, and the number of siliques per plant [6]. This was associated with increased sorption complex saturation with calcium and magnesium cations, but mainly with a decrease in the soil content of labile aluminum and a reduction in its adverse impact on the growth and development of oilseed rape [5]. Moreover, oilseed rape belongs to plants with high nutritional requirements for calcium. With a seed yield at a level of 2–4 t of seed, this plant takes up from 100 to 200 kg · ha⁻¹ Ca [44] and the incorporation of CaO + MgO in fertilization fully met the nutritional requirements for this nutrient. Numerous studies on this subject have shown the beneficial effect of liming of acidic soils on oilseed rape production effects [10, 13, 15, 19, 21, 38].

Alongside nitrogen, potassium and calcium, oilseed rape also has a high demand for sulfur [23, 44]. The incorporation of sulfur and magnesium into the soil without changing its pH resulted in a significant increase in the oilseed rape yield not only in relation to the control treatment, but also compared to the basic NPK fertilization treatment, which is in agreement with other studies [15, 26, 27, 31]. In the present research, the application of sulfur in fertilization contributed to an increase in the number of pods per plant and the thousand seed weight relative both to the control treatment and the basic NPK fertilization treatment, which is consistent with the results obtained by Malarz et al. [26]. Foliar feeding increased the seed yield in relation to the plants sprayed with water, but no significant differences were found between the foliar fertilizers applied. Jarecki and Bobrecka-Jarmo [12] demonstrated a beneficial effect of urea application on the number of pods per plant, whereas under the conditions of the present study, apart from an increase in the number of pods per plant, a higher thousand seed weight was also obtained, which corresponds to the results of other authors [18]. This could have been due to the increased activity of the major plant physiological processes [3, 20, 28].

The mineral composition

Lining beneficially affected soil phosphorus transformations, because a higher content of this nutrient was found both in seed and straw. The results of other authors' research reveal better utilization of phosphorus and many other nutrients by crop plants as influenced by liming [22, 25, 43]. The inclusion of MgSO_4 in fertilization increased the sulfur content in seed and straw of winter oilseed rape and the magnesium content in straw. According to many authors, the use of sulfur in fertilization increases the uptake of this nutrient by the plant and affects the nitrogen balance in winter oilseed rape, primarily the biosynthesis of protein nitrogen compounds [32, 46]. This is the justification for the highest nitrogen content in rapeseed in the treatment with the application of NPK + MgSO_4 in fertilization [34, 36].

The lower content of N, P and S in winter rapeseed after application of Ekosol U was attributable to the complete absence of one nutrient (S) or a low content of the other nutrients (N and P) in this fertilizer. Furthermore, the nutrients were diluted due to the highest yield in this treatment, most probably on account of the occurrence of micronutrients in the fertilizer [31, 47]. On the other hand, the increase in the nitrogen content in seed and straw and in the potassium content in straw under the influence of Insol PK was due to the occurrence of potassium in the fertilizer and its application in combination with a 5% urea solution and their uptake by the aerial part of the plant [12]. The soil fertilization treatments applied successively increased the uptake of N, P, K, Ca and Mg, in proportion to the seed and straw yield obtained. Only the highest sulfur uptake was closely related to the application of this nutrient in fertilizer form [41], which may be due to the low presence of available forms of this nutrient in the soil.

Foliar feeding increased the uptake of almost all macronutrients analyzed, which is in agreement with the reports of other authors [4, 33]. But it decreased the uptake of sulfur, which could have resulted from a hidden deficiency of this nutrient in the soil [35].

Yield quality parameters

The soil fertilization treatments used and the application of foliar fertilizers caused differences in the analyzed yield quality parameters of winter oilseed rape. The increase in the protein content in rapeseed in the treatment with NPK + MgSO_4 was attributable to the effect of sulfur on the plant nitrogen balance [16], but a higher protein yield was obtained in the limed plot due to a significant difference in the yield between the fertilization treatments compared. Numerous papers in the scientific literature characterize oilseed rape as a plant that favorably responds to liming of excessively acidified soils [6, 15, 21]. This finds confirmation in the present study, because the treatment with liming, in addition to its positive effect on yield, was also the most favorable in terms of the oil content and yield [17]. Feeding of oilseed rape with both foliar fertilizers had a particularly beneficial influence on the oil content and yield, but much better effects were obtained after application of Ekosol U than Insol PK. This could have been associated with the micronutrients supplied in the fertilizer and their impact on the activation of processes associated with oil synthesis in the plant [2]. The factors used in the experiment slightly affected the values of the elemental ratios of both $\text{K}/(\text{Ca} + \text{Mg})$ and N/S in the plant. Generally, the value of the $\text{K}/(\text{Ca} + \text{Mg})$ ratio differed from the optimal value and indicates potassium deficiency, probably associated with natural loss of this element at the end of the vegetation [34] as well as with non-exchangeable binding of K^+ ions incorporated with fertilization into the soil [1]. The higher value of the $\text{K}/(\text{Ca} + \text{Mg})$ ratio in straw in the NPK + MgSO_4 treatment was due to the synergic effect of incorporated sulfate sulfur (VI) on potassium uptake with the absence of the antagonistic effect of calcium ions supplied in the liming treatment [33, 34]. The inclusion of sulfur in fertilization resulted in a narrowing of the N/S ratio in seed and straw of oilseed rape, whereas foliar feeding showed a tendency towards widening the N/S ratio [32]. In the present study, the soil fertilization and foliar feeding treatments used did not result in significant differences in the composition of fatty acids in the winter rapeseed oil [27, 39, 45] in spite of the fact that there are reports in the literature showing a higher proportion of necessary unsaturated fatty acids under the influence of fertilization [24].

CONCLUSION

- ▶ In growing winter oilseed rape, soil fertilization and foliar feeding had a beneficial effect on the individual yield components, except for plant density.
- ▶ The foliar fertilizers increased the yield of winter oilseed rape at a similar level. Ekosol U increased the oil content and yield to a greater extent than Insol PK, at the same time decreasing the seed protein content.
- ▶ The individual soil fertilization treatments increased the removal of all macronutrients, whereas in the case of the foliar fertilizers applied Insol PK increased the uptake of N, P, K and Ca, while Ekosol U the uptake of N, K, Ca and Mg.
- ▶ The best production and quality effects for the primary yield were obtained in the NPK + CaO + MgO soil fertilization treatment, while the application of MgSO_4 more increased the protein content in seed.
- ▶ Ekosol U increased the fat content and yield to a greater extent than Insol PK. The experimental factors used did not affect the fatty acid content.

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