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EFFECTS OF FOLIAR FEEDING UNDER DIFFERENT SOIL FERTILIZATION CONDITIONS ON THE YIELD STRUCTURE AND QUALITY OF WINTER WHEAT (*Triticum aestivum* L.)

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Abstract

The aim of the study was to analyse foliar feeding of winter wheat cv. 'Kobra' in combination with different soil fertilization treatments with calcium and magnesium compounds. The foliar fertilizers INSOL PK + 5% urea solution and EKOSOL U were applied 3 times during the during the growing season in four soil fertilization treatments: control without fertilization, NPK, NPK + $MgSO_4 \times 7H_2O$, and NPK + CaO + MgO. The investigations involved a 3-year field experiment established on medium soil with a pH of 4.2 in 1 mole KCl × dm^{-3} and with the granulometric composition of clayey silt. The soil was characterised by a low content of available phosphorus and potassium as well as a very low content of sulphur and magnesium. The foliar fertilizers applied and the soil fertilization treatments had a varied effect on the yield parameters, the macronutrient content in grain and straw, and the content and quality of gluten. Among the soil fertilization treatments, the best production results and quality parameters of winter wheat were obtained after the application of the dose with magnesium lime. The foliar fertilizers had a greater impact on yield and gluten content than on the mineral composition of winter wheat grain and straw.

Key words: *Triticum aestivum*, foliar feeding, yield components, macronutrients, crude protein, gluten

INTRODUCTION

The dynamic growth of the Earth's population requires us to continuously increase the production of plants intended for human consumption or animal fodder in order to meet the food demand. Cereals are a primary raw material for production of consumer goods, with the greatest importance attached to wheat, rice, and maize. Given the increasing urbanisation, higher crop yields are mainly achieved by improving productivity per unit area rather than by increasing the crop acreage.

Winter wheat is a plant with specific habitat requirements. The cultivation of wheat aimed at improving the productivity and quality of crop yields leads to the introduction of cultivars with higher nutrient demand into farming. A high rate of fertilization causes an environmental burden associated with unused nutrients [1, 2] and therefore, apart from soil fertilization, foliar fertilizers containing mainly N, Mg, and micronutrients are used in intensive farming [3–5]. The study showed greater effectiveness of foliar feeding compared to soil fertilization [6–8]. Foliar feeding allows fertilizer consumption to be reduced by improving the economic indicators of soil fertilization [9]. Combined application of foliar fertilizers with plant protection treatments lowers production costs and simultaneously improves the effectiveness of pesticides so that they can be used at a minimal dose [10, 11].

The aim of the study was to determine the effect of foliar fertilization combined with soil fertilization treatments with calcium and magnesium compounds on yield and basic quality parameters of winter wheat.

MATERIALS AND METHODS

A three-year field experiment was established using a randomised block design in Rudnik (50°53'23.99"N, 22°57'59.89"E) on clayey silt with a pH of 4.2 in 1 mole KCl × dm^{-3}, characterised by a low content of available phosphorus and potassium as well as a very low content of sulphur and magnesium. The climatic parameters during the study period compared with the long-term means are presented in Figure 1. The experimental design consisted of 3 treatments receiving foliar fertilization (1. control treatment/spraying with water, 2. INSOL PK + 5% urea solution, 3. EKOSOL U) and 4 treatments of soil fertilization (1. control/no fertilization, 2. NPK, 3. NPK + $MgSO_4 \times 7H_2O$, 4. NPK + CaO + MgO), in 3 replicates.

Immediately after harvest of the previous crop, magnesium oxide lime was applied to randomly chosen 48 m^2 plots according to single hydrolytic acidity. Mineral fertilization with Amofoska 4-16-18 and 4.5S as well as ammonium nitrate were applied at the rates of 102 kg N × ha^{-1}, 28 kg × P ha^{-1}, and 61 kg K × ha^{-1}. Additionally, each year before sowing the winter wheat (*Triticum aetivum* L.) cultivar 'Kobra', magnesium sulphate at a dose of 19 kg Mg × ha^{-1} was applied to randomly chosen plots. In the plots treated with INSOL PK with the addition of urea, the nitrogen dose was reduced by 20.7 kg N ha^{-1}, since that amount was supplied through foliar feeding with the 5% urea solution spray liquid.

Foliar feeding was used 3 times during the growing season at the stages of tillering, stem elongation, and ear emergence. The foliar fertilizers were used in each soil fertilization treatment at the following doses: INSOL PK – 6 $dm^3 \cdot 300\ dm^{-3} \times ha^{-1}$ and EKOSOL U – 2 $dm^3 \times 300\ dm^{-3} \times ha^{-1}$. INSOL PK contained (%): P – 4.4 and K – 15.8, whereas EKOSOL U contained (%): 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; and Zn – 0.1.

The *Triticum aetivum* was harvested at the full maturity stage and samples were taken from 1 m^2 in 3 replicates. The grain and straw yields as well as the major yield components, i.e. grain weight per ear, number of ears/m^2, number of grains per ear, and 1000-grain weight, were assessed in the samples.

After mineralization in concentrated sulphuric acid with the addition of hydrogen peroxide, the grain and straw were assayed for total N with the Kjeldahl method; K, Ca, and Mg with the AAS method using a Hitachi Z-8200 polarized Zeeman atomic absorption spectrophotometer; and P by the vanadium-molybdate colorimetric method using a Cecil 2011 colorimeter. Total sulphur was determined according to B u t t e r s - C h e n e r y [12]. The macronutrient removal was calculated as the sum of a nutrient in the primary yield and in the straw based on the nutrient content in the organs. The qualitative assessment of the yield comprised K : (Ca + Mg) equivalent ratios, N : S mass ratios, total protein content (N x 5.7), protein yield, and gluten content and its weakening according to the Polish standard PN-ISO-74041.

The results obtained were statistically analysed by analysis of variance and presented as means from the 3-year study period (1999-2001). The significance test was conducted using T-Tukey's multiple confidence intervals at a significance level of 0.05.

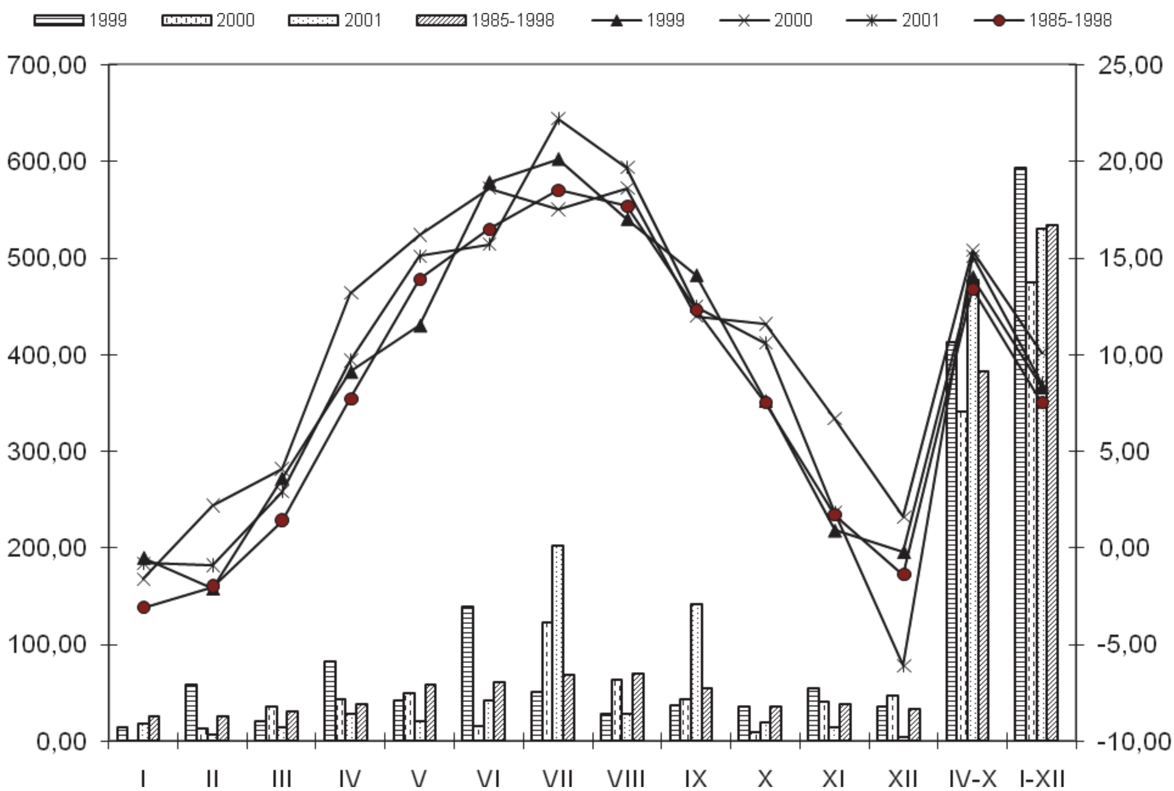

Fig. 1. Climatic conditions in the study period

RESULTS

Yield potential

The soil fertilization treatments applied in the experiment caused differences in the grain and straw yields and in all the yield components. Grain and straw yields as well as 1000-grain weight, number of ears, and number of grains per ear exhibited the highest values after the application of NPK with CaO + MgO fertilization. In turn, the magnesium sulphate $MgSO_4$ addition produced the highest increase in the number of spikelets per ear (Table 1). The foliar fertilizers increased the yield and yield components in comparison with the control with the exception of the number of grains per ear. Among the foliar fertilizers applied, INSOL PK exerted a better effect on the winter wheat yield than EKOSOL U. The interaction between soil fertilization and foliar feeding had a significant impact only on the number of grains per ear.

The mineral composition of winter wheat

The content of macronutrients in winter wheat grain determined in the experiment is presented in Table 2. Both soil fertilization and foliar feeding changed the macronutrient content in the grain. Fertilization with the addition of the CaO + MgO doses significantly increased the contents of nitrogen, potassium, calcium, magnesium, and sulphur in comparison with the other soil fertilization treatments. The introduction of $MgSO_4$ to the fertilization treatment resulted in the highest S content but did not increase the magnesium content.

Deacidification of the soil also significantly increased the content of nitrogen, phosphorus, potassium, calcium, and magnesium in winter wheat straw in comparison with the control or the basic fertilization treatment (Table 3). Fertilization with the addition of the $MgSO_4$ dose significantly increased the sulphur content in straw and reduced the phosphorus content in comparison with the other treatments.

Foliar feeding had a significantly lower effect on the mineral composition than soil fertilization. Compared with the control treatment, the foliar fertilizers caused a significant increase in the content of nitrogen, calcium, and magnesium, while EKOSOL U additionally increased the sulphur content in winter wheat grain (Table 3). The foliar fertilizers applied significantly increased the content of nitrogen, phosphorus, and magnesium in straw, whereas INSOL PK increased the calcium content.

In the control treatment, which did not involve soil fertilization, the lowest values of the nutrient removal differed significantly from those obtained in the other fertilization treatments (Table 4).

The NPK + CaO + MgO treatment was characterised by the greatest removal of the analysed macronutrients; only in the case of sulphur the removal of this element was higher after the application of NPK + $MgSO_4$. The interaction between foliar feeding and soil fertilization had a significant impact on the removal of all the nutrients analysed.

Yield quality parameters

In the experiment, both soil fertilization and foliar feeding hada similar effect on the protein content in winter wheat grain, compared with the control (Table 5). No significant differences were found between the foliar fertilizers applied and the different treatments of soil fertilization. The soil fertilization exerted a more beneficial effect on the protein yield than that of the foliar fertilizers. All soil fertilization treatments increased the protein yield in relation to the control; furthermore, a significantly higher protein yield was obtained in the NPK + CaO +MgO treatment than in the other soil fertilization treatments (Table 5). The content of gluten depended on the soil fertilization treatments to a greater degree than on the foliar fertilizers applied, as indicated by the significant differences found between each fertilization treatment. Similar doses of INSOL PK and EKOSOL U increased the value of this parameter in relation to the control. Gluten weakening, whose value varied depending on soil fertilization and foliar fertilizers applied, is an important indicator of gluten quality. Generally, a higher content of gluten was accompanied by higher weakening values (Table 5).

The factors applied in the experiment resulted in a similar K : (Ca+Mg) ratio in winter wheat grain and straw at a level of 0.7–1.0 : 1, and in a clear narrowing trend was found in the values under the application of the foliar fertilizers (Table 6). The use of the foliar fertilizers increased the N : S ratio in the grain. In turn, among the soil fertilization treatments applied, only NPK + $MgSO_4$ significantly reduced the N : S ratio in winter wheat grain and straw, whereas the foliar fertilizers increased the ratio values, with the exception of EKOSOL U which decreased the value of this parameter (Table 6).

Table 1
Grain and straw yield as well as the yield structure of foliar fertilized winter wheat under different soil fertilization conditions

Foliar fertilizer (A)	Soil fertilization (B)	Grain yield	Straw yield	Thousand grain weight	Number of ears	Number of spikelets per ear	Number of grains per ear
		t ha^{-1}	t ha^{-1}	[g]	[pcs] (per square metre)	[pcs]	[pcs]
WATER		2.5	3.5	34.5	319.7	13.3	25.6
INSOL PK	Control	3.0	4.8	35.9	377.6	14.5	26.0
EKOSOL U		2.7	4.0	35.9	338.3	14.1	25.5
WATER		4.0	5.7	37.5	414.3	14.0	28.9
INSOL PK	NPK	4.4	6.3	39.1	417.3	14.6	29.9
EKOSOL U		4.2	5.8	38.1	438.2	15.1	29.5
WATER		4.3	5.7	37.8	422.5	14.3	29.4
INSOL PK	NPK + $MgSO_4$	4.6	6.5	39.8	426.5	15.3	30.7
EKOSOL U		4.5	5.7	39.1	424.7	15.2	30.6
WATER		4.6	5.7	39.4	432.9	14.3	32.1
INSOL PK	NPK + CaO + MgO	5.2	7.0	41.7	471.8	14.9	32.4
EKOSOL U		4.9	6.4	40.0	445.8	14.7	30.2
$LSD_{0.05}$ for (AxB)		n.s.	n.s	n.s.	46.9	n.s.	n.s.
	Control	2.8	4.1	35.5	345.2	14.0	25.7
Mean (B)	NPK	4.2	5.9	38.3	423.3	14.6	29.4
	NPK + $MgSO_4$	4.5	6.0	38.9	424.6	14.9	30.2
	NPK + CaO + MgO	4.9	6.4	40.3	450.2	14.6	31.6
$LSD_{0.05}$ for B		0.3	0.3	1.5	21.2	0.7	2.0
WATER		3.9	5.1	37.3	397.3	14.0	29.0
INSOL PK	Mean (A)	4.3	6.2	39.1	423.3	14.8	29.7
EKOSOL U		4.1	5.5	38.3	411.8	14.8	29.0
$LSD_{0.05}$ for A		0.1	0.2	1.2	16.7	0.5	n.s.

Table 2
Macronutrient content in winter wheat grain after application of foliar fertilizers under different soil fertilization conditions

Foliar fertilizer (A)	Soil fertilization (B)	N	P	K	Ca	Mg	S
		[g kg^{-1}d.m.]					
WATER		17.40	2.66	4.54	0.53	1.11	0.66
INSOL PK	Control	17.84	3.11	4.45	0.82	1.27	0.76
EKOSOL U		17.75	2.86	4.71	0.55	1.21	1.10
WATER		19.33	2.47	4.35	0.67	1.10	1.04
INSOL PK	NPK	20.21	2.56	4.18	0.79	1.14	0.88
EKOSOL U		21.91	2.77	3.94	0.55	1.17	1.23
WATER		18.38	2.41	4.33	0.51	1.12	1.09
INSOL PK	NPK + $MgSO_4$	20.19	2.48	4.18	0.65	1.21	1.05
EKOSOL U		20.78	2.56	4.10	0.45	1.15	1.31
WATER		18.40	2.58	4.35	0.73	1.15	0.94
INSOL PK	NPK + CaO + MgO	21.65	2.82	4.14	0.87	1.28	1.00
EKOSOL U		20.75	2.86	5.15	0.61	1.24	1.06
$LSD_{0.05}$ for (AxB)		n.s	0.67	0.67	n.s	n.s.	0.20
	Control	17.66	2.62	4.56	0.70	1.20	0.84
Mean (B)	NPK	20.48	2.60	4.15	0.68	1.14	1.05
	NPK + $MgSO_4$	19.78	2.48	4.21	0.73	1.16	1.15
	NPK + CaO + MgO	20.27	2.75	4.54	0.85	1.23	1.00
$LSD_{0.05}$ for B		1.45	n.s	0.30	0,07	0.09	0.09
WATER		18.38	2.53	4.39	0.61	1.12	0.93
INSOL PK	Mean (A)	19.97	2.75	4.24	0.78	1.22	0.92
EKOSOL U		20.30	2.57	4.48	0.54	1.19	1.17
$LSD_{0.05}$ for A		1.14	n.s	n.s.	0.06	0.07	0.07

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

Foliar fertilizer (A)	Soil fertilization (B)	N	P	K	Ca	Mg	S
		[g kg^{-1}d.m.]					
WATER		3.90	0.57	5.61	2.27	0.56	0.34
INSOL PK	Control	5.58	0.56	5.81	2.62	0.82	0.39
EKOSOL U		4.30	0.56	6.05	2.30	0.72	0.41
WATER		4.76	0.54	6.33	2.36	0.65	0.52
INSOL PK	NPK	5.34	0.76	6.02	3.04	0.81	0.41
EKOSOL U		6.59	0.61	6.20	2.39	0.85	0.37
WATER		4.39	0.55	6.57	2.22	0.66	0.70
INSOL PK	NPK + $MgSO_4$	5.63	0.55	6.58	2.64	0.80	0.79
EKOSOL U		5.75	0.53	6.15	2.33	0.82	0.80
WATER		4.76	0.63	6.70	2.36	0.92	0.45
INSOL PK	NPK + CaO + MgO	6.36	0.64	6.90	3.10	0.92	0.57
EKOSOL U		7.32	0.82	6.84	2.80	1.13	0.50
$LSD_{0.05}$ for (AxB)		1.23	0.13	n.s.	n.s.	0.15	0.16
	Control	4.59	0.56	5.82	2.40	0.70	0.38
Mean (B)	NPK	5.56	0.64	6.18	2.60	0.77	0.43
	NPK + $MgSO_4$	5.26	0.55	6.43	2.40	0.76	0.76
	NPK + CaO + MgO	6.15	0.69	6.81	2.75	0.99	0.51
$LSD_{0.05}$ for B		0.55	0.06	0.67	0.36	0.07	0.07
WATER		4.45	0.57	6.30	2.31	0.70	0.50
INSOL PK	Mean (A)	5.73	0.63	6.32	2.85	0.84	0.54
EKOSOL U		5.99	0.63	6.31	2.45	0.88	0.52
$LSD_{0.05}$ for A		0.44	0.05	n.s.	0.29	0.05	n.s.

Table 4
Removal of macronutrients after application of foliar fertilizers of winter wheat under different soil fertilization conditions

Foliar fertilizer (A)	Soil fertilization (B)	N	P	K	Ca	Mg	S
		[kg ha^{-1}]					
WATER		57.54	9.18	29.42	15.35	4.61	5.66
INSOL PK	Control	79.92	13.14	42.57	23.50	7.62	7.36
EKOSOL U		63.83	11.30	36.73	27.29	6.47	8.49
WATER		107.24	14.81	53.58	19.57	7.72	10.03
INSOL PK	NPK	117.39	17.91	58.64	32.50	9.36	11.72
EKOSOL U		130.84	16.68	54.48	33.42	9.58	11.18
WATER		104.65	14.88	56.11	20.37	8.33	15.80
INSOL PK	NPK + $MgSO_4$	130.91	16.91	65.38	29.18	10.35	13.38
EKOSOL U		123.87	15.91	52.13	31.07	9.31	16.97
WATER		113.61	17.04	57.45	26.13	10.61	10.72
INSOL PK	NPK + CaO + MgO	180.43	20.62	71.99	55.85	12.66	11.69
EKOSOL U		149.56	20.56	66.98	35.94	13.25	10.36
$LSD_{0.05}$ for (AxB)		38.88	1.57	6.36	5,90	1.38	2.54
	Control	67.10	11.21	36.24	11.24	6.24	3.93
Mean (B)	NPK	118.49	16.47	55.57	17.27	8.89	7.36
	NPK + $MgSO_4$	119.81	15.90	57.87	15.78	9.33	9.97
	NPK + CaO + MgO	147.86	19.41	65.47	20.36	12.17	8.70
$LSD_{0.05}$ for B		17.45	0.70	2.85	1.15	0.62	0.38
WATER		95.76	13.98	49.14	13.93	7.82	6.89
INSOL PK	Mean (A)	127.16	17.14	59.64	19.50	9.99	7.80
EKOSOL U		117.02	16.11	52.58	15.06	9.65	7.99
$LSD_{0.05}$ for A		13.74	0.55	2.25	0.90	0.49	0.30

Table 5
Quality parameters of winter wheat after application of foliar fertilizers under different soil fertilization conditions

Foliar fertilizer (A)	Soil fertilization (B)	Total protein (N × 5.7) [g kg^{-1} d.m.]	Protein yield [kg ha^{-1}]	Gluten content [% d.m.]	Gluten weakening [mm]
WATER		99.18	289.88	19.56	6.56
INSOL PK	Control	101.69	353.69	21.22	7.89
EKOSOL U		101.16	335.95	19.89	8.33
WATER		110.20	462.20	21.33	7.44
INSOL PK	NPK	115.10	537.62	23.67	9.11
EKOSOL U		124.89	518.31	22.44	10.11
WATER		104.79	489.95	22.67	9.67
INSOL PK	NPK + $MgSO_4$	115.10	568.85	24.33	9.67
EKOSOL U		118.43	545.36	26.11	10.44
WATER		104.88	551.48	24.44	10.56
INSOL PK	NPK + CaO + MgO	123.41	585.04	28.11	11.33
EKOSOL U		118.26	605.87	30.44	11.56
$LSD_{0.05}$ for (AxB)		n.s.	n.s.	2.76	n.s.
	Control	100.67	277.17	20.22	7.59
Mean (B)	NPK	116.75	498.67	22.48	8.89
	NPK + $MgSO_4$	112.77	508.05	24.37	9.93
	NPK + CaO + MgO	115.51	575.80	27.67	11.15
$LSD_{0.05}$ for B		8.29	54.55	1.24	0.83
WATER		104.76	413.19	22.00	8.56
INSOL PK	Mean (A)	113.84	499.25	24.33	9.50
EKOSOL U		115.68	482.40	24.72	10.11
$LSD_{0.05}$ for A		6.53	42.95	0.97	0.66

Table 6
Relationships between elements in winter wheat grain and straw after application of foliar fertilizers under different soil fertilization conditions

Foliar fertilizer (A)	Soil fertilization (B)	K : (Ca + Mg) in grain	K : (Ca + Mg) in straw	N/S in grain	N/S in straw
WATER		1.0	0.9	26.4	11.5
INSOL PK	Control	0.8	0.8	23.5	14.3
EKOSOL U		1.0	0.9	16.1	10.5
WATER		0.9	1.0	18.6	9.2
INSOL PK	NPK	0.8	0.7	23.0	13.0
EKOSOL U		0.8	0.8	17.8	17.8
WATER		0.9	1.0	16.9	6.3
INSOL PK	NPK + $MgSO_4$	0.8	0.9	19.2	7.1
EKOSOL U		0.9	0.9	15.9	7.2
WATER		0.9	0.9	19.6	10.6
INSOL PK	NPK + CaO + MgO	0.7	0.8	21.7	11.1
EKOSOL U		1.0	0.8	19.6	14.6
Mean		0.9	0.9	19.5	11.1
	Control	0.9	0.8	21.0	12.1
Mean (B)	NPK	0.8	0.8	19.5	12.9
	NPK + $MgSO_4$	0.8	0.9	17.2	6.9
	NPK + CaO + MgO	0.8	0.8	20.3	12.1
Mean		0.8	0.8	19.5	11.0
WATER		0.9	0.9	19.8	8.9
INSOL PK	Mean (A)	0.8	0.8	21.7	10.6
EKOSOL U		0.9	0.8	17.4	11.5
Mean		0.9	0.8	19.6	10.3

DISCUSSION

Yield potential

Wheat represents plants that are sensitive to acidic soil, and therefore it produced the highest yields in the CaO + MgO fertilization treatment. Numerous studies carried out on this research problem have confirmed this finding [13–16]. The application of the deacidifying fertilizer had a beneficial impact on all the winter wheat yield components, as it limited the presence of mobile aluminium in the soil to a level of 28 mg Al kg^{-1} in comparison with the amount of 140 mg Al kg^{-1} in the other soil fertilization treatments [17]. The introduction of sulphur and magnesium to the soil without changing the pH value did not induce significant changes in the yields of winter wheat compared with the basic NPK treatment, as demonstrated by Łabuda et al. [18] in their investigations of oats. The different response of these cereals to the application of magnesium sulphate is related to the higher tolerance of oats to acidic soil pH than that of wheat. Foliar feeding increased the grain yield, but to a lesser extent than soil fertilization, since it had no effect on the number of grains per ear. Although a great number of studies have indicated a beneficial impact of foliar application of nutrients [19–23], there are also reports on the absence of plant response to foliar feeding [24, 25].

The mineral composition

The content of the analysed macronutrients in winter wheat grain and straw depended on the type of soil fertilization applied; only the phosphorus content in the grain was similar in all the soil fertilization treatments. Soil liming applied as a basic deacidification treatment increased nutrient use and resulted in higher soil bioactivity [18, 26]. The highest nitrogen content in the grain and straw in this fertilization treatment may have been related to the higher mineralisation rate and the enhanced activity of nitrifying bacteria. The higher content of phosphorus resulted from limited chemical sorption of the nutrient in soil [27], whereas calcium and magnesium were supplied with the deacidifying fertilizer.

The application of $MgSO_4$ in the fertilization treatment increased the content of sulphur and magnesium, but reduced the amount of phosphorus in winter wheat grain and straw, which may suggest phosphate binding to Mg^{2+} ions in sparingly soluble forms at the stage of application of the fertilizers, as they were used in the same period. There are literature reports that show lower phosphorus content in plants resulting from sulphur fertilization [26, 28].

Foliar feeding caused an increase in the content of N, Ca, and Mg in winter wheat grain and straw. However, the differences should be attributed to the increased uptake and utilisation of soil nutrients resulting from the application of the foliar fertilizers rather than to the direct effects of nutrient supply with these fertilizers [4]. Michałek et al. [23, 29] report that the higher nutrient uptake from soil induced by foliar feeding is related to enhanced photosynthesis, transpiration, and plant respiration [30–32].

The soil fertilization treatment had a greater effect on nutrient removal than foliar feeding. In the NPK + CaO + MgO treatment, N, P, K, Ca, and Mg exhibited the highest values of removal, since the reduction in the amount of mobile aluminium maintains the plant root system in full efficiency [34]. In turn, the greatest sulphur removal in the $MgSO_4$ fertilization treatment resulted from the low abundance of absorbable forms of this nutrient in the soil.

Yield quality parameters

The experimental factors applied had a similar impact on the protein content in winter wheat grain. However, the soil fertilization treatments exerted a greater effect on the protein yield than the foliar fertilizers. The beneficial impact of soil fertilization on the protein content and yield was associated with the nitrogen rate [34, 35]. In turn, the increased content of protein and gluten in the foliar feeding treatment may have resulted from nutrient supply in the critical periods of increased demand when nutrient uptake by the root system did not cover the nutritional requirements of wheat [11, 36]. The quality of gluten was correlated with its content, since the higher content was accompanied by higher weakening, i.e. worse gluten quality. The results obtained are in agreement with the findings reported by Makarewicz et al. [37]. A favourable effect of foliar fertilizers on wheat quality parameters has also been demonstrated in other papers [4, 3, 22, 38].

The values of the calculated nutrient ratios in the conducted experiment were similar, but a narrower N : S ratio in winter wheat grain and straw was only obtained in the treatment with sulphur addition. The K/(Ca + Mg) and N : S ratios were different from the optimal ranges; only the N : S ratio in the grain fertilized with sulphur addition was most similar to 15 : 1, regarded as an optimal value [39–41], and indicated a low soil sulphur level [42]. The K/(Ca + Mg) ratio values that were lower than the optimum 1.6 – 2.1 : 1 resulted from the low content of available potassium in the soil, which led to non-exchangeable binding of part of the potassium supply introduced into the soil with the fertilizers.

CONCLUSIONS

1. In comparison with foliar feeding, soil fertilization exerted a more substantial effect on winter wheat yield, individual yield components, and macronutrient content in the grain and straw.

2. Foliar feeding had a positive impact on the quality parameters of winter wheat. EKOSOL U was more efficient due to the content of micronutrients in its elemental composition, whereas INSOL PK had a greater effect on yield.
3. Foliar feeding and soil fertilization increased micronutrient removal. The highest values of N, P, K, Ca, and Mg removal were obtained after application of INSOL PK and NPK + CaO + MgO. The application of magnesium sulphate in the fertilization treatment resulted in higher sulphur removal and a narrower N : S ratio in winter wheat grain and straw.
4. The best yield quantity and quality parameters were obtained in the NPK + CaO + MgO soil fertilization treatment; INSOL PK and EKOSOL U exhibited similar effects.

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Oddziaływanie dolistnego dokarmiania w warunkach zróżnicowanego nawożenia doglebowego na strukturę plonu i jakość pszenicy ozimej (*Triticum aestivum* L.)

Streszczenie

Celem przeprowadzonych badań była analiza dolistnego dokarmiania pszenicy ozimej odmiany ‘Kobra’ na zróżnicowanych wariantach nawożenia doglebowego związkami wapnia i magnezu. Nawozy dolistne INSOL PK + 5% roztwór mocznika i EKOSOL U stosowano 3-krotnie w okresie wegetacji na czterech wariantach nawożenia doglebowego: kontrola bez nawożenia, NPK, NPK + $MgSO_4 \cdot 7H_2O$, NPK + CaO + MgO. Badania prowadzono w oparciu o trzyletnie doświadczenie polowe, na glebie średniej o pH 4,2 w 1 mol $KCl \cdot dm^{-3}$ i składzie granulometrycznym pyłu gliniastego. Gleba charakteryzowała się niską zawartością fosforu i potasu przyswajalnego oraz bardzo niską zawartością siarki i magnezu. Stosowane nawozy dolistne i warianty nawożenia doglebowego różnicowały wskaźniki plonowania, zawartość makroelementów w ziarnie i słomie oraz zawartość i jakość glutenu. Z zastosowanych wariantów nawożenia doglebowego najlepsze efekty produkcyjne i parametry jakościowe w uprawie pszenicy ozimej uzyskano z udziałem wapna magnezowego w dawce według pojedynczej kwasowości hydrolitycznej. Nawozy dolistne w większym stopniu oddziaływały na plonowanie i zawartość glutenu niż skład mineralny ziarna i słomy pszenicy ozimej.

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