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CHANGES IN NITROGEN AND MAGNESIUM CONTENTS IN PEA UNDER THE EFFECT OF NITROGEN FERTILIZATION

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ABSTRACT

Background. The aim of the conducted research was to determine the changes in nitrogen and magnesium contents in pea (*Pisum sativum* L.) and in soil under the effect of diversified nitrogen doses, as well as to calculate bioaccumulation factors and to demonstrate the relationships between the studied characteristics.
Material and methods. In a two-year-long field experiment, carried out at the experimental plot of the Siedlce University of Natural Sciences and Humanities, four plots with different fertilization levels were established: 0 (control plot), N1, N2, and N3 (N1 – 10, N2 – 20, and N3 – 30 kg·ha^{-1}). No phosphorus or potassium fertilization was applied because soil richness in assimilable phosphorus was established as very high, and in assimilable potassium as high. In the plant and soil material, total nitrogen content was established with the CHN/S method and total magnesium content with the ICP-AES method. Nitrogen and magnesium bioaccumulation factors and a coefficient of correlation were calculated.
Results. Nitrogen fertilization (10, 20 and 30 kg·ha^{-1}) significantly diversified nitrogen content in seeds, straw, and pod walls of pea (*Pisum sativum* L.) and magnesium content in seeds and pod walls. Average nitrogen contents in pea were as follows: seeds (37.3) > roots (14.0) > straw (10.6) > pod walls (9.2) g·kg^{-1} d.m. Magnesium content went in the opposite direction: pod walls (2.97) > straw > (2.20) > roots (1.68) > seeds (1.18) g·kg^{-1} d.m. Total nitrogen content in the soil varied between 1.96 g·kg^{-1} and 2.31 g·kg^{-1} of soil, and total magnesium content between 0.75 g·kg^{-1} and 0.79 g·kg^{-1} of soil. Nitrogen and magnesium bioaccumulation factors in the pea biomass were high.
Conclusion. The established nitrogen and magnesium contents in the dry matter of pea were within the limits of partition values that determine the acceptable amounts of those elements in fodder. The applied nitrogen fertilization at the doses of 10-30 kg·ha^{-1} did not affect negatively the changes in nitrogen and magnesium contents in pea and in the soil.

Key words: bioaccumulation, magnesium, N fertilization, nitrogen, *Pisum sativum* L., soil

INTRODUCTION

Pea (*Pisum sativum* L.) is a basic cultivated plant from the legume group. High sensitivity to weather conditions, unstable yield, variable profitability, and low competitiveness have a significant effect on the low popularity of pea cultivation (Grabowska *et al.*, 2007; Księżak *et al.*, 2018; Symanowicz and Kalembasa, 2012). Soil quality and fertilization have a decisive effect on the chemical composition of pea (Filipek, 2001; Wilczewski, 2007). Improper mineral fertilization may lead to nutrient imbalance in the soil and plants and decrease the quality and quantity of the obtained yield. Applied nitrogen fertilization in pea cultivation at doses of 20, 30, and 35 kg·ha^{-1} (Bujak and Frant, 2010; Faligowska and Szukała, 2010; Księżak, 2009; Woźniak *et al.*, 2014), as well as at 40 kg·ha^{-1} (Małecka-Jankowiak *et al.*, 2016) are

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regarded as the so-called starting dose. In pea cultivation a major nitrogen source is N_2 from the atmosphere, which is bound by the biological reduction process. Nitrogen content in pea seeds can range, on average, from 35.2 g·kg^{-1} d.m. (Księżak, 2009) to 38.0 g·kg^{-1} d.m. (Pietrzak, 2011). The amount of N_2 symbiotically bound by legumes, including pea, depends on the harvest stage, yield structure, nitrogen content, mineral fertilization, and soil and weather conditions (Pietrzak, 2011). According to Romheld and Kirkby (2009), there is a need to change the approach to the question of magnesium assimilability in plants and to creating new soil tests for this element. Many authors, including Anke (1987), Falkowski *et al.* (2000), and Kabata-Pendias (2011), indicate that good quality fodder should contain about 2 g·kg^{-1} d.m. of magnesium. Patorczyk-Pytlik (2009) states that in Poland as much as 59% of the analysed fodder samples do not meet the standards of optimal magnesium content.

In the literature there is a lack of data concerning changes in nitrogen and magnesium contents in pea and soil under the effect of diversified nitrogen doses in the conditions of very high soil richness in assimilable phosphorous and high richness in assimilable potassium.

In the present research, the study hypothesis assumed was that the applied nitrogen fertilizer doses would not negatively affect the changes in nitrogen and magnesium contents in pea (*Pisum sativum* L.) and in the soil.

The aim of the conducted research was to determine the changes in nitrogen and magnesium contents in pea (*Pisum sativum* L.) and in soil under the effect of diversified nitrogen doses, as well as the calculation of bioaccumulation factors and a demonstration of the relationships between the studied characteristics.

MATERIAL AND METHODS

The two-year-long field experiment was carried out (in the years 2010 and 2012) at the experimental plot of the Siedlce University of Natural Sciences and Humanities (52°17' N; 22 °28' E) with the totally random method in four repetitions (on plots with an area of 3 m^2). In the study, four plots with different fertilization levels were established: 0 (no fertilization), N1; N2; and N3. Nitrogen was applied at the doses of 10, 20, and 30 kg·ha^{-1}. The field experiment was set up on soil with neutral pH (pH in KCl mol·dm^{-3} – 6.86) with the texture of clay sand. Soil richness in assimilable phosphorus was established as very high, in assimilable potassium as high and in assimilable magnesium as average.

Seeds of the pea cultivar 'Lasso' were inoculated with the bacteria *Rhizobium leguminosarum* and sown in the amount of 125 seeds per m^2 at the depth of 5–6 cm and at a row spacing of 20 cm. Nitrogen fertilization (ammonium sulphate) was applied in the spring before seed sowing. During pea growth, maintenance treatments were performed and soil samples were collected in April, May, June and July from the *Ap* level (depth 0–30 cm).

Test plants after harvest were dried. Seeds, straw, pod walls, and roots were separated, and medium samples were collected for analyses and ground in a laboratory mill. Soil samples were dried, ground in a mortar, and sieved through a 2 mm mesh sieve. In the plant and soil material the total nitrogen content was established with the CHN/S method on an autoanalyzer CHNS/O Series II 2400 by Perkin Elmer with a thermal conductivity detector (TCD) and acetanilide as the reference material, and the total magnesium content with the ICP-AES method on an emission spectrophotometer with inductively induced plasma (Szczepaniak, 2009). Nitrogen and magnesium bioaccumulation factors were calculated as the ratio of nitrogen and magnesium total contents in plant to the total contents of those elements in the soil. Results were statistically processed using two-factor analysis of variance (ANALWAR-5.2-FR), and significant differences were calculated with the Tukey's test at the significance level of $P \leq 0.05$. Correlation coefficients ($P \leq 0.05$) between the studied characteristics were calculated using the program Statistica (Statistica Pl 13.1; Statsoft 2020).

The years of the experiment were characterized by varied weather conditions during the growing period, although they were both abundant in respect of the amount of precipitation. Total precipitation was higher than the long-term mean by 94.2 mm in 2010 and by 23.8 mm in 2012. Rainfall lower than the long-term means was observed in April, June and July in 2010 and in July and August in 2012. The second growing period (2012) was more favourable for the accumulation of potassium and magnesium in the field pea yield. Mean air temperatures in the years of the study remained at the level close to the long-term mean, and the mean monthly air temperature was only 0.8°C higher than the long-term mean. Almost in all months of growth the mean air temperature was slightly higher than the long-term mean. Only in May 2010 was it at the level of the long-term mean, and in June 2012 it was lower by 0.2°C than the long-term mean.

RESULTS

The applied nitrogen fertilization at the doses of 10, 20, and 30 kg N·ha^{-1} and the study years significantly diversified nitrogen content in pea seeds, straw, and pod walls (Table 1). A significant increase in nitrogen content in seeds was found after the application of 30 kg N·ha^{-1} in comparison with the plot with the application of 10 kg N·ha^{-1}. Seeds of the test plants collected in the second study year accumulated significantly lower amounts of nitrogen (by 16.5%) in comparison with the first study year. Also, the significantly highest amount of nitrogen was found in pea straw after the pre-sowing application of ammonium sulphate at the dose of 30 kg N·ha^{-1}. In the second study year, significantly more nitrogen was found in the straw. Pod walls of pea fertilized with 30 kg N·ha^{-1} in the second study year contained the highest amount of nitrogen. Nitrogen content in roots was significantly diversified by the study years. A significant decrease in nitrogen content in the roots was noted in the second study year. The content decreased by 28.2%. Average nitrogen content in pea was as follows (in g·kg^{-1} d.m.): seeds (37.3) > roots (14.0) > straw (10.6) > pod walls (9.2). Nitrogen content in the seeds significantly correlated with nitrogen content in the straw (r = 0.97). Also nitrogen content in the pod walls positively correlated with nitrogen content in the roots (r = 0.88).

Table 1. Nitrogen content in pea, g·kg^{-1} d.m.

Fertilization	Seeds			Straw			Pod walls			Roots		
	Study years											
	2010	2012	average	2010	2012	average	2010	2012	average	2010	2012	average
0	44.1^{b}	31.3^{a}	37.7^{A}	8.6^{b}	11.8^{b}	10.4^{B}	9.2^{b}	8.5^{a}	8.8^{A}	16.3^{a}	12.1^{a}	14.2^{A}
N1	38.4^{a}	32.3^{a}	35.3^{A}	6.4^{a}	10.7^{a}	8.5^{A}	6.6^{a}	8.9^{a}	7.7^{A}	15.9^{a}	10.1^{a}	13.0^{A}
N2	38.8^{a}	34.4^{a}	36.6^{A}	7.9^{b}	12.6^{b}	10.3^{B}	10.8^{c}	10.4^{b}	10.6^{B}	17.4^{a}	11.4^{a}	14.4^{A}
N3	41.4^{a}	37.8^{b}	39.6^{B}	13.3^{c}	12.9^{b}	13.1^{C}	8.6^{b}	11.0^{b}	9.8^{B}	15.5^{a}	13.1^{a}	14.3^{A}
Average	40.6^{B}	33.9^{A}	37.3	9.1^{A}	12.0^{B}	10.6	8.8^{A}	9.7^{B}	9.2	16.3^{B}	11.7^{A}	14.0

Explanations: values in the column for interaction factors marked with different small letters differ significantly ($P \leq 0.05$); different capital letters in the line and column for factors mark significant differences; N1–10, N2–20, N3–30 kg N·ha^{-1}

On the basis of the conducted research, a significant effect of diversified nitrogen fertilization on magnesium contents in pea seeds, pod walls, and roots was found (Table 2). Study years significantly affected changes in magnesium contents in the straw, pod walls, and roots of the test plants. The highest amounts of magnesium were found in the pod walls (2.97 g·kg^{-1} d.m.), whereas the lowest was in pea seeds (1.18 g·kg^{-1} d.m.). Applied fertilization at the doses of 20 kg N·ha^{-1} and 30 kg N·ha^{-1} significantly affected the increase in magnesium contents in seeds and pod walls in comparison with the control plot. In the roots a significant increase in the amount of this element was noted. In the second study year significantly higher magnesium contents in pea straw and pod walls were found. The interaction between nitrogen fertilization and the study years significantly affected the changes in magnesium contents in the seeds and roots. Magnesium content in the seeds significantly correlated with nitrogen content in the pod walls (r = 0.93), with nitrogen content in the straw (r = 0.79), and with nitrogen content in the roots (r = 0.98). Magnesium content in the pod walls negatively correlated with magnesium content in the roots (r = -0.92).

On the basis of the conducted statistical calculations, significant differences in nitrogen content at the level of soil *Ap* (0–30 cm) under the effect of nitrogen fertilization were found (Table 3). Significantly lower nitrogen content was found in soil fertilized with 10 kg N·ha^{-1} on all of the dates of soil samples collection. Significantly more nitrogen was found in the first experimental year. Nitrogen content in pea roots significantly correlated with nitrogen content in the soil (r = 0.96). Also nitrogen content in the pod walls correlated with total nitrogen content in the soil (r = 0.75). Magnesium content in pea seeds positively correlated with nitrogen content in the soil (r = 0.90).

Table 2. Magnesium content in pea, g·kg^{-1} d.m.

Fertilization	Seeds			Straw			Pod walls			Roots		
	Study years											
	2010	2012	average	2010	2012	average	2010	2012	average	2010	2012	average
0	1.23^{b}	1.13^{a}	1.18^{A}	2.02^{a}	2.52^{a}	2.27^{A}	2.53^{a}	3.14^{a}	2.83^{A}	1.84^{a}	1.73^{c}	1.78^{B}
N1	1.11^{a}	1.14^{a}	1.13^{A}	1.93^{a}	2.41^{a}	2.17^{A}	2.76^{b}	3.16^{a}	2.96^{B}	2.05^{b}	1.26^{b}	1.65^{B}
N2	1.20^{b}	1.20^{a}	1.20^{B}	1.75^{a}	2.53^{a}	2.14^{A}	2.72^{b}	3.24^{a}	2.98^{B}	1.93^{a}	0.88^{a}	1.40^{A}
N3	1.17^{a}	1.23^{b}	1.20^{B}	1.80^{a}	2.63^{a}	2.22^{A}	2.92^{c}	3.33^{b}	3.12^{C}	1.72^{a}	0.83^{a}	1.28^{A}
Average	1.18^{A}	1.17^{A}	1.18	1.87^{A}	2.52^{B}	2.20	2.73^{A}	3.22^{B}	2.97	1.88^{B}	1.17^{A}	1.53

Explanations: values in the column for interaction factors marked with different small letters differ significantly ($P \leq 0.05$); different capital letters in the line and column for factors mark significant differences; N1–10, N2–20, N3–30 kg N·ha^{-1}

Table 3. Total nitrogen content in the soil during pea growth season, g·kg^{-1}

Fertilization	Sampling date											
	April			May			June			July		
	Study years											
	2010	2012	average	2010	2012	average	2010	2012	average	2010	2012	average
0	2.35^{c}	1.70^{a}	2.03^{B}	2.00^{b}	1.80^{a}	1.90^{A}	2.30^{b}	1.80^{a}	2.05^{B}	2.95^{d}	1.80^{a}	2.38^{B}
N1	1.55^{a}	1.60^{a}	1.58^{A}	1.45^{a}	2.10^{a}	1.78^{A}	1.45^{a}	1.80^{a}	1.63^{A}	1.95^{a}	1.90^{a}	1.93^{A}
N2	2.30^{c}	2.20^{b}	2.25^{C}	2.55^{c}	2.40^{b}	2.48^{B}	2.15^{b}	2.00^{a}	2.08^{B}	2.60^{c}	2.10^{b}	2.35^{B}
N3	2.05^{b}	2.20^{b}	2.13^{B}	2.25^{b}	2.10^{a}	2.18^{B}	2.05^{b}	2.10^{b}	2.08^{B}	2.25^{b}	2.30^{b}	2.28^{B}
Average	2.06^{B}	1.93^{A}	1.99	2.06^{A}	2.10^{A}	2.08	1.99^{A}	1.93^{A}	1.96	2.44^{B}	2.03^{A}	2.31

Explanations: values in the column for interaction factors marked with different small letters differ significantly ($P \leq 0.05$); different capital letters in the line and column for factors mark significant differences; N1–10, N2–20, N3–30 kg N·ha^{-1}

The main sources of magnesium in the soil in the conducted study were from the reserves of the above element in the soil and residue after forecrop harvest. Total magnesium content was low and significantly diversified under the effect of nitrogen fertilization for soil samples collected in May, June, and July (Table 4). The highest magnesium content (0.93 g·kg^{-1}) was characteristic for soil collected in May in the second study year from plots fertilized with 20 kg N·ha^{-1}. Magnesium content in the soil positively correlated with nitrogen content in the soil (r = 0.88) and with nitrogen content in pea roots (r = 0.74).

Total nitrogen uptake with pea yield is the sum of the nitrogen uptake in seed, straw, and pod wall of the yield (Table 5). Nitrogen fertilization and the study year significantly diversified nitrogen uptake in the seed and straw yield and in total nitrogen uptake by the test plants. A significantly higher total nitrogen uptake (199 kg N·ha^{-1}) was found for fertilization with 30 kg N·ha^{-1} in the second study year.

Table 4. Total magnesium content in the soil during pea growth season, g·kg^{-1}

Fertilization	Sampling date											
	April			May			June			July		
	Study years											
	2010	2012	average	2010	2012	average	2010	2012	average	2010	2012	average
0	0.69^a	0.69^a	0.69^A	0.76^b	0.83^b	0.79^B	0.74^c	0.84^b	0.79^B	0.90^c	0.78^a	0.84^B
N1	0.63^a	0.85^a	0.74^A	0.62^a	0.79^a	0.70^A	0.59^a	0.86^b	0.73^A	0.62^a	0.80^a	0.71^A
N2	0.73^a	0.91^a	0.82^A	0.82^c	0.93^c	0.87^C	0.67^b	0.88^b	0.77^B	0.81^b	0.83^b	0.82^B
N3	0.69^a	0.81^a	0.75^A	0.75^b	0.85^b	0.80^B	0.65^a	0.77^a	0.71^A	0.75^b	0.75^a	0.75^A
Average	0.68^A	0.82^B	0.75	0.73^A	0.85^B	0.79	0.66^A	0.84^B	0.75	0.77^A	0.79^A	0.78

Explanations: values in the column for interaction factors marked with different small letters differ significantly ($P \leq 0.05$); different capital letters in the line and column for factors mark significant differences; N1–10, N2–20, N3–30 kg N·ha^{-1}

Table 5. Nitrogen uptake with pea yield, kg·ha^{-1}

Fertilization	Seeds			Straw			Pod walls			Sum		
	Study years											
	2010	2012	average	2010	2012	average	2010	2012	average	2010	2012	average
0	104.9^a	90.2^a	97.5^A	46.1^c	40.2^a	43.1^A	8.9^a	7.7^a	8.3^A	159.8^a	138.0^a	148.9^A
N1	143.8^c	113.1^b	128.4^B	32.1^a	51.6^c	41.8^A	7.4^a	9.4^a	8.4^A	183.3^b	174.1^b	178.7^B
N2	130.0^b	110.1^b	120.0^B	38.8^b	45.4^b	42.1^A	9.5^a	8.3^a	8.9^A	178.2^b	163.7^b	171.0^B
N3	105.5^a	129.3^c	117.4^B	63.9^d	59.4^d	61.6^B	7.8^a	10.4^a	9.1^A	177.1^b	199.0^c	188.1^C
Average	121.0^B	110.7^A	115.8	45.2^A	49.1^B	47.2	8.4^A	8.9^A	8.7	174.6^B	168.7^A	171.6

Explanations: values in the column for interaction factors marked with different small letters differ significantly ($P \leq 0.05$); different capital letters in the line and column for factors mark significant differences; N1–10, N2–20, N3–30 kg N·ha^{-1}

Nitrogen fertilization, study years, and interaction between the studied factors significantly diversified magnesium uptake in the yield (Table 6). Average total magnesium uptake in the yield was about 16.32 kg Mg·ha^{-1}. Significantly higher average magnesium uptake in the seed, straw, and pod wall yield and total uptake were noted for the plots fertilized with 10 kg N·ha^{-1}. It ought to be assumed that the application of higher nitrogen doses contributed to the occurrence of ion antagonism between NH_4^+ and Mg^{2+}.

Calculated nitrogen and magnesium bioaccumulation factors (Table 7) were high. Average nitrogen bioaccumulation factor values may be presented as a series of decreasing values: seeds (16.89) > straw (4.86) > pod walls (4.2). The applied nitrogen fertilization significantly diversified the values of nitrogen bioaccumulation factors in pea seeds and straw in the first study year. Average values of magnesium bioaccumulation factors were different from those for nitrogen: pod walls (3.85) > straw (2.84) > seeds (1.52). Statistical calculations demonstrated a significant effect of nitrogen fertilization on the values of magnesium bioaccumulation factors in the pod walls in the first study year.

Table 6. Magnesium uptake with pea yield, kg·ha^{-1}

Fertilization	Seeds			Straw			Pod walls			Sum		
	Study years											
	2010	2012	average	2010	2012	average	2010	2012	average	2010	2012	average
0	2.93^{a}	3.28^{a}	3.10^{A}	10.38^{b}	8.55^{a}	9.47^{A}	2.45^{a}	2.82^{b}	2.64^{B}	15.76^{b}	14.65^{a}	15.20^{A}
N1	4.17^{b}	3.99^{b}	4.08^{C}	9.75^{a}	11.62^{b}	10.68^{B}	3.11^{c}	3.35^{d}	3.23^{D}	17.02^{b}	18.95^{b}	17.99^{B}
N2	4.02^{b}	3.83^{b}	3.92^{C}	8.56^{a}	9.09^{a}	8.23^{A}	2.39^{a}	2.59^{a}	2.49^{A}	14.97^{a}	15.51^{a}	15.24^{A}
N3	2.97^{a}	4.21^{c}	3.59^{B}	8.64^{a}	12.10^{b}	10.37^{B}	2.65^{b}	3.13^{c}	2.89^{C}	14.26^{a}	19.44^{b}	16.85^{B}
Average	3.52^{A}	3.82^{B}	3.67	9.33^{A}	10.34^{B}	9.83	2.65^{A}	2.97^{B}	2.81	15.50^{A}	17.13^{B}	16.32

Explanations: values in the column for interaction factors marked with different small letters differ significantly ($P \leq 0.05$); different capital letters in the line and column for factors mark significant differences; N1–10, N2–20, N3–30 kg N·ha^{-1}

Table 7. Nitrogen and magnesium bioaccumulation factor (BF) in pea

Fertilization	Nitrogen						Magnesium					
	Seeds		Straw		Pod walls		Seeds		Straw		Pod walls	
	Study years						Study years					
	2010	2012	2010	2012	2010	2012	2010	2012	2010	2012	2010	2012
0	14.95^{a}	17.39^{a}	2.91^{a}	6.55^{a}	3.12^{a}	4.72^{a}	1.37^{a}	1.45^{a}	2.24^{a}	3.23^{a}	2.81^{a}	4.02^{a}
N1	19.69^{b}	17.00^{a}	3.28^{a}	5.63^{a}	3.38^{a}	4.68^{a}	1.79^{a}	1.42^{a}	3.11^{a}	3.01^{a}	4.45^{b}	3.95^{a}
N2	14.92^{a}	16.38^{a}	3.04^{a}	6.00^{a}	4.15^{a}	4.95^{a}	1.48^{a}	1.44^{a}	2.16^{a}	3.05^{a}	3.36^{a}	3.90^{a}
N3	18.40^{b}	16.43^{a}	5.91^{b}	5.61^{a}	3.82^{a}	4.78^{a}	1.56^{a}	1.64^{a}	2.40^{a}	3.51^{a}	3.89^{a}	4.44^{a}
Average	16.99^{A}	16.80^{A}	3.78^{A}	5.95^{B}	3.62^{A}	4.78^{A}	1.55^{A}	1.49^{A}	2.48^{A}	3.20^{A}	3.63^{A}	4.08^{A}

Explanations: values in the column for interaction factors marked with different small letters differ significantly ($P \leq 0.05$); different capital letters in the line for years mark significant differences; N1–10, N2–20, N3–30 kg N·ha^{-1}

DISSCUSION

The nitrogen fertilization, applied in the study in the form of ammonium sulphate, in pea (*Pisum sativum* L.) cultivation may have resulted in ion imbalance in the soil. The result of fertilization is an increase in acidification and in ion H^+ and Al^{3+} concentrations, which, as a result of an antagonistic effect, may have hindered the supply of magnesium to plants.

Nitrogen fertilization at the doses of 10, 20, and 30 kg N·ha^{-1} significantly diversified the nitrogen level in pea plants, as well as the uptake of this element in the seed, straw, and pod wall yield. The present study demonstrated that the highest average nitrogen contents in seeds, straw, and pod walls, as well as the highest total nitrogen uptake in pea yield were obtained with the application of 30 kg N·ha^{-1}. Similar nitrogen contents in pea seeds, straw, pod walls, and roots have been found in an earlier study by Symanowicz *et al.* (2017), in which 20 kg N·ha^{-1} was applied, as well as diversified potassium fertilization. Also in research on faba bean conducted by Kalembasa *et al.* (2020), a nitrogen dose of 30 kg N·ha^{-1} was found to be the optimum for nitrogen uptake by test plants, which attained a level of 194 kg N·ha^{-1}. A nitrogen uptake twice as high (353.4 kg N·ha^{-1}), in comparison with the present research, was obtained during quantitative research on the biological possibility of reducing nitrogen by the bacteria *Rhizobium galegae* that coexists with goat's rue (Kalembasa and Symanowicz 2010). In the conditions of a pot experiment (Wysokiński *et al.* 2013), after a pre-sowing application of nitrogen in the form of ^{15}N with 10.2 at% enrichment, a nitrogen content in pea seeds was established at the level of 29.8 g·kg^{-1} d.m. Also, in their work the nitrogen content in pea straw and pod walls were at a lower level in comparison with the present study. Woźniak *et al.* (2014) and Piotrowska and Wilczewski (2012) suggested that the growth system and the applied intercrop may determine a biological reduction of molecular nitrogen. The nitrogen content found in the biomass of pea grown for ploughing-in as a green fertilizer (Piotrowska and Wilczewski, 2012) was between 2.35% and 2.65% (23.5–26.5 g·kg^{-1} d.m.). The amount of nitrogen introduced into the soil in the current study ranged between 54.8–105.8 kg N·ha^{-1}, depending on the study year. Changes in nitrogen contents in seeds, straw, pod walls, and roots in the present study may also have been related to the rich soil high in assimilable forms of potassium. Such a possibility has been suggested by: Andrzejewska *et al.* (2015); Wang *et al.* (2010), and Zia-Ul-Hag *et al.* (2013).

The decreased content of magnesium in pea seeds and its uptake was a consequence of higher nitrogen content in seeds. Magnesium uptake in pea is said to be affected by the occurrence of ion antagonism between NH_4^+ and Mg^{2+} Jamroz *et al.*, 2001; Symanowicz, 2016). According to Woźniak *et al.* (2014), magnesium content in pea seeds did not depend on the growth system or the study years and was 0.86–1.02 g·kg^{-1} d.m. In studies conducted in the USA, in which pea of different genotypes was grown (Amarakoon *et al.*, 2012), magnesium contents in pea seeds were similar to those found in the present study (1.35 g·kg^{-1} d.m.). According to Symanowicz *et al.*, 2017, the favourable precipitation distribution and temperatures during growth in the second study year of their study contributed to the relocation of higher amounts of magnesium to pea straw and pod walls. According to Anke (1987), Jamroz *et al.* (2001) and Symanowicz (2016), the nitrogen and magnesium contents determined in our own research are at the optimal level. The results of the present study concerning nitrogen and magnesium contents in the soil are in line with the studies by Hajduk *et al.* (2009), Pakuła and Kalembasa (2012) and Żarczyński *et al.* (2008). Studies by Johnston (2009) point to an increased magnesium content (1.44 g·kg^{-1} d.m.) in arable soils in which magnesium fertilization was applied.

All the calculated nitrogen and magnesium bioaccumulation factors in the particular pea parts were high, according to the scale proposed by Kabata-Pendias, 2011. According to that scale the level of bioaccumulation in plants is as follows: 0.001–0.01 no bioaccumulation, 0.01–0.1 low bioaccumulation, 0.1–1.0 medium bioaccumulation, and 1.0–10.0 high bioaccumulation. The nitrogen bioaccumulation in the seeds of the test plants in our own research exceeded the high level, although according to Anke (1987) and Jamroz *et al.* (2001) the nitrogen content in the seeds did not exceed acceptable norms.

CONCLUSIONS

Nitrogen fertilization significantly diversified nitrogen contents in the seeds, straw, and pod walls of pea (*Pisum sativum* L.) and magnesium contents in seeds and pod walls. The average nitrogen contents in pea were as follows: seeds (37.3) > roots (14.0) > straw (10.6) > pod walls (9.2) $g \cdot kg^{-1}$ d.m. Magnesium contents went in the opposite direction: pod walls (2.97) > straw > (2.20) > roots (1.68) > seeds (1.18) $g \cdot kg^{-1}$ d.m. The highest amounts of nitrogen were found in seeds and straw after the application of the nitrogen dose of 30 $kg \cdot ha^{-1}$, whereas in the pod walls and roots it was at the dose of 20 $kg \cdot ha^{-1}$. Magnesium contents in the particular plant parts of pea were ambiguously varied under the effect of subsequent nitrogen doses (only in pea pod walls was more magnesium found under the effect of increasing nitrogen doses).

Total nitrogen content in the soil was between 1.96 $g \cdot kg^{-1}$ and 2.31 $g \cdot kg^{-1}$ of soil. Depending on the date of sample collection a significant increase in nitrogen content in the soil was noted with nitrogen fertilization at the doses of 20 $kg \cdot ha^{-1}$ and 30 $kg \cdot ha^{-1}$. Total magnesium content in the soil was at a more constant level (0.75–0.79 $g \cdot kg^{-1}$ of soil). Nitrogen and magnesium bioaccumulation factors in pea biomass were at a high, but acceptable level. The applied nitrogen fertilization at the doses of 10–30 $kg \cdot ha^{-1}$ did not negatively affect the changes in nitrogen and magnesium contents in pea and in the soil.

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ZMIANY ZAWARTOŚCI AZOTU I MAGNEZU W GROCHU SIEWNYM POD WPŁYWEM NAWOŻENIA AZOTOWEGO

Streszczenie

Celem przeprowadzonych badań było określenie zmian zawartości azotu i magnezu w grochu siewnym (*Pisum sativum* L.) i w glebie pod wpływem zróżnicowanych dawek azotu, obliczenie współczynników bioakumulacji i wykazanie zależności pomiędzy badanymi cechami. W dwuletnim doświadczeniu polowym przeprowadzonym w obiekcie doświadczalnym Uniwersytetu Przyrodniczo-Humanistycznego w Siedlcach uwzględniono cztery obiekty nawozowe: 0 (obiekt kontrolny), N1, N2, N3 (N1–10; N2–20; N3–30 kg·ha^{-1}). Nie stosowano nawożenia fosforem i potasem, ponieważ zasobność gleby w przyswajalny fosfor określono jako bardzo wysoką, a w przyswajalny potas jako wysoką. W materiale roślinnym i glebowym oznaczono całkowitą zawartość azotu metodą CHN/S oraz magnezu metodą ICP-AES.

Obliczono współczynniki bioakumulacji azotu i magnezu oraz współczynniki korelacji. Nawożenie azotem istotnie różnicowało zawartość azotu w nasionach, słomie i strączynach grochu siewnego (*Pisum sativum* L.) oraz magnezu w nasionach i strączynach. Średnie zawartości azotu w grochu siewnym przedstawiają się następująco: nasiona (37.3) > korzenie (14.0) > słoma (10.6) > strączyny (9.2) $g \cdot kg^{-1}$ s.m. Odwrotnie kształtowała się zawartość magnezu: strączyny (2.97) > słoma > (2.20) > korzenie (1.68) > nasiona (1.18) $g \cdot kg^{-1}$ s.m. Całkowita zawartość azotu w glebie wynosiła 1.96–2.31 $g \cdot kg^{-1}$ gleby, a magnezu 0.75–0.79 $g \cdot kg^{-1}$ gleby. Współczynniki bioakumulacji azotu i magnezu w biomasie grochu siewnego kształtowały się na wysokim poziomie. Oznaczone zawartości azotu i magnezu w suchej masie grochu siewnego mieściły się w zakresie liczb granicznych określających dopuszczalne ilości tych pierwiastków w paszy.

Słowa kluczowe: azot, bioakumulacja, gleba, magnez, nawożenie N, *Pisum sativum* L.