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IMPACT OF MULTI-ANNUAL MINERAL FERTILIZATION WITH NPKCa ON THE CONTENT AND UPTAKE OF MAGNESIUM BY EASTERN GALEGA

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Abstract

This paper presents the changes in the magnesium content in soil and plants and in the uptake of this element in yield under the influence of NPKCa fertilization. Eastern galega (*Galega orientalis* Lam.) was cultivated in 2005-2009. A field experiment was conducted on the experimental plots of the Siedlce University of Natural Sciences and Humanities. Thirteen levels of fertilization were included in the study: without fertilization, N_{20}, P_{50}, K_{150}, $N_{20}P_{50}K_{150}$, $N_{20}P_{50}$, $N_{20}K_{150}$, $P_{50}K_{150}$, $N_{20}P_{50}K_{150}Ca_{150}$, $P_{50}K_{150}Ca_{150}$, Ca_{150}, $N_{20}K_{150}Ca_{150}$, $N_{20}P_{50}Ca_{150}$. Three swaths of the test plants were harvested at budding in each year of the study. The total content of magnesium in soil and in plants was determined with the ICP-AES method on an emission spectrophotometer with inductively-coupled plasma. The applied mineral fertilization with NPKCa did not have any significant impact on the average magnesium content in soil. The highest (significantly) content of magnesium was determined in eastern galega biomass harvested from the plots fertilized with Ca_{150} as dolomite calcium in all years of the experiment (the mean for the years: 2.91 g kg^{-1} d.m.). The average content of Mg in the subsequent swaths was as follows (in g kg^{-1} d.m.): swath I (2.04) < swath II (3.23) > swath III (2.39). The determined content of magnesium in eastern galega in the subsequent years of the experiment ranged between 2.22 g kg^{-1} d.m. in 2006 and 2.83 g kg^{-1} d.m. in 2008. The highest uptake of magnesium in eastern galega yield (73.78 kg Mg ha^{-1}) was recorded on a plot fertilized with $N_{20}P_{50}Ca_{150}$ in 2008.

Keywords: NPKCa fertilization, soil, eastern galega, magnesium, uptake.

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INTRODUCTION

Eastern galega (*Galega orientalis* Lam.) is a perennial legume plant, which is rich in macro- and microelements (Kalembasa, Symanowicz 2009, Raig et al. 2001, Symanowicz, Kalembasa 2004). It may be a good forecrop for winter wheat after multi-annual cultivation (Ignaczak, Szczepanek 2005). In research conducted in the Podlasie region with ^{15}N isotope, a large potential for biological reduction of N_2 by eastern galega has been determined (Kalembasa, Symanowicz 2010) after introduction of *Rhizobium galegae* bacteria to soil (Peoples et al. 1995, Reichel et al. 1984). The following factors have a decisive impact on the yield and chemical composition of seeds of other plants and eastern galega biomass: soil, atmospheric conditions, fertilization, developmental stage and the year of cultivation (Gugała, Zarzecka 2010, Symanowicz, Kalembasa 2012, Valkonen 1993, Virkajärvi, Varis 1991). The research results in Lithuania indicate that the chemical composition of galega at the flowering stage is superior to that of traditional forage crops (Baležentiené, Mikulionieně 2006). The highest magnesium content (3.6 g kg^{-1} d.m.) was determined in galega dry matter, indicating a good feed value of this crop. The use of magnesium is gaining importance (Santamaria et al. 2014). Its deficit contributes towards a reduction of both quantity and quality of yields and may cause a disease, namely, grass tetany. There is, however, no data available in the literature on quantitative changes in the content of magnesium in eastern galega biomass and in soil with diversified mineral fertilization.

The objective of this paper was to investigate changes in the content of total magnesium in soil and three swaths of eastern galega under the influence of multi-annual fertilization with NPKCa, and changes in the uptake of this element with yield.

MATERIAL AND METHODS

A 5-year field experiment was set up with a completely randomized method in three replications, on the experimental plots of the Department of Soil Science and Agricultural Chemistry at the Siedlce University of Natural Sciences and Humanity. Thirteen levels of fertilization were included in the study: without fertilization, N_{20}, P_{50}, K_{150}, $N_{20}P_{50}K_{150}$, $N_{20}P_{50}$, $N_{20}K_{150}$, $P_{50}K_{150}$, $N_{20}P_{50}K_{150}Ca_{150}$, $P_{50}K_{150}Ca_{150}$, Ca_{150}, $N_{20}K_{150}Ca_{150}$, $N_{20}P_{50}Ca_{150}$.

The field experiment was conducted on soil of loamy sand containing 31.5 g kg^{-1} of carbon in organic compounds, 1.66 g kg^{-1} of total nitrogen, and pH in 1mol KCl dm^{-3} – 6.6. The content of available forms of phosphorus and potassium in soil determined with the Egner-Riehm's method was high (80 mg kg^{-1} P and 140 mg kg^{-1} K) and the content of magnesium determined with the Schachtschabel's method was average (50 mg kg^{-1}). Eastern galega was sown in the third decade of April 2004 at 2-3 cm deep in the amount of 24 kg ha^{-1} and in 12-15 cm rows. Mechanically scarified seeds were sown into soil inoculated with *Rhizobium galegae* bacteria. Plants started to sprout after two weeks. However, the first year was assumed to be preliminary to the actual study due to the slow rate of growth that occurred in it. In the subsequent years, the following fertilization scheme was implemented: N – 20 kg ha^{-1} as 34% ammonium nitrate applied in early spring; P – 50 kg ha^{-1} as triple superphosphate applied in autumn; K – 150 kg ha^{-1} as 60% potassium salt at two doses: dose I (100 kg K ha^{-1}) applied in early spring, dose II (50 kg K ha^{-1}) applied after the first swath; Ca – 150 kg ha^{-1} as dolomite calcium applied in autumn. During vegetation, agricultural procedures such as weeding were performed. The subsequent three swaths of eastern galega were harvested at budding. The samples of soil were collected in spring and autumn. The content of total magnesium was determined with the ICP-AES method in soil and plant material after drying, comminution and dry mineralization. The results of determinations were statistically processed with the analysis of variance and significant differences were calculated with the Tuckey's test at $p = 0.05$.

The average air temperatures and monthly precipitations in the plant growing seasons of the experimental years are presented in Table 1. The atmospheric conditions exerted a large impact on the content of total magnesium in the Ap horizon of the soil profile and on its uptake by the test plant.

Table 1

Meteorological conditions in 2005-2009 according to the meteorological station in Siedlce

Years	Months						Mean/Sum
	April	May	June	July	August	Sept.	
Mean monthly air temperature (^{o}C)							
2005	8.6	13.0	15.9	20.2	17.5	15.0	15.0
2006	8.4	13.6	17.2	22.3	18.0	15.4	15.8
2007	8.3	14.5	18.2	18.5	18.6	13.1	15.2
2008	9.1	12.7	17.4	18.4	18.5	12.2	14.7
2009	10.0	12.8	15.8	19.3	17.3	14.3	14.9
Multiyear average 1987-2000	7.8	12.5	17.2	19.2	18.5	13.1	14.7
Total monthly rainfalls (mm)							
2005	12.3	64.7	44.4	86.5	45.4	15.8	269.1
2006	29.8	39.6	24.0	16.2	227.6	22.0	359.2
2007	21.2	59.1	59.9	70.2	31.1	67.6	309.1
2008	28.2	85.6	49.0	69.8	75.4	63.4	371.4
2009	1.8	19.9	54.5	18,8	31.9	4.5	131.4
Multiyear average 1987-2000	38.6	44.1	52.4	49.8	43.0	47.3	275.2

Excessively high temperatures limited the uptake of magnesium whereas a large volume of precipitation caused extensive leaching of this element deep into the soil profile.

RESULTS AND DISCUSSION

Dolomite calcium and magnesium reserves in soil were the main source of magnesium for eastern galega in the conducted experiment. The highest content of magnesium was determined in soil sampled from the plots fertilized with Ca, NPCa, PKCa, NKCa in different combinations of the fertilization with ammonium nitrate, triple superphosphate, potassium salt and dolomite calcium (Tables 2, 3).

Table 2

Changes of the total magnesium content in soil (g kg^{-1}) – spring

Mineral fertilization	Years of the research					Mean
	2005	2006	2007	2008	2009	
0	0.65	0.61	0.79	0.61	0.30	0.59
N_{20}	0.69	0.65	0.83	0.74	0.37	0.66
P_{50}	0.71	0.68	0.89	0.74	0.34	0.67
K_{150}	0.75	0.64	0.82	0.77	0.31	0.66
$N_{20}P_{50}K_{150}$	0.76	0.67	0.73	0.73	0.31	0.64
$N_{20}P_{50}$	0.79	0.70	0.79	0.77	0.36	0.68
$N_{20}K_{150}$	0.77	0.70	0.83	0.81	0.35	0.69
$P_{50}K_{150}$	0.79	0.72	0.85	0.83	0.33	0.70
$N_{20}P_{50}K_{150}Ca_{150}$	0.82	0.76	0.77	0.91	0.36	0.72
$P_{50}K_{150}Ca_{150}$	0.82	0.80	0.88	1.04	0.38	0.78
Ca_{150}	0.84	0.81	0.81	1.01	0.35	0.76
$N_{20}K_{150}Ca_{150}$	0.84	0.79	0.87	1.06	0.39	0.79
$N_{20}P_{50}Ca_{150}$	0.81	0.79	0.87	1.00	0.41	0.78
Mean	0.77	0.72	0.82	0.85	0.35	0.70
$LSD_{0.05}$	0.03	0.16	n.s.	0.23	n.s.	n.s.

The highest content of magnesium was recorded in soil in 2008, both during the spring and autumn sampling. A very small content of magnesium in soil in 2009 was caused by high precipitation in the autumn of 2008 and the leaching of the element deep into the soil profile as well as its absorption by plants (Sienkiewicz et al. 2011). A lower content of total magnesium was determined in the samples of soil collected in spring from the Ap horizon in comparison with the sampling that took place in autumn (Tables 2, 3).

The average content of magnesium (g kg^{-1} d.m.) in eastern galega biomass was significantly diversified by mineral fertilization with NPKCa and in the subsequent years of the study (Table 4). The lowest content of magnesium (2.23 and 2.25 g kg^{-1} d.m.) was determined in eastern galega fertilized with $P_{50}K_{150}$, K_{150} and $N_{20}P_{50}K_{150}$. Galega harvested from the plots fertilized

Table 3

Changes of the total magnesium content in soil (g kg^{-1}) – autumn

Mineral fertilization	Years of the research					Mean
	2005	2006	2007	2008	2009	
0	0.79	0.65	0.77	0.69	0.28	0.64
N_{20}	0.77	0.71	1.02	0.87	0.31	0.74
P_{50}	0.82	0.72	0.80	0.86	0.36	0.71
K_{150}	0.86	0.72	0.76	0.83	0.37	0.71
$N_{20}P_{50}K_{150}$	0,87	0.73	0.78	0.72	0.32	0.68
$N_{20}P_{50}$	0.85	0.76	0.78	0.88	0.28	0.71
$N_{20}K_{150}$	0.83	0.76	0.79	0.83	0.31	0.70
$P_{50}K_{150}$	0.83	0.76	0.86	0.89	0.31	0.73
$N_{20}P_{50}K_{150}Ca_{150}$	0.79	0.80	0.86	0.92	0.34	0.74
$P_{50}K_{150}Ca_{150}$	0.86	0.84	0.88	1,03	0.42	0.81
Ca_{150}	0.90	0.86	0.79	1.10	0.39	0.81
$N_{20}K_{150}Ca_{150}$	0.86	0.82	0.89	0.97	0.60	0.83
$N_{20}P_{50}Ca_{150}$	0.85	0.83	0.78	1.08	0.60	0.83
Mean	0.84	0.77	0.83	0.90	0.38	0.74
$LSD_{0.05}$	n.s.	0.14	n.s.	0.32	0.23	n.s.

Table 4

The content of magnesium in biomass of eastern galega (g kg^{-1} d.m.)

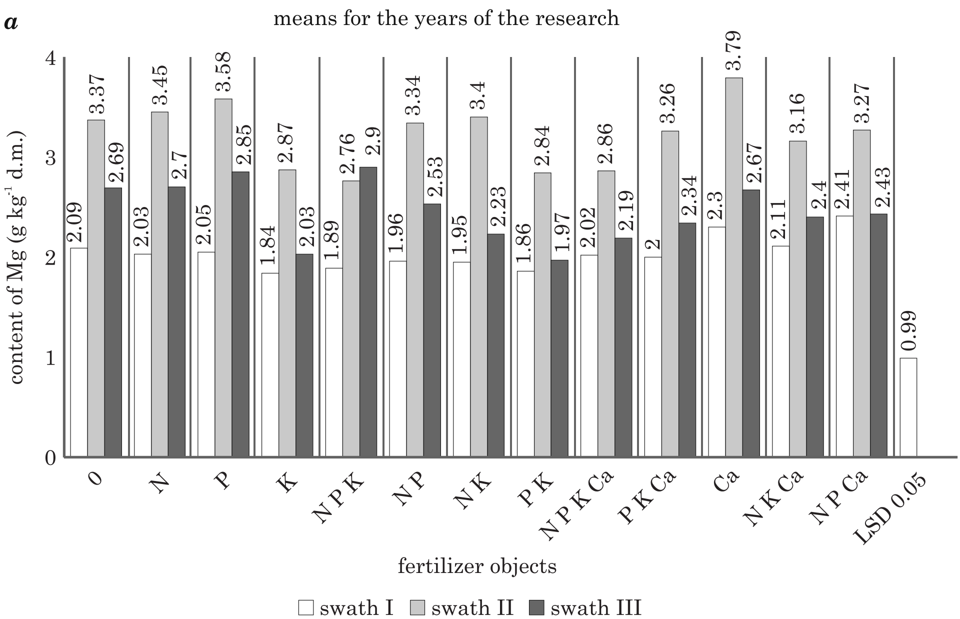
Mineral fertilization	Years of the research					Mean
	2005	2006	2007	2008	2009	
0	2.75	2.51	2.79	2.85	2.69	2.72
N_{20}	2.77	2.20	2.90	3.13	2.63	2.73
P_{50}	3.07	2.35	2.87	3.05	2.78	2.82
K_{150}	2.42	2.03	2.40	2.27	2.13	2.25
$N_{20}P_{50}K_{150}$	2.42	1.86	2.31	2.46	2.18	2.25
$N_{20}P_{50}$	2.61	2.30	2.80	3.09	2.58	2.68
$N_{20}K_{150}$	2.68	2.17	2.50	2.80	2.49	2.53
$P_{50}K_{150}$	2.48	1.85	2.31	2.35	2.14	2.23
$N_{20}P_{50}K_{150}Ca_{150}$	2.44	1.94	2.43	2.58	2.39	2.36
$P_{50}K_{150}Ca_{150}$	2.59	2.19	2.47	2.85	2.57	2.53
Ca_{150}	2.70	2.77	2.95	3.14	3.00	2.91
$N_{20}K_{150}Ca_{150}$	2.57	2.23	2.50	2.99	2.50	2.56
$N_{20}P_{50}Ca_{150}$	2.82	2.42	2.76	3.18	2.47	2.73
Mean	2.64	2.22	2.61	2.83	2.50	2.56
$LSD_{0.05}$	0.26	0.36	0.28	0.85	0.72	0.55

The data in the table are means (n = 3)

with Ca_{150} applied as dolomite calcium contained significantly more magnesium (2.91 g kg^{-1} d.m.). Grzegorczyk et al. (2013) also reported high magnesium content of biomass in *Trifolium pretense* (2.8 g kg^{-1} d.m.) growing in mineral soil habitats. The content of magnesium in biomass of eastern galega was similar to the values reported by other authors (Kozłowski et al. 2012, Symanowicz, Kalembasa 2012). In the study by Zielewicz et al. (2013), a decrease of magnesium in eastern galega biomass was observed for II and III regrowths. The determined amounts of Mg in the biomass of the test plant were within the permissible ranges of nutrition standards for livestock animals (Jamroz et al. 2001). In the research by Wierzbowska, Żuk-Gołaszewska (2014), magnesium levels in fenugreek seeds (2.13-2.60 g kg^{-1} d.m.) remained constan, regardless of the seed inoculation with *Rhizobium meliloti* or nitrogen fertilization.

The magnesium content in eastern galega harvested in the subsequent swaths (Figure 1*a*) is as follows (in g kg^{-1} d.m.): swath II (3.23) > swath III (2.39) > swath I (2.04). Statistical calculations demonstrated significant differences in the content of magnesium in eastern galega biomass from swath II between two fertilized objects ($N_{20}P_{50}K_{150}$ – 2.76 g kg^{-1} and Ca_{150} – 3.79 g kg^{-1}). The significantly highest amounts of magnesium were determined in galega harvested in swath II in the subsequent years of the experiment (Figure 1b). The magnesium content in the dry matter of eastern galega of I, II and III swath was significantly differentiated between the successive years of the experiment. The results are similar to the findings of a study on the effect of eastern galega seed inoculation (*Galega orientalis* Lam.) on the content of macroelements (Symanowicz, Kalembasa 2004, 2010). According to Jamroz et al. (2001), the magnesium content of about 2 g kg^{-1} is sufficient to cover the nutritional needs of animals. Patorczyk-Pytlik (2009) showed that a sward of grassland tobe usually has a low value as fodder regarding its mineral composition. According to that study, 59% of pasture sward did not satisfy the feeding requirements of dairy cattle in terms of the magnesium content.

a



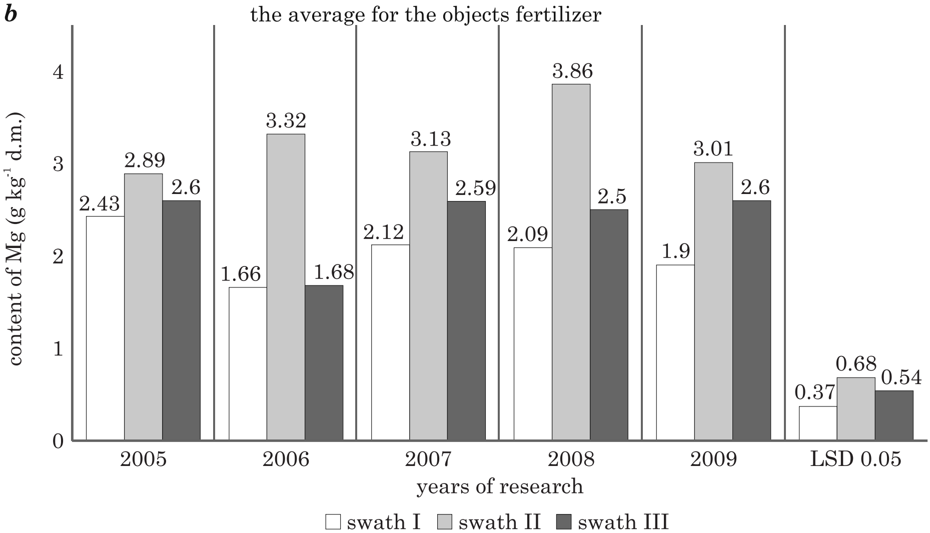


Fig. 1. Changes in the content of magnesium in biomass in of eastern galega swaths I, II and III

The uptake of magnesium with the biomass of yield was significantly correlated with the content of Mg in plants and dry matter yield of eastern galega. The highest (significant) uptake was recorded under the influence of $N_{20}K_{150}Ca_{150}$ and $N_{20}P_{50}Ca_{150}$ doses (Table 5). In the subsequent years, the uptake of magnesium in yield increased systematically. This fact should be associated with the accumulation of this element in soil after an annual appli-

Table 5

Uptake of magnesium in the yield of eastern galega (kg Mg ha^{-1})

Mineral fertilization	Years of the research					Mean
	2005	2006	2007	2008	2009	
0	9.27	21.08	15.67	26.22	33.95	21.27
N_{20}	9.14	23.98	25.81	61.35	46.21	32.90
P_{50}	17.00	21.85	15.78	45.44	37.58	27.49
K_{150}	9.32	21.11	27.12	33.14	38.51	26.21
$N_{20}P_{50}K_{150}$	33.66	24.55	24.49	49.20	51.01	36.49
$N_{20}P_{50}$	19.26	30.13	28.00	47.28	42.05	33.28
$N_{20}K_{150}$	17.74	27.99	36.50	53.76	45.32	36.18
$P_{50}K_{150}$	16.89	20.53	33.03	41.83	36.87	29.99
$N_{20}P_{50}K_{150}Ca_{150}$	28.67	30.26	30.62	49.28	46.65	37.07
$P_{50}K_{150}Ca_{150}$	38.69	24.31	29.39	52.72	51.35	38.66
Ca_{150}	10.72	14.68	18.29	33.60	34.17	21.82
$N_{20}K_{150}Ca_{150}$	30.81	27.21	33.25	70.56	58.65	43.29
$N_{20}P_{50}Ca_{150}$	37.73	32.91	32.29	73.78	41.84	43.02
Mean	22.31	25.09	27.14	49.52	43.87	33.38
$LSD_{0.05}$	5.26	4.21	6.73	7.33	6.49	7.84

The data in the table are means (n = 3) cations of dolomite calcium into the soil. The highest average uptake of magnesium in yield (49.52 kg Mg ha^{-1}) was recorded in 2008. In the next year, the uptake of magnesium by the test plant was reduced, which was due to a smaller content of magnesium in soil and high precipitation in autumn 2008.

A lower uptake of magnesium has been reported by Żarczyński et al. (2008), who claimed that the magnesium accumulation potential of eastern galega was at 13.8-23.9 kg Mg ha^{-1}. A large degree of magnesium release from soil and its incorporation into the circulation by cultivating perennial plants (including eastern galega) has been indicated by Żarczyński et al. (2008). The application of magnesium in doses of 8.8 kg ha^{-1} or 25 kg ha^{-1} increased the pasture herbage yield and Mg content by 40% (Santamaria et al. 2014). However, Mg was applied in combination with other nutrients and therefore the above increase could have been caused by Mg and other nutrients applied.

CONCLUSIONS

1. The NPKCa mineral fertilization did not have any significant impact on the average content of total magnesium determined in soil.

2. The significantly highest content of magnesium was determined in eastern galega harvested from the plots fertilized with Ca_{150} applied as dolomite calcium in all years of the experiment (the mean for all years: 2.91 g kg^{-1} d.m.).

3. The average content of Mg in the subsequent swaths was as follows (g kg^{-1} d.m.): swath I (2.04) < swath II (3.23) > swath III (2.39).

4. The determined content of magnesium in eastern galega in the subsequent years of the experiment ranged between 2.22 g kg^{-1} d.m. in 2006 and 2.83 g kg^{-1} d.m. in 2008.

5. The highest uptake of magnesium with eastern galega yield (73.78 kg Mg ha^{-1}) was recorded on the plot fertilized with $N_{20}P_{50}Ca_{150}$ in 2008.

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