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Effect of nitrogen fertilisation of *Galega orientalis* Lam. on the yield and content K, Na, Ca and Mg in the plant and soil

Wpływ nawożenia azotem *Galega orientalis* Lam. na plon oraz zawartość K, Na, Ca i Mg w roślinie i glebie

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Słowa kluczowe: nawożenie $(^{15}NH_4)_2SO_4$, rutwica wschodnia, K, Na, Ca, Mg, zawartość

Abstract
The aim of this study is to determine the response of biomass yield and the content of K, Na, Ca and Mg in the eastern galega and soil under the influence of nitrogen in the form of $(^{15}NH_4)_2SO_4$. Three-year field experiment (2005–2007) was carried out on experimental plots belonging to the University of Natural Sciences - Humanities in Siedlce (52°17′N, 22°28′E). Nitrogen ^{15}N was applied as ammonium sulphate at a dose of early spring 1.66 g N·m^{-2}. In each year of the study were collected three cuts of eastern galega budding phase. Shown yield of dry weight of the test plant. The content of K, Na, Ca and Mg in the eastern galega and soil were determined by ICP-AES emission spectrometer with inductively coupled plasma. Subsequently, the uptake and marked weight ratios of macronutrients.
Under the influence of nitrogen in the form of ammonium sulphate, dry matter yield of eastern galega (average of 3 years of research and 3 swaths) increased by 29.7%. Fertilisation with nitrogen contributed to the reduction of K content, increasing the content of Na, Ca, Mg, in a test plant and to increase the pick, all the elements analysed with the yield of biomass. Nitrogen fertilisation resulted in a reduction in the quantitative ratios K: (Ca + Mg), (K + Na) : (Ca + Mg), K: Ca, K : Mg and the total content of the analysed elements in the soil (average of the years).

Streszczenie
Celem pracy było określenie reakcji plonu biomasy oraz zawartości K, Na, Ca i Mg w rutwicy wschodniej i w glebie pod wpływem nawożenia azotem w formie $(^{15}NH_4)_2SO_4$. Doświadczenie polowe trzyletnie (2005-2007) przeprowadzono na poletkach doświadczalnych należących do Uniwersytetu Przyrodniczo – Humanistycznego w Siedlcach (52°17′N, 22°28′E). Azot ^{15}N stosowano w formie siarczanu amonu wczesną wiosną w dawce 1,66 g N·m^{-2}. W każdym roku badań zbierano trzy pokosy rutwicy wschodniej w fazie pąkowania. Określono plon suchej masy rośliny testowej. Zawartość potasu, sodu wapnia i magnezu w rutwicy wschodniej i w glebie oznaczono metodą ICP-AES na spektrofotometrze emisyjnym z plazmą wzbudzaną indukcyjnie. Następnie obliczono pobranie i stosunki wagowe oznaczonych makroelementów.
Pod wpływem nawożenia azotem w formie siarczanu amonu plon suchej masy rutwicy wschodniej (średnia z 3 lat badań i 3 pokosów) zwiększył się o 29,7%. Nawożenie azotem wpłynęło na zmniejszenie zawartości potasu, zwiększenie zawartości sodu, wapnia, magnezu w roślinie testowej oraz zwiększenie pobrania wszystkich analizowanych pierwiastków z plonem biomasy. Nawożenie azotem wpłynęło na zmniejszenie stosunków ilościowych K:(Ca+Mg), (K+Na):(Ca+Mg), K:Ca, K:Mg i całkowitej zawartości analizowanych pierwiastków w glebie (średnie z lat).

1. INTRODUCTION

Nitrogen fertilisation used to grow plants for feed determines the quantity and quality of biomass abstracted. Use extreme caution for Fabaceae plant nitrogen fertilisation, since it can lead to imbalance in the content of basic nutrients in the feed [Jamroz *et al*. 2001]. Carried out in the Central-Eastern Poland, multidirectional research on the adaptation of eastern galega has shown that it can be grown under conditions of climate and soil in Eastern Poland [Symanowicz and Kalembasa 2004, Symanowicz *et al*. 2005]. Dry matter yield a eastern galega, Fabaceae with great possibilities of molecular biological nitrogen reduction, on average, 379.7 kg N ha^{-1} [Symanowicz *et al*. 2005]. This feature indicates high profitability and the ability to crop it for fodder purposes. Dry matter yield can be used as feed for livestock and poultry in the form of green fodder, hay, dried, silage and concentrate protein [Jamroz *et al*. 2001, Raig *et al*. 2001]. It is a rich source of macronutrients [Symanowicz and Kalembasa 2010] and good forecrop for succeeding crops [Ignaczak and Szczepanek 2005, Mazur and Mazur 2010, Szpunar-Krok and Bobrecka-Jamro 2005, Trabelsi *et al*. 2009]. Proper absorption of K, Na, Ca and Mg from the feed is related to their content and optimal proportionate manner [Jamroz *et al*. 2001]. Baletentienë and Mikulionienë [2006] showed that eastern galega matter yield distinguished preferred mineral composition compared to other plants, grasses, Fabaceae (e.g. clover).
In the study, the research hypothesis was that the choice of starting dose of 1.66 g N·m^{-2} in the form of ammonium sulphate can achieve high yield and optimum levels of selected macronutrients in the dry matter of eastern galega. Research of multi-fertiliser

(also using ^{15}N to determine the amount of nitrogen reduced by dry matter yield biologically eastern galega) was conducted to determine the contribution of yield and changes in the content of K, Na, Ca and Mg in the biomass of the eastern galega (*Galega orientalis* Lam.) and in the soil under the influence of fertilisation ^{15}N in the form of ammonium sulphate.

2. MATERIALS AND METHODS

Study side and experimental design. The 3-year field experiment was carried out in plantation established in 1997 on an experimental field owned by the University of Natural Sciences and Humanities in Siedlce (52°17'N, 22°28'E). The soil on which eastern galega was cultivated was of loamy sand (LS) type and had neutral reaction (pH in 1 mol KCl·dm^{-3}-7.04). Its abundance in available phosphorus and potassium was considered as very high (Table 1). Because of very high soil fertility and also availability of P and K (Table 1), phosphorus and potassium fertiliser were not applied. These results correspond to the data reported by Ulön and Mattisson [2003].

The experiment was performed in a completely randomised method with four replications of three included treatments. First treatment: 1. control (with no fertilisation); 2. $(^{15}NH_4)_2SO_4$. Second treatment: swaths (I, II, III). Third treatment: years of research (1st - 2005, 2nd - 2006, 3rd-2007). Nitrogen was applied in the form of $(^{15}NH_4)_2SO_4$ at the amount of 1.66 g per 1 m^2 in early spring. The tested plant was *Gale* eastern galega (*Galega orientalis* Lam.) varieties. Experimental microplot area was 3 m^2. The swaths of eastern galega were harvested at budding stage in each year of the study.

Sampling and analyses. During the harvesting of subsequent cuts at budding phase of eastern galega , samples of herbage were collected, dried and ground. Each year soil samples were collected from the subsurface horizon (0–20 cm), air-dried and sieved through a 2-mm mesh, and subsamples were then stored in plastic bottles for further chemical analysis. Plant material was dried out at 105°C, then ground. The samples were mineralised following the wet chemistry method in concentrated HCl and HNO_3 at 3:1 in a multiwave sample preparation System Magnum II, Ertec (Wroclaw, Poland). The total content of K, Na, Ca and Mg in tested plant and soil was determined with the ICP-OES Optima 3200RL, Perkin Elmer (Waltham, USA) [Szczepaniak 2005]. In the soil samples, the following parameters were assessed: pH - by potentiometric method after extraction in 1 mol KCl·dm^3 (soil:solution extraction ratio 1:2.5) using a pH meter HI pH 301 with electrode Hi 1131 Hanna Istruments (Póvoa de Varzim, Portugal); total carbon and total nitrogen-by dry combustion using a autoanalyser series II CHNS/O 2400, Perkin Elmer (Waltham. USA).

Meteorological conditions. Meteorological data from the years of research were obtained from the hydrological and meteorological station in Siedlce. The average monthly temperature in the consecutive vegetation seasons was comparable (15°C to 15.8°C) and significantly higher compared to the multi-annual records. The average precipitation during the vegetation seasons was lower than the multi-annual sum, except for 2 years of research, when it was slightly higher (by 15.5 mm) because of heavy rainfalls in August, which were three-fold higher than the multi-annual sum [Kalembasa and Symanowicz 2010].

To determine the temporal and spatial variability of meteorological elements and the assessment of their effect on the course of plant growth, Sielianinov's hydrometric coefficient (K) was calculated by Bac *et al*. [1993], multiplying the total monthly precipitation by one-tenth of the total mean daily temperatures for this month (Table 2). From the calculated ratio of hydrothermal, the first year of study was characterised by a favourable distribution of temperature, rainfall varied and marked by weak drought (K=0.95). The growing season of the second (K=1.26) and third year of the study (K=1.13) were characterised by the absence of drought.

Statistical analysis. Results from chemical determinations were subjected to statistical analysis using analysis of variance, Statistica 10 PL software (StatSoft Inc. 2014), and significant differences determined by Tukey's test. The criterion for significance was set at P<0.05.

Table 1. Chemical characteristics of experimental soils

Samples	pH_{KCl}	N_{tot} (g·kg^{-1})	C_{tot} (g·kg^{-1})	P* (mg·kg^{-1})	K* (mg·kg^{-1})
1*	7.04	2.0 ± 0.04	29.8 ± 0,03	230 ± 1.25	187 ± 0.08
2	6.68	2.4 ± 0.02	27.2 ± 0.03	210 ± 1.30	183 ± 0.07

1 - Control - with no fertilisation; 2 - after nitrogen fertilisation $(^{15}NH_4)_2SO_4$; P*, K* - available forms; N_{tot}, C_{tot}, P*, K* - the data in the table are means of three replications*

Table 2. Sielianinov's hydrothermic coefficient (K) in individual month of growth (hydrological and meteorological station in Siedlce)

Years of research	Month						
	April	May	June	July	August	September	Mean
1st–2005	0.5	1.66	0.93	1.43	0.86	0.35	0.95
2nd–2006	1.2	0.99	0.46	0.24	4.21	0.48	1.26
3rd–2007	0.8	1.35	1.10	1.26	0.56	1.72	1.13

K<0.5 - high drought; 0.51–0.69 - drought; 0.7–0.99 - weak drought; K>1 - no drought

3. RESULTS AND DISCUSSION

Dry matter yield of goat's rue eastern obtained from plots fertilised with ^{15}N swaths for the next 3 years and in subsequent studies are presented in Table 3. The statistical analysis showed a significant increase in yield under the influence of nitrogen fertilisation at a dose of 16.6 g·m^{-2} in the form of $(^{15}NH_4)_2SO_4$ in early spring (average 29.7%) for the plots without fertilisation. Indeed, the greatest total (three swaths), the yield of dry weight of the test plant was obtained in the first year of the study object fertilised with nitrogen (10.92 t·ha^{-1}). Eastern galega harvested crop in the next swath and years of research significantly reduced. Yield of second and the third swath was 2-fold and 3.8 times lower, respectively, compared to the first swath. A significant effect of nitrogen fertilisation was observed only for the first cut, in the first year of study. This was related to the intensification of the process of biological N_2 reduction at harvest-time consecutive swaths of vegetation. Similar results were recorded in the study Andrzejewska and Ignaczak [2001], Raiga *et al*. [2001], Symanowicz and Kalembasa [2010].

Table 3. Dry matter yield of eastern galega (t·ha^{-1})

Fertilisation	Swaths (average years)			Years of research (yield of three swaths)			Average of years
	I	II	III	2005	2006	2007	
0	3.50	2.08	1.19	7.45	7.52	5.34	6.77
$(^{15}NH_4)_2SO_4$	5.33	2.30	1.15	10.92	8.31	5.09	8.78
Average	4.41	2.19	1.17	9.18	7.91	5.21	7.77
$NIR_{0.05}$ for: fertilisation (F) - 0.45; swaths (S) - 0.48; years of research (Y) - 0.48; F x S - 0.97; F x Y - 0.99; Y x S - 0.99.							

On the basis of statistical calculations demonstrated significant effects of test agents on the content of K, Na, Ca and Mg in the eastern galega dry weight (Table 4). Under the influence of nitrogen fertilisation of eastern galega was reported a reduction in K of 14.4% and an increase in the content of Na of 11.1%, Ca 4% and Mg 11% in relation to the eastern galega without fertilisation. In the dry weight of the test plant II and III was determined significantly lower content of K and Na, and increased Ca and Mg in relation to that determined in the swath. Indeed, the highest content of analysed elements characterised by dry matter yield was collected in the first year of the study. The results concerning the content of Na and Mg confirmed previous studies of Symanowicz and Kalembasa [2010], and the reported differences in the content of K and Ca [Symanowicz and Kalembasa 2010, 2012]. They demonstrated the ion antagonism between elements designated, Hołubowicz-Kliza [2009], but also with the characteristics of the test plant species [Benedycki *et al*. 2001, Jamroz 2001 Falkowski, *et al*. 2000, Sądej 1999, Wysokiński and Kalembasa 2011]. Also, Kozlowski *et al*. [2012] dry matter yield in terms of analysing the use of marked feed similar amounts of K, Ca and Mg in the second year of the study.

Table 4. Content K, Na, Ca i Mg (g·kg^{-1}) in the dry matter of eastern galega

Fertilisation	Swaths (average of years)			Year of research (average of three swaths)			Average of the years
	I	II	III	2005	2006	2007	
K							
0	13.18	6.83	9.09	13.49	6.30	9.31	9.70
$(^{15}NH_4)_2SO_4$	10.38	6.20	8.33	9.14	7.38	8.30	8.30
Average	11.78	6.52	8.71	11.32	6.84	8.85	9.00
Na							
0	0.58	0.58	0.47	0.79	0.45	0.38	0.54
$(^{15}NH_4)_2SO_4$	0.58	0.65	0.58	1.08	0.42	0.31	0.60
Average	0.58	0.61	0.52	0.94	0.43	0.34	0.57
Ca							
0	10.19	25.95	22.34	24.65	18.52	15.30	19.49
$(^{15}NH_4)_2SO_4$	11.53	25.12	24.15	22.55	19.67	18.58	20.27
Average	10.86	25.53	23.25	23.60	19.09	16.94	19.88
Mg							
0	1.92	3.42	2.56	2.91	2.42	2.58	2.64
$(^{15}NH_4)_2SO_4$	2.11	3.79	2.90	3.06	2.83	2.91	2.93
Average	2.01	3.61	2.73	2.99	2.62	2.75	2.78

$NIR_{0.05}$ for:	K	Na	Ca	Mg
Fertilisation (F)	0.33	0.06	0.73	0.09
Swaths (S)	0.49	0.09	1.08	0.13
Years (Y)	0.49	0.09	1.08	0.13
F x S	0.57	n. s.	1.26	n. s.
F x Y	0.69	0.13	1.52	n. s.
Y x S	0.84	0.16	1.86	0.22

Download elements analysed with the yield of eastern galega are shown in Table 5. Nitrogen fertilisation $(^{15}NH_4)_2SO_4$ increased the download of K, Na, Ca and Mg with the yield of the test plant. This increase was the result higher yields of eastern galega obtained under the influence of nitrogen fertilisation. Amount of K, Na and Mg successive swaths with the yield decreasing, and the combined underwent increased uptake of Ca for the second swath in relation to the first swath. The largest aggregate download elements analysed with the yield of eastern galega was in the first year of the experiment. In subsequent years, studies have shown reduced downloading of K, Na, Ca and Mg. This same relationship has been demonstrated based on the experience of meadow with respect to Ca and Mg [Sapek and Sapek 2011]. Considering download, individual elements can be downloaded from their average yield of the test plants presented in the following order: Ca>K>Mg>Na. Also, research conducted by Wilczewski [2007] have shown that plants - pea, serradella cultivated, yellow lupine grown in stubble intercrop accumulated in above-ground biomass and harvest leftovers have similar amounts of K (66.2 - 85.4 kg·ha^{-1}) and much smaller Ca and Mg.

Table 5. Uptake of K, Na, Ca and Mg (in kg·ha^{-1}) with yield in the dry matter of eastern galega

Fertilisation	Swaths (average of years)			Years of research (uptake in three swaths)			Average of the years
	I	II	III	2005	2006	2007	
K							
0	46.13	14.21	10.28	100.50	47.38	49.71	65.86
$(^{15}NH_4)_2SO_4$	55.32	14.26	9.48	99.81	61.33	42.25	67.80
Average	50.72	14.23	9.88	100.15	54.35	45.98	66.83
Na							
0	2.03	1.21	0.56	5.88	3.38	2.03	3.76
$(^{15}NH_4)_2SO_4$	3.09	1.49	0.67	11.79	3.49	1.58	5.62
Average	2.56	1.35	0.61	8.83	3.43	1.80	4.69
Ca							
0	35.66	53.98	26.58	183.64	139.27	81.70	134.87
$(^{15}NH_4)_2SO_4$	61.45	57.78	27.77	246.25	163.46	94.57	168.09
Average	48.55	55.88	27.17	214.94	151.36	88.13	151.48
Mg							
0	6.72	7.11	3.05	21.68	18.20	13.78	17.89
$(^{15}NH_4)_2SO_4$	11.25	8.72	3.33	33.41	23.52	14.81	23.91
Average	8.98	7.91	3.19	27.54	20.86	14.29	20.90

Table 6. Weight ratios of the K, Na, Ca and Mg in dry matter of eastern galega

Fertilisation	Swaths (average of years)			Years of research (average of the swaths)			Average of years
	I	II	III	2005	2006	2007	
K : (Ca + Mg)							
0	1.09	0.23	0.36	0.49	0.30	0.52	0.44
$(^{15}NH_4)_2SO_4$	0.76	0.21	0.30	0.36	0.32	0.39	0.36
Average	0.92	0.22	0.33	0.42	0.31	0.45	0.40
(K + Na) : (Ca + Mg)							
0	1.14	0.25	0.38	0.52	0.32	0.54	0.56
$(^{15}NH_4)_2SO_4$	0.80	0.24	0.32	0.40	0.35	0.40	0.38
Average	0.97	0.24	0.35	0.46	0.33	0.47	0.47
K : Ca							
0	1.29	0.26	0.41	0.55	0.34	0.61	0.50
$(^{15}NH_4)_2SO_4$	0.90	0.25	0.34	0.40	0.37	0.45	0.41
Average	1.09	0.25	0.37	0.47	0.35	0.53	0.45
K : Mg							
0	6.86	2.00	3.55	4.63	2.60	3.61	3.67
$(^{15}NH_4)_2SO_4$	4.92	1.63	2.87	2.99	2.61	2.85	2.83
Average	5.89	1.81	3.21	3.81	2.60	3.23	3.25

The quantitative ratios of the analysed elements are shown in Table 6. The small content of K and Na, and high Ca and Mg formed on an incorrect level, the average ratio of K: (Ca + Mg), (M + Na) :(Ca + Mg) and K: Ca and K Mg in terms of nutrition. The proper relationship between the components specified only marked for the first swath. The results were confirmed in optimal ratios presented in the study Falkowski *et al*. [2000], which are for K (Ca + Mg) below 2.2 and the K:Mg - 6:1.

On the basis of statistical calculations were demonstrated a reduction in the total K, Na, Ca and Mg level in soil humus under the influence of nitrogen (Table 7).

Table 7. The total content of K, Na, Ca and Mg (g·kg^{-1}) in soil

Fertilisation	Years of research			Average of years
	2005	2006	2007	
K				
0	0.69	0.70	0.76	0.72
$(^{15}NH_4)_2SO_4$	0.64	0.63	0.78	0.68
Average	0.66	0.66	0.77	0.70
Na				
0	0.20	0.15	0.15	0.17
$(^{15}NH_4)_2SO_4$	0.16	0.12	0.14	0.14
Average	0.18	0.13	0.15	0.15
Ca				
0	6.05	4.80	5.78	5.54
$(^{15}NH_4)_2SO_4$	6.26	4.17	5.30	5.25
Average	6.16	4.48	5.54	5.39
Mg				
0	0.68	0.66	0.84	0.73
$(^{15}NH_4)_2SO_4$	0.73	0.55	0.83	0.71
Average	0.70	0.60	0.84	0.72
$NIR_{0.05}$ for:	K	Na	Ca	Mg
Fertilisation (F)	n. s.	0.01	n. s.	n. s.
Years of research (Y)	0.06	0.02	0.71	0.07
Y x F	n. s.	n. s.	n. s.	0.10
F x Y	n. s.	n. s.	n. s.	0.08

The marked contents of K, Na, Ca and Mg in the soil, in the period of studies (g·kg^{-1}) were as follows: Ca (4.48–6.16)>Mg (0.60–0.84)>K (0.66–0,77)>Na (0.13–0.18). Considering the years of research, it is clear that the total content of the analysed elements forms decreased significantly after the completion of the second year of the study (except K), and after the third year of the experiment, the contents of K and Mg increased compared to the first year of the study. Similar results were obtained in studies Hajduk *et al*. [2009], which found no reduction in the content of Mg and K in light soils as a result of Fabaceae crops. The work content of K, Na and Mg in the soil tests confirms the research of Pakuła and Kalembasa [2012] on Luvisols rainfall-glial and deluvial Siedlce Plateau.

4. CONCLUSIONS

1. Nitrogen fertilisation (1.66 g N·m^{-2}) significantly increased the dry matter yield summary of eastern galega, the yield of I swath and the yield obtained in the first year of studies.
2. Fertilisation with ammonium sulphate resulted in a reduction in K and increase in the content of Na, Ca and Mg in the dry weight of the test plant.
3. Collection of the analysed elements with the yield of eastern galega increased under the influence of nitrogen fertilisation.
4. Nitrogen fertilisation resulted in a reduction in the quantitative ratios of K:(Ca + Mg), (K + Na):(Ca + Mg), K:Ca, K:Mg.
5. The content of total forms of K, Na, Ca and Mg in the soil fertilised with nitrogen was lower for plants without fertilisation.

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