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THE EFFECT OF POTASSIUM FERTILIZATION ON LITHIUM AND ALUMINIUM CONTENT IN EASTERN GALEGA (*Galega orientalis* Lam.) AND IN THE SOIL

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ABSTRACT

Background. The aim of the presented research was to trace changes in lithium and aluminium content in eastern galega subjected to varied levels of potassium fertilization and then to compare the obtained results with permitted animal nutrition standards and to calculate bioaccumulation factors.
Material and methods. The three-year field experiment was conducted on experimental plots belonging to the University of Natural Sciences and Humanities in Siedlce. The research included three factors: I – potassium fertilisation (four levels): K0, K1, K2, K3; II – the years of conducting research (three years); III – eastern galega harvest cut dates (three dates each year). Phosphate fertilizers were applied at a rate of P – 23 $kg \cdot ha^{-1}$, and potassium K0 – 0; K1 – 124; K2 – 166; K3 – 207.5 $kg \cdot ha^{-1}$. Nitrogen fertilization was not applied because the research was carried out on a perennial plantation.
Results. Diversified potassium fertilization significantly affected changes in the lithium and aluminium content in galega plants and in the soil. Fertilization at a rate of 166 kg of potassium per hectare increased the content of lithium and aluminium in the test plants. A decrease in the content of the analyzed elements in the eastern galega dry weight was found in the successive years of the research and in the harvesting dates. Significantly, the highest total lithium content was found in soil fertilized with potassium at a rate of 124 $kg \cdot ha^{-1}$, while for aluminium content it was after the application of 207.5 $kg \cdot ha^{-1}$ of potassium. The bioaccumulation factors of lithium and aluminium in the eastern galega biomass were at medium and low levels, respectively.
Conclusion. The determined contents of lithium and aluminium in eastern galega dry weight remained below the permitted values for these elements in feed.

Key words: bioaccumulation, eastern galega, PK fertilisation, trace elements

INTRODUCTION

Lithium and aluminium belong to the group of trace elements whose level in fodder plants can be a measure of their nutritional value. In plants intended for feed, monitoring the level of these elements is necessary because in excess they adversely affect the growth and development of plants as well as affecting animal health. Sources of excess trace elements in fodder and field crops can be soil, water, air, emitted dust settling on the above-ground parts of plants, mother rock as well as mineral fertilizers, natural fertilizers and organic fertilizers (Gorlach, 1991; Kabata-Pendias, 2011). During intense fertilization with potassium in the cultivation of perennial bean plants with a deep root system ionic antagonism may occur in relation to lithium and aluminium ions (Kabata-Pendias, 2011). The

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presence of lithium in easily soluble forms and mobile aluminium in the deeper layers of soil is dangerous for plants. These elements inhibit plant development by causing disturbances in nutrient uptake and transport, as well as causing poor rooting (Gorlach and Gambuś, 2000). The content of lithium and aluminium in soils and plants shows great variation depending on the type of soil (Sobczyński *et al*., 2004; Symanowicz and Kalembasa, 2010) and plant species (Kalembasa and Malinowska, 2009; Kalembasa and Wiśniewska, 2009a; Kalembasa *et al*., 2015; Symanowicz and Kalembasa, 2009). Potassium fertilization may limit the content and uptake of lithium by plants (Bernard, 2015; Jurkowska *et al*., 1996; Malinowska and Kalembasa, 2011). It can also weaken lithium transport from the roots to the above-ground parts of plants (Jurkowska *et al*., 1995).

The research hypothesis adopted in this study was that the applied doses of potassium fertilizers would not increase the lithium and aluminium content in eastern galega (*Galega orientalis* Lam.) and in the soil.

The aim of the presented research was to trace changes in lithium and aluminium content in eastern galega subjected to varied levels of potassium fertilization, calculate bioaccumulation factors and demonstrate the relationship between the studied traits.

MATERIAL AND METHODS

The three-year field experiment was conducted on experimental plots belonging to the University of Natural Sciences and Humanities in Siedlce (52^o 17'N; 22^{o}28'E). The soil on which the galega was grown was formed of loamy sand (LS), it was characterized by a neutral reaction (pH in KCl mol·dm^{-3} – 7.04) and contained the following amounts of general forms of macronutrients in g·kg^{-1}: N – 2.18; P – 1.03; K – 0.83; Mg – 0.81 and trace elements in mg·kg^{-1}: Li – 2.38; Al – 2536. Soil richness in assimilable phosphorus and potassium determined by the Enger-Riehm method was ascertained as medium, and richness in assimilable magnesium determined by the Schachtschabel method as low. The research included three factors: I – potassium fertilisation (K0, K1, K2, K3); II – the years of research (three years); III – galega harvest dates (three dates). Phosphate fertilizers in the form of triple superphosphate were applied in autumn at a rate of P – 23 kg·ha^{-1}, and potassium (K1 – 124; K2 – 166; K3 – 207.5 kg·ha^{-1}) in the form of potassium salt 60% was applied at two rates (in early spring – up to 124 kg·ha^{-1} and any remainder after the first harvest date). Nitrogen fertilization was not applied because the research was carried out on a perennial plantation. In each year of the research, test plants were collected at the budding stage. Samples of whole galega plants were collected during harvest and they were then dried and ground. The total lithium and aluminium content in the test plants and in the soil was determined after dry digestion using the ICP-AES method on an inductively-coupled plasma emission spectrometer (Szczepaniak, 2009). The total nitrogen content was determined on a Perkin Elmer autoanalyser CHN/O Series II 2400 with a thermal conductivity detector (TCD) and acetanilide was the reference material. Bioaccumulation factors of lithium and aluminium were calculated according to Ociepa *et al*. (2014):

$$BF_{\text{Li (Al)}} = [C_{\text{p (Li, Al)}}] : [C_{\text{s (Li, Al)}}]$$

$BF_{\text{Li (Al)}}$ – bioaccumulation factor lithium (aluminium),
$C_{\text{p (Li, Al)}}$ – content of Li or Al in the plant,
$C_{\text{s (Li, Al)}}$ – content of Li or Al in the soil.

The results were statistically analysed using three-factor ANOVA analysis of variance. Significant differences were determined using Tukey's test at a significance level of $P < 0.05$. For significant differences, simple regression equations and correlation coefficients between selected traits were determined using the Statistica PL 12 software (Statsoft, 2019).

RESULTS

The mean content of lithium in the eastern galega amounted to 15.16 mg·kg^{-1} DM and was significantly different depending on the factors studied and their interaction (Table 1). Considering the effect of potassium fertilization on changes in lithium content in eastern galega biomass, it should be stated that fertilization at a rate of 166 kg of potassium per hectare significantly increased lithium levels (by 28.5%) in relation to the results obtained for the control treatment. The determined lithium content in test plants significantly decreased during the successive years of the study. Significantly, the largest mean amounts of lithium were determined in the first harvest cut of eastern galega. The mean lithium content in the 2nd and 3rd cut of the harvested plants were at a similar level. The significantly highest lithium content (20.09 $mg \cdot kg^{-1}$ DM) was found in eastern galega fertilized with potassium at a rate of 166 $kg \cdot ha^{-1}$ in the second year of the study.

The mean content of aluminium in eastern galega plants was 89.48 $mg \cdot kg^{-1}$ DM (Table 2). Changes in the level of aluminium in the test plants were analogous to the differences in lithium content. Significantly, the highest mean aluminium content was determined in the biomass of plants fertilized with potassium at a rate of 166 $kg \cdot ha^{-1}$, collected from the 1st cut in the first year of the research. The level of applied potassium fertilization, the research year, the harvest dates and interaction of the studied factors significantly differentiated the lithium content in the soil (Table 3). After analysing the effects of the potassium rates applied in the presented study it should be stated that the highest level of lithium was found in the soil fertilized with potassium at a rate of 124 $kg \cdot ha^{-1}$. When considering the years of the research the lithium content can be presented in the following series: 1st year> 2nd year> 3rd year. Statistical calculations showed that the highest lithium content was found in the soil after harvesting the second cut of the 3 years of the study of eastern galega (*Galega orientalis* Lam.). The significantly highest lithium content (4.41 $mg \cdot kg^{-1}$) was found in the soil taken from the ground fertilized with potassium at a rate of 124 $kg \cdot ha^{-1}$ in the first year of the study.

Analysis of variance showed that the level of applied potassium fertilization, the research year, the dates of harvest cuts as well as interactions between the studied factors had a significant effect on the aluminium content in the soil (Table 4). The soil fertilized with potassium at a rate of 207.5 $kg \cdot ha^{-1}$ was characterized by the highest content of this element. Over the 3 years of the research the determined mean aluminium content in the soil decreased significantly. The same relationship was noted for the harvesting dates of successive cuts of eastern galega. The aluminium content in the soil was significantly correlated with the lithium content in the soil ($r = 0.72$; $Al_s = 1576 + 525Li_s$; Fig 1d).

Table 1. Lithium content in eastern galega (*Galega orientalis* Lam.), $mg \cdot kg^{-1}$ DM

Dose of potassium	Research years (means of the 3 harvest dates)			Harvest dates (means of the 3 years)			Mean
	1	2	3	I	II	III	
K0	17.23^{ad}	15.35^{ac}	7.61^{ab}	15.84^{ac}	11.96^{ab}	12.39^{ab}	13.98^{A}
K1	19.90^{de}	16.78^{bc}	7.52^{ab}	15.38^{ac}	12.31^{ab}	16.50^{bd}	14.73^{A}
K2	19.08^{cd}	20.09^{de}	14.72^{bc}	17.28^{cd}	18.36^{ce}	18.24^{ce}	17.96^{B}
K3	17.94^{be}	17.64^{ce}	8.02^{ad}	15.94^{bd}	15.35^{bd}	12.31^{ac}	14.53^{A}
Mean	18.54^{C}	17.46^{B}	9.47^{A}	16.11^{B}	14.50^{A}	14.86^{A}	15.30

Explanations: values in the line and column for interaction factors indicated with different small letters differ significantly ($P < 0.05$); different capital letters in the line and column for factors indicated significant differences
K0 – 0; K1 – 124; K2 – 166; K3 – 207.5 $kg \cdot ha^{-1}$

Table 2. Aluminium content in eastern galega (*Galega orientalis* Lam.), mg·kg^{-1} DM

Dose of potassium	Research years (means of the 3 harvest dates)			Harvest dates (means of the 3 years)			Mean
	1	2	3	I	II	III	
K0	129.14^{cf}	65.66^{ad}	76.67^{be}	110.95^{be}	60.56^{bc}	99.96^{bd}	90.49^{B}
K1	98.89^{ae}	76.06^{bd}	66.47^{ac}	102.82^{ae}	51.78^{ab}	86.83^{ac}	80.47^{A}
K2	106.25^{bf}	95.20^{ce}	85.96^{cd}	112.30^{bf}	84.00^{de}	91.11^{ae}	95.80^{C}
K3	94.45^{ae}	92.90^{ce}	86.16^{cd}	114.35^{cf}	68.56^{cd}	90.59^{ae}	91.17^{B}
Mean	107.18^{C}	82.45^{B}	78.81^{A}	110.10^{C}	66.22^{A}	92.12^{B}	89.48

Explanations: values in the line and column for interaction factors indicated with different small letters differ significantly ($P < 0.05$); different capital letters in the line and column for factors indicated significant differences
K0 – 0; K1 – 124; K2 – 166; K3 – 207.5 kg·ha^{-1}

Table 3. Lithium content in soil, mg·kg^{-1}

Dose of potassium	Research years (means of the 3 harvest dates)			Harvest dates (means of the 3 years)			Mean
	1	2	3	I	II	III	
K0	3.39^{ad}	3.38^{bd}	1.25^{ac}	2.44^{ab}	2.93^{ad}	2.66^{ac}	2.67^{A}
K1	4.41^{cf}	3.79^{ce}	1.43^{bd}	3.20^{bc}	3.32^{bc}	3.11^{bc}	3.21^{D}
K2	4.01^{bf}	3.08^{ae}	1.62^{cd}	3.34^{cf}	2.86^{ae}	2.54^{ad}	2.91^{B}
K3	4.10^{bf}	3.36^{be}	1.70^{cd}	3.06^{bd}	3.40^{be}	2.71^{ac}	3.05^{C}
Mean	3.99^{C}	3.40^{B}	1.50^{A}	3.01^{B}	3.13^{C}	2.75^{A}	2.96

Explanations: values in the line and column for interaction factors indicated with different small letters differ significantly ($P < 0.05$); different capital letters in the line and column for factors indicated significant differences
K0 – 0; K1 – 124; K2 – 166; K3 – 207.5 kg·ha^{-1}

Table 4. Aluminium content in soil, mg·kg^{-1}

Dose of potassium	Research years (means of the 3 harvest dates)			Harvest dates (means of the 3 years)			Mean
	1	2	3	I	II	III	
K0	3120^{ad}	3036^{ac}	2654^{ab}	3138^{ae}	2720^{ac}	2952^{bd}	2937^{A}
K1	3546^{dg}	3181^{bf}	2735^{be}	3245^{cf}	3163^{ce}	3055^{cd}	3154^{C}
K2	3170^{be}	3281^{cf}	2828^{cd}	3236^{be}	3120^{bd}	2924^{ac}	3093^{B}
K3	3390^{cg}	3299^{ce}	3323^{df}	3432^{dg}	3380^{df}	3201de	3338^{D}
Mean	3307^{C}	3199^{B}	2885^{A}	3263^{C}	3096^{B}	3033^{A}	3130

Explanations: values in the line and column for interaction factors indicated with different small letters differ significantly ($P < 0.05$); different capital letters in the line and column for factors indicated significant differences
K0 – 0; K1 – 124; K2 – 166; K3 – 207.5 kg·ha^{-1}

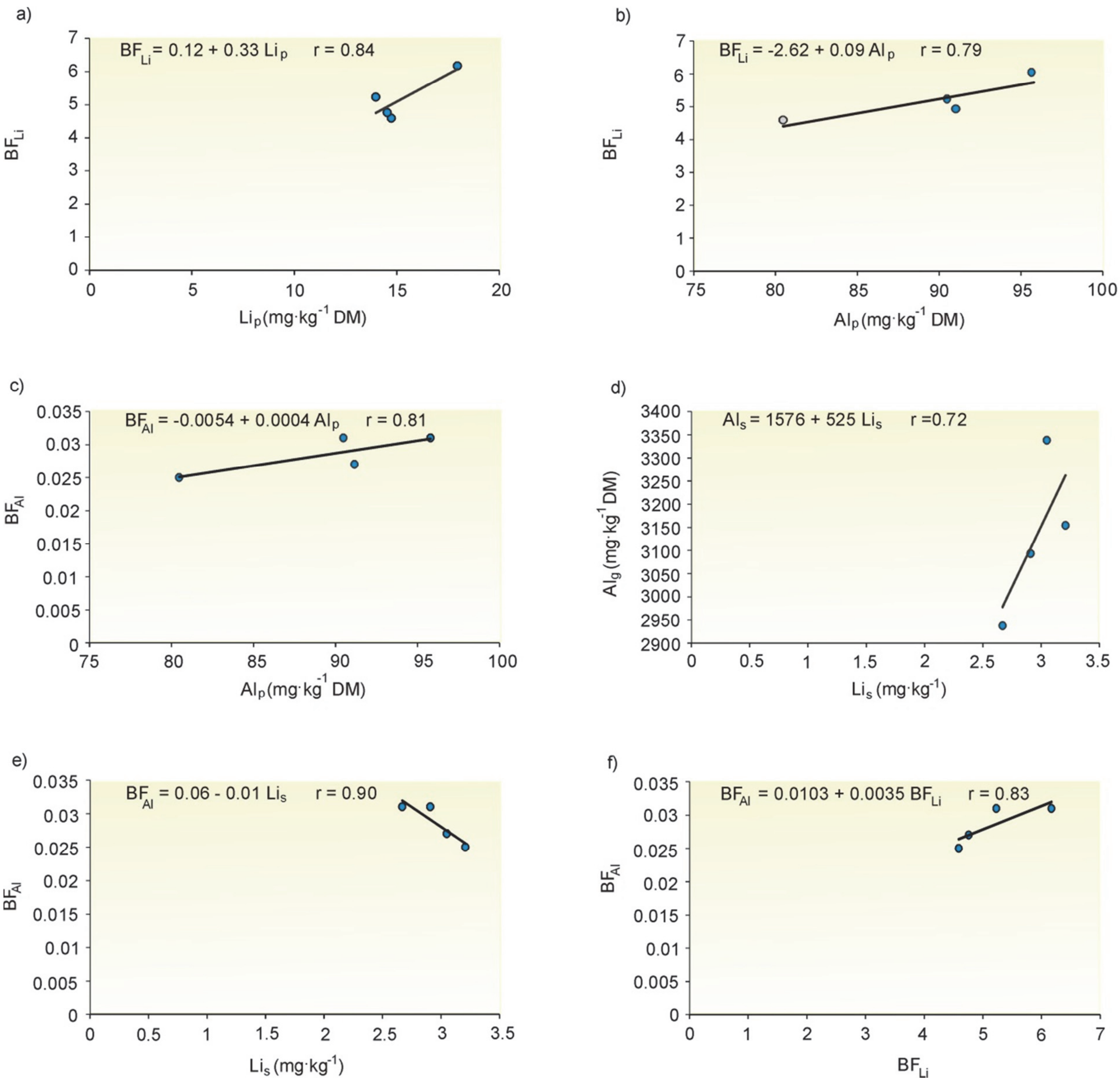

Fig. 1. The relations between lithium content in plant (Li_p) and bioaccumulation factor of lithium (BF_{Li}), aluminium content in plant (Al_p) and bioaccumulation factor of lithium (BF_{Li}) and bioaccumulation factor of aluminium (BF_{Al}), lithium content in soil (Li_s) and aluminium content in soil (Al_s) and bioaccumulation factor of aluminium (BF_{Al}), bioaccumulation factor of lithium (BF_{Li}) and bioaccumulation factor of aluminium (BF_{Al})

The mean value of the lithium bioaccumulation factor calculated for eastern galega was 5.19 (Table 5). The highest value of the lithium bioaccumulation factor was calculated for test plants collected from treatments fertilized with potassium at a rate of 166 kg·ha^{-1} in the third year of the experiment. In the successive years of research and for successive cuts within years (harvest dates), the value of the lithium bioaccumulation factor increased. The obtained values of the lithium bioaccumulation factors were significantly correlated with the content of lithium and aluminium in plants (r = 0.84; r = 0.79). This relationship is presented by simple regression equations: $BF_{Li} = 0.12 + 0.33_{Lip}$ and $BF_{Li} = -2.62 + 0.09_{Alp}$ (Fig 1a and 1b).

The calculated aluminium bioaccumulation factors for eastern galega plants were small (Table 6). They ranged from 0.016 to 0.041. They generally decreased with increasing potassium rates. The calculated bioaccumulation factors in successive years of the research decreased. Also, the mean values of these factors were lower for plants harvested in the successive yearly cuts of eastern galega. The bioaccumulation factors of aluminium were significantly correlated with the content of aluminium in the plants and lithium in the soil and with the lithium bioaccumulation factors (r = 0.81; r = -0.90; 0.83). These relationships are confirmed by the linear regression equations: $BF_{Al} = -0.0054 + 0.0004_{Alp}$; $BF_{Al} = 0.06 - 0.01_{Lis}$; $BF_{Al} = 0.0103 + 0.0035BF_{Li}$ (Fig 1c, e, f).

Table 5. Bioaccumulation factors of lithium

Dose of potassium	Research years (means of the 3 harvest dates)			Harvest dates (means of the 3 years)			Mean
	1	2	3	I	II	III	
K0	5.08	4.54	6.09	6.49	4.08	4.66	5.23
K1	4.51	4.43	5.26	4.81	3.71	5.30	4.59
K2	4.76	6.52	9.09	5.17	6.42	7.18	6.17
K3	4.37	5.25	4.72	5.21	4.51	4.54	4.76
Mean	4.65	5.13	6.31	5.35	4.63	5.40	5.19

K0 – 0; K1 – 124; K2 – 166; K3 – 207.5 $kg \cdot ha^{-1}$

Table 6. Bioaccumulation factors of aluminium

Dose of potassium	Research years (means of the 3 harvest dates)			Harvest dates (means of the 3 years)			Mean
	1	2	3	I	II	III	
K0	0.041	0.022	0.029	0.035	0.022	0.034	0.031
K1	0.028	0.024	0.024	0.032	0.016	0.028	0.025
K2	0.033	0.029	0.030	0.035	0.027	0.031	0.031
K3	0.028	0.028	0.026	0.033	0.020	0.028	0.027
Mean	0.032	0.026	0.027	0.034	0.021	0.030	0.029

K0 – 0; K1 – 124; K2 – 166; K3 – 207.5 $kg \cdot ha^{-1}$

DISCUSSION

The diversified potassium fertilization used in the cultivation of eastern galega (*Galega orientalis* Lam.) significantly affected changes in the lithium and aluminium content in the test plants and in the soil. It also affected changes in the lithium and aluminium bioaccumulation factors.

The lithium contents in plants determined in the present research were within the range of acceptable values at the optimal level (Anke, 1987; Gorlach, 1991; Kabata-Pendias, 2011). The lithium contents in the eastern galega were within the range determining the optimal lithium content in fodder plants for animal feed. Acceptable lithium contents are 5–50 mg·kg^{-1} DM (Gorlach, 1991). It should be noted that even with the increased potassium rates no clear antagonism between potassium and lithium was identified. In the studies of Gorlach and Gambuś (2000); Malinowska and Kalembasa (2011); Symanowicz and Kalembasa (2010) the average content of lithium in the test plants at the level of 15.13 mg·kg^{-1} DM was the effect of low lithium content in the soil

Lithium content values similar to those from the present research were found in ryegrass plants of the second and third cut in the first year of a pot study (Malinowska and Kalembasa, 2011) in which sewage sludge was used. In the study by these authors, higher amounts of lithium were determined in maize and sunflower in the second and third years of their research. The results obtained in the present research on lithium are in line with the study by Godlewska (2018), in which the test plants were maize and cocksfoot. The diversity of lithium content in plants is indicated by the study by Kalembasa *et al*. (2015), in which Titanite and NPK mineral fertilization were used. In their experiment the determined lithium content in celery was in the range of 19.85–47.52 mg·kg^{-1} DM. Similar relationships are indicated in the study by Symanowicz and Kalembasa (2010), in which, apart from mineral fertilization, waste brown coal, sewage sludge and mixtures of these wastes were used. It should be assumed that the content of lithium in plants is determined by the soil (Kośla, 2009; Kalembasa and Jaremko, 2006), by mineral fertilizers (Kabata-Pendias, 2011; Shahzad *et al*., 2016) as well as by mineral and organic waste materials introduced into the soil (Kabata-Pendias and Mukherjee, 2007; Kalembasa and Wiśniewska, 2009b). It should be noted that the use of the optimal rates of mineral fertilizers, natural fertilizers and organic fertilizers as well as organic and mineral waste materials has a positive effect on maintaining the optimal lithium contents in test plants (Kalembasa and Malinowska, 2009; Kalembasa and Wiśniewska, 2009a). According to Kloke *et al*., (1984), the values of lithium bioaccumulation factors calculated in the present research were at an average level. Significantly larger (2.5 times) values of lithium bioaccumulation factors for maize were presented in the study by Antonkiewicz *et al*. (2017). However, in the study by those authors, carried out in the conditions of hydroponic cultures, the applied addition of lithium was in the concentration range 0.0 –256 mg Li·dm^{-3} of medium.

The aluminium content in feed plants has recently been of interest because excessive concentrations of this element may pose a threat to animal health. The results of own research did not confirm the results of the study by Kabata-Pendias (2011), in which ionic antagonism was found between K^{+} and Al^{3+} as well as excessive aluminum content in plants. The use of potassium in increased rates had an unequivocal effect on the aluminium content in eastern galega plants. It should be added that the experiment was carried out on neutral soil. According to Sobczyński *et al*. (2004) the majority of aluminium in the soil is bound in minerals and is not available to plants.

According to (Eriksson 2001), lithium content in the top layer of soil is strongly correlated with a clay fraction having a diameter below 0.02 mm. While according to Schrauzer (2002) the lithium content in different soils can range from 0.002-63 mg Li·kg^{-1}. Ammari *et al*., (2011) report that the content of water-soluble lithium in the level of Ap (0–20 cm) was 0.95–1.04 mg Li·dm^{-3}. Haddadin *et al*. (2002) state that after extraction with 0.1 mol·dm^{-3} ammonium acetate the lithium content in soil ranged from 13.1 to 25.4 mg Li·kg^{-1}. A long-term study carried out by Mazur and Sądej (2007) showed that the content of mobile aluminium in lessive and brown soils was at a level of 0.5–1.0% of the total aluminium content in the soil. There is evidence that the potential content of aluminium in the soil may be affected by the content of this element in organic waste materials introduced into the soil (Kalembasa and Symanowicz, 2009; Kalembasa and Wiśniewska, 2009a; Symanowicz and Kalembasa, 2010). The high content of total forms of aluminium in the soil in the present research was not reflected in the values of the bioaccumulation factors of this element. The low calculated values of the aluminium bioaccumulation factors indicate that good quality feed was obtained under all of the studied combinations.

CONCLUSIONS

The applied potassium fertilization rates significantly differentiated the content of lithium and aluminium in eastern galega. The highest content of these elements were found in test plants collected from fertilizing treatment K2 (166 kg·ha^{-1} K). The significantly highest total lithium content was found in the soil fertilized with potassium at a rate of 124 kg·ha^{-1}, while for aluminium content it was after the application of 207.5 kg·ha^{-1} potassium. The bioaccumulation factors of lithium in eastern galega biomass were of medium level and of aluminium they were low. The determined contents of aluminium and lithium in eastern galega stayed within the acceptable range of content of these elements in animal feed.

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WPŁYW NAWOŻENIA POTASEM NA ZAWARTOŚĆ LITU I GLINU W RUTWICY WSCHODNIEJ (*Galega orientalis* Lam.) I W GLEBIE

Streszczenie

Celem przedstawionych badań było prześledzenie zmian w zawartości litu i glinu w rutwicy wschodniej pod wpływem zróżnicowanego nawożenia potasem, a następnie porównanie uzyskanych wyników z aktualnymi normami żywienia zwierząt oraz obliczenie współczynników bioakumulacji. Trzyletnie doświadczenie polowe przeprowadzono na poletkach doświadczalnych należących do Uniwersytetu Przyrodniczo-Humanistycznego w Siedlcach. W badaniach uwzględniono trzy czynniki: I – nawożenie (cztery poziomy : K0, K1, K2, K3); II – lata prowadzenia badań (trzy lata) ; III – terminy zbioru rutwicy wschodniej (trzy terminy). Nawozy fosforowe stosowano w dawce 23 $kg \cdot ha^{-1}$ P, a potasowe: K1 – 124; K2 – 166; K3 – 207.5 $kg \cdot ha^{-1}$. Nie stosowano nawożenia azotem, ponieważ badania prowadzono na plantacji wieloletniej. Zróżnicowane nawożenie potasem istotnie wpłynęło na zmiany zawartości litu i glinu w rutwicy wschodniej oraz w glebie. Nawożenie w dawce 166 kg potasu na hektar wpłynęło na zwiększenie zawartości litu i glinu w roślinach testowych. Kolejne lata badań i terminy zbioru wpłynęły na zmniejszenie zawartości analizowanych pierwiastków w suchej masie rutwicy wschodniej. Istotnie największą ogólną zawartością litu charakteryzowała się gleba nawożona potasem w dawce 124 $kg \cdot ha^{-1}$, natomiast glinu po zastosowaniu 207.5 $kg \cdot ha^{-1}$ potasu. Współczynniki bioakumulacji litu i glinu w biomasie rutwicy wschodniej kształtowały się na średnim i niskim poziomie. Oznaczone zawartości litu i glinu w suchej masie rutwicy wschodniej mieściły się poniżej zakresu liczb granicznych określających dopuszczalne ilości tych pierwiastków w paszy.

Słowa kluczowe: bioakumulacja, nawożenie PK, pierwiastki śladowe, rutwica wschodnia