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Effect of phosphorus and potassium fertilisation on the contents and chromium and nickel uptake by goat's rue (*Galega orientalis* Lam.)

Wpływ nawożenia fosforem i potasem na zawartość i pobranie chromu i niklu przez rutwicę wschodnią (*Galega orientalis* Lam.)

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Abstract

The paper presents the changes in chromium and nickel content in goat's rue biomass cultivated in the years 2005–2007. Field test was carried out on the experimental field belonging to the University of Natural Sciences and Humanities in Siedlce. The tests included six objects with constant phosphorus fertilisation and differentiated potassium fertilisation. During each year of the tests, three cuts of the test plant in budding stage were harvested. Total Cr and Ni content in the plant and soil was determined using inductively coupled plasma-atomic emission spectrometer. The uptake of the elements being analysed with the crop of dry mass of the test plant was calculated.

Phosphorus and potassium fertilisation had significant influence on the increase in chromium and nickel content in goat's rue biomass. The highest content of chromium was determined on P_{50} object and of nickel on $P_{50}K_{150}$ object. The lowest content of Cr and N was determined in the test plant cultivated on control objects. The highest content of chromium and nickel was found in soil taken from the control object. The highest uptake with crop was observed for goat's rue fertilised with P_{50} dose and of nickel with $P_{50}K_{150}$ dose.

Streszczenie

W pracy przedstawiono zmiany w zawartość chromu i niklu w biomasie rutwicy wschodniej uprawianej w latach 2005 – 2007. Doświadczenie polowe prowadzono na polu doświadczalnym, należącym do Uniwersytetu Przyrodniczo-Humanistycznego w Siedlcach. W badaniach uwzględniono sześć obiektów ze stałym nawożeniem fosforowym i zróżnicowanym nawożeniem potasowym. W każdym roku prowadzenia badań zbierano trzy pokosy rośliny testowej w fazie pąkowania. Całkowitą zawartość Cr i Ni w roślinie i w glebie oznaczono na spektrofotometrze emisyjnym z plazmą wzbudzaną indukcyjnie (ICP-AES). Obliczono pobranie analizowanych pierwiastków z plonem suchej masy rośliny testowej.

Nawożenie fosforowo – potasowe istotnie wpłynęło na zwiększenie zawartości chromu i niklu w biomasie rutwicy wschodniej. Najwięcej chromu oznaczono na obiekcie P_{50}, a niklu na obiekcie $P_{50}K_{150}$. Najmniejszą zawartość Cr i Ni oznaczono w roślinie testowej uprawianej na obiektach kontrolnych. W glebie pobranej z obiektu kontrolnego oznaczono najwięcej chromu i niklu. Największe ilości chromu z plonem pobrała rutwica wschodnia nawożona dawką P_{50}, a niklu dawką $P_{50}K_{150}$.

1. INTRODUCTION

In animal feeding, chromium and nickel are classified as microelements [Gorlach 1991, Jamroz et al. 2001, Kabata-Pendias and Pendias 2001], essential for the function of the animal body. It is necessary to monitor the content of these elements in plants intended for feed, since the excess or deficiency thereof has negative influence on plant growth and development, as well as on animal health status, especially in the case of ionic antagonism between phosphorus, potassium, and chromium and nickel. For Fabaceae family cultivation, chromium and nickel deficiency is frequently observed in the intensive process of biological N_2 reduction and phosphorus and potassium fertilisation [Broos et al. 2005, Symanowicz and Kalembasa 2012], despite the low uptake. Chromium plays an important role in a plant in the metabolism of some proteins, fats and glucose. It is a component of enzymes (trypsin). Nickel is also a component of enzymes (urease and hydrogenase), it has catalytic functions, and in the case of deficiency thereof toxic amounts of urea are accumulated in the above-ground parts of the plants [Kabata-Pendias and Pendias 2001].

The aim of the tests presented herein was to investigate the changes in chromium and nickel content in goat's rue biomass and soil under the influence of differentiated PK fertilisation, and then to compare the obtained results with the acceptable limits for animal feeding and to calculate the uptake of elements being analysed with the crop of the test plant.

2. MATERIALS AND METHODS

Field test was carried out during the years 2005–2007 on the plantation set up in 1997 on test fields belonging to the University of Natural Sciences and Humanities in Siedlce (52°17′N, 22°28′E). Soil, in which goat's rue was cultivated, was made of loamy sand (LS) and was characterised by neutral pH value. The content of available phosphorus determined by Egner-Riehm method was defined as medium (52 mg P•kg^{-1}) and for potassium as low (46 mg K•kg^{-1}). Total chromium and nickel content in soil, where goat's rue (*Galega orientalis* Lam.) was cultivated, was 9,55 mg Cr•kg^{-1} and 4,81 mg Ni•kg^{-1}, respectively.

The tests comprised the following fertilisation objects: control object, P_{50}, K_{100}, $P_{50}K_{150}$, $P_{50}K_{200}$ and $P_{50}K_{250}$. Phosphorus fertilisers in the form of triple superphosphate were applied in autumn, and potassium fertilisers in the form of potassium salt (60% K_2O) were applied in two doses (early spring and after the first cut).

During each year of the tests, three cuts of the test plant were harvested in budding stage (in May, July and September). During harvesting the subsequent cuts of goat's rue (*G. orientalis* Lam.), green mass samples of whole goat's rue plants were taken, which were then dried and fragmented. During each year of the tests in autumn, soil samples were also taken. Total chromium and nickel content in the test plant and in soil was determined following "cold" mineralisation by using inductively coupled plasma-atomic emission spectrometer [Szczepaniak, 2005].

Test results were compiled statistically using three-factor analysis of variance (ANOVA; STATISTICA 10 PL pack), and significant differences were calculated using Tukey's test at the significance level of α = 0,05.

3. RESULTS AND DISCUSSION

Average chromium content in goat's rue dry mass harvested in budding stage was 0,47 mg•kg^{-1} (Table 1) and was significantly diversified under the influence of the factors being tested and synergism thereof.

The highest content of chromium was found in test plant biomass harvested in the third cut. In the next years considerably lower contents of chromium were determined. The highest content of chromium was determined in the test plant harvested from P_{50}, where the lowest crops of goat's rue were obtained [Symanowicz and Kalembasa 2010]. Probably, this element was concentrated in the obtained crop. The next increasing potassium doses (up to K_{200} dose) resulted in the increased content of chromium in goat's rue biomass compared with the control object. Potassium dose increased to 250 kg•ha^{-1} resulted in the reduced content of the element being analysed, possibly due to the antagonism between Cr and K and neutral pH value of the soil [Kabata-Pendias and Pendias 2001, Kwiatkowska-Malina and Maciejewska 2011]. The obtained results did not support the previous studies by Symanowicz et al. [2004], in which changes in heavy metals content in goat's rue biomass were investigated, depending on the type of seed infection with various microbial strains (Cyanophyta *Nostoc*, *Rhizobium gelegae*). In these tests, five times greater content of chromium was determined in goat's rue leaves and four times greater in stems. The determined chromium content in goat's rue biomass harvested in subsequent cuts, years of cultivation and objects fertilised with PK was within the limit values of acceptable content of trace elements in feed [Anke 1987], and according to Gorlach [1991] and Jamroz et al. [2001] the value was within the optimal range.

Nickel content determined in the test plant was approximately 1,38 mg•kg^{-1} dry mass (Table 2) and was considerably diversified under the influence of the factors being tested and synergism thereof.

Considering experimental factors, it should be stated that actually the highest content of nickel was determined in test plant biomass harvested in the first cut (1,78 mg•kg^{-1} dry mass), in the third year of the tests (1,5 mg•kg^{-1} dry mass) and on $P_{50}K_{150}$ (1,62 mg•kg^{-1} dry mass). Statistical calculations demonstrated significant differences

Table 1. The content of chromium (mg•kg^{-1}d.m.) in the biomass of goat's rue

Fertilisation	Cuts			Years			Means (2005–2007)
	I	II	III	2005	2006	2007	
0	0,44	0,35	0,42	0,61	0,28	0,31	0,40
P_{50}	0,63	0,50	0,72	0,80	0,63	0,43	0,62
K_{100}	0,43	0,28	0,57	0,51	0,34	0,44	0,43
$P_{50}K_{150}$	0,43	0,34	0,52	0,56	0,34	0,39	0,43
$P_{50}K_{200}$	0,52	0,37	0,58	0,69	0,38	0,40	0,49
$P_{50}K_{250}$	0,45	0,37	0,60	0,61	0,41	0,40	0,47
Means	0,48	0,37	0,57	0,63	0,40	0,35	0,47

$LSD_{0,05}$: cuts (C) – 0,04; years (Y) – 0,04; fertilisation (F) – 0,06; YxC – 0,08; CxY – 0,11; FxC – 0,08; CxF – 0,06; FxY – 0,11; YxF – 0,09.

Table 2. The content of nickel (mg•kg^{-1}d.m.) in the biomass of goat's rue

Fertilisation	Cuts			Years			Means (2005–2007)
	I	II	III	2005	2006	2007	
0	1,15	0,75	1,18	1,31	0,81	0,55	1,03
P_{50}	1,64	1,10	1,04	1,31	1,08	1,39	1,26
K_{100}	1,99	1,15	1,35	1,29	1,57	1,65	1,50
$P_{50}K_{150}$	1,88	1,32	1,66	1,52	1,63	1,71	1,62
$P_{50}K_{200}$	2,09	1,07	1,15	1,23	1,49	1,59	1,44
$P_{50}K_{250}$	1,92	1,17	1,17	1,17	1,45	1,69	1,42
Means	1,78	1,09	1,26	1,30	1,34	1,50	1,38

$LSD_{0,05}$: cuts (C) – 0,09; years (Y) – 0,09; fertilisation (F) – 0,15; YxC – 0,15; CxY – 0,15; FxC – 0,19; CxF – 0,15; FxY – 0,26; YxF – 0,26.

in nickel content between individual goat's rue cuts and between year 2005 and 2006 of the tests. Analysing the changes in nickel content in goat's rue, resulting from potassium fertilisation, significant nickel content increase up to K_{150} dose was observed. The determined nickel content did not exceed the acceptable limits of harmfulness or toxicity of this element in feed [Anke 1987, Gorlach 1991, Gorlach and Gambuś 2000, Kabata-Pendias, Pendias 2001]. Similar nickel content was determined in the Italian ryegrass fertilised with mushroom substrate [Kalembasa and Wiśniewska 2004].

Average total chromium content in humus level in soil was 9,55 mg•kg⁻¹ (Table 3) and was considerably diversified under the influence of the factors being tested and synergism thereof.

Considering experimental factors, it should be stated that actually the highest content of chromium was determined in soil after the first cut (9,72 mg•kg⁻¹ dry mass), in the second year of the tests (10,00 mg•kg⁻¹) and on the control object (10,45 mg•kg⁻¹).

The obtained results were supported by the studies by Spiak et al. [2004], in which soils from environmental friendly farms were subjected to analysis. Statistical calculations demonstrated significant differences in chromium content in soil between the first and second goat's rue cut and between years of tests. A significant reduction in chromium content up to K_{200} dose was observed in soil due to potassium fertilisation.

Total average nickel content determined in soil was 4,81 mg•kg⁻¹ and was maintained at a low level (Table 4).

Factors being tested and synergy thereof resulted in significant diversification of this value. Statistical analysis demonstrated significant reduction in the content of this element in soil sampled after subsequent cuts and years of studies. Due to phosphorus and potassium fertilisation, nickel content in soil was increased compared with the control object and reached the highest value (5,06 mg•kg⁻¹) following $P_{50}K_{150}$ fertilisation. Results obtained in own tests remained at a low level and did not exceed acceptable content in the surface soil layer, amounting to 20–50 mg•kg⁻¹ [Gorlach and Gambuś 2000]. Higher nickel content was determined in tests by Spiak and Wall [2004], in which serpentinite soils were tested.

Average chromium and nickel uptake with goat's rue (*G. orientalis* Lam.) crop during the years 2005–2007 was as follows: chromium – 3915 mg•ha⁻¹ (Table 5), and nickel 11495 mg•ha⁻¹ (Table 6). The highest uptake of chromium and nickel for the test plant was observed for the crop of the first cut harvested in budding stage.

The highest total uptake of Cr and Ni from three cuts of goat's rue was observed in the first year of the tests. Considering PK fertilisation, it should be stated that the greatest uptake of chromium was observed for goat's rue fertilised with P_{50} dose and of nickel with $P_{50}K_{200}$ dose. The above-mentioned calculations were done based on the paper by Symanowicz and Kalembasa [2010].

4. CONCLUSIONS

1. P_{50} and $P_{50}K_{200}$ fertilisation had significant influence on the increase in chromium content in goat's rue biomass, and increasing K doses resulted in the significant increase of nickel content in the test plant.
2. Chromium and nickel content determined in goat's rue biomass was below the range of limit values that define the acceptable amounts of these elements in feed.
3. The highest content of chromium was determined in soil taken from the control object, and of nickel in soil fertilised with $P_{50}K_{150}$ dose.
4. The highest uptake of chromium was observed for goat's rue fertilised with P_{50} dose, and of nickel with $P_{50}K_{200}$ dose.

Table 3. The content of chromium in soil (mg•kg⁻¹)

Fertilisation	Cuts			Years			Means (2005–2007)
	I	II	III	2005	2006	2007	
0	11,43	10,38	9,54	8,06	12,40	10,89	10,45
P_{50}	11,05	10,02	10,13	10,35	10,89	9,96	10,40
K_{100}	8,20	8,61	8,41	8,64	8,59	7,97	8,40
$P_{50}K_{150}$	7,96	8,78	8,48	8,69	8,76	7,77	8,41
$P_{50}K_{200}$	9,77	9,89	9,80	10,85	9,72	8,88	9,82
$P_{50}K_{250}$	9,91	10,18	9,45	10,21	9,62	9,71	9,85
Means	9,72	9,64	9,30	9,47	10,00	9,20	9,55

$LSD_{0,05}$: cuts (C) – 0,31; years (Y) – 0,31; fertilisation (F) – 0,55; YxC – 0,54; CxY – 0,54; FxC – 0,67; CxF – 0,54; FxY – 0,95; YxF – 0,77.

Table 4. The content of nickel in soil (mg•kg⁻¹)

Fertilisation	Cuts			Years			Means (2005–2007)
	I	II	III	2005	2006	2007	
0	4,63	3,89	4,09	5,69	3,54	3,05	4,09
P_{50}	5,64	4,84	4,98	6,36	4,46	4,15	4,98
K_{100}	5,04	5,27	4,77	5,45	4,35	4,50	4,77
$P_{50}K_{150}$	5,65	5,63	5,06	5,49	5,50	4,20	5,06
$P_{50}K_{200}$	4,95	4,93	4,92	5,51	5,10	4,13	4,92
$P_{50}K_{250}$	5,61	5,39	5,03	5,13	5,64	4,31	5,03
Means	5,26	4,99	4,81	5,61	4,77	4,06	4,81

$LSD_{0,05}$: cuts (C) – 0,14; years (Y) – 0,14; fertilisation (F) – 0,25; YxC – 0,25; CxY – 0,25; FxC – 0,31; CxF – 0,25; FxY – 0,43; YxF – 0,35.

Table 5. Uptake of chromium in the field of dry matter of goat's rue (mg•ha^{-1})

Fertilisation	Cuts			Years			Means (2005–2007)
	I	II	III	2005	2006	2007	
0	1540	728	450	4544	2106	1655	2708
P_{50}	2457	1465	1210	8320	5330	2872	5270
K_{100}	1604	619	1060	4447	2638	3049	3354
$P_{50}K_{150}$	1757	1064	1139	5992	3087	3272	4606
$P_{50}K_{200}$	2808	1073	1369	8211	4028	3800	5194
$P_{50}K_{250}$	1539	725	900	3703	2927	2960	3229
Means	1925	936	1026	5790	3364	2579	3915

Table 6. Uptake of nickel in the field of dry matter of goat's rye (mg•ha^{-1})

Fertilisation	Cuts			Years			Means (2005–2007)
	I	II	III	2005	2006	2007	
0	4025	1560	1404	9759	6091	2937	6973
P_{50}	6396	3223	1747	13493	9137	9285	10710
K_{100}	7423	2541	2511	11249	12183	11434	11700
$P_{50}K_{150}$	7689	4132	3635	16264	14800	14347	15228
$P_{50}K_{200}$	11286	3103	2714	14637	15794	15105	15264
$P_{50}K_{250}$	6566	2293	1755	7102	10353	12506	9755
Means	7138	2758	2268	11947	11269	11055	11495

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