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OPTIMALISATION OF MINERAL FERTILIZATION IN GOLDENROD (*Solidago virgaurea* L. ssp. *virgaurea*) CULTIVATED FOR PHARMACEUTICAL PURPOSES

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Abstract. In a field experiment, the growth and yielding of goldenrod (*Solidago virgaurea* L. ssp. *virgaurea*) and leiocaroposide content in herb depending on different NPK fertilization level and soil type were analysed. Mineral fertilization level was the factor that significantly affected yielding and parameters of goldenrod growth. Along with NPK level increase a tendency to increase number of stems, their height and inflorescences length as well as a significant increase of goldenrod raw material yields and at the same time decrease of leiocarposide content was observed. Increasing mineral fertilization doses were especially effective on poor in nutrients slightly loamy sand. Significantly higher raw material yields, but characterized by lower leiocarposide content were collected on rich in nutrients heavy loamy sand.

Key words: goldenrod, yield, growth, mineral fertilization level, soil type, leiocarposide, mineral elements

INTRODUCTION

Solidago virgaurea L. (goldenrod) is a known medicinal plant with diuretic, spasmolytic, anti-inflammatory, antihypertensive, immunostimulating, antiphlogistic, antimycotic and antioxidant activity [Melzig, 2004, Yarnell, 2002, Hiller and Bader 1996, Wichtl 1994, Bohr and Plescher 1997, Apati et al. 2003]. The pharmacological activity of *Solidaginis Herba* is caused by the presence of phenolic glycosides (leiocarposide), quercetin, rutin, saponins, diterpenes, inulin, essential oil and tannins [Melzig, 2004, Kalemba 1998, Lück et al. 2000]. This species is originated from Europe but now it can be found almost all over the world. Goldenrod raw material was collected mainly from nature so far, but some commercial plantations of this species arose in Germany and Poland in the last few years [Bohr and Plescher 1997, 1999, Kołodziej 2002, 2007]. There are, however, a very few data regarding soil and nutrition demands of goldenrod,

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thus a necessity to work out a technology of its field cultivation had arisen. Earlier studies showed that phosphorous and potassium played an important role in goldenrod plant proper growth as well as active substances accumulation, while nitrogen application resulted in higher aboveground parts yields [Kołodziej 2002, 2007, Kucharski and Mordalski 2006].

MATERIAL AND METHODS

A field experiment lasting three years (2001-2003) was carried out on two experimental fields of the University of Life Sciences in Lublin, located on slightly loamy sand (Trzciniec near Chodel) and heavy loamy sand (Wólka Gościeradowska). Slightly loamy sand (51º7'46''N, 22º10'59''E; marked in the text as PS) was poor in mineral constituents while heavy loamy sand (50º52'8''N, 22 º2'2''E; marked as PG in the text) contained higher amounts of macro- and microelements. The soil characteristics are given in Table 1.

Table 1. Characteristics of soils under investigation (acc. to Agrochemical Station in Lublin)
Tabela 1. Charakterystyka badanych gleb (wg Stacji Chemiczno-Rolniczej w Lublinie)

Soil Gleba	pH_{KCl}	Humus Próchnica %	Content of mineral compounds ($mg \cdot kg^{-1}$ of soil) Zawartość składników mineralnych ($mg \cdot kg^{-1}$ gleby)						
			available forms – formy dostępne			total – ogólna			
			P	K	Mg	Zn	Cu	Mn	Fe
PS	4.7	1.53	12.2	24.9	2.0	7.8	1.10	43.1	300
PG	5.9	1.03	91.5	80.5	31.2	7.9	2.10	184.5	799

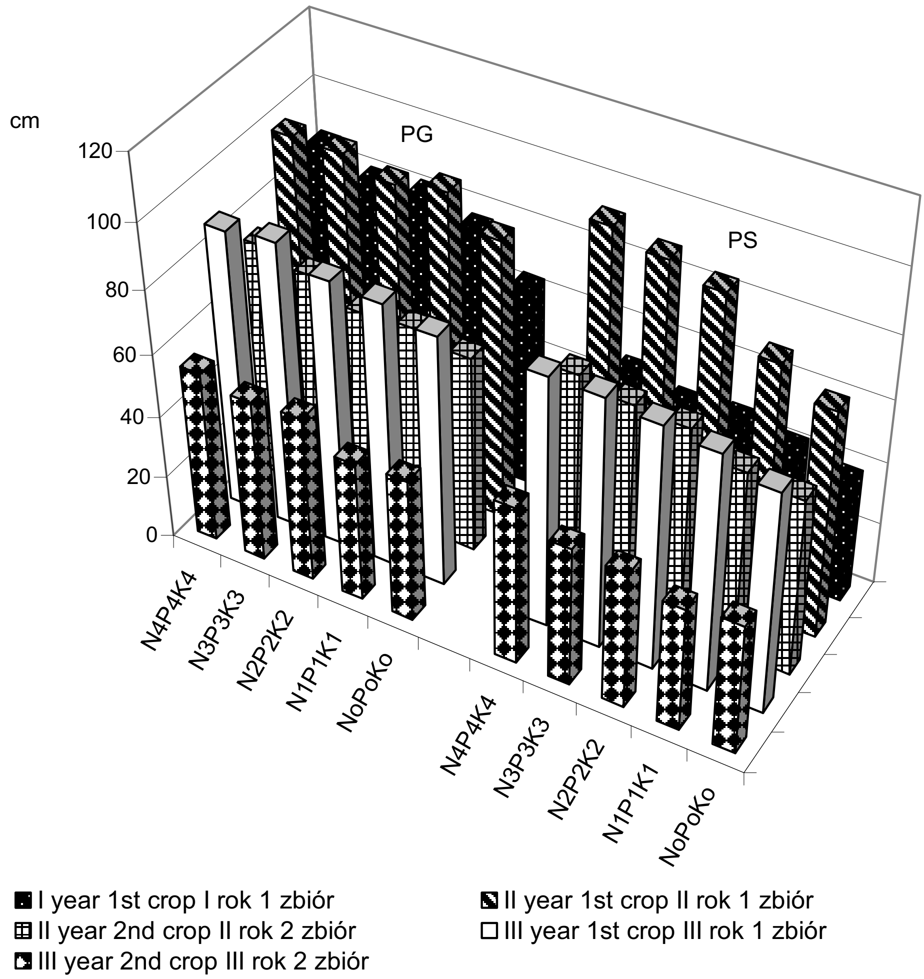
PS – slightly loamy sand – piasek słabo gliniasty
PG – heavy loamy sand – piasek gliniasty mocno pylasty

Goldenrod (*Solidago virgaurea* L. ssp. *virgaurea*) diaspores (achenes) obtained from local populations occurring in nature nearby Lublin were sown at the beginning of March in multicell trays. Then seedlings were transplanted into the field in 40 × 15 cm spacing at the end of April on plots of 5 m^2. Every year, before the beginning of plants vegetation the following compounds were applied respectively: nitrogen – in a form of ammonium nitrate 34% N, phosphorous – in a form of a single superphosphate 7.9% P and potassium – in a form of potassium salt (KCl) 48.1% K according to following design: $N_oP_oK_o$ – control object without mineral fertilization, $N_1P_1K_1$ – with 20 kg N, 30.3 kg P, 24.1 kg K, $N_2P_2K_2$ – with 40 kg N, 61.1 kg P, 48.2 kg K, $N_3P_3K_3$ – with 60 kg N, 91.6 kg P, 72.3 kg K and $N_4P_4K_4$ – with 80 kg N, 122.2 kg P and 96.4 kg K per hectare. Raw material was harvested every year at the beginning of blooming stage (at 10–15 cm height). In the first year of vegetation goldenrod was harvested only once – at the end of August, while in the following two years of cultivation – twice a year: at the end of July and at the beginning of September. Before the harvest, 3 randomly chosen plants per plot were measured, and after that herb was dried in temperature 35°C. The experimental design was a randomized complete block design with four replications. Data were analyzed with the SAS general linear model procedure (version 8.2 SAS Institute, Cary, N.C.). Testing for significance of mean effects and interactions on all variables was calculated using ANOVA analysis of variance. The chemical determination of leiocarposide content (by HPLC method from the first crop in two following years of cultivation) was performed in Phytochemical Laboratory in Klęka. While chosen macro- and microelement contents (using AAS method after previous dry ashing of plant material (1 g obtained from the first crop in the first, second and third year of cultivation) and dissolving it in 6N HCl (10 cm^3) were determined in Central Apparatus Laboratory in University of Life Sciences in Lublin.

RESULTS AND DISCUSSION

Experimental factors significantly affected morphological parameters, yields and chemical composition of goldenrod (tables 2–5, figure 1).

In the first year of the experiment goldenrod created rosette of leaves and only 24–30% of plants formed up to 5 stems. Their height ranged from 44 (on slightly loamy sand) to 78 cm (on heavy loamy sand) and inflorescence length was 23 and 37 cm, respectively. Thus yields of raw material was extremely low (on an average 72.4 g m^{-2} on slightly loamy sand and 213.6 g m^{-2} on heavy loamy sand – tables 2, 3). In following two years of cultivation all plants was blooming, so higher yields of herb (both from single plants as well as from unit area) were obtained. In the second year of cultivation plants formed the highest number of stems and the longest inflorescences (especially on slightly loamy sand and at the first harvest). Similar dimensions of goldenrod plants observed Lück et al. [2000] and Kołodziej [2008]. Plants collected during the second harvest were characterised by the smaller number (from 2 to 5) of lower stems with short inflorescences (on an average 30 cm lower with 20 cm shorter inflorescences in comparison to July cutting – figure 1, table 2). This is why raw material yields obtained during the autumn harvesting were on an average 60% lower than those from summer cutting. Generally, drug yield was at the same level as obtained by Lück et al. [2000], but higher than stated by Bohr and Plescher [1997], Galambosi et al. [1993] and Gruszczyk and Kiełtyka [2005]. It is worth to emphasize that independently from the experimental factors, in the last year of cultivation there was observed a considerable decrease of goldenrod yielding potential (caused mainly by pests – *Galenuca tanaceti* L. and *Aphis* ssp.). Bohr and Plescher [1997] also observed that in the third year of cultivation goldenrod yielding is unstable and pests could damage plantation. Therefore, plantation should be utilized through two vegetation periods. Independently from the fertilization level, higher plants with longer inflorescences and as a result – higher yields of *Soliadaginis Virgaureae Herba* were collected on heavy loamy sand (on an average by 15% in comparison to those from slightly loamy sand), which agrees with our earlier results [Kołodziej 2007, 2002].



Explanation: as in table 2 – Wyjaśnienia: jak w tabeli 2

Fig. 1. Average height of goldenrod plant depending on soil type and fertilization
Rys. 1. Średnia wysokość roślin nawłoci w zależności od typu gleby i nawożenia

Along with increasing NPK level a tendency to increase number of stems, average plant height as well as inflorescence length and a significant increase of goldenrod raw material yields (both from single plants as well as from unit area) was noted (tables 2, 3, 4).

The lowest dose of mineral fertilizers – $N_1P_1K_1$ application caused about 17% (on slightly loamy sand) or 20% (on heavy loamy sand) increase of goldenrod yields (total from three years of cultivation). Double dose of fertilizers ($N_2P_2K_2$) used was connected with respectively 43% (on slightly loamy sand) and 25% (on heavy loamy sand) total yield increase, while triple doses ($N_3P_3K_3$) caused respectively 62% and 50% yield increase. Further increase of NPK level brought about 10% increase of total goldenrod

Table 2. The effect of soil type and fertilization on the length of inflorescence and number of stems of goldenrod plant
Tabela 2. Wpływ typu gleby i nawożenia na długość kwiatostanu i liczbę łodyg nawłoci

Soil Gleba	Fertilization Nawożenie	Length of inflorescence – Długość kwiatostanu, cm					Number of stems per plant – Liczba pędów na roślinie				
		I year (I rok)	II year (II rok)		III year (III rok)		I year (I rok)	II year (II rok)		III year (III rok)	
		1st crop 1 zbiór	1st crop 1 zbiór	2nd crop 2 zbiór	1st crop 1 zbiór	2nd crop 2 zbiór	1st crop 1 zbiór	1st crop 1 zbiór	2nd crop 2 zbiór	1st crop 1 zbiór	2nd crop 2 zbiór
PS	$N_oP_oK_o$	18	37	23	29	15	1	6	4	6	3
	$N_1P_1K_1$	20	46	29	34	19	3	7	6	5	3
	$N_2P_2K_2$	21	54	33	38	20	3	7	5	8	4
	$N_3P_3K_3$	26	65	32	48	20	4	8	6	6	5
	$N_4P_4K_4$	29	66	35	45	23	5	8	8	5	5
Mean – Średnio		23	54	30	39	19	3	7	6	6	4
PG	$N_oP_oK_o$	29	56	30	37	21	2	8	5	6	4
	$N_1P_1K_1$	34	53	33	38	22	4	10	5	11	5
	$N_2P_2K_2$	36	57	38	46	22	4	9	6	8	5
	$N_3P_3K_3$	41	57	41	52	28	5	11	5	7	6
	$N_4P_4K_4$	44	56	45	50	27	5	12	4	7	6
Mean – Średnio		37	56	37	45	24	4	10	5	8	5
Source of variation Źródło zmienności											
Soil – Gleba		0.87	1.09	1.73	1.69	0.84	0.38	0.27	0.38	0.45	0.36
Fertilization level Poziom nawożenia		1.95	2.46	3.89	3.78	1.89	0.86	0.61	0.86	1.03	0.81
Interaction – Interakcja		3.24	4.09	NS	NS	3.13	1.44	1.01	1.44	1.68	NS

NS, **, * – nonsignificant or significant at $P \leq 0.05$ or 0.1, respectively by Tukey's test; PS – slightly loamy sand, PG – heavy loamy sand; $N_oP_oK_o$ – control object without mineral fertilization, $N_1P_1K_1$ – with 20 kg N, 30.3 kg P, 24.1 kg K, $N_2P_2K_2$ – with 40 kg N, 61.1 kg P, 48.2 kg K, $N_3P_3K_3$ – with 60 kg N, 91.6 kg P, 72.3 kg K and $N_4P_4K_4$ – with 80 kg N, 122.2 kg P and 96.4 kg K per hectare

NS, **, * – nieistotna lub istotna przy $P \leq 0,05$ lub 0,1, odpowiednio wg testu Tukeya; PS – piasek słabo gliniasty, PG – piasek gliniasty mocno pylasty; $N_oP_oK_o$ – obiekt kontrolny bez nawożenia mineralnego, $N_1P_1K_1$ – z zastosowaniem 20 kg N, 30,3 kg P, 24,1 kg K, $N_2P_2K_2$ – z zastosowaniem 40 kg N, 61,1 kg P, 48,2 kg K, $N_3P_3K_3$ – z zastosowaniem 60 kg N, 91,6 kg P, 72,3 kg K i $N_4P_4K_4$ – z zastosowaniem 80 kg N, 122,2 kg P i 96,4 kg K na 1 hektar

Table 3. The effect of soil type and fertilization on the yield of goldenrod herb (in g air dry matter $\cdot m^{-2}$)
Tabela 3. Wpływ typu gleby i nawożenia na plony ziela nawłoci (w g powietrznie suchej masy $\cdot m^{-2}$)

Soil Gleba	Fertilization Nawożenie	I year – I rok	II year – II rok			III year – III rok		
		yield plon	1st crop 1 zbiór	2nd crop 2 zbiór	total yield plon ogółem	1st crop 1 zbiór	2nd crop 2 zbiór	total yield plon ogółem
PS	$N_oP_oK_o$	61	278	176	454	161	106	267
	$N_1P_1K_1$	71	362	170	532	197	117	314
	$N_2P_2K_2$	71	518	196	714	201	134	335
	$N_3P_3K_3$	76	534	204	738	309	149	458
	$N_4P_4K_4$	83	588	238	826	290	152	442
Mean – Średnio		72	456	197	653	232	132	363
PG	$N_oP_oK_o$	147	350	74	424	304	138	442
	$N_1P_1K_1$	216	438	92	530	338	136	474
	$N_2P_2K_2$	222	498	64	562	343	140	483
	$N_3P_3K_3$	248	606	72	678	464	138	602
	$N_4P_4K_4$	235	644	64	708	419	103	522
Mean – Średnio		214	507	73	580	374	131	504
Source of variation Źródło zmienności								
Soil – Gleba		3.01	3.43	2.2	2.98	4.71	NS	3.95
Fertilization level Poziom nawożenia		6.76	7.71	4.94	6.69	10.57	7.79	8.85
Interaction Interakcja		11.25	12.8	8.22	11.13	17.57	12.96	14.72

Explanation: as in table 2 – Wyjaśnienia: jak w tabeli 2

Table 4. Air dry weight (g $\cdot plant^{-1}$) of aboveground parts of single plant of goldenrod and leiocarposide content (%) depending on soil type and fertilization
Tabela 4. Powietrznie sucha masa (g $\cdot roślina^{-1}$) części nadziemnych pojedynczych roślin nawłoci oraz zawartość lejokarpozydu w zależności od typu gleby i nawożenia

Soil Gleba	Fertilization Nawożenie	Weight of aboveground parts (g $\cdot plant^{-1}$) Masa części nadziemnych (g $\cdot roślina^{-1}$)					Leiocarposide content Zawartość lejokarpozydu %	
		I year –I rok	II year– II rok		III year – III rok			
		yield plon	1st crop 1 zbiór	2nd crop 2 zbiór	1st crop 1 zbiór	2nd crop 2 zbiór	I year (I rok)	II year (II rok)
PS	$N_oP_oK_o$	6.4	39.2	13.2	15.1	7.5	1.20±0.03[z]	0.71±0.01
	$N_1P_1K_1$	6.2	44.5	11.3	32.9	7.8	1.24±0.03	0.59±0.02
	$N_2P_2K_2$	7.3	50.4	17.4	34.9	8.4	1.12±0.02	0.76±0.01
	$N_3P_3K_3$	7.8	63.3	19.7	38.8	9.6	1.20±0.04	0.48±0.01
	$N_4P_4K_4$	8.3	67.1	20.5	40.8	11.2	1.05±0.03	0.42±0.02
Mean – Średnio		7.2	52.9	16.4	32.5	8.9	1.16	0.59
PG	$N_oP_oK_o$	17.6	54.7	21.3	38.4	8.0	1.17±0.03	0.63±0.03
	$N_1P_1K_1$	17.7	62.5	24.8	44.1	10.1	1.10±0.09	0.54±0.01
	$N_2P_2K_2$	18.2	68.4	26.7	65.6	6.7	1.04±0.07	0.58±0.02
	$N_3P_3K_3$	20.3	80.7	31.2	74.4	8.1	1.03±0.04	0.50±0.009
	$N_4P_4K_4$	22.4	78.9	31.8	70.0	6.6	1.02±0.04	0.44±0.008
Mean – Średnio		18.8	69.0	27.2	58.5	7.9	1.07	0.54
Source of variation Źródło zmienności								
Soil – Gleba		0.61	1.09	0.97	1.85	0.32	0.028	0.012
Fertilization level Poziom nawożenia		1.36	2.46	2.19	4.15	0.72	0.064	0.026
Interaction Interakcja		2.26	4.09	3.64	6.90	1.19	0.106	0.043

Explanation: as in table 2, z – means ±SE – Wyjaśnienia: jak w tabeli 2, z – średnia ±SE

Table 5. Content of chosen macro- and microelements in air dry matter of goldenrod herb as depending on soil type and fertilization (mean from the first harvest in three following years of cultivation)

Tabela 5. Zawartość wybranych makro- i mikroelementów w powietrznie suchej masie ziela nawłoci w zależności od typu gleby i nawożenia (średnio z pierwszego zbioru w trzech kolejnych latach uprawy)

Soil Gleba	Fertilization Nawożenie	Average content (%) Średnia zawartość (%)				Average content (mg· kg^{-1} of dry matter) Średnia zawartość (mg· kg^{-1}suchej masy)			
		P	K	Ca	Mg	Cu	Zn	Fe	Mn
PS	$N_oP_oK_o$	0.40±0.06^z	2.71±0.29	0.98±0.09	0.16±0.008	9.00±1.27	48.28±7.62	64.02±5.46	504.88±25.6
	$N_1P_1K_1$	0.39±0.05	2.88±0.02	0.97±0.06	0.13±0.01	9.40±0.7	44.50±5.97	61.25±18.6	442.55±13.6
	$N_2P_2K_2$	0.39±0.07	3.02±0.50	0.82±0.07	0.13±0.01	9.61±0.8	45.54±5.45	61.86±5.18	520.27±2.17
	$N_3P_3K_3$	0.40±0.03	3.10±0.01	0.86±0.12	0.13±0.008	9.36±2.02	48.89±8.49	61.80±5.33	514.83±12.9
	$N_4P_4K_4$	0.40±0.09	3.17±0.08	0.88±0.26	0.14±0.005	9.54±1.20	42.56±3.14	60.20±0.29	517.44±55.9
Mean – Średnio		0.40	2.98	0.90	0.14	9.38	45.95	61.83	499.99
PG	$N_oP_oK_o$	0.46±0.09	2.67±0.3	0.87±0.07	0.22±0.03	8.68±0.69	29.34±4.53	78.00±5.08	55.33±18.6
	$N_1P_1K_1$	0.44±0.04	2.82±0.33	0.84±0.08	0.20±0.008	8.68±0.38	29.13±3.09	74.07±2.36	56.46±11.3
	$N_2P_2K_2$	0.47±0.09	3.06±0.5	0.84±0.05	0.20±0.03	8.65±1.33	30.51±2.01	78.90±3.98	58.54±18.9
	$N_3P_3K_3$	0.46±0.06	3.22±0.44	0.92±0.2	0.20±0.005	8.78±0.22	30.60±0.85	72.22±7.45	67.50±12.8
	$N_4P_4K_4$	0.47±0.08	3.44±0.51	0.98±0.07	0.20±0.005	9.75±0.53	28.16±1.59	73.82±3.07	61.61±1.2
Mean – Średnio		0.46	3.04	0.89	0.20	8.91	29.55	75.40	61.09
Source of variation Żródło zmienności									
Soil – Gleba		0.045	NS	NS	0.010	NS	0.032	4.768	81.043
fertilization level – Poziom nawożenia		NS	0.510	NS	0.023	NS	NS	NS	NS
Interaction – Interakcja		NS	NS	NS	NS	NS	NS	NS	NS

Explanation: as in table 2, z – means ±SE – Wyjaśnienia: jak w tabeli 2, z – średnia ±SE yields on slightly loamy sand, but at the same time 6% decrease on heavy loamy sand in comparison to triple dose of fertilizers (table 3). Similar relationships obtained Kołodziej [2006] in the case of ribwort plantain, Komosa [2000] in chrysanthemum and Pacholak et al. [2007] in apples. Therefore, the highest doses of mineral fertilizers are well-grounded on poor in nutrients, sandy soils, while 60 kg N · ha^{-1}, 91,6 kg P · ha^{-1}, 72,3 kg K · ha^{-1} is enough on rich in nutrients soils. Kucharski and Mordalski [2006] recommended similar mineral fertilization doses. As far as air dry weight of aboveground parts from single plants is concerned the same tendency as in the yields collected from the unit area was noted (Table 4).

Raw material quality for pharmaceutical purposes is determined by active substance content. In the experiment goldenrod herb contained relatively high amount of leiocarposide (0.5% is recognized as a minimal amount), extremely differentiated in two years studied. Its concentration fluctuated from between 0.42 and 1.24% (table 4) and was higher than the one reported by Lück et al. [2000], Gruszczyk and Kiełtyka [2005] or Hiller and Bader [1996]. The highest active constituent content was observed on the plots without fertilization or fertilized with the lowest doses. Along with NPK level increase a tendency to decrease leiocarposide content was observed. Similarly as in our earlier research, goldenrod raw material obtained from slightly loamy sand was characterized by higher active substances content [Kołodziej 2002, 2008].

As far as mineral composition is concerned, independently from the soil type, there was a tendency to increase P, K, Cu and Mn and at the same time decrease of Ca and Fe content in goldenrod raw material along with increasing NPK fertilization doses. *Solidaginis Virgaureae Herba* collected from heavy loamy sand was characterized by slightly higher P, K, Mg, Fe and at the same time lower other nutrients studied content in comparison to the one obtained from slightly loamy sand (table 5). It is worth to emphasize that raw material obtained from slightly loamy sand contained almost eight-times higher amount of Mn. In earlier studies [Kołodziej 2000] similar relationships were observed. Generally, along with increasing mineral fertilization level there was observed an increase of macro elements content in aboveground parts of goldenrod. The same tendency was observed in the case of eggplants [Markiewicz et al. 2008].

CONCLUSIONS

NPK fertilization level and soil type significantly affected yields of goldenrod, quality parameters and content of active compounds in raw material. Higher raw material yields (on an average by 15%), but at the same time characterized by lower leiocarposide content were collected on heavy loamy sand. Along with NPK level increase a tendency to increase number of stems, their height and inflorescences length as well as a significant increase of yields and decrease of leiocarposide content in goldenrod raw material was observed. Additional mineral fertilization doses were especially effective on poor in nutrients soil (slightly loamy sand).

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OPTYMALIZACJA NAWOŻENIA MINERALNEGO NAWŁOCI POSPOLITEJ (S*olidago virgaurea* L. ssp. *virgaurea*) UPRAWIANEJ NA CELE FARMACEUTYCZNE

Streszczenie. W doświadczeniu porównywano wzrost, plonowanie oraz zawartość lejokarpozydu i składników mineralnych w zielu nawłoci pospolitej (*Solidago virgaurea* L. ssp. *virgaurea*) w zależności od warunków glebowych i zróżnicowanego nawożenia mineralnego NPK. Poziom nawożenia mineralnego w istotny sposób wpłynął na plonowanie i badane parametry wzrostu roślin nawłoci, wraz z jego wzrostem notowano tendencję do zwiększanie liczby i wysokości łodyg oraz długości kwiatostanów a także istotny wzrost plonów surowca, z jednoczesnym obniżeniem nim zawartości lejokarpozydu. Zastosowanie zwiększonych dawek nawożenia mineralnego było szczególnie efektywne na ubogim w składniki pokarmowe piasku słabo gliniastym. Istotnie większe plony surowca zielarskiego (średnio o 15%) charakteryzującego się jednocześnie mniejszą zawartością lejokarpozydu zebrano na zasobnym w składniki pokarmowe piasku gliniastym mocnym.

Słowa kluczowe: nawłoć pospolita, plony, wzrost, poziom nawożenia mineralnego, typ gleby, lejokarpozyd, składniki mineralne

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