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Goldenrod (*Solidago virgaurea* L. ssp. *virgaurea*) reaction to foliar fertilization

Reakcja nawłoci pospolitej (*Solidago virgaurea* L. ssp. *virgaurea*) na nawożenie dolistne

Summary. In a four-year-long field experiment the effect of foliar fertilization with 2% Ekolist, the origin of diasporas and soil conditions on goldenrod morphological parameters, yields and chemical composition was studied. Experimental factors significantly affected morphological parameters, yields and chemical composition of goldenrod plants. Independently of the experimental factors, in the second and third years of goldenrod cultivation the highest yields of herb were obtained, whereas in the fourth year a considerable decrease of the yielding potential was observed. Significantly higher yields of *Soliadaginis Herba* characterized by the highest stems and inflorescences, and the content of leiocarposide and macroelements were collected on heavy loamy sand. On the other hand, the highest stems and inflorescences as well as yields of raw material and active compounds were noted on plots with plants obtained from diasporas collected from the natural state near Puławy, whereas the lowest one from Rabinówka. During four years of goldenrod culture, significantly heavier aboveground parts of plants (on average by 8%), characterised by the highest content of leiocarposide as well as mineral compounds content were found on the plots after Ekolist application.

Key words: goldenrod, *Solidago virgaurea* L., foliar fertilization, soil, seeds origin

INTRODUCTION

Goldenrod is a perennial herb species native to Poland, which grows naturally on forest glades, on well-drained, sandy soils with low pH. Its raw material has been collected mainly from nature so far, and often mixed up with other *Solidago* species with different therapeutic properties. However, some commercial plantations of European goldenrod appeared in Germany and Poland in the last few years [Bohr and Plescher 1997, 1999, Lück *et al*. 2000, Kucharski i Mordalski 2006, Kołodziej 2007]. Therefore, a necessity to work out a technology of its field cultivation has arisen.

Studies upon *Soliadginis Herba* biological activity confirm a very wide and pharmacologically variable range of metabolites included action (strong diuretic with anti-inflammatory, antispasmodic, antimicrobial, analgesics, immunostimulative, anticancer and antihypertensive) [Blumenthal *et al.* 1998, Melzig 2004]. Clinically, goldenrod extracts are utilized as an adjunct therapy in patients with lower urinary tract infections and to prevent the formation of kidney stones [Yarnell 2002, Melzig 2004]. About 100 active components are responsible for goldenrod biological action (leiocarposid and flavonoids are considered to be the most important) [Kalemba 1992, 1998, Bader *et al*. 1998, Melzig 2004].

Although goldenrod is cultivated on a small area, there is noted a high demand for its raw material. Adequate mineral fertilisation, soil conditions as well as the sowing material quality is considered as essential for satisfying yields with a high content of active substances [Galambosi *et al*. 1993, Bohr and Plescher 1999, Lück *et al*. 2000, Kołodziej 2002, Kucharski i Mordalski 2006]. Thus, it is very important to be acquainted with goldenrod reaction to the factors mentioned above.

MATERIAL AND METHODS

A field experiment lasting four years was carried out on two experimental fields at the University of Life Sciences in Lublin. It was located in on slightly loamy sand (Trzciniec near Chodel: 51º7'46''N, 22º10'59''E) and heavy loamy sand (Gościeradów: 50º52'8''N, 22 º2'2''E). Slightly loamy sand (marked in the text as **PS**) was characterized by low pH 1 n KCl – 4.7, very low phosphorus and magnesium (12.2 mg P·kg^{-1} and 2.0 mg Mg·kg^{-1} of soil) and low potassium content (24.9 mg K·kg^{-1} of soil) with 43.1 mg Mn·kg^{-1}, 1.1 mg Cu·kg^{-1}, 7.8 mg Zn·kg^{-1}, 300 mg Fe·kg^{-1}of the soil, while heavy loamy sand (marked as **PG** in the text) was characterized by pH 1 n KCl – 5.9, very high phosphorus (91.5 mg P·kg^{-1} of soil) and low potassium and magnesium content (80.5 mg K·kg^{-1} and 31.2 mg Mg·kg^{-1} of soil) with 184.5 mg Mn·kg^{-1}, 2.1 mg Cu·kg^{-1}, 7.9 mg Zn·kg^{-1}, 799 mg Fe·kg^{-1}of the soil. Goldenrod seedlings previously produced in multicell trays were transplanted onto the field at 40 × 15 cm spacing at the end of April. There were used three kinds of diasporas (seeds) collected in autumn from natural state in south eastern part of Poland (**A** – Dubiecko near Przemyśl: 49 º50'41''N, 22 º23'15'E, **B** – Rabinówka near Tomaszów Lub.: 50 º25'27''N, 23 º23'3''E, **C** – Puławy: 51 º24'21''N, 21 º59'0''E) for seedlings production. Another experimental factor was foliar fertilization with a 2% solution of Ekolist® Standard (produced by Ekoplon SA, Poland) using a hand-held sprayer. Each plot was sprayed with 300 ml of solution per plot (on control plots, without Ekolist application, the spraying was carried out with water). Sprayings were performed three-times in each of four vegetation periods (in the middle of May, June and July). Additionally, every year in spring mineral fertilization in the following amounts was used: 40 kg N ha (in the form of ammonium nitrate 34% N), 40 kg P ha (in form of a single superfosphate 7.9% P) and 60 kg K ha in the form of of potassium salt 48.1% K). The experiment was conducted as multifactor (in complete randomisation design) with three replications on plots of 10 m^2.

Goldenrod raw material (herb) was harvested every year in the first 10 days of August, then weighed, measured and after drying at the temp. 38ºC, air dry weight of single aboveground part was obtained (as an average from three plants per plot). Next, the chemical analysis (using HPLC method) of leiocarposide content in Phytochemical Laboratory in Klęka and chosen macro- and microelements content using ASA method in Central Apparatus Laboratory in University of Life Sciences in Lublin were performed. The data were analyzed with the SAS general linear model procedure (version 8.2 SAS Institute, Cary, N.C.). Testing the significance of mean effects and interactions on all variables was calculated using ANOVA analysis of variance.

RESULTS AND DISCUSSION

Experimental factors significantly affected morphological parameters, yields and chemical composition of goldenrod plants (Tab. 1–4).

In the first year of the experiment goldenrod created rosettes of leaves and only a few plants per plot – short stems with inflorescence, thus yields of raw material was extremely low (on an average 75.5 g · m^{-2} on slightly loamy sand and 245.8 g · m^{-2} on heavy loamy sand) (Tab. 1, 2). In the second and third years of goldenrod cultivation almost all of plants bloomed, so the highest yields of herb (both from single plants as well as from a unit area) were obtained. Herb yield was at the same level as that obtained by Lück *et al*. [2000], but higher than that found by Galambosi *et al*. [1993] and Gruszczyk and Kiełtyka [2005]. Similarly, at the same time plants created the highest stems with the longest inflorescences (Tab. 2). It is worth to emphasize that independently of the experimental factors, in the last year of cultivation there was observed a considerable decrease of goldenrod yielding potential (caused partially by pests), indicating that the cultivation of this species on commercial plantations should last three years at the longest. Independently of foliar fertilization and diasporas origin, higher yields of *Soliadaginis Herba* were collected on heavy loamy sand (on an average by 20% in comparison to those from slightly loamy sand), which is consistent with our earlier results [Kołodziej 2002]. The highest stems and inflorescences as well as yields of goldenrod raw material were noted on plots with plants obtained from diasporas collected from the natural state near Puławy (C), whereas the lowest one from Rabinówka (B). Similarly, Lück *et al*. [2000] as well as Galambosi *et al*. [1993] stated that the proper sowing material is essential for successful replacement from the natural habitat and a high quality of the herb. Independently of the other experimental factors, foliar fertilization positively affected the average height of plants, inflorescence length and yields of goldenrod raw material. Significantly heavier aboveground parts of plants (on an average by 8%), characterised by the highest stems (by 4 cm) with longer inflorescences (by 0.6 cm) were found on the plots after Ekolist application (Tab. 1, 2), whereas the smaller ones were observed on the control plots (without foliar fertilization). Positive effects of foliar fertilization were also observed in the case of vegetable and herbs production. Kołota and Osińska [1994] proved that Ekolist application resulted in a 20.3% increase in cabbage, 7.3% in cucumbers and 10.8% in onion yields. At the same time Berbeć *et al*. [2003] showed that foliar fertilization with Ekolist stimulated thyme growth, which resulted in the increase of herb yields (by 15–26%). In the case of American ginseng foliar fertilization with Ekolist and Mikrosol U resulted in a significant increase of both above ground parts and roots yield [Magdziak and Kołodziej 2007].

Table 1. Yields of goldenrod herb obtained from 1 m^2 and from a single plant in the following years of cultivation depending on experimental factors
Tabela 1. Plony ziela nawłoci z 1 m^2 oraz z pojedynczych roślin w kolejnych latach uprawy w zależności od czynników doświadczenia

Soil Gleba	Seeds origin Pochodzenie nasion	Ekolist application Stosowanie Ekolistu	Yields of herb (in g of air d m · m^{-2}) Plony ziela (w g s.m. · m^{-2})					Yields of herb (in g of air d m · $plant^{-1}$) Plony ziela (w g s.m. · $roślina^{-1}$)				
			1st	2nd	3rd	4th	mean średnio	1st	2nd	3rd	4th	mean średnio
PS*	A**	+	95.0	515.6	637.6	319.1	391.8	9.80	48.45	70.44	49.44	44.53
	B	+	51.6	657.8	547.0	212.3	367.2	7.02	45.45	65.02	42.02	39.88
	C	+	85.8	1114	959.0	550.5	677.4	7.87	52.00	84.52	49.54	48.48
	A	-	110.8	733.4	686.0	251.3	445.4	6.49	49.91	65.76	48.05	42.55
	B	-	39.1	668.0	591.8	199.6	374.6	5.57	42.12	58.43	43.43	37.38
	C	-	70.8	737.0	830.3	387.1	506.3	5.43	47.53	59.05	45.76	39.43
PG	A	+	352.0	1243	847.2	446.5	722.3	15.90	52.42	59.62	59.99	46.97
	B	+	100.5	584.6	612.5	300.8	399.6	12.11	53.52	60.01	60.61	46.55
	C	+	302.2	1123	781.5	453.1	665.1	13.42	49.23	52.33	53.25	42.04
	A	-	317.0	839	831.0	437.7	606.2	17.62	51.41	52.74	51.65	43.34
	B	-	135.4	517.5	696.6	291.7	410.3	10.63	49.92	53.59	52.00	41.52
	C	-	267.6	1006	818.7	449.3	635.4	14.33	50.83	51.54	50.92	41.88
Mean with Ekolist – Średnio z Ekolistem			164.5	873.2	730.8	380.4	537.2	11.02	50.17	65.31	52.48	44.74
Mean without Ekolist – Średnio bez Ekolistu			156.8	750.2	742.4	336.1	496.4	10.00	48.60	56.84	48.63	41.02
LSD $_{0.05}$ for: soil – $NIR_{0.05}$ dla: gleby – A			3.91	20.7	5.74	19.55		0.529	1.113	1.756	1.832	
Seeds origin – Pochodzenie nasion – B			5.78	30.65	8.50	28.94		0.783	n.s.	2.600	2.712	
Ekolist application – Stosowanie Ekolistu – C			3.91	20.70	5.74	19.55		0.529	n.s.	1.756	1.832	
Interaction – Interakcja		A × B	10.14	53.66	14.89	50.66		1.371	2.885	4.552	n.s.	
		A × C	n.s.	39.10	10.85	39.92		0.999	n.s.	3.317	3.461	
		B × C	n.s.	53.66	14.89	50.66		n.s.	n.s.	4.552	4.749	

* PG – heavy loamy sand, piasek gliniasty mocny; PS – slightly loamy sand, piasek słabo gliniasty
** Explanations like in Material and methods, wyjaśnienia w rozdziale Materiał i metody

Table 2. Average height of plant and length of inflorescence of goldenrod in the following years of cultivation depending on experimental factors

Tabela 2. Średnia wysokość roślin oraz długość kwiatostanu nawłoci w kolejnych latach uprawy w zależności od czynników doświadczenia

Soil Gleba	Seeds origin Pochodzenie nasion	Ekolist application Stosowanie Ekolistu	Height of plant (in cm) Wysokość roślin (w cm)					Length of inflorescence (in cm) Długość kwiatostanu (w cm)				
			1st	2nd	3rd	4th	Mean Średnio	1st	2nd	3rd	4th	Mean Średnio
PS*	A**	+	64.4	68.1	90.2	64.8	71.9	25.8	39.2	30.7	21.8	29.4
	B	+	60.8	81.9	97.3	70.8	77.7	35.0	44.1	61.6	46.1	46.7
	C	+	50.6	89.1	103.1	85.9	82.2	14.8	61.5	29.5	53.6	39.9
	A	-	42.7	72.3	85.1	64.2	66.1	19.6	43.8	21.1	41.5	31.5
	B	-	47.8	72.3	84.1	62.2	66.6	20.2	45.2	52.9	40.0	39.6
	C	-	48.7	86.5	93.2	75.3	75.9	18.8	40.5	29.4	40.5	32.6
PG	A	+	77.3	94.2	86.1	59.5	79.3	35.6	33.9	23.9	39.8	33.3
	B	+	73.5	82.1	74.5	40.2	67.6	44.6	31.8	39.8	22.9	34.8
	C	+	80.5	93.1	89.2	68.9	82.9	46.8	35.0	25.0	41.1	37.0
	A	-	84.1	85.2	84.6	68.5	80.6	42.6	41.5	21.5	50.2	39.0
	B	-	70.0	89.3	68.8	43.5	67.9	42.4	31.4	41.4	32.1	36.8
	C	-	84.8	89.3	84.9	62.5	80.5	42.9	31.0	29.0	47.3	37.6
Mean with Ekolist – Średnio z Ekolistem			67.9	84.8	90.1	65.0	76.9	33.8	40.9	35.1	37.6	36.8
Mean without Ekolist – Średnio bez Ekolistu			63.0	82.5	83.5	62.5	72.9	31.1	38.9	32.6	42.1	36.2
LSD $_{0.05}$ for: soil – $NIR_{0.05}$ dla: gleby – A			2.92	1.37	2.69	1.43		2.43	3.15	1.48	n.s.	
Seeds origin – Pochodzenie nasion – B			n.s.	2.03	3.99	2.12		3.60	n.s.	2.19	4.27	
Ekolist application – Stosowanie Ekolistu – C			2.92	n.s.	2.69	1.43		2.43	n.s.	1.48	n.s.	
Interaction – Interakcja		A × B	7.58	3.55	6.99	3.71		6.31	8.16	3.85	7.48	
		A × C	5.52	n.s.	5.09	2.71		4.59	n.s.	2.81	5.45	
		B × C	7.58	n.s.	n.s.	3.71		6.31	8.16	3.85	7.84	

PG – heavy loamy sand, piasek gliniasty mocny; PS – slightly loamy sand, piasek słabo gliniasty
** explanations like in Material and methods, wyjaśnienia w rozdziale Materiał i metody

Table 3. Leiocarposide content and its theoretical yield in goldenrod raw material in three years of cultivation depending on experimental factors

Tabela 3. Zawartość i teoretyczne plony lejokarpozydu w surowcu nawłoci w kolejnych latach uprawy w zależności od czynników doświadczenia

Soil Gleba	Seeds origin Pochodzenie nasion	Ekolist application Stosowanie Ekolistu	Leiocarposide content % Zawartość lejokarpozydu %			Yields of leiocarposide (in kg · ha^{-1}) Plony lejokarpozydu (w kg · ha^{-1})			
			1st	2nd	3rd	1st	2nd	3rd	Total Ogółem
PS*	A**	+	1.60	1.33	1.11	15.2	68.6	70.8	154.6
	B	+	0.92	1.05	1.06	4.7	69.0	57.9	131.8
	C	+	1.18	1.17	1.08	10.1	130.4	103.6	244.0
	A	-	0.70	0.58	0.97	7.8	42.8	66.5	117.2
	B	-	0.94	0.54	1.15	3.7	36.1	68.1	107.8
	C	-	1.08	0.94	1.17	7.7	69.3	97.1	174.1
PG	A	+	1.0	1.42	0.98	35.3	176.6	83.0	294.9
	B	+	0.89	1.20	0.89	9.0	70.2	54.5	133.7
	C	+	0.97	1.11	0.91	29.3	124.7	71.1	225.1
	A	-	0.78	0.64	0.54	24.6	54.0	44.8	123.5
	B	-	0.47	0.53	0.47	6.3	27.4	32.7	66.5
	C	-	0.97	0.80	0.68	25.8	80.8	55.7	162.3
Mean with Ekolist – Średnio z Ekolistem			1.09	1.21	1.01	18.8	106.3	73.3	196.4
Mean without Ekolist – Średnio bez Ekolistu			0.82	0.67	0.83	12.2	50.5	60.6	123.2
LSD $_{0.05}$ for: soil – $NIR_{0.05}$ dla: gleby – A			0.033	n.s.	0.026	0.37	3.99	3.01	
Seeds origin – Pochodzenie nasion – B			0.049	0.058	0.039	0.55	5.91	4.47	
Ekolist application – Stosowanie Ekolistu – C			0.043	0.039	0.026	0.37	3.99	3.01	
Interaction – Interakcja		A × B	0.086	1.011	0.067	0.96	10.35	7.82	
		A × C	0.063	0.073	0.049	0.70	7.54	5.70	
		B × C	0.086	1.011	0.067	0.96	10.35	7.82	

PG – heavy loamy sand, piasek gliniasty mocny; PS – slightly loamy sand, piasek słabo gliniasty
** explanations like in Material and methods, wyjaśnienia w rozdziale Materiał i metody

Table 4. Chosen macro- and microelements content in goldenrod herb (mean from four following years of cultivation)

Tabela 4. Zawartość wybranych makro- i mikroelementów w zielu nawłoci (średnio z czterech kolejnych lat uprawy)

Soil Gleba	Seeds origin Pochodzenie nasion	Ekolist application Stosowanie Ekolistu	Average content (in %) Średnia zawartość (w %)				Average content (in mg· kg^{-1} of d m) Średnia zawartość (w mg· kg^{-1} sm)			
			P	K	Ca	Mg	Cu	Zn	Fe	Mn
PS*	A**	+	0.32	2.65	0.85	0.12	11.82	66.02	96.35	679.64
	B	+	0.34	2.91	0.84	0.13	13.17	52.40	102.28	442.64
	C	+	0.32	2.69	0.87	0.10	12.80	58.07	83.56	648.04
	A	-	0.32	2.83	0.89	0.09	8.04	52.09	103.45	504.83
	B	-	0.34	2.97	0.73	0.08	12.97	59.93	67.20	487.44
	C	-	0.30	2.67	0.82	0.09	11.01	68.56	116.11	752.99
PG	A	+	0.56	3.11	0.89	0.16	14.10	44.48	157.86	83.62
	B	+	0.40	3.09	0.63	0.16	8.68	30.15	102.05	53.93
	C	+	0.62	2.99	0.95	0.18	12.17	35.30	88.90	60.33
	A	-	0.45	2.98	0.83	0.17	8.58	39.88	72.22	80.33
	B	-	0.39	2.93	0.80	0.17	9.65	31.17	73.82	55.17
	C	-	0.50	2.99	0.84	0.18	9.83	38.72	73.98	63.10
Mean with Ekolist – Średnio z Ekolistem			0.42	2.90	0.84	0.14	12.12	47.74	105.17	328.03
Mean without Ekolist – Średnio bez Ekolistu			0.38	2.90	0.82	0.13	10.01	48.39	84.45	324.06
LSD $_{0.05}$ for: soil – NIR$_{0.05}$ dla: gleby – A			0.034	0.351	n.s.	0.007	0.227	0.411	n.s.	20.012
Seeds origin – Poc hodzenie nasion – B			0.050	n.s.	0.055	n.s.	0.336	0.608	3.031	29.630
Ekolist application – Stosowanie Ekolistu – C			0.034	n.s.	n.s.	0.007	0.227	0.411	2.047	n.s.
Interaction – Interakcja		A × B	0.088	n.s.	0.097	0.019	0.588	1.064	5.308	51.874
		A × C	0.064	n.s.	n.s.	0.014	n.s.	0.775	3.868	n.s.
		B × C	n.s.	n.s.	n.s.	n.s.	0.588	1.064	5.308	51.874

PG – heavy loamy sand, piasek gliniasty mocny; PS – slightly loamy sand (piasek słabo gliniasty)
** explanations like in Material and methods, wyjaśnienia w rozdziale Materiał i metody

Raw material quality for pharmaceutical purposes is determined by the active substance content. In the experiment goldenrod herb contained a relatively high amount of leiocarposide (0.5% is recognized as a minimal amount). Its content ranged from 0.47% to 1.60% (Tab. 3) and was higher than that reported by Lück *et al*. [2000], Gruszczyk and Kiełtyka [2005] or Hiller and Bader [1996]. Similarly, like in the case of height and yields of aboveground parts of plants, a higher active compound content was stated on plots with plants obtained from diasporas collected from the natural state near Puławy (C) but grown on slightly loamy sand. What is more, an increase in leiocarposide content in goldenrod raw material from the plots additionally fertilised with Ekolist was observed (from 0.18% in the third to 0.54% year of vegetation) – Table 3. In the experiment, a tendency to increase its content on plots with a higher length of inflorescences was noted, which is consistent with Bohr and Plescher [1997] results, who noticed that leiocarposide is accumulated mainly in goldenrod flower heads and leaves. Leiocarposide content and goldenrod herb yields enable to calculate theoretical leiocarposide yields. It significantly depended on the experimental factors, the highest being in the second and third years of vegetation, on heavy loamy sand (on average by 4.7% in comparison to that obtained on slightly loamy sand), on plots with plants obtained from diasporas collected from the natural state near Puławy (C) and after Ekolistapplication (on average by 37.2%) – Table 3. The same relationship in the case of ginseng was observed by Magdziak and Kołodziej [2007].

As far as mineral composition is concerned, independently of other experimental factors foliar fertilization positively affected macro-and microelements content in the aboveground parts of goldenrod plants. *Solidaginis Herba* collected from heavy loamy sand contained a slightly higher content of macroelements and at the same time a lower content of microelements in comparison to that obtained from slightly loamy sand (Tab. 4). In our earlier studies [Kołodziej 2002] we observed similar relationships. There were not observed significant differences in chosen mineral constituents content depending on the origin of diasporas. However, in the course of the experiment there was a tendency to increase mineral compounds content in goldenrod raw material after Ekolist application.

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Streszczenie. W czteroletnim doświadczeniu polowym badano wpływ nawożenia dolistnego 2% Ekolistem, pochodzenia nasion oraz gleby na parametry morfologiczne, plony i skład chemiczny nawłoci. Zastosowane czynniki eksperymentalne w istotny sposób wpłynęły na parametry morfologiczne, plony i skład chemiczny roślin nawłoci. Niezależnie od pozostałych czynników doświadczenia największe plony ziela otrzymano w drugim i trzecim roku uprawy, a w kolejnym roku obserwowano znaczne zmniejszenie potencjału plonowania roślin. Istotnie wyższe plony *Soliadaginis Herba*, charakteryzujące się najdłuższymi łodygami i kwiatostanami oraz zawartością lejokarpozydu i makroelementów otrzymano na piasku gliniastym mocnym. Jednocześnie najdłuższe pędy i kwiatostany, a także plony surowca o najwyższej zawartości związków aktywnych notowano na poletkach otrzymanych z niełupek zebranych ze stanu naturalnego w pobliżu Puław, zaś najmniejsze z Rabinówki. Podczas czterech kolejnych lat uprawy nawłoci istotnie wyższe plony części nadziemnych roślin (średnio o 8%), charakteryzujące się dłuższymi pędami i kwiatostanami a także większą zawartością lejokarpozydu oraz składników mineralnych stwierdzono na poletkach opryskiwanych Ekolistem.

Słowa kluczowe: nawłoć pospolita, *Solidago virgaurea* L., nawożenia dolistne, pochodzenie nasion