Selected Features of Canadian Goldenrod That Predispose the Plant to Phytoremediation

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ABSTRACT

Solidago canadensis (Canadian goldenrod) is an invasive plant species occurring in Poland. Canadian goldenrod tolerates a wide range of habitat conditions, it grows in landfills and soils contaminated with heavy metals. The paper presents the selected biometric features of the plant which indicate the possibility of its use for phytoremediation purposes. The analysis was based on the results of own research and literature data. The biometric features of the plant chose for the research are: aboveground biomass (which reaches about 4.4 tons d.m/ha on a surface covered with the plant in more than 70%), the possibility of annual collection of the aboveground parts and their use for energy purposes, extensive roots and rhizomes system ensuring soil stabilization, high accumulation of some metals in the underground parts of the plant.

Keywords: aboveground biomass, underground biomass, phytostabilization, *Solidago canadensis*

INTRODUCTION

Various plant species are used in the phytoremediation processes to treat soil contaminated with heavy metals [Laghlimi et. al. 2015]. The selection of plants for phytoremediation depends e.g. on the type and depth of soil contamination. The plants which are frequently used for this purpose tolerate high levels of heavy metals in the soil. They easily take up metals from the soil and either stabilize them in roots or relocate them to their aboveground parts. The plants are characterized by rapid growth, high biomass and ease of collection [Kabała et al. 2010, Laghlimi et al. 2015, Salt et al. 1995, Susarla et al. 2002]. Although the list of plant species used in phytoremediation is long, there is still the need to identify new species which have the ability to remove heavy metals from the soil and can be used for industrial purposes [Laghlimi et al. 2015]. The significance of seasonal flowering plants is often emphasized in phytoremediation. Annual or seasonal harvest of their aboveground parts contributes to the systematic removal of metals from the soil [Sinha et al. 2013]. In phytoremediation, it is also reasonable to use the species that overgrow various habitats, e.g. mining dumps or industrial waste dumps [Thangavel and Subhuram 2004].

The Canadian goldenrod (*Solidago canadensis* L.) is the plant that has recently received much attention because of its invasive nature. The native range of the goldenrod is North America [Weber and Jacobs 2005]. In Europe and Asia, *S. canadensis* is quickly entering new areas [Huang and Guo 2005]. This species tolerates a wide range of habitat conditions [Huang et al. 2007, Jin et al. 2004, Szymura and Wolski 2006]. It also shows high tolerance to heavy metals contamination [Huang et al. 2007, Xiang et al. 2010]. It occurs in abandoned arable fields [Rola and Rola 2010, Szymura and Wolski 2006], as well as in post-industrial wastelands [Antonijevic et al. 2012, Nowińska et al. 2012, Vega et al. 2004]. In the places of occurrence, especially in anthropogenic habitats, it forms extensive and compact fields [Holeksa et al. 2015, Szymura and Wolski 2006]. *S. canadensis* is a perennial plant. Every year, it produces aboveground ramets and underground rhizomes. Individual clones form dense clusters, depending on the age of the maple,

composed of many ramets. Canadian goldenrod also reaches high aboveground biomass, estimated at about 7.7 tones of fresh matter per ha, with over 70% coverage of the area [Jezierska-Domaradzka and Domaradzki 2012]. The plant has an extensive root and underground rhizomes system. The roots diverge to the base of the ramets and reach a depth of at least 20 cm [Weber 2000].

The information on selected goldenrod features that predispose it as a plant that could be used in phytoremediation of the soils contaminated with heavy metals is poorly recognized. The purpose of this paper is to analyze the selected goldenrod features that predispose the plant for phytoremediation purposes. The analysis was based on the literature data and own research, covering the selected biometric features of *S. canadensis* occurring in two locations in Poland, differing in the time of occurrence of the goldenrod.

MATERIAL AND METHODS

The plant for study was collected in the locations in Poland situated about 350 km from each other: Siedlce (52° 10′ N, 22° 17′ E) and Olkusz (50° 16′ N, 19° 33′ E). In the last decade, *S. canadensis* began to appear massively in the vicinity of Siedlce [Rzymowska 2015]. In the vicinity of Olkusz, numerous sites of *S. canadensis* were recorded as early as in the 1980s [Guzikowa and Maycook 1986, Holeksa et al. 2015].

At each location, 25 sites were randomly selected for the study. The stands where the goldenrod occurred occupied an area of at least 500 m^2. Three plots (3×3 m) were selected at each site. The goldenrod samples were cut out of each selected plot using a 0.16 m^2 frame, and then the underground parts of the plant, containing rhizomes and roots, were dug from a depth of up to 20 cm. In the field, the degree of coverage of a selected position with the goldenrod, the density of ramets and the length of cut ramets were measured. A representative sample of the aboveground parts of the plant (20 ramets) was taken from each plot. In the laboratory, the aboveground parts of the plant, i.e. leaves, stems and inflorescences, were separated from each other. The fresh mass was determined, and then the dry mass was determined by drying at 60°C. The percentage share of leaves, stems and inflorescences in the dry matter of the plant was calculated. The underground parts of the plant were washed thoroughly under running

water, and then rinsed in distilled water. The rhizomes were separated from the roots. After drying at 60°C, the weight of rhizomes and roots was measured and the percentage of rhizomes in the underground parts of the plant was determined.

The normality of data was tested using the Shapiro-Wilk test. In order to compare the values of the measured parameters in the samples collected in Siedlce and Olkusz, the Mann-Whitney test (not normally distributed data) or t-test (normally distributed data) were used.

RESULTS AND DISCUSSION

The average percentage cover of *S. canadensis* of the studied sites was about 70% and the density of ramets per m^2 of the surface varied within the range of 12–89 (Table 1). These parameters were significantly correlated (R = 0.67, p < 0.001) (Fig. 1).

The mean dry biomass of the aboveground parts of *S. canadensis* per 1 ramet was above 10 g and of underground parts – about 7 g (Table 1). There were no significant differences in the mass of aboveground and underground parts of *S. canadensis* in the two studied locations.

In both locations, among the aboveground parts of the plant, stems corresponded to about 54% of the ramet biomass. The average percentage share of leaves and inflorescences was comparable and amounted to slightly over 20%. Among the underground parts, rhizomes constituted the dominant share in biomass in the two locations (Table 2).

There were no significant relationships (p > 0.05) between the dry mass of the aboveground and underground parts of the goldenrod and the density of ramets (R = – 0.05 and R = – 0.06, respectively) and between the dry mass of the aboveground and underground parts and the percentage cover of plots with the goldenrod (R = – 0.06 and R = – 0.07). There was also no significant correlation between the height of ramets and the density (R = 0.17) as well as the height of ramets and the percentage coverage (R = 0.15).

The mass of 1 ramet and the density of ramets on the plots were taken into account to calculate the goldenrod biomass per 1 m^2 (Table 3). The fresh mass of the aboveground parts varied in the range 119–2735 g/m^2, the dry biomass of the aboveground parts ranged from 50.9 to 1136 g/m^2 and the dry biomass of underground parts was in the range
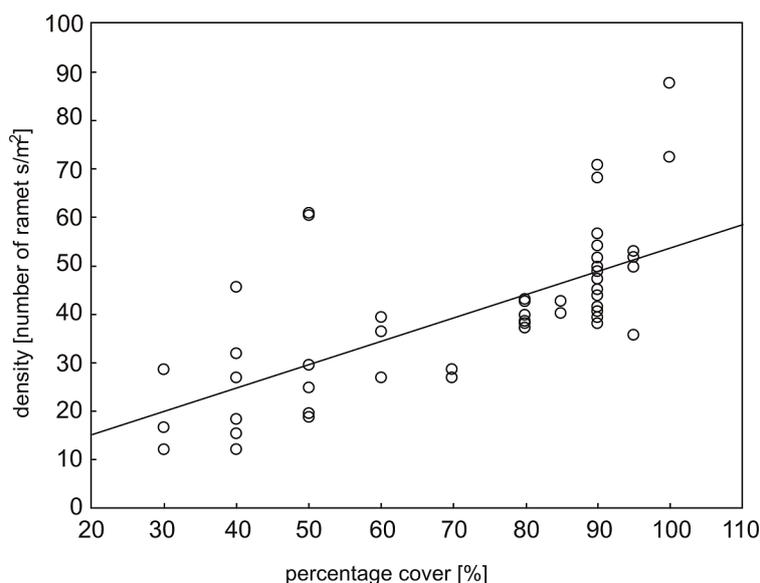
Fig. 1. Correlation between percentage cover and density of ramets of *Solidago canadensis*

Table 1. The mean values ± SD and the range of measured parameters: percentage cover, density, height of ramets, dry mass of the aboveground and underground parts calculated for 1 ramet of *Solidago canadensis* in Siedlce and Olkusz

Parameter		Unit	Siedlce	Olkusz	Values of statistiacal tests
Percentage cover		%	72.2 ± 24.1 (30 − 100)	72.8 ± 23.1 (30 − 95)	Z = 0.32, p = 0.75
Density		number of ramets/m²	45 ± 18.3 (15 − 89)	36 ± 12.3 (12 − 54)	t = 2.03, p = 0.048, df = 48
Height of ramet		cm	121.4 ± 28.6 (35 − 193)	116.6 ± 28.9 (39 − 198)	t=4.604, p < 0.001, df=3095
Dry mass of parts	aboveground	g/ramet	10.4 ± 4.2 (2.73 − 19.2)	11.9 ± 2.6 (8.45 − 16.9)	t = 1.59, p = 0.12, df = 48
	underground		7.28 ± 2.18 (3.5 − 13.0)	6.3 ± 2.8 (2.33 − 13.3)	t =1.33, p = 0.19, df = 48

Table 2. Percentage of individual morphological parts in dry biomass of *Solidago canadensis* in aboveground and underground parts per 1 ramet

Parts of plant		Siedlce	Olkusz	t-test values
Aboveground parts	Stems	54.1 ± 5.42	54.5 ± 6.22	t=0.25, p=0.81
	Leaves	23.7 ± 4.94	24.4 ± 5.90	t=0.47, p=0,64
	Inflorescenses	22.2 ± 4.22	21.1 ± 5.00	t=0.87,p=0.39
Underground parts	Rhizomes	68.2 ± 6.40	72.2 ± 10.9	t=1.59, p=0.12
	Roots	31.8 ± 6.40	27.8 ± 10.9	t=1.59, p=0.12

$32.8–564.4$ g/m². There were no differences in the aboveground and underground goldenrod biomass calculated per 1 m² of area in the two locations.

The results for the biomass of the aboveground parts of *Solidago canadensis* obtained for our study are about 1 ton higher than the values measured by Jezierska-Domaradzka and Domaradzki [2012]. The authors harvested the aboveground parts of the goldenrod before the flowering period. For our research, the samples were taken during the period of intensive flowering of the plant.

The share of inflorescences in the biomass of the aboveground parts of *S. candensis* was above 20%, which is about 1 ton d.m./ha. The inflorescence biomass probably determined the larger results. The goldenrod biomass obtained for our study is comparable to e.g. the biomass of *Calamagrostis epigejos* [Grzelak et al. 2016] and about a half of the biomass of e.g. *Miscanthus giganteus*, *Helianthus tuberosus* or *Sida hermaphrodita* [Kabała et al. 2010] (Table 4). The listed plant species, in addition to their use in phytoremediation of soils

Table 3. Fresh and dry mass of aboveground and dry mass of underground parts of *Solidago canadensis* calculated per 1 m^2

Parameter	Unit	Siedlce	Olkusz	Mann-Whitney test values
Fresh mass of aboveground parts	g/m^2	1034 ± 605.8 (119 – 2735)	999 ± 485 (251 – 2274)	Z=0.31, p=0.76
Dry mass of aboveground parts		473 ± 273 (50.9 – 1136)	409 ± 193 (93.6 – 880)	Z=0.76, p=0.45
Dry mass of underground parts		303 ± 118 (81.8 – 564.4)	254 ± 181 (32.8 – 407)	Z=1.82, p=0.07

contaminated with heavy metals, are also characterized by a high energy value comparable to brown coal (Table 5). Due to the high biomass of the aboveground parts and high energy value of the goldenrod, the possibility of using the plant for energy purposes was indicated [e.g. Biskupski et al. 2012, Patrzałek et al. 2012].

There is relatively little research on the content of metals in individual morphological parts of the goldenrod. The research carried out by Nowińska et al. [2012] on the accumulation of selected heavy metals (Pb, Zn, Hg) in the aboveround *Solidago* parts collected from the flotation settler of zinc and lead ores as well as the coal mining waste dump showed a relatively low metal content in the examined parts of the plant. In turn, Antonijevic et al. [2012] reported that *S. canadensis* occurring in a region heavily contaminated with metals (Copper Mining and Smelting Complex Bor in Serbia) accumulates individual metals in various proportions in the aboveground and underground parts. For example, the

Zn content in the aboveground goldenrod parts is comparable to its content in the roots, the Mn content is higher in the aboveground parts than in the roots, while the Cu, As and Pb contents are higher in the roots than the stems and leaves. Similarly, Antonijevic et al. [2012] and Yang et al. [2008] indicate a high accumulation of Pb in roots and rhizomes of *S. canadensis*. The authors report that the ratio of the Pb content in underground *S. canadensis* parts to the aboveground parts is 31 at 300 mg Pb/kg soil, and 110 at 600 mg Pb/kg soil. Xiang et al. [2010] emphasize the role of roots of *S. canadensis* as an accumulator of lead. Similarly, Majtkowski et al. [2011] determined a higher accumulation of Pb and Cr in the roots than the aboveground parts of *S. canadensis* collected in the area contaminated with sewage sludge from the wastewater treatment plant in Bydgoszcz (Poland). The research conducted by Tomiyasu et al. [2005] showed that the *Solidago* roots accumulate far more Hg than its stems and leaves. Fu et al. [2017] identified *S. canadensis* as

Table 4. Comparison of the biomass of aboveground goldenrod parts with the biomass of other plant species used for remediation and energy purposes

Species of plant	Reference field [tons dry mater/ha]	References
Solidago canadensis	4.4 (max – 11.4)	In this paper
	3.3	Jezierska- Domaradzka and Domaradzki [2012]
Miscantus x giganteus	10 (max -25)	Kabała et al. [2010]
Helianthus tuberosus	8	
Sida hermaphrodita	9 (max – 25)	
Calamagrostis epigejos	4,03–4,47	Grzelak et al. [2016]

Table 5. Heating value of brown coal and selected plant species

Charge	Heating value [MJ·kg^{-1} d.m.]	References
Brown coal	21.8–30.2	Patrzałek et al. [2012]
Species of plant:		
Solidago sp.	19.3	
Miscantus x giganteus	19.5	Godin et al. [2013]
Helianthus tuberosus	17.6	
Sida hermaphrodita	14.4	Lisowski et al. [2018]
Calamagrostis epigejos	17,5	Grzelak et al. [2016]

a plant tolerant to cadmium accumulation and a potential species for phytoremediation.

According to the presented literature, due to a very extensive root system (Photo 1), goldenrod tends to accumulate more of some metals, e.g. Pb in roots than in its aboveground parts.

The literature lacks the information on the metals content in rhizomes of the plant. Our research shows that rhizomes make up about 70% of the biomass of underground parts of *S. canadensis*. With roots they can play a significant role in the accumulation of some metals. In addition, an extensive underground system can play a stabilizing role and prevent the erosion of soil which is especially important in landfills containing large amounts of metals.

The results of the studies showed that such parameters as density and the percentage cover of plots with *S. canadensis* have no effect on the biomass of the aboveground and underground parts of the goldenrod and the height of its ramets. The goldenrod biomass is also not affected by the time of goldenrod occurrence at the sites. In the areas overgrown by the goldenrod (including contaminated sites e.g. landfills), the plant may create a protective barrier for the areas adjacent to it.

Photo 1. Underground parts of *Solidago canadensis*

CONCLUSIONS

The features of *Solidago canadensis* that predispose the plant for the phytoremediation purposes are:
- high tolerance to heavy metals soil contamination;
- high biomass of the aboveground parts, comparable to the biomass of other plant species used in phytoremediation;
- possibility of annual harvesting of the aboveground parts and their high energy value comparable to other plant species used in phytoremediation;
- extensive roots and rhizomes system that stabilizes the soil and provides protection against erosion.

Due to high accumulation of selected metals in the roots, the Canadian goldenrod can be considered as a metal phytostabilizer (e.g. Pb, Cr, Hg) in contaminated soils.

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