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Accumulation of nutrients in the aboveground biomass of *Reynoutria japonica* from suburban area

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ABSTRACT

Reynoutria japonica is an invasive species, characterised by rapid growth and abundant biomass. It is undesirable in the environment due to its negative impact on other plant species and on the physicochemical properties of the soil in its surroundings. Current research concentrates mainly on the use of biomass of this species as a fertiliser or additive enriching the quality of compost. The aim of the study was to assess the chemical composition (C, N, P, K, Mg, Zn, Cu, Mn, Fe) of the *R. japonica* biomass from the suburban zone in terms of its use as an additive enriching the quality of compost. The results of the research indicate that both the leaves and stems of *R. japonica* were sufficiently rich in nutrients (N, P, K, Mg) and at the same time safe due to the small amounts of heavy metals contained in them (Zn, Cu, Fe, Mn). The values of the bioconcentration factor (BCF) for N, P, K and Mg in leaves as well as N, P and K in thin and thick stems were >1, which indicates that the above-ground biomass of *R. japonica* is a valuable source of macronutrients. At the same time, the BCF values for Zn were ~1.06, while for Fe, Mn, and Cu both in the leaves and in the stems were <1, which confirms that the above-ground biomass of *R. japonica* from the suburban zone is a valuable component of compost, in which the analysed heavy metals will play the role of micronutrients. There were also highly statistically significant differences ($p<0.001$) in Zn and Mn content and ($p<0.01$) in the case of C, N, P, Mg, Fe and Cu between the leaves and stems of *R. japonica*.

Keywords: biomass management, invasive species, forest, soil, bioconcentration factor, translocation factor.

INTRODUCTION

Reynoutria japonica is an alien species, imported to Europe in the 19th century as an ornamental and fodder plant, characterised by rapid growth and abundant biomass. Currently, it is considered a highly expansive invasive species [Sołtysiak and Brej, 2014, Bzdęga et al., 2018], which spreads very quickly, occupying larger and larger areas. It prefers heavily transformed anthropogenic habitats [Mandák et al., 2004]. It inhabits both urban areas, ruderal places, i.e. roadsides, rubble, landfills, as well as parks, suburban meadows and river valleys [Tokarska-Guzik et al. 2006]. This species also easily penetrates forests, especially riparian forests, while it is less common in agricultural areas [Alberternst and Böhmer, 2011]. According to literature reports, *R. japonica* is an undemanding species in terms of soil conditions, characterised by a wide ecological amplitude. It thrives on several types of soils, with diverse physicochemical properties, both acidic and neutral (pH=3.5–7.4), [Alberternst and Böhmer, 2011, Parzych, Sobisz, 2024]. It tolerates high air temperatures, drought, salinity and periodic floodings [Shaw and Seiger, 2002], but is sensitive to negative temperatures. It is characterised by a high tolerance to soil contamination, e.g. with sulphur compounds or heavy metals (Cd, Cr, As, Pb), [Rahmanova et al., 2014, Ibrahimpašić et al., 2020]. The strongly developed root system of *R. japonica* adversely affects the surrounding plants. Literature data indicate that many invasive plants produce chemicals in the leaves or roots that inhibit the growth of other plant species in their vicinity [Vrchotová and Šerá, 2008, Murrell et al., 2011]. Due to the threat to native species and the damage it causes [Aguilera et al. 2010] it is undesirable in the natural environment. Therefore, it is recommended to remove *R. japonica* before the flowering period and destroy its shoots, as it regrows easily [Romański et al., 2014]. The increase in the interest of scientists in this species is mainly related to its rapid spread, special resistance to environmental pollution [Alberternst and Bohmer, 2006, Bailey et al., 2007, Bradley et al., 2010], negative impact on the physicochemical properties of the soil [Rahmanov et al., 2014, Colleran et al., 2020] and the possibility of using its abundant biomass as a fertiliser [Cvejić et al., 2021] or an additive enriching the quality of compost [Bajor et al., 2004, Day et al., 2009].

The aim of the study was: (1) to determine whether the above-ground biomass of *R. japonica*, inhabiting the forest area in the suburban zone of Słupsk, is sufficiently rich in macronutrients, (2) safe due to heavy metals accumulated in the leaves and stems, and (3) to assess whether, due to the chemical composition (C, N, P, K, Mg, Fe, Mn, Zn, Cu), the removed biomass can be used as an additive enriching the quality of compost.

MATERIALS AND METHODS

Research area

Monitoring studies covered the site of *R. japonica* (Figure 1) located in the suburban zone of Słupsk, at the edge of the forest. This knotweed occupies an area of about 30 m^2. In its immediate vicinity, the trees of *Pinus sylvestris, Quercus robur, Picea abies, Acer platanoides* and *Acer pseudoplatanus* grow. In the growing season, the above-ground shoots of *R. japonica* reached a maximum height of 2 m, and the diameter of the lower parts of the shoots was even 30 mm. Abundant aboveground biomass, especially large leaves, effectively limited the inflow of light to the substrate, which adversely affected the functioning of other plant species in the vicinity of *R. japonica*. The chemical composition of the leaves and stems was evaluated in the summer, immediately before the flowering period.

Sampling and analyses

For physicochemical and chemical tests, samples of leaves, thin shoots (with a diameter of 5–10 mm), thick shoots (20–30 mm) and soil samples (from a depth of 0–10 cm) were taken in ten repetitions. A total of 40 samples were taken, including 10 leaf samples, 10 samples of thin shoots, 10 samples of thick shoots and 10 samples of soil. The samples were subjected to preliminary preparation, including drying using a thermos-circulation, at a temperature of 65 °C to a constant weight. Subsequently, the soil was ground in a mortar, sieved through a 1 mm sieve and poured into tightly closed polyethylene string bags. After drying, plant samples were homogenised in a laboratory grinder (IKA, basic A11). In soil samples, the pH in an aqueous solution was determined using the potentiometric method and the organic matter content was determined by the weight loss method, after roasting the samples in a muffle furnace at 550 °C. The content of C and N was determined on a CHNS analyser (Flash Smart, ThermoScientific), which was calibrated using methionine as the reference material (Certificate number analysis – 291468, ThermoScientific). In soil and plant samples, the content of K, Mg, Fe, Mn, Zn and Cu was determined by atomic absorption spectrometry (ASA, iCE3500 ThermoScientific) in the flame version after mineralisation of samples in a microwave oven in a mixture of 65% HNO_3 and 30% H_2O_2 (ETHOS EASY, MILESTONE). The P content was determined using the spectrophotometric method (UV-VIS, Hitachi U-5100). All analyses were performed in triplicate.

Quality control of research results

The results of the experimental measurements agreed with the recommended reference value materials. Recoveries were calculated as a ratio of the determined value to the certified one and were within the confidence intervals of the certified values. Recoveries were as follows: 99 ± 1% (C), 98 ± 2% (N), 97 ± 3% (P), 98 ± 2% (K), 97± 3% (Mg), 100 ± 1% (Fe), 98 ± 1% (Mn), 100 ± 1% (Cu) and 98 ± 2% (Zn).

Preparation of results

Calculations and figures were performed using the software package Statistica 13.3 (Stat soft Inc., USA). The tables provide minimum and maximum values, medians, standard deviations, and coefficients of variation. The nonparametric Kruskall-Walis test was used to compare the nutrient content in leaves (L), thin stems (S-t) and thick stems (S_T), at $p<0.05$. The bioavailability

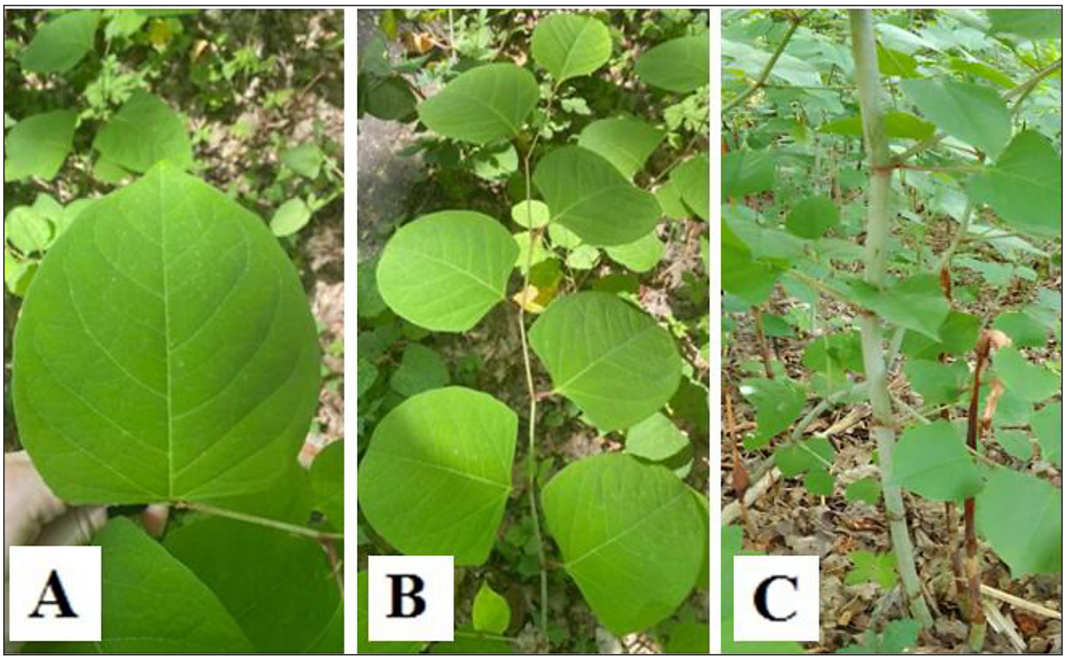

Figure 1. Leaves (A), thin stem (B) and thick stem (C) of *R. japonica* (photo Prakhoryk)

of nutrients for *R. japonica* was characterised by the bioconcentration factor (BCF). BCF was calculated as the ratio of each nutrient content in leaves, thin stems and thick stems to its content in the soil. The mobility of nutrients within biomass elements was expressed by translocation factor (TF). Translocation coefficients were calculated for the nutrient content in the ratios L/S-T, L/S-T and S-t/S-T.

RESULTS AND DISCUSSION

Physicochemical properties of soil

The soil samples from the rhizosphere of *R. japonica* showed a neutral reaction (Table 1), with the pH values varying from 6.54 to 7.56. On the area of 30 m^2, a slight variation in soil pH (Cv=5.74%) was demonstrated, which was associated with the distribution of *R. japonica* shoots. Soil pH is a crucial property affecting the availability to plants of both nutrients and potentially toxic substances. Taking into account all nutrients, the pH range 5.5–7.0 is considered optimal for mineral plant nutrition. Forest soils typically exhibit a pH of 3.0–6.0, especially under pine or spruce stands. In the case of deciduous stands, soil acidification is usually lower [Bednarek et al., 2005]. Varied soil pH in the rhizosphere of *R. japonica* was demonstrated by Rahmanov et al. [2019] conducting research in urban parks of southern Poland, as well as Alberternst and Böhmer [2011].

The content of organic matter in the soil samples ranged from 5.42 to 8.62% and showed a variation of 15.01% (Table 1). The source of soil organic matter (OM) in forests are plant debris, from trees and shrubs [Bednarek et al. 2005]. Plant leaf fall is an important link in the circulation of matter and the flow of energy. Its quantity and quality affect the morphology as well as properties of soils and plant nutrition [Parzych and Trojanowski, 2009]. Soil organic matter is a dynamic system, subject to constant changes during the growing season, leading to its complete decomposition [Jonczak, Parzych, 2016]. Most of the chemical elements are bound by the organic matter of the soil. Forest soils, characterised by a significant amount of organic matter in the topsoil layers, can accumulate much larger amounts of heavy metals than sandy or humus-poor soils [Traczewska, 2011].

In the summer, the soils under *R. japonica* were characterised by a very low content of macronutrients (Table 1). Nitrogen remained at the level of 0.0222% to 0.0798% and showed the greatest diversity (Cv= 38.49%) among the analysed elements. Nitrogen is a key component for plant growth, taken in much higher amounts than other nutrients [Curtin and Wen, 1999]. In the growing season, very low contents of N, P, K and Mg were demonstrated in soil samples, which was associated with intensive growth of *R. japonica* shoots. Phosphorus, potassium and magnesium showed variation, expressed as the coefficient of variation, at the levels of 16.91%, 14.45% and 20.29%, respectively. Intensive growth and development of plants in the growing season causes substantial changes in the content of nutrients in the soil and groundwater [Parzych 2010, 2011], especially if they occur in mobile forms, bioavailable for plants. As a result of nutrient uptake by plants, soil pH changes. According to Kabata-Pendias and Pendias [2001] most macronutrients, i.e. N, P, K and Mg present in the soil are bioavailable to plants at pH 6.0 to 8.0. The obtained data indicate that the pH of forest soil in the suburban zone of Słupsk favoured the uptake of macronutrients by *R. japonica,* but limited the mobility of Zn, Cu, Mn and Fe (Table 1), the bioavailability of which is greatest at pH<5.5. Zinc, copper, manganese, and iron perform crucial functions in plants as micronutrients. Their content in the leaves and shoots of *R. japonica* is significant, especially when used in the composting process [Parzych, 2022].

The content of Fe, Mn, Zn and Cu in the rhizosphere of *R. japonica* was differentiated (Table 1), but did not exceed the permissible level for forest soils. The highest variability was observed in the case of manganese (Cv=34.60%) and the lowest in iron (Cv=10.40%). The presence of trace elements in the soil depends on their content in the bedrock and the nature of soil formation processes. The Fe content in soils varies widely, from trace amounts to several percent. The average Mn content in forest soils is usually up to 500 mg/kg [Ostrowska et al., 1991], and in other soils up to 1300 mg/kg [Kabata-Pendias and Pendias, 1999]. According to literature data, the Zn content in the organic layers of forest soils is most often up to 200 mg/kg [Ostrowska et al., 1991], and in mineral layers up to 40 mg/kg [Kabata-Pendias and Pendias, 1999]. The total Cu content in forest soils in Poland ranges from 1.2 to 35.0 mg/kg in mineral layers and from 0.2 to 43 mg/kg in organic layers [Ostrowska et al., 1991]. Mobility in soil and assimilation of micronutrients for plants is related to soil pH. The greatest mobility of Cu, Zn, Mn and Fe compounds occurs in an acidic environment, at pH 4.0–5.5, and Mn also at pH~8 [Kabata-Pendias and Pendias, 1999]. This information indicates that the pH of soils in the rhizosphere of *R. japonica*, in the suburban zone of Słupsk, limited the solubility and mobility of zinc, copper and iron compounds (Table 1), and thus had a limiting effect on their absorption by plants.

Accumulation of C, N, P, K, Mg, Fe, Mn, Zn and Cu in the aboveground biomass of *R. japonica*

The tested fragments of above-ground biomass were characterised by a diverse content of nutrients. Very good supply of *R. japonica* leaves with basic macro and micronutrients was demonstrated (Figure 2). According to literature data, the content of macronutrients in the leaves of plants occurring in forests varies within wide limits and takes values from 1.3 to 3.1% (N), from 0.1 to 0.4% (P), from 0.5 to 1.2% (K), from 0.1 to 0.4% (Mg), [Ostrowska and Porębska, 2002]. Very good content of macronutrients (N, P, K, Mg) in the analysed samples indicates the suitability of above-ground *R. japonica* biomass from

Table 1. Physicochemical properties of soil from rhizosphere of *R. japonica*

Parameter	Minimum	Maximum	Median	Sd	Cv, %
pH	6.54	7.56	7.21	0.41	5.74
OM, %	5.42	8.62	6.46	1.03	15.01
N, %	0.0222	0.0798	0.0578	0.0208	38.49
P, mg/kg	223.01	346.97	296.48	49.12	16.91
K, mg/kg	1479.00	2082.50	1671.00	244.28	14.45
Mg, mg/kg	1495.00	2585.00	2020.00	420.35	20.29
Fe, mg/kg	5636.50	7166.00	6094.00	654.51	10.40
Mn, mg/kg	338.20	812.20	509.03	191.97	34.60
Zn, mg/kg	23.37	47.85	37.02	9.03	24.42
Cu, mg/kg	4.24	8.93	6.67	1.58	24.09

Note: pH=-log[H^+], OM – organic matter, Sd – standard deviation, Cv – coefficient of variation.

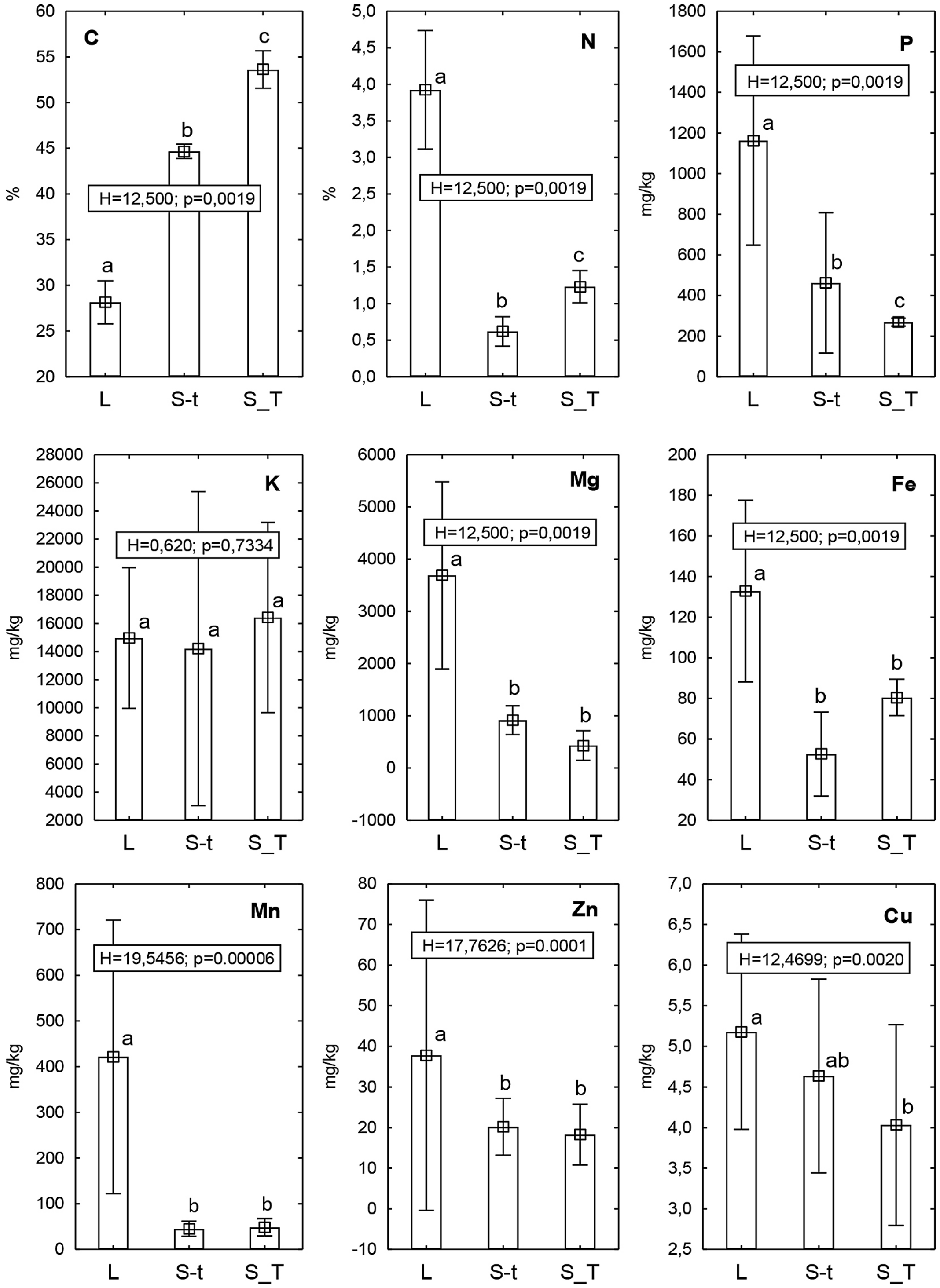

Figure 2. Content of C, N, P, K, Mg, Fe, Mn, Zn and Cu (mean and standard deviation) in leaves and stems of *R. japonica* with Kruskall-Walis test results. L- leaves, S-t – thin stems, S_T– thick stems

the suburban zone for composting. During the compost formation, the components accumulated therein are gradually released from the plant biomass. Macronutrients released in mobile and easily digestible forms become a valuable source of nutrients, enriching the quality of compost. The content of Mn, Fe, Cu and Zn in *R. japonica* biomass was also at a good level (Figure 2). Significantly higher contents of Mn (493 mg/kg), Fe (370 mg/kg), Cu (10.4 mg/kg) and Zn (82.5 mg/kg) in the leaves of *R. japonica* were found in Warsaw [Ostrowska and Porębska, 2002].

The highest amounts of N, P, Mg, Fe, Mn, Zn and Cu occurred in the leaves, and C and K in thick stems of *R. japonica* (Figure 2). Highly statistically significant differences in the Zn and Mn content ($p<0.001$) as well as C, N, P, Mg, Fe and Cu ($p<0.01$) were demonstrated when comparing leaves with stems. Only in the case of potassium, no statistically significant differences were observed. Most plants have a high ability to assimilate and accumulate K in above-ground biomass. According to Falkowski et al. [2000], the content of 17,000 mg/kg is assumed to be optimal. Potassium is one of the highly mobile elements in plants and is easily transferred from one organ to another, therefore no statistically significant differences were found in the above-ground biomass fragments studied. This is important especially with K deficiencies in the soil. Potassium may then be moved from the older leaves to the younger ones.

The mobility of nutrients from soil to above-ground biomass is very well characterised by values of bioconcentration factors (BCF). The BCF values for N, P, K and Mg in leaves and N, P and K in thin and thick stems assumed values >1 (Table 2), which indicates that the above-ground biomass of *R. japonica* is a valuable source of macronutrients. At the same time, the BCF values for Zn amount to 1.06, and for Fe, Mn, and Cu both in the leaves and in the stems they remain below 1, which indicates that the above-ground biomass of *R. japonica* from the suburban zone of Słupsk is a valuable component enriching the quality of compost, in which the analysed heavy metals play the role of micronutrients [Ostrowska and Porębska, 2002, Parzych, 2022]. Using the translocation factor (TF), the mutual relations between the content of nutrients in the tested biomass fragments were compared. It was shown that the leaves contain much higher amounts of N, P, K, Mg, Fe, Mn, Zn and Cu than thin shoots and more P, Mg, Fe, Mn, Zn and Cu than thick shoots (Table 2). The values of TF > 1 in the case of P, Mg, Zn and Cu confirm the efficient translocation of these elements from thick to thin shoots, and the greatest mobility (TF>8) from stems to leaves was shown by Mn. The mobility of manganese in plants is related to its important function. Mn is an essential element, facilitating the uptake and transport of other nutrients in plants [Alejandro et al., 2020]. It affects, among others, the uptake of Fe, Ca and Mg by plants and acts as a defence against pathogens [Tripathi et al., 2022]. It also contributes to the synthesis of lignin, a structural component of cell walls.

Literature data indicate that soils in urban and suburban areas often contain increased contents of Zn, Cu, Mn and Fe, which also affects their increased accumulation in plants [Grzebisz et al., 2002; Finžgar et al., 2007]. Increased content of some heavy metals in the needles and bark of coniferous species has also been shown [Sut-Lohmann et al., 2020, Jonczak et al., 2021]. However, it turns out that in forest areas, far from potential sources of pollution, the situation is much better. The content of heavy metals in the soil is much lower, in addition, the bioavailability of these metals to plants is limited by the neutral and slightly alkaline soil (Table 1). Therefore, the pH of the soil, in the suburban zone of Słupsk, at the test site favoured moderate accumulation of zinc, copper, manganese and iron in the leaves and stems of *R. japonica.* However, the research conducted by Böhmová and Šoltes [2017] and Rahmonova et al. [2019] indicates that *R. japonica* is characterised by a high potential for accumulation in aboveground biomass of other heavy metals, i.e. Cd or Pb, if it occurs on the soils contaminated with these elements. The preliminary but

Table 2. Bioconcentration factors (BCF) and translocation factors (TF) (mean ± sd) of N, P, K, Mg, Fe, Mn, Zn and Cu in aboveground biomass of *R. japonica* (L- leaves, S-t – thin stems, S_T– thick stems)

Elements	BCF			TF		
	L/soil	S-t/soil	S_T/soil	L/S-t	L/S_T	S-t/S_T
N	72.29±8.0	13.65±8.2	28.13±18.9	1.13±0.16	0.04±0.00	0.52±0.12
P	4.12±1.3	1.67±0.8	0.95±0.2	2.64±0.51	4.32±0.88	1.71±0.60
K	9.05±2.2	8.55±3.7	7.86±0.7	1.16±0.41	0.94±0.25	0.91±0.42
Mg	1.87±0.7	0.45±0.1	0.21±0.1	4.11±1.26	9.35±3.68	2.22±0.43
Fe	0.02±0.0	0.01±0.0	0.01±0.0	2.55±0.26	1.65±0.25	0.65±0.12
Mn	0.85±0.4	0.09±0.0	0.10±0.0	9.25±2.49	8.92±3.57	0.96±0.25
Zn	1.06±0.4	0.59±0.2	0.54±0.2	2.12±1.90	2.21±1.50	1.14±0.28
Cu	0.83±0.2	0.74±0.2	0.66±0.3	1.13±0.16	1.31±0.21	1.17±0.24

promising research results described by Cvejić et al. [2021] on the use of *R. japonica* biomass in the production of organic fertilizer offer hope for new possibilities for the management of the aboveground biomass of this species.

CONCLUSIONS

It was found that the samples of *R. japonica* from the suburban zone of Słupsk constitute a valuable material, regarding the abundance of their above-ground biomass. The results of the conducted research indicate that both the leaves and stems of *R. japonica* were sufficiently rich in nutrients (N, P, K, Mg) and at the same time safe due to the lesser amounts of heavy metals contained in them (Zn, Cu, Fe, Mn). The BCF values for N, P, K and Mg in leaves as well as N, P and K in thin and thick stems were >1, which indicates that the above-ground biomass of *R. japonica* is a valuable source of macronutrients. At the same time, the BCF values for Zn were ~1.06, and for Fe, Mn, and Cu both in the leaves and in the stems they were <1, which confirms that the above-ground biomass of *R. japonica* from the suburban zone is a valuable component of compost, in which the analysed heavy metals will play the role of micronutrients. In addition, highly statistically significant differences ($p<0.001$) in Zn and Mn content ($p<0.01$) were demonstrated in the case of C, N, P, Mg, Fe and Cu between the leaves and the knotweed stems.

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