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Research Article

COMPARING CAREX SPECIES OF MID-FOREST SPRING ECOSYSTEMS IN TERMS OF ABILITY TO ACCUMULATE MACRO- AND MICROELEMENTS

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ABSTRACT
The aim of the research was to compare the accumulative macro- and microelements in the shoots of *Carex acutiformis*, *Carex echinata*, *Carex paniculata*, *Carex remota* and *Carex rostrata*. The content of components in the shoots of the plants was analyzed in relation the chemical composition of the soil. The research was done within the area of four mid-forest spring niches situated in the valley of a tributary of the Słupia River located within the area of Leśny Dwór Forest Inspectorate (Northern Poland). The examined species of *Carex*, in comparison to other plants in spring niches, were characterized by an average capacity to accumulate both macro- and microelements, which results in little interest in these species when planning artificial buffer zones. Out of the analyzed species, the shoots of *C. echinata* accumulated the largest quantities of Mg, Zn and Mn, the shoots of *C. paniculata* –Fe, *C. remota* – K, Ni, Al and Sr, *C. acutiformis* – N and P, and the shoots of *C. rostrata* –Ca and Cu. Similarities between the species of *Carex*, which resulted from their accumulative properties, were discovered. *C. echinata* and *C. rostrata* were characterized by high levels of bioconcentration factors (BF) for Sr, Cu and Ca and low BF for K. C. *paniculata* and *C. remota* represented high BF levels for Ni and Mg and low BF levels for Sr, Al, Mn, Cu, Ca, Fe and N. On the other hand, *C. acutiformis* was characterized by high BF levels for P, K and Mn. In spite of an average accumulative capacity, the examined species of *Carex* were characterized by highly developed surface and underground zones which had effective impact on the retention of pollutants.

Keywords: *Carex acutiformis*, *Carex echinata*, *Carex paniculata*, *Carex remota*, *Carex rostrata*, nutrients, bioconcentration factor

INTRODUCTION

Flora and fauna of spring areas is characterized by a rich diversity [Decamps et al. 2004, Dosskey et al. 2010, Pielech et al. 2015]. Specific physical and chemical properties affecting the surface of underground waters form the species arrangement of the flora found there. The headwater species, water species and the species of rushes occur mainly at the bottom of the niches. However, on the peatbogs elevated over the bottom of a niche, both forest and meadow species are present. Headwater ecosystems are often inhabited by sedges which prefer the areas with a high table of ground waters, mainly pond marshy meadows and flood marshy meadows [Grzelak et al. 2006] with moderate soil fertility [Grzelak et al. 2015]. Patches of sedge rushes are formed usually by common species such as: *Carex acutiformis, Carex echinata*, *Carex paniculata*, *Carex remota* czy *Carex rostrata*. The species composition of the vegetation of spring niches is vital from the viewpoint of the capacity of particular species to accumulate specific quantity of micro- and macro elements in their shoots. The uptake of nutrients by plants depends, to a large extent, on several factors, such as: age, species, development stage, and the on interaction of synergic and antagonistic character [Kabata-Pendias and Pendias 1999, Chiquan and Kuiyi 2001, Veselkin et al. 2014]. The quantity of the components taken up is conditioned by the physiological demand for particular components [Kabata-Pendias and Szteke 2005], but they can also be taken up passively, which is connected with the environmental pollution [Parzych et al. 2015]. The differences in the quantity of accumulated elements are found not only among species, but they also depend on the vegetation season and the availability of components [Zhang et al. 2009]. The species composition of the forest headwater ecosystems is closely connected with the chemical composition of soils [Jonczak et al. 2014, Jonczak at al. 2015a] and the flowing waters [Osadowski 2006, Parzych et al. 2016] and is generally characterized by a high diversity [Pielech et al. 2015]. The interactions between plants, the water and the soil at these areas are very close and diverse [Karlssonet et al. 2005]. Plants, as an integral part of spring ecosystems, play an important role because they are efficient in the removal of nutrients and other pollutants, providing multiple ecological benefits [Hazlett et al. 2008, Lee et al. 2009, Yu et al. 2014, Galal and Shehata 2015].

The aim of the research was to compare the accumulative properties of five species of *Carex* in terms of macro and microelements. The content of components in the shoots of the plants was analyzed in relation to the chemical composition of the soil. Recognition of accumulative properties of the species of *Carex* and an adequate management of species composition of plants in river valleys is one of the most effective strategies undertaken to obtain good quality surface and ground waters.

MATERIAL AND METHODS

Research area

The research was conducted within the area of four mid-forest spring niches situated in the valley of a tributary of the Słupia River lcoated within the area of Leśny Dwór Forest Inspectorate (54°19'N; 17°10'E). It is the area with the average annual precipitation about 770 mm and the average annual ambient temperature of about 7.6°C [Kirschenstein and Baranowski 2008]. The area of the Kamienna River catchment is nearly entirely covered with forests of a spatially diverse species composition with the prevalence of beech, pine and spruce in its plateau part, and common alder (*Alnus glutinosa*) at the bottom of the valley. The tree stand grew over a domed moor made up of forest peat with the layers of forest and sedge peat, cut by headwater streams. Among the streams, domed peat bogs were formed, which, by retaining water contribute to swamping of the area and a development of species diversity, to which *Carex* has substantial contribution: *Carex acutiformis* Ehrh., *Carex echinata* Murray, *Carex paniculata* L., *Carex remota* L. and *Carex rostrata* Stokes. In addition to *Carex* in the spring niches, the presence of the following species was determined: *Galium palustre* L., *Lycopus europaeus* L., *Lythrum salicaria* L., *Lysimachia vulgaris* L., *Solanum dulcamara* L., *Cardamine amara* L., *Chrysosplenium alternifoliu* L. and *Scirpus sylvaticus* L.

SAMPLING PROCEDURE

At the beginning of the experiment, samples from the layers 0–10 cm, 10–20 cm and 20–30 cm were taken from the rhizosphere of the selected species of *Carex*. However, due to the distribution of roots of the *Carex* species at different depths, in a subsequent part of the paper, the mean values for the layer 0–30 cm were used along with standard deviation. The way of taking samples and the methods applied for the analysis of micro and macro elements in the soil of the examined spring niches were described in the paper by Jonczak et al. [2014]. The samples of the overground shoots of sedge for the chemical analysis were taken three times during the vegetation season (May, July, September) over the period of three years (2012–2014). The samples comprised the over-ground shoots originating from more than ten specimens of a given species, from which a mixed sample was made for each species separately. In total, 9 samples of each species of *Carex* were taken (*Car_acu, Car_ech, Car_pan, Car_ rem* and *Car_ ros*).

Sampling analysis

After the transport to the laboratory, the plant material was cleaned of the mineral parts of the soil, flushed in the distilled water, and dried to constant mass at the temperature of 65°C. Then, it was homogenized in a laboratory grinder (IKA 11). The content of total nitrogen was established through the application of the Kieldahl method (Büchi 350K) and phosphorus by means of the molybdenum blue method (spectrophotometer UV-VIS U5100 Hitachi) after mineralization in the mixture of 98% H_2SO_4 and 30% H_2O_2. In order to mark the metallic elements, the samples of plants and soil were digested wet in the mixture of 65% HNO_3 and 30% H_2O_2. The concentration of K, Mg, Ca, Zn, Cu, Ni, Mn and Fe in plants was determined with atomic absorption spectrometry (AAS), (Aanalyst 300, Perkin Elmer) and Al and Sr – by means of the microwave plasma atomic emission spectrometry (Agilent 4100, MP-AES). The tests were carried out following the original standards of Merck (KGaA, 1g/1000ml). The quality of the obtained results was verified based on certified reference materials (CRM 060, aquatic plant).

Statistical analysis

The statistical significance pertaining to the variability of the content of macro and microelements in the plant shoots was verified by means of the nonparametric Kruskal Wallis test. The plant's ability to take up macro- and trace elements from soils calculated using the bioconcentration factor (BF). This factor was calculated as the following ratio: the concentration of element in shoots of plants/concentration of element in soil [Harasimiuk 2006, Yoon et al. 2006]. The data related to the content of the components in the soil layers with the thickness of 0–30 cm comprising the main part of the roots of the examined plants were used For calculation of BF (Table 1). Hierarchical cluster analysis (Ward's methods) was used to classify *Carex* species into different groups based on the bioconcentration factor of macro- and microelements in shoots. All calculations were performed using Statistica 7.1 software package.

RESULTS AND DISSCUSION

Physicochemical properties of soil

Within the area of the examined spring niches, peaty saprophytic soils were found, which were characterized by spatially diverse thickness. The organic matter (OM) content within the rhizosphere of the plants (0–30 cm) remained, on average, at the level of 80.8–81.0% in niche 1, 2 and 3 and 21,9% in niche 4 [Jonczak and Parzych 2016]. The examined soil was characterized by a poor acid reaction. The soils in the niches: 1, 2 and 3 contained substantially more nitrogen than the soils in niche 4. The highest concentration of phosphorus and calcium with average potassium content was found in the soils in the niches 2 and 3. In the soils of niche 4, the low concentration of N, P and Ca was discovered along with a high content of K. Only Mg was found at a similar level in the soils of all four niches. The content of microelements remained within the limits of the natural concentration, reflecting low level of anthropogenic pollution of the area under consideration (Table 1). The examined soil represented a series of specific characteristic features resulting from their functioning within the area of headwa-

Table 1. Mean values ± standard deviation physicochemical properties of soil (0–30 cm) taken from rhizosphere of *Carex* species

Parameter		*Carex echinata*	*Carex paniculata*	*Carex remota*	*Carex acutiformis*	*Carex rostrata*
pH		5.7±0.1	6.5±0.1	5.7±0.1	6.0±0.1	5.5±0.1
OM, %		81.0±1.8	80.9±0.5	81.0±1.8	80.8±2.8	21.9±6.0
N	mg·kg^{-1}	30740.0±1326	31800.0±2553	30740.0±1326	26800.0±932	8440.0±921
P		1061.8±400	838.9±200	1061.8±400	511.2±200	597.2±200
K		377.6±100	352.0±200	377.6±100	150.1±100	661.8±300
Mg		879.2±100	1100.2±400	879.2±100	1024.4±40	906.3±300
Ca		18791.7±1400	24320.9±800	18791.7±1400	24201.7±600	7606.6±3600
Sr		78.9±0.5	100.0±7.4	78.9±0.5	99.5±6.1	44.9±24
Cu		10.9±0.1	8.9±1.5	10.9±0.1	10.5±0.5	6.7±0.5
Ni		6.9±0.5	7.1±0.8	6.9±0.5	17.9±1.8	6.1±4.8
Zn		58.5±9	47.6±23	58.5±9	45.2±5.6	33.3±8.1
Mn		623.9±198	302.2±158	623.9±198	104.7±257	180.4±123
Fe		15997.9±3300	2777.6±200	15997.9±3300	1576.8±	5739.4±6900
Al		2021.4±200	1106.6±300	2021.4±200	677.8±30	4863.6±4200

ters, as a transit zone between the underground and surface part of water circulation in the river catchments [Jonczak 2011]. The continuous flow of ground waters concentrated over the mineral substratum towards the river and connected with the above-mentioned process, results in characteristic vertical gradients of the concentration of various element fractions [Jonczak et al. 2015a] as well as organic matter [Jonczak and Parzych 2016]. The chemical properties of the uppermost layer of the soil depend, to a large extent, on the plant deposition. In the forest stand of grey alder growing in niche 1, it was characterized by a high abundance as to N and Ca and was relatively poor in terms of P.K and Mg. The content of Fe, Al and Mn was characteristic for these elements and low when compared to the other macroelements. The low contents of Cu and Zn confirm limited anthropogenic contamination of the investigated ecosystem with these metals [Jonczak et al. 2016]. Leaves, as the main component of the litter fall, were nearly completely decomposed during the year [Jonczak et al. 2015b].

Macroelements and iron contents in shoots of *Carex*

The macroelements are responsible for a proper growth and development of plants. The shoots of the examined *Carex* species were characterized by a substantial diversity in their concentration. The largest quantities of nitrogen were accumulated by *C. acutiformis* (14 843.3 mg·kg^{-1}), and the lowest by *C. remota* (10 053.3 mg·kg^{-1}), (Fig. 1). Nitrogen concentration in the shoots was diverse during vegetation seasons at the level ranging from 15.6% (C. *paniculata*) to 44.2% (*C. remota*). In spite of the substantial nitrogen content in the soil (Table 1), the concentrations of this biogenic material in the surface shoots of *Carex* were relatively low (Fig. 1), which shows that a substantial part of bioavailable forms of nitrogen was washed out of the reach of roots by the flowing water [Grzelak et al. 2015]. In the period 2012–2014, no statistically significant differences were found in the concentration of nitrogen in the shoots of the species of *Carex* (Fig. 1), which indicates the stability of the examined spring niches. According to Yu et al. [2014] nitrogen is accumulated in the largest quantities in above ground shoots of plants, and its total content in plants ranges between 13 000 to 31 000 mg·kg^{-1} [Ostrowska and Porębska 2002]. The results of research done by Czerwiński and Pracz [1995a] show that *C. rostrata* growing in soils abundant with bioavailable forms of nitrogen, accumulates much higher quantities of N (20 200 mg·kg^{-1}) in the the surface shoots then in the examined spring niches. The results of the research done by Choo et al. [2002] indicate that *C. rostrata* takes up both NH_4^+ and NO_3^- ions, no matter whether they occur in excess or in deficiency.

The average content of phosphorus in the shoots of *Carex* remained at the level from 1895.6 mg·kg^{-1} (C. *paniculata*) to 2225.0 mg/kg (*C. acutiformis*) showing variability during the period of research from ranging from 15.1% (*C. echinata*) to 27.1 % (*C. rostrata*), (Fig. 1). As in the case of nitrogen, no statistically significant differences were found in the concentration of phosphorus among the species (Fig. 1), which was confirmed by the research done by Choo et al. (2002). The species of *Carex* from spring niches accumulated phosphorus at a similar level, independent of the physical and chemical properties of the soils (Fig. 1). The spring water flowing through the niches contained very small quantities of phosphates (Parzych et al. 2016), which influenced the small concentration of P in shoots of plants. The soils within the area of spring niches were relatively poor in phosphorus (Table 1). For forest ecosystems with little content of phosphorus in the soil, decaying pieces of organic matter were deposited in the streams on the way of the water-flow [Jonczak et al. 2016, Parzych et al. 2016]. Phosphate ions belong to a group of biogenic substances essential for the production of biomass in the plants [Kelly et al. 2007]. According Ostrowska and Porębska [2002] the average phosphorus content in majority of species is between 1000 to 4000 mg·kg^{-1}.

The examined species of *Carex* were characterized by high potassium content**.** The largest quantities of K were found in the shoots of *C. remota* (25 086.7 mg·kg^{-1}), and the smallest in the shoots of *C. echinata* (18 288.5 mg·kg^{-1}), (Fig. 1). During the research, the content under consideration changed at the level from 17.7% (*C. remota*) to 27.0% (*C. acutiformis*). Higher concentrations of K than the optimum ones characteristic for most species of plants were found in the shoots of *Carex* (5000–12 000 mg·kg^{-1}), Ostrowska and Porębska [2002]. The high potassium content in the shoots of *Carex* was confirmed in the research of Choo et al. [2002], which reports that in the ecosystems with small quantity of bioavailable

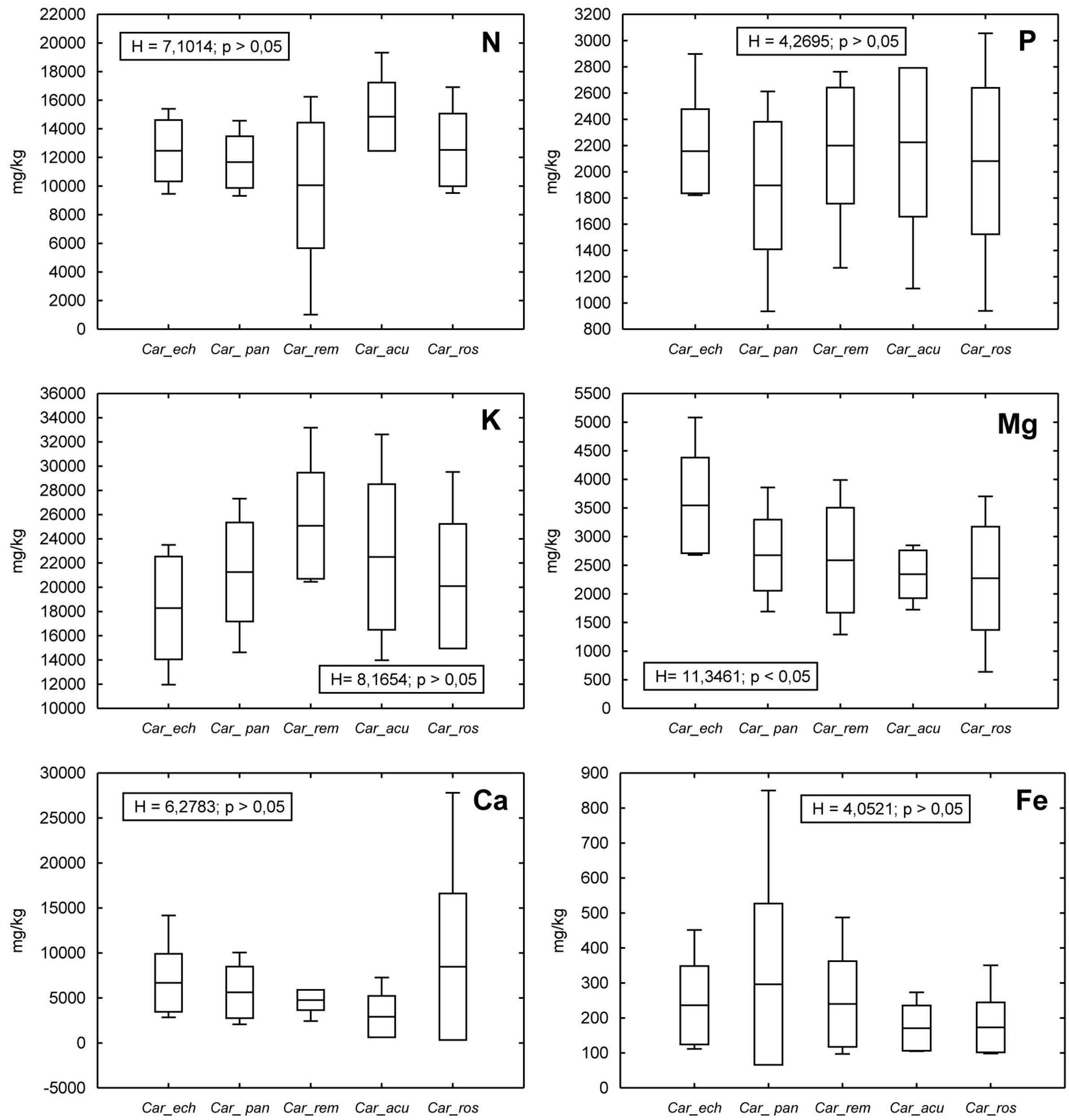

Figure 1. Mean, standard deviation and minimum and maximum of concentration of N, P, K, Mg, Ca and Fe in shoots of *Carex* species in headwater riparian forest with Kruskal-Wallis's test results. (*Car_ech – Carex echinata, Car_pan – Carex paniculata, Car_rem – Carex remota, Car_acu – Carex acutoformis, Car_ros – Carex rostrata*)

forms of nitrogen (NH_4^+ and NO_3^-), *Carex* species accumulates large quantities of potassium. The obtained research results indicate the lack of statistically significant differences in the accumulation of potassium by the examined species of *Carex* (Fig. 1). High concentration of potassium in the shoots of *C. rostrata* (13 100 mg·kg^{-1}) was documented by Czerwiński and Pracz [1995], and in other species of plants in spring niches by Parzych et al. [2017]. Plants usually show a great capacity to potassium absorption and accumulation in the surface mass. Potassium is a microelement which is often taken up in excess by plants, frequently exceeding their nutritional needs [Krzywy 2007]. The high concentration of K in shoots of plants limits the uptake of other components, especially Mg. In addition, potassium is characterized by a high mobility [Ranade-Malvi 2011] and can be easily washed out of soils.

The average content of magnesium in the shoots of *Carex* remained at the level from 2272.7 mg·kg^{-1} (*C. rostrata*) to 3545.8 mg·kg^{-1} (*C. echinata*), (Fig. 1) and was within the natural content of this element in plants. The analysis of the obtained results shows significant statistical differences in the concentration of magnesium in the shoots of the examined species of *Carex* (Fig. 1). During the period of the research work, variability of concentration of Mg in shoots of *Carex* was observed at the level of 18.4% (*C. acutiformis*) to 40.3% (*C. rostrata*). Somehow, the lower levels of Mg in shoots of *C. rostrata* (2000 mg·kg^{-1}) were disclosed by Czerwiński and Pracz [1995]. Magnesium is taken up by plants in the form of Mg^{2+} ions which are found in the soil solution. The concentration of Mg in the shoots of plants depends on the species, age and a part of the plant. The surface parts of plants are more abundant in this element than roots. Due to numerous important functions of magnesium in metabolism of plants, it has a big impact both on the vegetative and generative development of parts of plants [Kabata-Pendias and Pendias 1999]. For the proper growth and development of plants, the occurrence of Mg at the minimum level of 1000 to 1300 mg·kg^{-1} is necessary [Falkowski et al. 2000].

Out of the examined species of *Carex,* the largest average quantities of calcium were found in the shoots of *C. rostrata* (8665.6 mg·kg^{-1}), and the lowest in *C. acutiformis* (2922.7 mg·kg^{-1}), (Fig. 1). During three vegetation seasons, a significant variability pertaining to the concentration of Ca in the shoots of *Care*x, from 25.4% (*C. remota*) to 97.2% (*C. rostrata*) was observed. The largest quantities of calcium appeared in the shoots at the end of vegetation seasons, which is connected with ageing of plants. The results of research by Czerwiński and Pracz [1995] show that the shoots of *C. rostrata* most often accumulate Ca at the level of 2500 mg·kg^{-1}. The optimum calcium content in most plants was from 1000 to 33 000 mg·kg^{-1} [Ostrowska and Porębska 2002]. Ca content in the shoots of plants is species characteristic and changes along with their growth and development. It also depends on the moisture of the habitat. High moisture of soils characteristic for mid-forest spring niches fosters the uptake of calcium by plants. It is generally most abundant in leaves [Falkowski et al. 2000]. Ca content is especially high in the shoots of many species belonging to *Urticaceae, Papilionaceae, Plantaginaceae* and *Rosaceae.*

Out of the examined species of *Carex*, the largest quantities of iron were accumulated by the shoots of *C. paniculata* (296.4 mg·kg^{-1}), and the lowest by *C. acutiformis* (170.7 mg·kg^{-1}). In the period 2012–2014, the content of Fe in the shoots of *Carex* varied, and the largest concentrations were observed at the beginning of vegetative seasons. The variability indices for particular species remained at the level from 39.2% (*C. acutiformis*) to 78.6 % (*C. paniculata*). Along with the growth and development of plants, concentrations of Fe in the shoots decreased. No significant statistical differences were determined in the content of Fe between the species of *Carex*, and their concentrations were within the range of values typical for many plants (50–375 mg·kg^{-1}) [Kabata-Pendias and Pendias 1999]. The level of toxicity characterizing Fe in the shoots of plants has not been determined so far, but is strictly species dependent. Iron is an element indispensable for the development of plants, and its key role is connected with the process of transformation of energy necessary mainly for the process of photosynthesis. Plants can take up iron in a form of Fe^{2+}, Fe^{3+} as well as chelates, and it is accumulated mainly in green parts, showing little mobility in the tissues of plants [Kabata-Pendias and Pendias 1999]. *C. remota,* under favorable conditions, can accumulate larger quantities of iron (1230–2150 mg·kg^{-1}) [Samecka-Cymerman and Kempers 2001] than in the examined spring niches.

Microelements contents in shoots of *Carex*

The plants are characterized by a variable demand in terms of microelements [Parzych et al. 2015]. The content of metallic elements in the shoots of *Carex* was species characteristic. The concentration of copper remained at the level from 2.1 mg·kg^{-1} (*C. paniculata*) to 16.1 mg·kg^{-1} (*C. rostrata*), showing the variability from 11.8% (*C. echinata*) to 69.9% (*C. remota*), (Fig. 2). Copper in the plants is an element of little mobility; in order to cover the physiological demand, its sufficient quantity for most plants is below 4–5 mg·kg^{-1} and is substantially diversified depending on the part of the plant, its developmental stage, species and variety. Its average content in the surface parts of the plants is most often from 5 to 20 mg·kg^{-1} [Kabata-Pendias and Pendias 1999]. The examined species of *Carex* accumulated copper in average quantities, not exceeding the level considered as toxic (>30 mg·kg^{-1}), [Kabata-Pendias and Pendias 1999]. Comparable quantities of Cu were found in the shoots of *C. rostrata* (12.6 mg·kg^{-1}) in northern Sweden [Stoltz and Greger 2002].

A similar situation was observed in the case of nickel. The largest quantities of this element were accumulated by the shoots of *C. acutiformis* (22.7 mg·kg^{-1}), and the lowest by *C. echinata* (9.3 mg·kg^{-1}), (Fig. 2). The examined species of

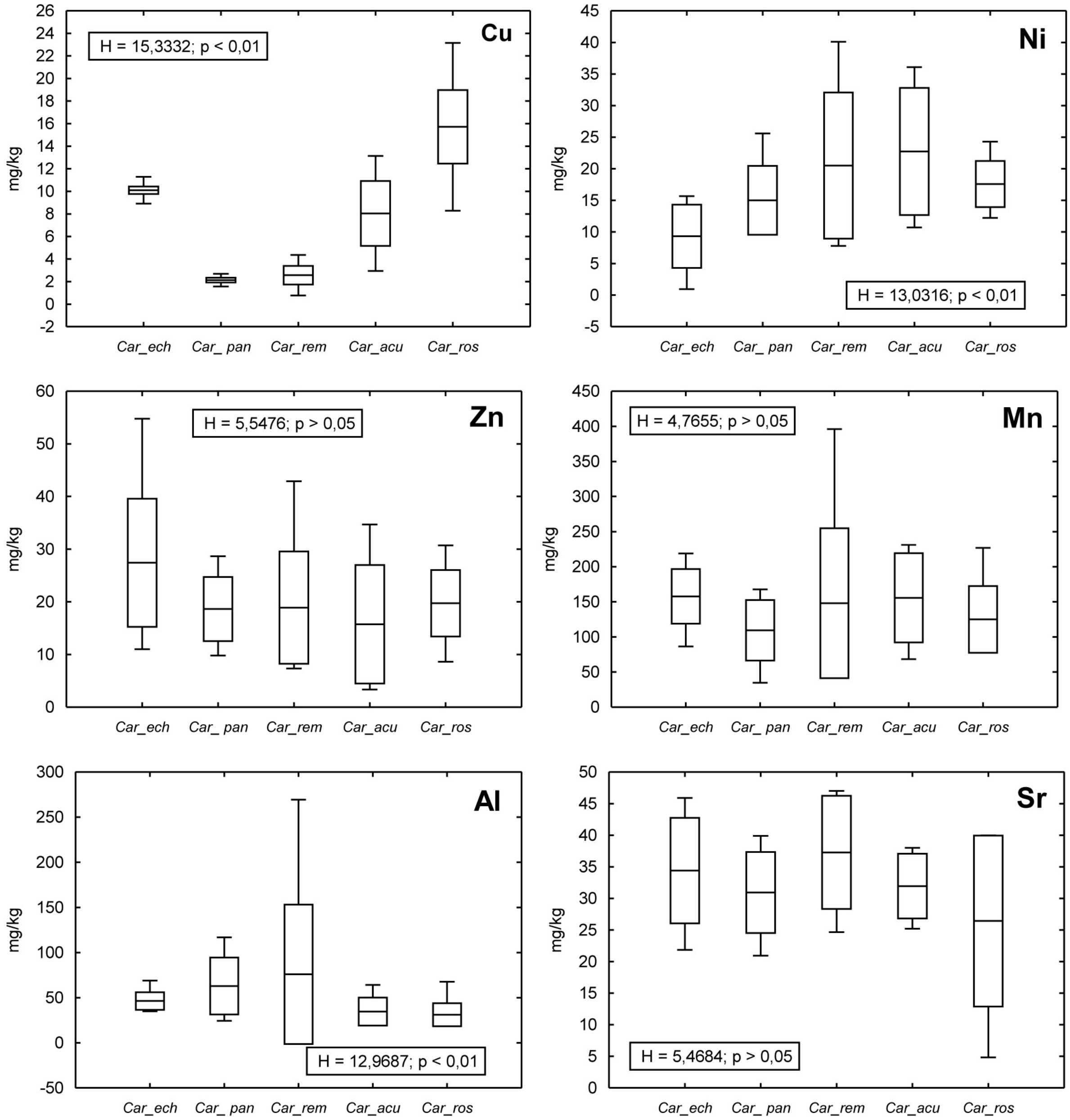

Figure 2. Mean, standard deviation and minimum and maximum concentration of copper, nickel, zinc, manganese, aluminum and strontium in shoots of *Carex* species in headwater riparian forest with Kruskal-Wallis's test results

Carex showed a higher content of Ni (>5 mg/kg) than it results from the physiological demand of most plants. Substantial diversity of the concentration factor of Ni (21.5–57.1%) in the shoots of *Carex* was observed, which results from the variable demand for this microelement during the vegetation season. Natural nickel content in plants is mostly 0.1–5.0 mg·kg^{-1} [Krzywy 2007], and in the ecosystems with high level of ground waters it is higher since nickel is easily bioaccumulated in plants which are sensitive bioindicators of waters [Sarosiek and Wożakowska-Natkaniec 1993].

The highest quantities of Zn were found in the shoots of *C. echinata* (27.4 mg·kg^{-1}), and the lowest in *C. acutiformis* (15.7 mg·kg^{-1}), (Fig. 2). During the research period, the diversity of Zn concentration of in the shoots of *Carex* remained at the level from 32.7% (*C. rostrata*) to 72.4% (*C. acutiformis*). The content of Zn in the shoots of *Carex* was within the acceptable limits for plants (10–70 mg·kg^{-1}) [Kabata-Pendias and Pendias 1999]. Plants take up Zn in the quantities which are proportional to its concentration in the soil. Zinc is an indispensable microelement for all plants [Deng et al. 2004]. In order to cover the physiological needs of most plants, the sufficient concentration is within the scope of 15–30 mg·kg^{-1} [Kabata-Pendias and Pendias 1999]. Zinc is characterized by a high mobility and is easily accumulated in plants. Much higher quantities of Zn than the quantities obtained in spring niches were accumulated by shoots of *C. rostrata* (90 mg·kg^{-1}) examined by Stoltz and Greger [2002] in Sweden.

Research proved that the average quantities of manganese were accumulated by the shots of *C. echinata* (157.7 mg·kg^{-1}), and the lowest in *C. paniculata* (109.5 mg·kg^{-1}), (Fig. 2). The variability of Mn concentration in the shoots of *Carex* was from 25.4% (*C. echinata*) to 72.9% (*C. remota*). The level of Mn content in the shoots of *Carex* was low, and no statistically significant differences between the species in accumulation of that metal were found. The physiological demand of most plants for manganese is varied; usually the sufficient level is 10–25 mg·kg^{-1} [Kabata-Pendias and Pendias 1999]. The concentration of about 500 mg·kg^{-1} can be toxic for most plants, and the tolerance for excess of manganese varies for particular species.

The aluminum content remained at the level from 31.1 mg·kg^{-1} in the shoots of *C. acutiformis* to 75.9 mg·kg^{-1} in the shoots of *C. remota* (Fig. 2). Concentration factors for Al in the shoots of *Carex* varied, depending on a species and were in the range from 22.9% (*C. echinata*) to 102.8% (*C. remota*). Out of the examined species, *C. remota* was visibly different from other species in respect to the concentration of aluminum in the shoots. Al content in the plants is usually from a few to 200 and 400 mg·kg^{-1}, while it is most often higher in the roots [Krzywy 2007]. According to Falkowski et al. [2000], aluminum can have a negative impact on the roots of plants with pH=6.5–6.8 and increases along with the decrease of pH of the soil. Excess of Al limits the uptake of nutrients, i.e. of P, Ca, Mg, K and N and increases the uptake of Fe and Mn [Kabata-Pendias and Pendias 1999].

The strontium content in the shoots of *Carex* remained at the level from 30.9 mg·kg^{-1} (C. *paniculata*) to 37.3 mg·kg^{-1} (*C. remota*). During the period of research, variability of concentration of Sr in the shoots of *Carex* was from 16.4% (*C. acutiformis*) to 57.1% (*C. rostrata*). The strontium content in plants varies substantially, depending on its occurrence in soil [Kabata-Pendias and Pendias 1999]. Plants accumulate it especially in the green shoots, most often in the quantity from over dozen or so to tens of mg·kg^{-1}. Sr belongs to the elements characterized by low mobility in environment. In addition, strontium uptake can be limited by high quantities of calcium, magnesium and potassium. Comparable Sr content in the shoots of *C. remota* was presented by Samecka-Cymerman and Kempers [2001].

The examined species of *Carex* showed variable accumulative properties in relation to macro- and microelements. Out of the examined species, the shoots of *C. echinata* accumulated the highest quantities of P, Mg, Zn and Mn, the shoots of *C. paniculata* – Fe, *C. remota* – K, Al and Sr, *C. acutiformis* – N and Ni, and the shoots of *C. rostata* – Ca and Cu. The average content of macro- and microelements in *Carex* shoots were as follows:

- *C. echinata*: K>N>Ca>Mg>P>Fe>Mn>Al>Sr>Zn>Cu>Ni
- *C. paniculata*: K>N>Ca>Mg>P>Fe>Mn>Al>Sr>Zn>Ni>Cu
- *C. remota*: K>N>Ca>Mg>P>Fe>Mn>Al>Sr>Ni>Zn>Cu
- *C. acutiformis*: K>N>Ca>Mg>P>Fe>Mn>Al>Sr>Ni>Zn>Cu
- *C. rostata*: K>N>Ca>Mg>P>Fe>Mn>Al>Sr>Zn>Ni>Cu

Ecological requirements for particular species [Veselkin et al. 2014], as well as the processes taking place in the rhizosphere of the plants [Stoltz and Greger 2002] had a significant impact on the process of uptake and accumulation of nutritional components by *Carex.* The main factor governing the availability of chemical elements for plants is the reaction of soils. Nitrogen is most available to plants at pH=6.0–8.0, phosphorus at pH=6.5–8.0, potassium, at pH=6.0–10.0, and calcium and magnesium at pH=6.5–8.5. Solubility of heavy metals is low in the case of neutral and alkaline reactions, and increases along with the lowering of pH value [Falkowski et al. 2000, Gworek 2006]. The increase in the mobility of Zn and Mn is most effective with pH=6, while Cu, Ni and Al at pH=5.5 and Fe at pH=4. Manganese, however, is characterized by increased solubility also in alkaline environment [Alloway 1995].

The bioconcentration factors of elements in shoots of *Carex species*

The bioconcentration factors values (BF) show significant variability of accumulative properties of the examined *Carex* species in relation to macro- and microelements contained in the soil (Table 2). The highest BF levels for potassium were found in the case of *C. acutiformis,* and the

Table 2. Average of bioconcentration factors values (BF) of macro- and microelements in *Carex* shoots

Elements	*Carex echinata*	*Carex paniculata*	*Carex remota*	*Carex acutiformis*	*Carex rostrata*	Range
N	0.41	0.37	0.33	0.55	1.67	0.33–1.67
P	2.03	2.26	2.07	4.35	3.58	2.07–4.35
K	48.43	60.40	64.44	149.91	32.66	32.66–149.91
Mg	4.03	2.43	2.94	2.29	2.09	2.09–4.03
Ca	0.36	0.23	0.25	0.12	0.56	0.12–0.56
Sr	0.44	0.31	0.47	0.32	0.80	0.31–0.80
Zn	0.47	0.39	0.32	0.35	0.66	0.32–0.66
Cu	0.93	0.24	0.24	0.77	2.66	0.24–2.66
Ni	1.35	2.11	2.97	1.27	2.88	1.27–2,97
Mn	0.25	0.36	0.24	1.49	0.67	0.25–1.49
Fe	0.01	0.11	0.02	0.11	0.03	0.01–0.11
Al	0.02	0.06	0.04	0.05	0.01	0.01–0.06

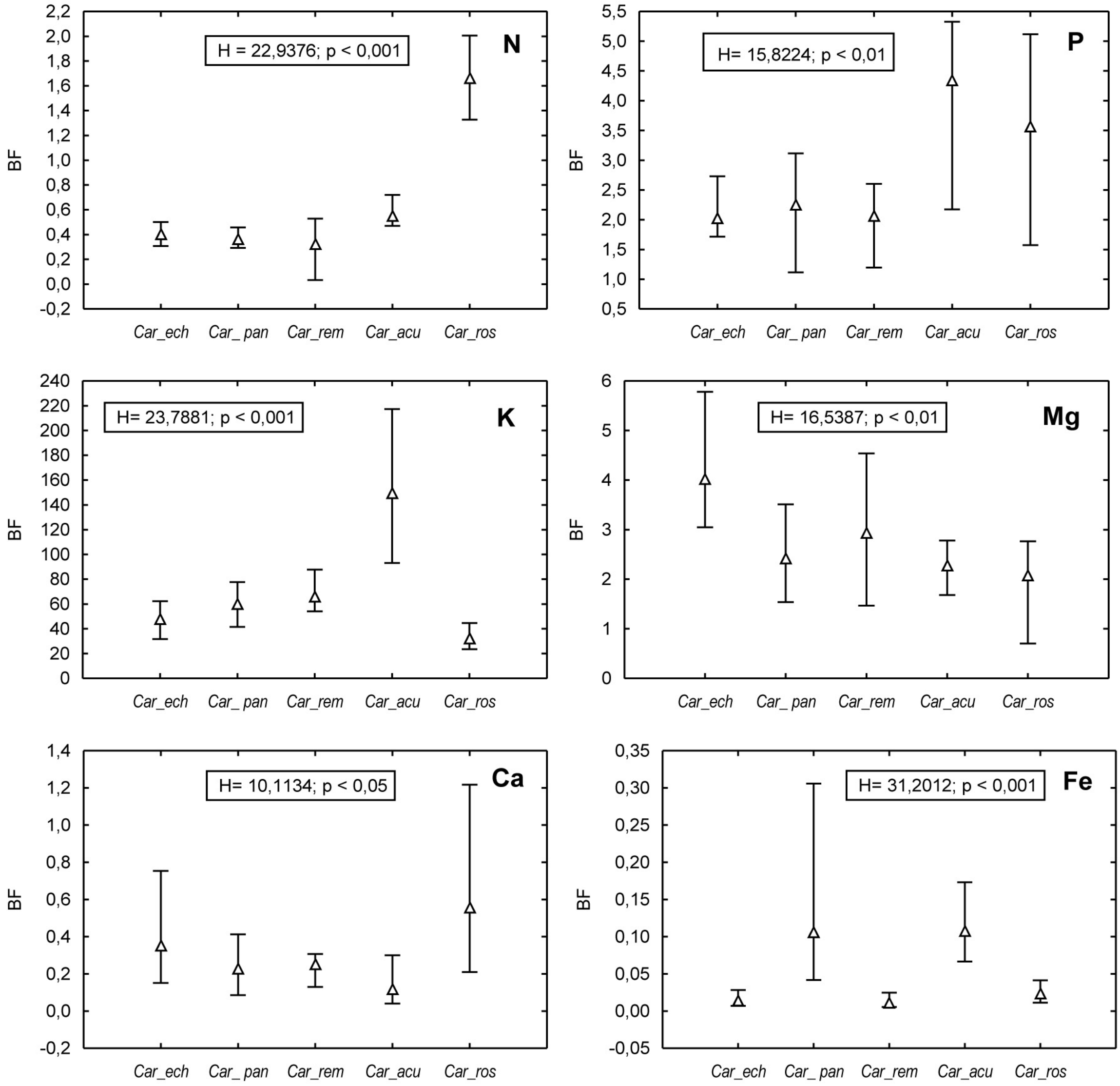

Figure 3. Median, minimum and maximum values of bioconcentration factors (BF) of N, P, K, Mg, Ca and Fe in plants from headwater riparian forest with Kruskal-Wallis's test results

lowest in the case of *C. rostrata* shoots. Much lower BF levels were found in the case of macroelements (P, Mg, N, Ca). Out of the microelements, the highest BF levels were established for Ni, Cu and Mn. The lowest BF levels were found in the case of Al and Fe. Out of the examined spe-

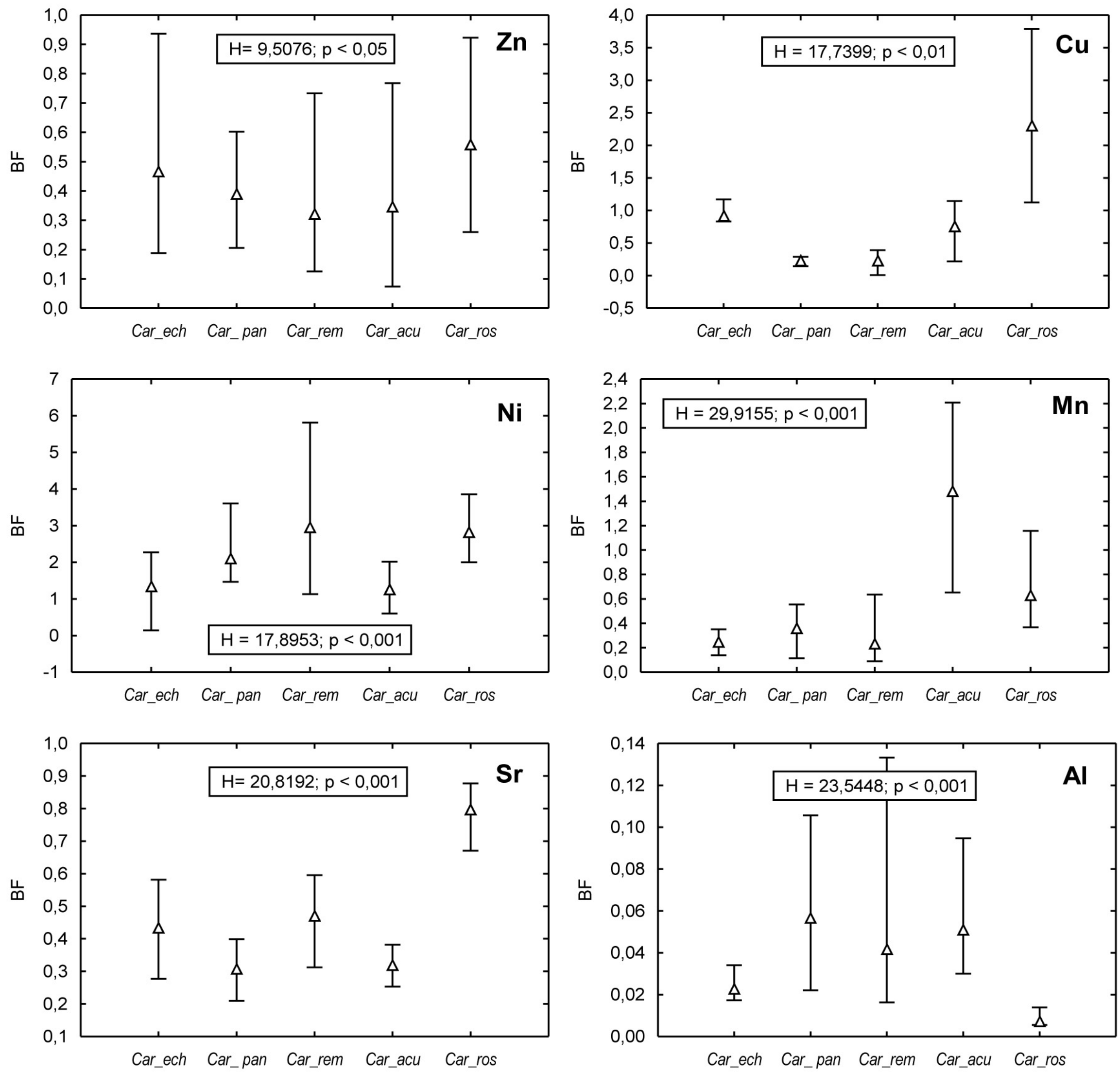

Figure 4. Median, minimum and maximum values of bioconcentration factors (BF) of Zn, Cu, Ni, Mn, Sr and Al in plants from headwater riparian forest with Kruskal-Wallis's test results

cies, *C. echinata* had the highest outstanding levels of BF for Mg, *C. paniculata* for Fe and Al, *C. remota* for Ni, *C. acutiformis* for P, K, Mn and Fe, and *C. rostrata* for N, Ca, Sr, Zn and Cu.

BF levels represented variability due to the diverse demand of the plants for such nutrients during the research period and due to their changeable chemical composition. Significant statistical differences were exhibited in the levels of BF (Kruskal Wallis's test) among the examined species of *Carex* (Fig. 3, 4) for all macro- and microelements.

Through the application of the Wards's method, the species of *Carex* were grouped depending on the similarities of bioconcentration factors (Fig. 5). The first group comprised C. *echinata* and *C. rostrata,* having high levels of BF for Sr, Cu and Ca and low levels of BF for K. The second group comprised *C. paniculata* and *C. remota,* characterized by high BF levels for Ni and Mg and low levels BF for Sr, Al, Mn, Cu, Ca, Fe and N. The third group comprised *C. acutiformis* characterized by high levels of bioconcentration factors for P, K and Mn.

CONCLUSIONS

The examined species of *Carex,* in comparison to other plants in spring niches, were characterized by an average capacity of accumulating both macro- and microelements, which results in little interest in these species when planning artificial buffer zones. Out of the analyzed species, the shoots of *C. echinata* accumulated the largest quantities of magnesium, zinc and manganese, the shoots

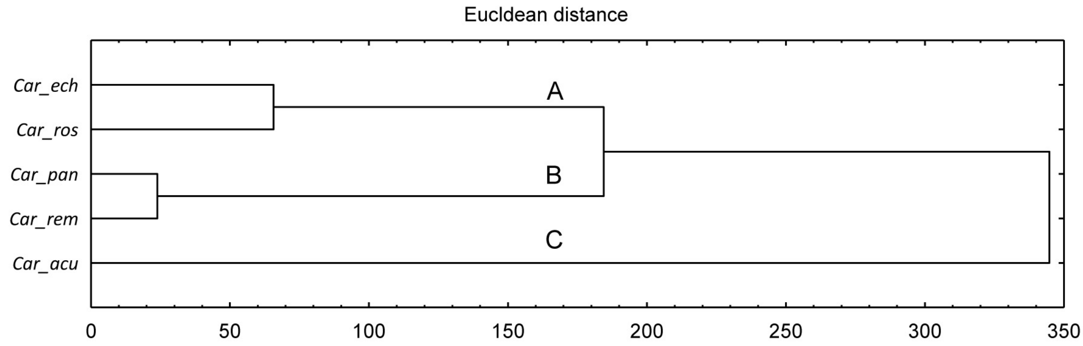

Figure 5. Variability of the investigated plant species in terms of the bioconcentration factors of chemical elements calculated in relation to soil (BF) (Euclidean distance, Ward's clustering method)

of *C. paniculata* of iron, *C. remota* potassium, nickel, aluminum and strontium respectively, *C. acutiformis* of nitrogen and phosphorus, and the shoots of *C. rostrata* of calcium and copper. Similarities between the species of *Carex,* which resulted from their accumulative properties, were discovered. *C. echinata* and *C. rostrata* were characterized by high levels of bioconcentration factors (BF) for Sr, Cu and Ca and the low BF for K. *C. paniculata* and *C. remota* represented high BF levels for Ni and Mg and low BF levels for Sr, Al, Mn, Cu, Ca, Fe and N. *Carex acutiformis* was characterized by high BF levels for P, K and Mn. In spite of an average accumulative capacity, the examined species of *Carex* were characterized by highly developed surface and underground zones which had an impact on the retention of pollutants.

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