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Lowland Sedge Meadows as a Potential Source of Macro and Micronutrient Supplementation

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Abstract: From the point of view of farming utilization, investigations on the recognition of the mineral composition of sedges appears important, appropriate and useful. Sedges are often found in many meadow and pasture communities. It is therefore worth paying attention to the mineral content of their tissues and their possible impact on the organisms of farm animals such as pigs. The basic objective of this study was to determine the concentration of selected macro and microelements: phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), silicon (Si), copper (Cu), zinc (Zn), chrome (Cr) and nickel (Ni) in the biomass of seven sedge species, potentially used as fodder, commonly occurring in natural sites in Central Europe. The material was collected twice during one growing season in the Krześniczka (N 52°37′14′ E 14°46′06′)—lubuskie voivodeship. The first harvest was carried out at the beginning of May, during the shooting and earring phase. The collected plant material included stems and leaves. The second harvest—the end of June—was collected at a time when the seedlings were developing flowers and young fruits, and their vegetative organs were developing dynamically. In June, the collected material represented organs in all possible development phases. The collected material was dried at a temperature of 65 °C, ground, and analyzed. The obtained results showed a difference in the content of microelements between the May and June harvest dates in the dry matter of all analyzed sedge species, which differed statistically significantly only in relation to copper. The harvest date had a statistically significant impact on the change in the content of macroelements in the dry matter of all analyzed sedge species and was associated with a decrease in the content of phosphorus, magnesium and calcium, while in the case of silicon, the delay in mowing resulted in an increase in the content of this element.

Keywords: *Carex*; macroelements; microelements; sedges; meadows

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1. Introduction

Sedges (*Carex* L., *Cyperaceae*), apart from grasses, are one of the most widespread groups of monocotyledonous herbaceous plants found very commonly worldwide. They constitute a group of very great ecological importance. Representatives of the genus occur in various habitats and are found in diverse plant communities, representing differing levels of substrate moisture contents, and at the same time exhibiting considerable tolerance

to variation in habitat conditions [1]. For this reason, many sedge species constitute a significant component of certain plant communities, occurring in them with high stability and frequency and playing an important role in vegetation. Sometimes, sedges form their own communities, in many cases in the form of single-species patches like *Carex riparia* Curt. or *C. acuta* L. Sometimes, although rarely, they can also act as pioneer species, for example, in the case of single-species patches, *C. praecox* Schreb. overgrowing ruderal or degraded habitats. As a common component of phytocoenosis, sedges play a role in various ecosystems, among other things due to their share in overall plant biomass, not only as living components, but also as important components of organic deposits in various types of peat bogs.

Green fodder plays a key role in the nutrition of ruminants, and its quality depends on the species composition of meadow and pasture swards. Sedges frequently occur in many meadow and pasture communities. For this reason, it is worth paying special attention to the content of important minerals in sedge organs, which would increase their importance as feed plants [2,3].

In addition to their share in biomass, sedges' organic matter content, digestibility and water content, the mineral composition, in the form of macro and microelements, are important [4]. Unfortunately, many researchers believe that sedges, as a component of swards, reduced yield values. This may be due to the fact that communities also occur in protected areas, where the delayed mowing date and, consequently, low feed value are related to the protection of bird breeding habitats [5,6]. The appropriate concentration of macro and microelements in plant organs is of great importance from the point of view of the economic usefulness of plants and plant communities, especially meadows and pastures [7,8]. The uptake of nutrients by plants and their concentrations in plants depends on several factors, such as: species, development stages, the total and plant-available amounts of elements, plant and soil properties [9–11]. Additionally, quantities of elements taken up by plants depend on their physiological demand [12,13].

The basic objective of this study was to determine the concentration of selected macro and microelements (P, K, Ca, Mg, Na, Fe, Si, Cu, Zn, Cr and Ni) in the biomass of seven sedge species, potentially used as fodder, commonly occurring in natural sites in Central Europe. The aim of the study was also to compare the content of macro and microelements in the dry matter of seven species of sedges in the development phase: (1) earring, (2) flowering and early fruiting. The results obtained can provide valuable comparative material for sedge research in other regions, highlighting their universal nature.

2. Materials and Methods

2.1. Material Collection

The study was carried out in the vegetation season of 2019 in Krześniczka (N 52°37′14′ E 14°46′06′)—lubuskie voivodeship, on plants from seven sedges species commonly occurring in Central European meadows: *Carex spicata* Huds., *C. muricata* L., *C. hirta* L., *C. disticha* Huds., *C. praecox* Schreb., *C. sylvatica* Huds., *C. remota* L.; *C. sylvatica* and *C. remota* are indeed species associated with forest communities, but due to their occurrence in forest edges and their associated penetration of the edges of meadow communities and feelings, they were also analyzed.

Plant material was collected from natural sites—meadows and pastures, xerothermic grasslands (treated as a transition zone between the meadow and the forest), as well as forest edges and clearings. Individual samples were collected in typical communities where the analyzed taxa occurred with the highest consistency and frequency, sometimes being dominant in a given plant patch. Plant communities in which the analyzed species were found occurred on the permanent grassland complex of the medium—2z and weak and

very weak—3z. The predominant soil type was peat-silt and peat and muck, as well as soil with mineral formations. It was recorded on peat-silt substrate associated with the class of rushes (*Phragmitetea*) *Carex disticha* (*Caricetum distichae*), while on the peat and muck there are species found in semi-natural wet and fresh meadows from the *Molinio-Arrhenatheretea* class—*C. spicata* (*Lolio-Cynosuretum*), *C. muricata* (*Arrhenatheretum elatioris*) and *C. hirta* (*Lolio-Polygonetum arenastri*). The taxa that appeared on mineral soils were *C. praecox* (*Diantho-Armerietum elongatae*), *C. remota* (outskirt of humid aluvial forest *Fraxino-Alnetum*, characteristic for *Alno-Ulmion* aliance and *Carici remotae-Fraxinetum* association) and *C. sylvatica*– outskirt of *Galio sylvatici–Carpinetum betuli*.

The material was collected twice during one growing season. The first harvest was carried out at the beginning of May, during the shooting and earring phase. The plant material collected included stems and leaves. The second collection—late June—was collected in a period when sedges have formed flowers and young fruits, and their vegetative organs are dynamically growing. Thus, in June, the collected material represented organs in all possible developmental phases.

In the case of all species studied, the analysis covered the aboveground parts. Samples from natural sites have been used to try to limit the impact of management on research results. This allowed the impact of chemical substances on the soil to be avoided to some extent. At the same time, this allowed us to avoid the situation of domination in the examined patches of species resistant to browsing, appearing under conditions of regular grazing.

Considering the climatic conditions for Krześniczka (period 1991–2021), the average annual temperature is 10.0 °C, while the average annual precipitation is about 663 mm. Analyzing multi-year data, July is both the warmest month (average 19.9 °C) and one with the highest rainfall—83 mm, while January is on average the coolest—0.2 °C and February the driest—41 mm [14,15].

2.2. Elemental Analysis Method

For each species three samples were collected in early May from three different patches located in different places. Therefore, for each species, the collected samples differed with respect to sites, but their plant species composition was the same or was achene micromorphology in some species of *Carex* (*Cyperaceae*), studied with scanning electron microscopy. The repeated collection of material from the same patches and observing the same principles was carried out at the end of June. Plant materials for the study were collected from lowland meadow communities in Poland. Collected material was dried at a temperature of 65 °C, ground and analyzed using the methods of [16]. The concentrations of K and Mg were determined by the method of atomic absorption spectrometry (ASA—Varian SpectrAA 220 FS atomic absorption spectrometer, Varian Inc., Palo Alto, CA, USA), with potassium determined by ESA (atomic emission spectrophotometry) and magnesium by ASA (atomic absorption spectrophotometry). In the cases of P, Ca, Na, Si and the trace elements, Cu, Zn, Mn, Fe, Cr and Ni, samples were first mineralized in a microwave-assisted acid digestion system (EPA method 3052, Ethos D microwave station, Milestone, Monroe, CT) and then elements were determined using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES: Agilent 5100 SVDV, Agilent Technologies, Santa Clara, CA, USA). Additionally, the concentrations of total carbon and nitrogen were measured by elementary analysis on the Vario Max. As a reference scale for the evaluation of elemental concentrations, the optimal and extreme values of elements for animal fodder were obtained from several sources [17–19].

2.3. Statistical Analysis

A one-way analysis of variance (ANOVA) using the Tukey test was used to demonstrate statistical differences for the mean content of the described macro and microelements of the studied biomass of the different sedge species. Using the unweighted mean pairwise clustering algorithm (UPGMA) and the Bray–Curtis similarity measure, similarities and differences between the sedge species studied were demonstrated. Statistical analyses were carried out using R Statistical Software (v4.4.0—'Puppy Cup') [20] using the agricolae package [21], while dendrograms were made in the PAST software (version 4.02) [22,23].

3. Results and Discussion

Micro and Macromineral Concentration in Studied Sedges—May, June, Comparison and Mean Content

The mineral composition was comparable in all species studied. However, differences were found in the concentrations of all the elements studied, as shown in Table 1. However, in order to demonstrate the differences between sedge species not only for individual months of harvest, but also for the average total contents of carbon, nitrogen and the C–N ratio, the data is presented in Table 2. On both harvest dates, the ranges of carbon content of the studied species were close to the mean. Carbon (C) concentration ranged in the first cut from 418.33 (*C. hirta*) to 439.33 g·kg^{-1} DM (*C. disticha*) and in the second for the same species oscillated at the limit 424–460.67 g g·kg^{-1} DM and was statistically significant. For the average carbon content (Table 2), two homogenous groups were formed for *C. disticha* (a) and *C. hirta* (d), while the remaining species belonged to several groups. The highest concentration of nitrogen in May was found in *C. muricata* (19.47 g·kg^{-1} DM) and the lowest in *C. praecox* (9.77 g·kg^{-1} DM), while in June the average concentration of this element ranged from 10.46 g·kg^{-1} DM in *C. praecox* to 20.58 g·kg^{-1} DM in *C. muricata*.

Table 1. This carbon and nitrogen content and C–N in dry aboveground of the *Carex* species with statistically significant differences (Tukey's test)—first and second cut (May, June). Mean values with standard deviation for each species are presented (statistically significant at $p < 0.01$).

Species	Carbon (C)		Nitrogen (N)		C−N	
	[g·kg^{-1} DM]					
	May	June	May	June	May	June
C. spicata	434.00 ^{ab} ± 6.00	440.00 ^{bcd} ± 2.00	18.88 ^{a} ± 1.06	19.48 ^{a} ± 0.90	23.03 ^{d} ± 1.14	22.62 ^{cd} ± 1.50
C. muricata	426.33 ^{bc} ± 4.93	435.67 ^{cd} ± 4.04	19.47 ^{a} ± 0.76	20.58 ^{a} ± 0.57	21.93 ^{d} ± 0.95	21.19 ^{d} ± 0.74
C. hirta	418.33 ^{c} ± 1.53	424.00 ^{e} ± 4.58	14.47 ^{b} ± 0.88	15.93 ^{bc} ± 1.89	28.99 ^{bc} ± 1.72	26.83 ^{bc} ± 2.72
C. disticha	439.33 ^{a} ± 5.86	460.67 ^{a} ± 6.66	17.70 ^{a} ± 0.34	18.06 ^{ab} ± 0.06	24.83 ^{cd} ± 0.79	25.50 ^{bcd} ± 0.33
C. praecox	436.33 ^{ab} ± 2.52	446.33 ^{bc} ± 2.52	9.77 ^{c} ± 0.52	10.46 ^{d} ± 0.73	44.76 ^{a} ± 2.27	42.82 ^{a} ± 2.90
C. sylvatica	434.00 ^{ab} ± 5.00	448.33 ^{b} ± 3.21	13.42 ^{b} ± 1.07	15.22 ^{c} ± 0.75	32.48 ^{b} ± 2.77	29.50 ^{b} ± 1.50
C. remota	420.00 ^{c} ± 2.65	433.33 ^{de} ± 3.05	14.06 ^{b} ± 0.95	15.00 ^{c} ± 1.00	29.98 ^{b} ± 2.21	28.98 ^{b} ± 1.79

^{a}, ^{b}, ^{c}, ^{d}, ^{e} —homogeneous groups.

For the average total nitrogen content (Table 2) four groups (a–d) were found, with only *C. spicata* being distinguished in the (ab) subgroup.

The carbon to nitrogen ratio (C–N), being an indicator of digestibility, exhibited the lowest values—most suitable for feeding purposes—in *C. spicata* (23.03) and *C. muricata* (21.93 in May and 21.19 in June). For both the first and second harvest dates, *C. praecox* was characterized by the highest (less suitable) values, 44.76 and 42.82, respectively.

Table 2. Carbon and nitrogen content and proportion C–N in dry matter aboveground of the *Carex* species with statistically significant differences (Tukey's test). Mean values with standard deviation for each species are presented (statistically significant at $p < 0.01$).

Species	C	N	C−N
	[g·kg^{-1} DM]		
	Mean ± SD		
C. spicata	437.00 ^{abc} ± 5.18	19.18 ^{ab} ± 0.94	22.82 ^{de} ± 0.98
C. muricata	431.00 ^{bcd} ± 6.51	20.02 ^{a} ± 0.85	21.56 ^{e} ± 0.86
C. hirta	421.17 ^{d} ± 4.35	15.20 ^{c} ± 1.54	27.91 ^{bc} ± 2.35
C. disticha	450.00 ^{a} ± 12.96	17.88 ^{b} ± 0.29	25.17 ^{cd} ± 0.65
C. praecox	441.33 ^{ab} ± 5.92	10.11 ^{d} ± 0.68	43.79 ^{a} ± 2.56
C. sylvatica	441.17 ^{ab} ± 8.70	14.32 ^{c} ± 1.29	30.99 ^{b} ± 2.57
C. remota	426.67 ^{cd} ± 7.74	14.53 ^{c} ± 1.01	29.48 ^{b} ± 1.88

^{a}, ^{b}, ^{c}, ^{d}, ^{e}—homogeneous groups.

Additionally, for the first date of harvest, a high C–N ratio was found for *C. sylvatica*. Statistical differences were also noticeable for the mean C–N ratio, where the only homogenous groups are: a (*C. praecox*), b (*C. sylvatica* and *C. remota*) and e (*C. muricata*). The remaining species were classified as subgroups.

The ratio of selected mineral elements is very significant for the quality of the fodder (Table 3). Among the studied sedge species, a suitable ratio of the Ca–P (close to optimum estimated as 2:1) was found in *C. remota* (appropriately 2.2:1, 2.1:1), *C. muricata* (2.3:1, 2.3:1) and *C. sylvatica* (2.7:1, 2.6:1).

Table 3. Proportion (ratio) of the selected elements for *Carex* species tissues in May and June.

Optimal Value	K−Na		K−Ca+Mg		Ca−P	
Species	**May**	**June**	**May**	**June**	**May**	**June**
C. spicata	10.3:1	12.8:1	3.8	4.8	1.4:1	1.2:1
C. muricata	5.6:1	6.3:1	2.7	3.2	2.3:1	2.3:1
C. hirta	8.7:1	10.3:1	2.8	3.1	3.2:1	5.6:1
C. disticha	2.6:1	2.4:1	1.3	1.4	1.7:1	1.4:1
C. praecox	6.1:1	7.1:1	1.8	1.8	4.4:1	6.5:1
C. sylvatica	14.5:1	16.8:1	2.9	3.3	2.7:1	2.6:1
C. remota	16.6:1	26.4:1	3.6	4.4	2.2:1	2.1:1

The K-Ca+Mg ratio in fodder should not exceed 2.2. Suitable values were determined in *C. disticha* (1.3 and 1.4) and *C. praecox* (1.8 and 1.8).

In the case of the K–Na proportions, suitable for fodder purposes (equal 5:1), were found only in *C. muricata* (5.6:1) and *C. praecox* (6.1:1), while for the second cut *C. muricata* (6.3:1) was characterized by slightly larger than optimal value.

The concentrations of the studied macroelements are presented in Table 4, showing statistically significant differences, regardless of the harvest date between individual sedge species.

Table 4. The main macromineral components of selected sedge species at the beginning of May and end of June with statistically significant differences (Tukey's test). Mean values with standard deviation for each species are presented (statistically significant at $p < 0.001$ for P, K, Ca, Mg, Na and $p < 0.01$ for Si).

Species	P (2.8–3.6)		K (17.0)		Ca (7.0–10)		Mg (2.0–3.0)		Na (1.5–2.5)		Si (9.0)	
	[g·kg^{-1} DM]											
	May	**June**	**May**	**June**	**May**	**June**	**May**	**June**	**May**	**June**	**May**	**June**
C. spicata	4.17 ^{a} ± 0.07	3.72 ^{a} ± 0.16	30.38 ^{b} ± 1.09	27.71 ^{b} ± 0.17	5.66 ^{d} ± 0.25	4.62 ^{c} ± 0.22	2.34 ^{bc} ± 0.48	1.11 ^{e} ± 0.02	2.95 ^{c} ± 0.07	2.17 ^{e} ± 0.05	5.10 ^{ab} ± 0.17	5.53 ^{c} ± 0.25
	*		*		**		*		***		si	
C. muricata	3.20 ^{bc} ± 0.22	2.67 ^{c} ± 0.11	27.74 ^{cd} ± 0.55	26.08 ^{bc} ± 0.94	7.47 ^{bc} ± 0.83	6.21 ^{b} ± 0.21	2.73 ^{b} ± 0.07	1.85 ^{b} ± 0.06	4.92 ^{a} ± 0.12	4.12 ^{b} ± 0.04	5.70 ^{a} ± 0.61	6.13 ^{bc} ± 0.15
	*		si		si		***		***		si	
C. hirta	2.10 ^{d} ± 0.19	1.13 ^{d} ± 0.13	25.63 ^{d} ± 1.18	24.91 ^{c} ± 1.12	6.82 ^{bcd} ± 0.21	6.28 ^{b} ± 0.35	2.21 ^{bc} ± 0.23	1.35 ^{d} ± 0.09	2.93 ^{c} ± 0.02	2.43 ^{d} ± 0.08	5.67 ^{a} ± 0.58	7.00 ^{a} ± 0.20
	**		si		si		**		***		*	
C. disticha	3.61 ^{ab} ± 0.24	3.19 ^{b} ± 0.08	12.81 ^{f} ± 0.23	10.52 ^{e} ± 0.50	6.02 ^{cd} ± 0.58	4.56 ^{c} ± 0.21	3.69 ^{a} ± 0.25	3.18 ^{a} ± 0.06	4.91 ^{a} ± 0.16	4.40 ^{a} ± 0.08	5.10 ^{ab} ± 0.17	6.63 ^{ab} ± 0.60
	*		**		*		*		**		*	
C. praecox	2.27 ^{d} ± 0.25	1.41 ^{d} ± 0.04	21.94 ^{e} ± 0.34	19.93 ^{d} ± 0.06	9.90 ^{a} ± 0.08	9.15 ^{a} ± 0.57	2.27 ^{bc} ± 0.25	1.59 ^{c} ± 0.03	3.62 ^{b} ± 0.29	2.80 ^{c} ± 0.10	6.07 ^{a} ± 0.11	7.00 ^{a} ± 0.17
	**		***		si		**		*		**	
C. sylvatica	2.97 ^{c} ± 0.24	2.58 ^{c} ± 0.21	28.11 ^{c} ± 0.84	27.71 ^{b} ± 1.57	8.14 ^{b} ± 0.95	6.73 ^{b} ± 0.40	1.65 ^{c} ± 0.31	1.41 ^{cd} ± 0.15	1.94 ^{d} ± 0.22	1.65 ^{f} ± 0.10	5.94 ^{a} ± 0.21	6.77 ^{ab} ± 0.21
	si		si		si		si		si		**	
C. remota	3.28 ^{bc} ± 0.30	2.51 ^{c} ± 0.13	39.58 ^{a} ± 0.53	36.48 ^{a} ± 0.37	7.25 ^{bcd} ± 0.66	5.19 ^{c} ± 0.10	3.83 ^{a} ± 0.38	3.11 ^{a} ± 0.02	2.38 ^{cd} ± 0.36	1.38 ^{g} ± 0.05	4.60 ^{b} ± 0.35	5.53 ^{c} ± 0.23
	*		**		**		*		**		*	

^{a}, ^{b}, ^{c}, ^{d}, ^{e}, ^{f}, ^{g}—homogeneous groups; *— statistically significant for $p < 0.05$; **—statistically significant for $p < 0.01$; ***— statistically significant for $p < 0.001$; si—statistically insignificant.

In the case of the first sample (early May) the highest concentration of phosphorus was observed in *C. spicata* (4.17 g·kg^{-1} DM), and the differences in relation to the remaining species were statistically confirmed. In three species: *C. muricata*, *C. disticha*, *C. remota*, recorded P levels were in the optimal range or almost optimal (3.0–4.0 g·kg^{-1} DM) for fodder purposes. Statistically, the lowest average P content in the lowest average P content in the dry matter, around 2.0 g·kg^{-1} DM, was found in two species—*C. hirta* and *C. praecox*. However, in the case of the second harvest date (June), four homogenous groups were recorded, with the highest concentrations of this macroelement in *C. spicata* (3.72 g·kg^{-1} DM). Except for *C. spicata*, only *C. disticha* had recorded P levels in the optimal range or almost optimal for fodder purposes. The mean levels of P in the biomass of the two taxa (*C. hirta* and *C. praecox*) showed visibly lower values, below 1.50 g·kg^{-1} DM. Additionally, statistically confirmed differences were noted in six analyzed species compared with each other over two sampling periods. In the research conducted by Junkevičius and Sabienė [19], the phosphorus concentration analyzed of the beginning of flowering for a mixture of five species of plants from the legume family was on average 2.48 (the highest content found in *Trifolium repens*—3.60), while the average for eight grass species was 2.33, with the highest concentration recorded for *Elymus repens*—3.31 g·kg^{-1} DM. By comparison, Vejnowic et al. [9] obtained a mean of 2.2 and a range of 1.1–3.7 g·kg^{-1}.

In the study by Meehan et al. [24] P concentration in dry matter of Spengels sedge was highest during the May period compared with all other periods of determination. It is worth noting that the problem of phosphorus deficiency in plants is more common and observed also in grasses.

The results obtained in the case of the sedges tested partially confirmed the existing data indicating a decrease in P content with the growing season and its subsequent stabilization. This may be related to the fact that larger amounts of P are accumulated in flowers than in leaves, e.g., Alldrege et al. [25], Meehan et al. [24].

In the case of potassium content, only *C. praecox* (21.94 g·kg^{-1} DM in May and 19.93 g·kg^{-1} DM in June) was close to the optimal value 17 g·kg^{-1} DM. However, in species such as: *C. spicata*, *C. muricata*, *C. hitra*, *C. sylvatica* and *C. remota*, the content of this macroelement was much higher for both the first and second sampling dates.

This may be related to the structure of the aboveground biomass, because all these species, except *C. hirta*, are characterized by intensive, early spring development of the clump and maintaining a large number of leaves throughout the entire growing season. *C. hirta* does not produce such a wealth of leaves, but it belongs to the group of stoloniferous species, and therefore one individual consists of many aboveground shoots. The species showing a clear potassium deficiency was *C. disticha*, where the content was 12.81 (May) and 10.52 g·kg^{-1} DM (June), respectively. Additionally, statistical differences allowed us to create six (first set) and five (second set) homogenous groups. The average potassium content in studies by other authors was around 16.5–18.0 g·kg^{-1} DM [19], 10–40 with mean 22.9 g·kg^{-1} [8] and 19.7–28.5 mg·g^{-1} [7]. Parzych et al. [10] showed comparable K contents in species of the *Carex* genus. At the same time, the content of this macroelement was comparable to that observed in, for example, *Holcus lanatus* and *Dactylis glomerata* Juknevičius and Sabienė [19], Babu and Savithramma [9].

Most of the investigated sedge species (6) were characterized by calcium concentrations ca. 7–10 g·kg^{-1} DM, within the optimal range of 6.0–9.0 g·kg^{-1} DM. The slightly lowest value was observed in *C. spicata*- 5.66 g·kg^{-1} DM (May) and *C. remota*—5.19 g·kg^{-1} DM (June). Four of the investigated sedge species (*C. muricata*, *C. hirta*, *C. praecox*, *C. sylvatica*) were characterized by calcium concentrations ca. 7–10 g·kg^{-1} DM. A clear deficiency was found in *C. spicata* (4.62 g·kg^{-1} DM) and *C. disticha* (4.56 g·kg^{-1} DM). The species (*C. praecox)* had the highest content of this macroelement, both in May and June. The

content of this macroelement in other authors ranged from 5.04 (grasses) to 14.70 g·kg^{-1} DM (legumes) [19], 2.3–14 with mean 7.1 g·kg^{-1} [8] and 29.8–40.9 mg·g^{-1} [9]. The research conducted by Meehan et al. [24] showed that the calcium concentrations in dry matter of Spangle's sedge were similar throughout the collection period but trended toward increased levels with maturation. The results of the research conducted by Janyszek-Sołtysiak et al. [4] showed the calcium content in species of the Carex genus ranging from (3.2–8.1g·kg^{-1} DM). The visibly lowest values were observed in *C. disticha* (4.58 g·kg^{-1} DM) and *C. lepidocarpa* (3.27 g·kg^{-1} DM). Research by Janyszek et al. [3] showed that the calcium content in the sward of the latter two species is similar to the content found in *C. vulpina* L. and *C. otrubae* Podp., which are characterized by a similar morphological structure and similar habitat.

The Mg content in the dry matter of the aboveground parts of the analyzed sedge species was significantly higher during the May harvest period, but the significance of differences was not confirmed only in the case of (*C. silvatica)*. The optimal level of magnesium (about 2.0–3.0 g·kg^{-1} DM) occurred in four investigated species and for the May harvest ranged from 2.21 g·kg^{-1} DM (*C. hirta*) to 3.83 g·kg^{-1} DM (*C. remota)*, while in June the almost optimal level of magnesium occurred in three of the investigated species—*C. disticha* (3.18 g·kg^{-1} DM), *C. remota* (3.11 g·kg^{-1} DM) and *C. muricata* (1.85 g·kg^{-1} DM). A slightly lower content was recorded during the first harvest for *C. sylvatica* 1.65 g·kg^{-1} DM. The remaining species from the June harvest showed a clearly visible deficiency of this element.

For comparison, Junkevičius and Sabienė [19] showed the average magnesium content in legumes was 3.03 (*Trifolium repens*—3.60 g·kg^{-1} DM), and the average in grasses was 1.44 (*Elymus repens*—3.31g·kg^{-1} DM). In research by Vejnovic et al. [8] Mg content was ranged from 1.1 to 3.9 (mean 2.2 g·kg^{-1}), but Al-Rowaily et al. [8] showed 11.3 to 17.2 mg·g^{-1}. In their study, Parzych et al. [11] showed the magnesium content in shoots of *C. rostrata* at the level of 2000 mg·kg^{-1}. The authors claim that magnesium is taken up by plants in the form of Mg^{+2} ions which are found in the soil solution. These authors believe that the concentration of Mg in the shoots of plants depends on the species, age and part of the plant. According to Falkowski et al. [17] 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.

The highest sodium content in May was determined for *C. praecox* (3.62 g·kg^{-1} DM), while in both May and June it was found in *C. muricata* (4.92 and 4.12 g·kg^{-1} DM) and *C. disticha* (4.91 and 4.40 g·kg^{-1} DM). It was worth adding that, in these cases, the optimal value (1.5–2.5 g·kg^{-1} DM) was exceeded. Sodium concentrations within the optimal levels (or close) were measured for the remaining of the studied species. Similarly to magnesium, the Na content in the dry matter of the aboveground parts of the analyzed sedge species was significantly higher during the May harvest period, but the significance of the differences was not confirmed only for (*C. sylvatica*).

In previous research conducted by Janyszek-Sołtysiak et al. [4] the highest content of sodium was also exceeded in the species *C. disticha* (4.42 g·kg^{-1} DM), while in the remaining sedge species it was at the optimal level. In studies by other authors, the average Na content ranged from 7.4 to 350.0 with mean 34.6 g·kg^{-1} DM in natural grasslands [8] and scope of 5.78–8.16 g·kg^{-1} in Al-Rowaily et al. [7].

Silicon is a popular component of plants, and its content varies in different species [26]. The amount of Si in the dry mass of the studied species was relatively similar. The limit value estimated at 9 g·kg^{-1} DM was not exceeded in any of the examined species both in May (from 4.60 g·kg^{-1} DM in *C. remota* to 6.07 g·kg^{-1} DM in *C. praecox*), and in June—from 5.53 mg·kg^{-1} DM u *C. spicata* and *C. remota* to 7.00 mg·kg^{-1} DM u *C. hirta* and *C. praecox*.

The silicon content in the analyzed dry matter of individual species was higher during the June harvest, and the significance of the difference was not confirmed only for *C. spicata* and *C. muricata*. The higher Si content in summer, June, is related to the plant's response to

biotic stress [27,28]; in addition, Ma and Yamaji [29] indicate a better ability to accumulate this element by monocotyledonous plants, which include sedges.

The average total content of macroelements in sedge biomass for May and June (Figure 1) indicates the occurrence of significant statistical differences and the formation of two homogenous groups (a, b) for phosphorus, calcium, magnesium and silicon. The box plot shows a relationship related to a higher content of five out of six macroelements (except silicon) at the beginning of the flowering period (early May) which translates into a greater abundance of macroelements and also contributes to improving the feed balance in this period.

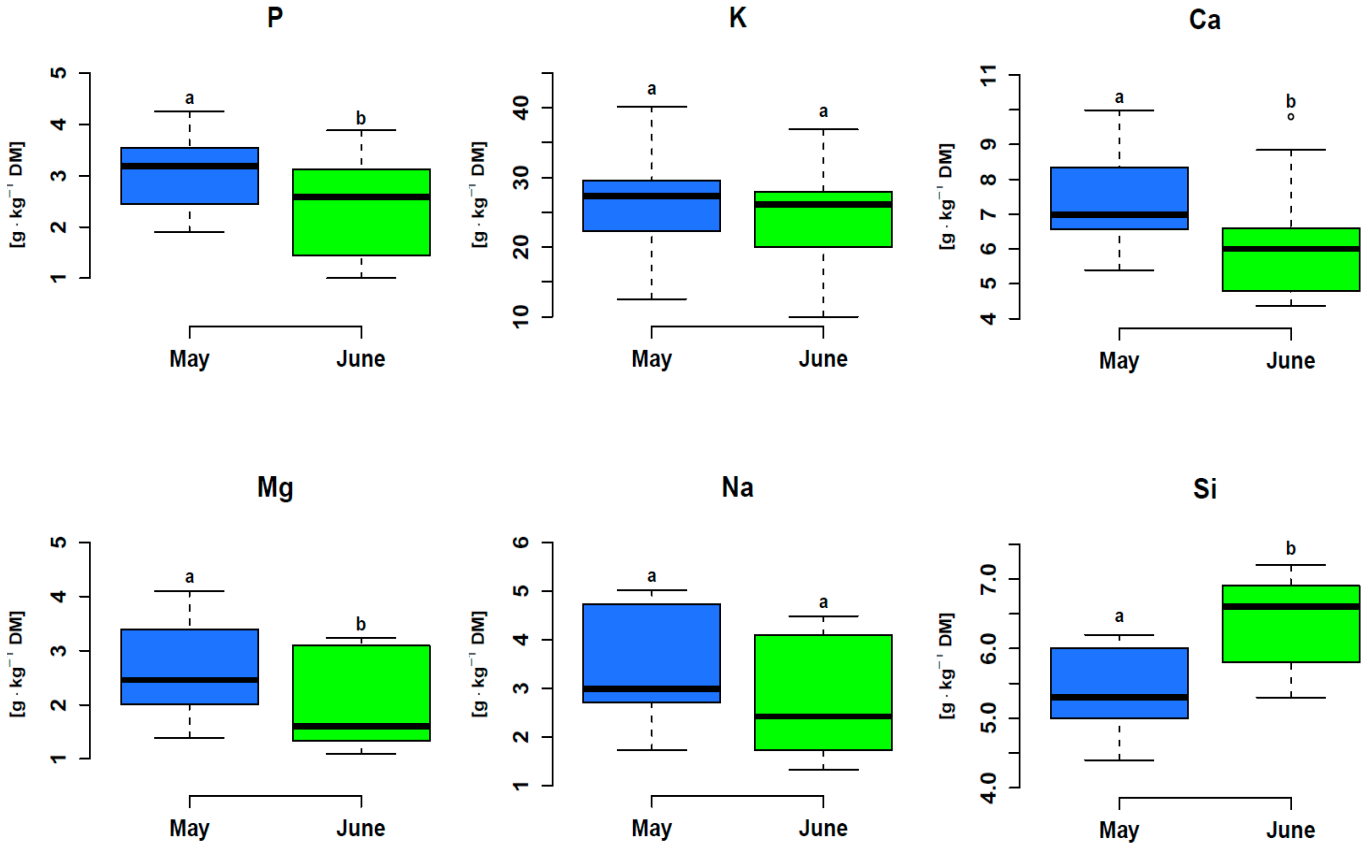


Figure 1. Average content of macroelements in dry sedge biomass for May and June (a, b—homogeneous groups).

The data obtained are reflected in Table 4, where both for individual species (the largest number of differences for P, Mg, Na and Si) and sampling period (K, Mg and Na-July) there are noticeable statistical differences in the content of the elements discussed.

In the case of trace elements (Table 5), the amount of copper (feed requirements estimated at approximately 10 mg) was relatively low in the biomass of five species: *C. spicata*, *C. muricata*, *C. disticha*, *C. praecox*, *C. remota* and was 6.68–7.50 mg·kg^{-1} DM in May (two homogeneous group) and 5.62–6.70 mg·kg^{-1} DM in June (four homogeneous group). Only two species—*C. hirta* (9.72 and 9.32 mg·kg^{-1} DM) and *C. sylvatica* (8.62 mg·kg^{-1} DM, May harvest) were the only species in the studied groups that showed a level of this microelement close to the optimal level. The other analyzed sedge species were characterized by higher copper content in plant material collected in May. The only exception was *C. disticha* (6.70 mg·kg^{-1} DM), both in material from May and June.

Table 5. The main macromineral components of selected sedge species at the beginning of May and end of June with statistically significant differences (Tukey's test). Mean values with standard deviation for each species are presented (statistically significant at $p < 0.001$ for Cu, Zn, Cr, Ni, Fe and $p < 0.01$ for Si).

Species	Cu (10)		Zn (50)		Cr (0.3–5.0)		Ni (0.1–5.0)		Fe (30)	
	[mg·kg−1 DM]									
	May	June	May	June	May	June	May	June	May	June
C. spicata	6.68 ^{b} ± 0.37	5.68 ^{d} ± 0.18	33.00 ^{b} ± 0.17	29.36 ^{b} ± 0.64	1.22 ^{bcd} ± 0.19	1.01 ^{c} ± 0.02	1.50 ^{bc} ± 0.42	1.28 ^{b} ± 0.04	18.80 ^{cd} ± 0.89	15.53 ^{c} ± 0.06
	*		***		si		si		**	
C. muricata	7.13 ^{b} ± 0.55	5.66 ^{d} ± 0.05	33.69 ^{b} ± 3.66	29.35 ^{b} ± 1.39	1.48 ^{abc} ± 0.47	1.12 ^{bc} ± 0.03	1.90 ^{ab} ± 0.22	1.34 ^{b} ± 0.05	26.22 ^{b} ± 2.43	22.88 ^{b} ± 0.15
	*		si		si		*		si	
C. hirta	9.72 ^{a} ± 0.34	9.32 ^{a} ± 0.42	57.18 ^{a} ± 4.50	52.80 ^{a} ± 1.42	0.96 ^{cd} ± 0.06	0.79 ^{d} ± 0.10	2.76 ^{a} ± 0.51	2.68 ^{a} ± 0.56	19.82 ^{c} ± 0.15	17.66 ^{c} ± 0.06
	si		si		si		si		***	
C. disticha	6.70 ^{b} ± 0.36	6.70 ^{c} ± 0.36	28.10 ^{bc} ± 0.95	26.10 ^{c} ± 0.95	0.80 ^{d} ± 0.16	0.62 ^{d} ± 0.05	0.10 ^{d} ± 0.06	0.05 ^{c} ± 0.00	15.41 ^{d} ± 0.70	13.17 ^{d} ± 0.06
	si		si		si		si		**	
C. pracox	6.76 ^{b} ± 0.25	5.62 ^{d} ± 0.11	21.18 ^{d} ± 1.24	18.50 ^{e} ± 0.89	1.29 ^{bcd} ± 0.06	1.24 ^{b} ± 0.05	1.57 ^{bc} ± 0.37	1.33 ^{b} ± 0.04	15.95 ^{cd} ± 0.66	12.85 ^{d} ± 0.22
	**		*		si		si		**	
C. sylvatica	8.62 ^{a} ± 0.33	8.37 ^{b} ± 0.40	25.93 ^{cd} ± 1.09	23.73 ^{cd} ± 1.10	1.76 ^{ab} ± 0.15	1.63 ^{a} ± 0.12	1.74 ^{bc} ± 0.43	1.65 ^{b} ± 0.09	14.83 ^{d} ± 1.91	12.03 ^{d} ± 0.20
	si		si		si		si		si	
C. remota	7.50 ^{b} ± 0.49	5.83 ^{d} ± 0.29	23.83 ^{cd} ± 1.36	22.13 ^{d} ± 1.20	1.90 ^{a} ± 0.13	1.64 ^{a} ± 0.07	0.78 ^{cd} ± 0.21	0.61 ^{c} ± 0.03	86.76 ^{a} ± 1.98	85.20 ^{a} ± 1.99
	**		si		*		si		si	

^{a}, ^{b}, ^{c}, ^{d}, ^{e}—homogeneous groups; *—statistically significant for $p < 0.05$; **— statistically significant for $p < 0.01$; ***— statistically significant for $p < 0.001$; si—statistically insignificant.

In the study by Parzych et al. [10] it can be noted that the concentration of copper remained at the level from 2.1 mg·kg^{-1} (*C. paniculata*) to 16.1 mg·kg^{-1} (*C. rostrata*); however Gralak et al. [30] obtained results for grasses ranging from 6.9 (*Festuca arundinacea*) to 8.9 mg·kg^{-1} (*Lolium perenne*). According to the authors 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 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}.

The highest concentrations of zinc detected, (optimal estimated at about 50 mg·kg^{-1} DM), were found (May, June) in *C. hirta* (57.18 and 52.80 mg·kg^{-1} DM). The remaining species showed a clear deficiency of this element from 21.18 to 33.69 mg·kg^{-1} DM in May and 18.50 to 29.36 mg·kg^{-1} DM in June. As in the case of copper, plant material collected in May showed higher zinc accumulation compared to the June harvest, and the significance of differences between the analyzed dates was confirmed for species *C. spicata* and *C. praecox*. The results of our own research were similar to those obtained by Kabata-Pendias and Pendias [31], where the Zn content in plant material of species of the *Carex* genus ranged from 10 to 70 mg·kg^{-1}. Similar results were also obtained in studies [7,8,30]. The authors believe that the uptake of Zn by plants largely depends on its content in the soil. This element is characterized by high mobility and is easily accumulated.

The chromium content for the May harvest ranged from 0.8 to 1.9 mg·kg^{-1} DM for *C. disticha* and *C. remota*, while in June it ranged from 0.62 to 1.64 mg·kg^{-1} DM for the same species. No shortage or excess of chromium was recorded in any of the species examined (optimal values estimated at 0.3–5 mg·kg^{-1} DM). Also, with regard to the concentration of chromium in plant material, a higher tendency was confirmed for the content of this microelement in plant material collected in May, but the significance of the differences was confirmed statistically only for *C. remota*. In earlier studies by Janyszek et al. [4] similarly neither excess nor deficiency of chromium was found.

The nickel content in both May and June was characterized by the lowest concentration of this element in *C. disticha* (0.1 and 0.05 mg·kg^{-1} DM), while the highest Ni concentration was recorded for *C. hirta* (2.76 and 2.68 mg·kg^{-1} DM). No excess or shortage of nickel was found in any species. Also, in the case of this micronutrient, a tendency towards higher concentrations in plant material from the May harvest was shown, and the significance of differences was only confirmed for *C. muricata*. Krzywy [32] considers that the content of nickel in plants ranges from 0.1 to 5.0 mg·kg^{-1} and in areas with a high ground water level it is easily bioaccumulated in plants and is a bioindicator of water.The concentration of iron also varied widely among the species studied, from 15.41 mg·kg^{-1} DM (*C. disticha*) to 86.76 mg·kg^{-1} DM (*C. remota*) in May and from the lowest in *C. sylvatica* (12.03 mg·kg^{-1} DM) and 12.85 mg·kg^{-1} DM (*C. praecox*) to 85.20 mg·kg^{-1} DM (*C. remota*) in June. The results obtained show a deficiency of this element in the six species studied. Only *C. remota* exceeds the optimal content of iron in fodder (ca 30 mg·kg^{-1} DM). Of the seven species, as many as four showed a statistically significant difference in the content of this micronutrient in plant material from May to June. These were: *C. spicata*, *C. hirta*, *C distiha* and *C praceox*. The average iron content in the studies of Al-Rowaily et al. [7] ranged from 16.93 to 38.44, while significantly higher concentrations of this element were recorded in grasses—104–151 mg·kg^{-1} [30]. In research by Parzych et al. [10] the largest quantities of iron were accumulated by the shoots of *C. panicula* (296 mg·kg^{-1}) and the lowest by *C. acutiformis* (170.7 mg·kg^{-1}). During the years of research (2012–2014) the content of Fe in the shoots of Carex varied, and the largest concentrations were observed at the beginning of vegetative seasons and, along with the growth and development of plants, concentrations of Fe in the shoots decreased. The above-mentioned authors believe that the

level of toxicity characterizing Fe in the shoots of plants has not been determined so far but is strictly species species-dependent. The results of our study, in relation to C. remota, confirm those obtained by Samecka-Cymerman and Kempers [33], and Parzych et al. [10], in which the same species was also characterized by high Fe concentrations. WhichThis, according to these authors, is probably due to the high solubility of iron, which is important in species growing on moist soils.

The analyzed micronutrients contained in the dry weight of all sedge species tested for the May and June harvests show statistically significant differences only for copper content (Figure 2). In addition, it can be noted that, both for individual sedge species (four) and in relation to the harvest date (May—two homogeneous groups, June—four homogeneous groups), the highest number of statistical differences was shown for copper (Table 5). In addition, the overall micronutrient content, due to the numerous occurrences of no statistical differences for Zn, Cr and Ni, is reflected in the quoted data from Table 5.

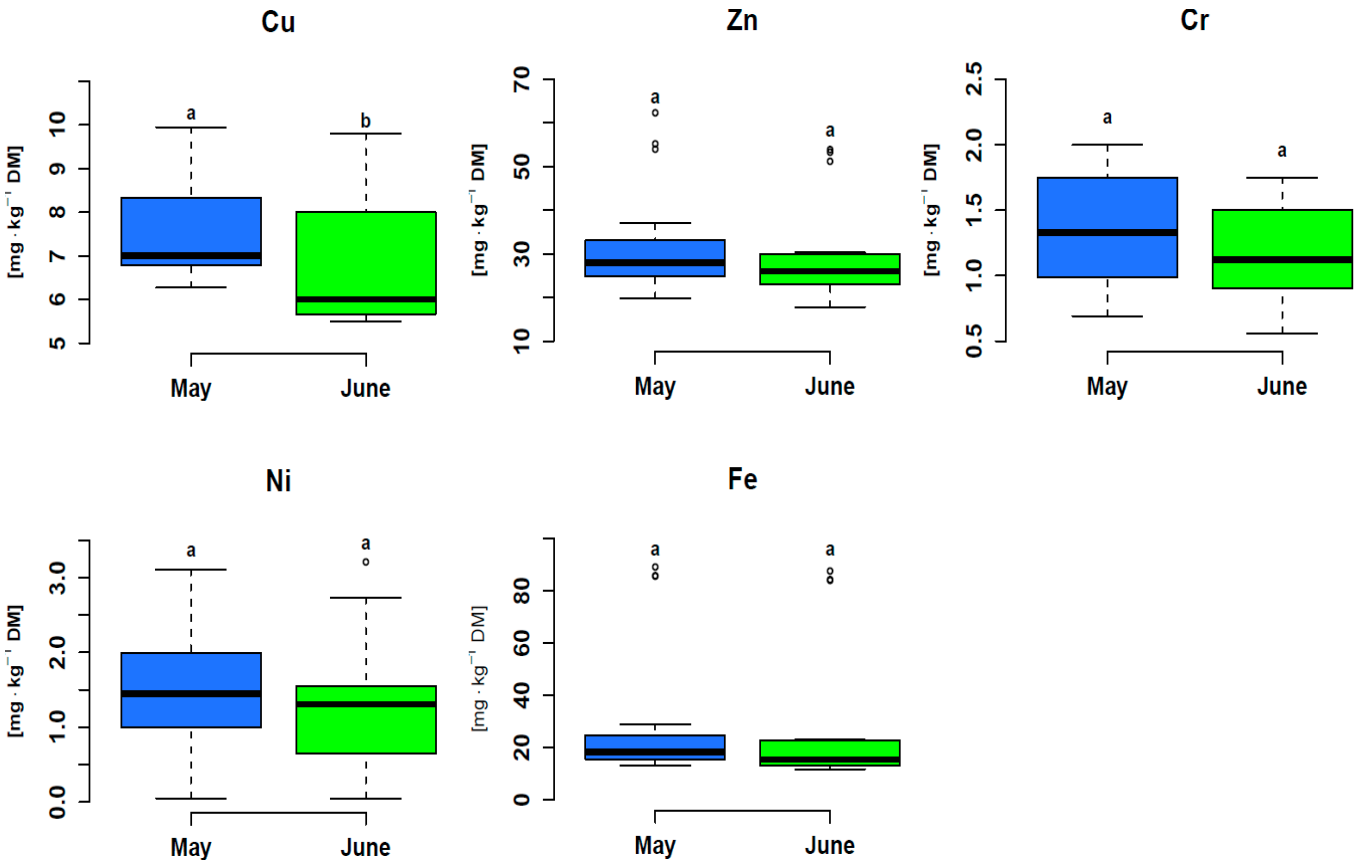


Figure 2. Average micronutrient contents of sedge dry biomass for May and June (a, b—homogeneous groups).

The similarity dendrite of the mean content of micro- and macronutrients contained in sedge biomass taken at the beginning of earring-May (Figure 3) indicates a clear distinctiveness of *C. remota* relative to the other clusters, with a similarity measure of 65%. This is justified by the fact that higher potassium and iron contents were recorded than in the other sedge species. The distinctiveness of *C. remota* in terms of iron content may be due to the fact that, in general, it is a species of moist deciduous forests with different habitat conditions than in grasslands. This also applies to the degree of light availability, which influences the accumulation capacity of the plant. Morphologically, it is a dense-stemmed plant with a high abundance of leaves produced throughout the growing season, which also influences the abundance of micro and macronutrients. The first level of similarity

(80%) distinguishes *C. hirta* from the other species, the second, with a similarity of 83%, is characterized by the specificity of *C. disticha* and the group of the other four clusters. Despite the lack of taxonomic and habitat relationships, *C. hirta* and *C. disticha* belong to the group of sedges [34]; both form stems that are relatively sparsely foliaged and the leaves begin to partially die back when the follicles mature. Another distinct pair are *C. praecox* and *C. sylvatica*, which do not share any common traits regarding habitat preference or similar morphological characteristics; both form stems that are relatively sparsely foliaged and the leaves begin to partially die back when the follicles mature.

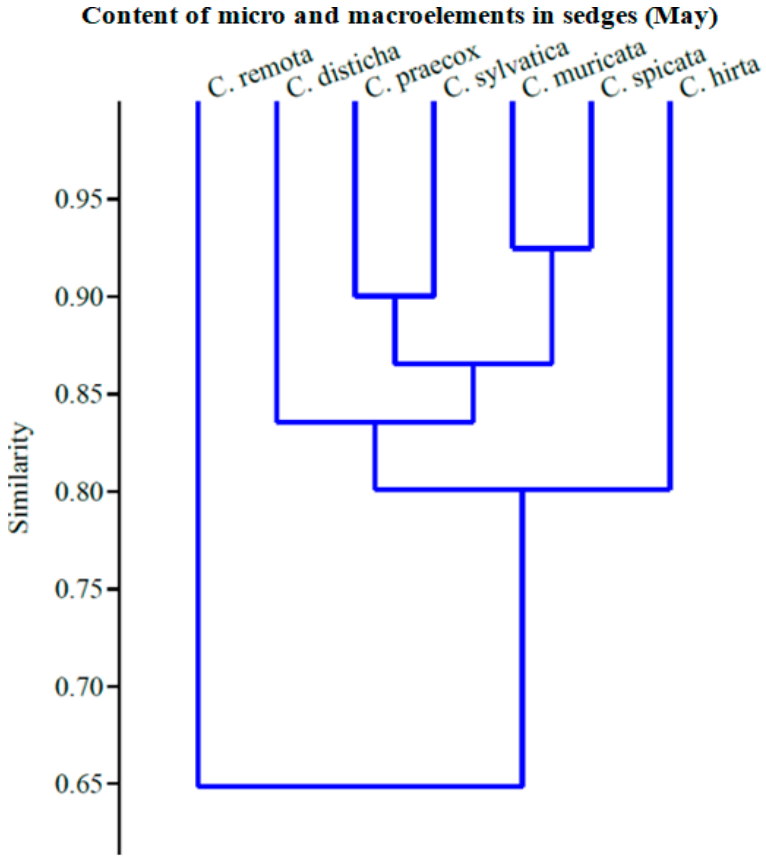


Figure 3. Classification dendrogram of the average micronutrient and macronutrient content of sedge dry biomass at the beginning of earring (May). Applied UPGMA pairwise clustering algorithm based on the Bray–Curtis similarity measure.

Another distinct pair are *C. praecox* and *C. sylvatica*, which do not share common characteristics regarding habitat preference, nor similar morphological features. The species with the most similar micronutrient and macronutrient content in aboveground organs were *C. muricata* and *C. spicata* (93%). It should be noted that both species prefer the same or very similar habitat conditions and occur in similar types of phytosociological units. Although, due to the fact that *C. spicata* is a much more common species, they vary in frequency and constancy of occurrence in individual plant communities. When considering the similarities obtained between the species, it should be noted that these are taxa showing close taxonomic affinities. They belong to the common section *Phaestoglochin* and, at the same time, show a very strong morphological similarity of organs, evident both in the form of dense clumps and vesicles, which may suggest a similar manner and capacity to accumulate different types of substances, including micro and macronutrients in the vegetative and generative parts, especially when comparing specimens growing within the same patch of sward.

The lines on the dendrograms represent the different degrees of similarity between groups or individuals in the data analysis, particularly in the context of clustering. A dendrogram illustrates the hierarchical structure of clustering, where the level on the vertical axis indicates the distance or differences between these groups. The height of the cut of the dendrogram indicates the number of clusters formed.

The dataset (seven species × eleven elements) representing the average micronutrient and macronutrient content of the sward of each species taken at the end of June presents itself similar to the first dataset (May). Significant distinctiveness of the *C. remota* cluster (62% convergence) was shown against the other two groups at the first level of similarity characterized by 78%, where deviation was shown by *C. hirta* against the other species (Figure 4). The second level stabilized at 82%, indicating the distinctiveness of *C. disticha*, while the third level was 84%. *C. spicata* and *C. muricata* were the most similar in terms of macro and micronutrient content (92%), similar to the May harvest.

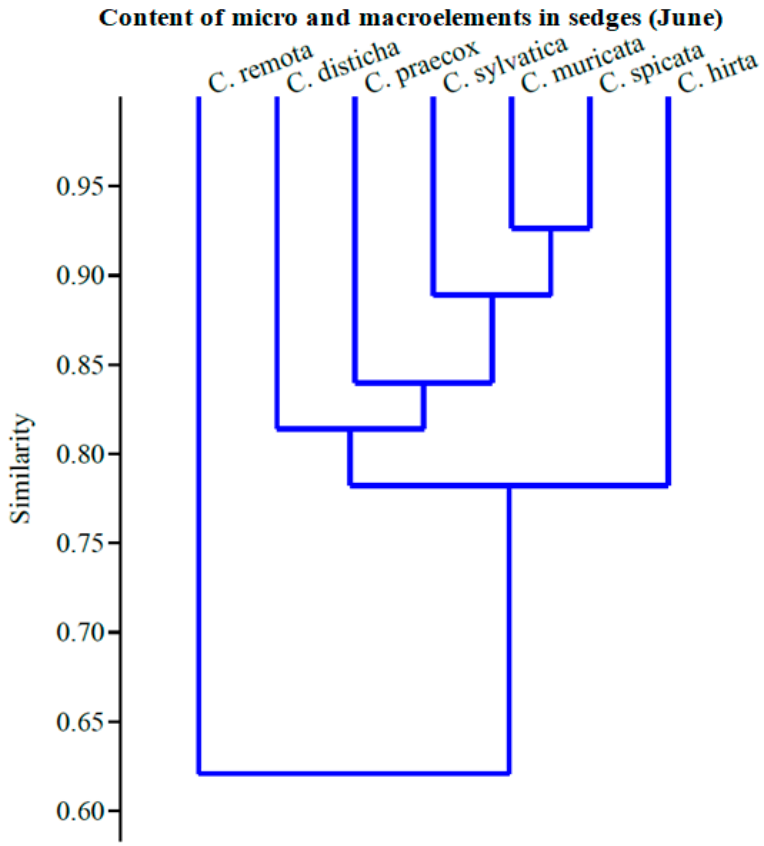


Figure 4. Classification dendrogram of the average micronutrient and macronutrient content of the dry biomass of the sedges studied at flowering and early fruiting (June). Applied UPGMA pairwise clustering algorithm based on Bray–Curtis's similarity measure.

The similarity dendrite of the mean macro and micronutrient contents combined for the sedges from May and June (Figure 5) shows strong similarity to the results obtained in the second sample (June). The similarity measure of *C. remota* with respect to the other clusters is 64%. The first level of similarity was recorded at a value of 79%, while the similarity of the second is equal to 83%. Similarity levels one to four show the distinctiveness of single species, and only at the fifth level is the group formed by *C. muricata* and *C. spicata* noticeable (92%).

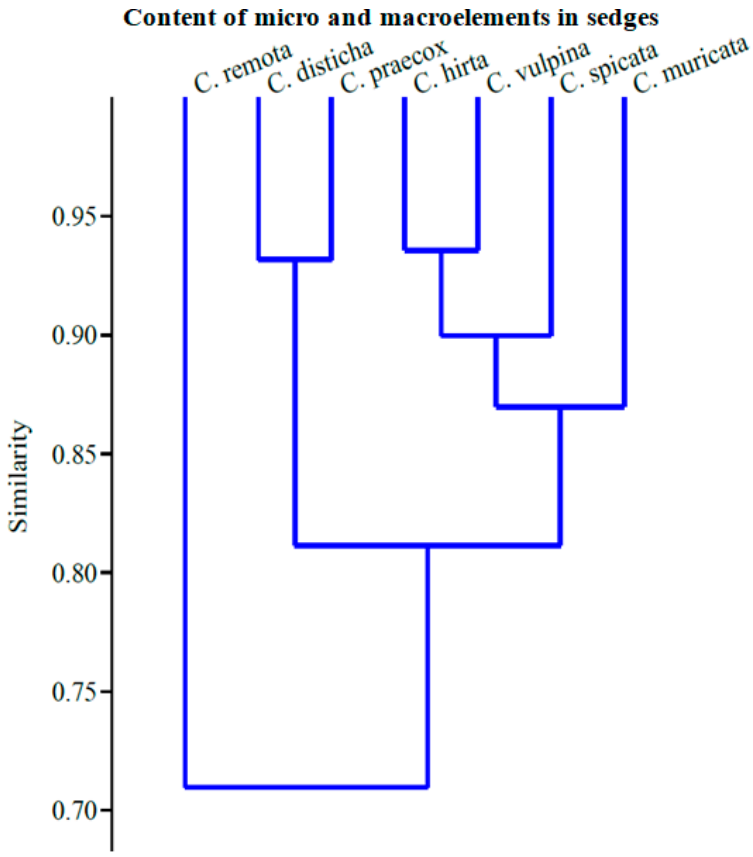


Figure 5. Classification dendrogram of the average micronutrient and macronutrient content of sedge dry biomass. Applied UPGMA pairwise clustering algorithm based on Bray–Curtis's similarity measure.

The level of minerals in the biomass is of great practical importance for the quality of the feed in relation to the nutritional requirements of individual animal species. This issue relates to both deficiency and excess of minerals, especially when levels toxic to living organisms are exceeded. The results obtained in this study show that the sedges analyzed are potentially a good source of macro and micronutrients, although far less significant than the dicotyledonous plants found in the meadow sward. The lower ability of monocotyledons, including grasses and sedges, to extract minerals is regulated physiologically and morphologically by monocotyledonous plants producing fewer cation exchange sites in their cell walls. Hence, their naturally lower content in these plants [17,18,35,36]. Although the study group of species did not show a single species with optimal concentrations of all analyzed minerals in its aboveground organs, some species were shown to have optimal concentrations of individual analyzed minerals. This applies in particular to *C. sylvatica* with regard to P, Ca, Na, Cu, Cr andNi content, *C. remota* P and Na, *C. muricata* P, Mg, Cr, Ni. However, *C. hirta* Cu, Zn, Cr and Ni, are the only species in this group characterized by the production of less leaf mass and more rapid drying of the leaves during the growing season, which occurs after the follicles have reached maturity.

This may have a potential role in the elements shown in *C. hirta*, among which there are insufficient levels of either of the macronutrients analyzed. The results obtained in the present study indicate that the contents of individual elements in the aboveground organs of the analyzed sedges remain relatively stable over the course of both study groups (from early May and late June). Forages, including grass fodder, are an important source of minerals in the diet of herbivores, and the nutritional value of plants is related, among other things, to the levels of macro and micronutrients in their organs. Therefore, species diversity

of vegetation patches, especially for their potential economic use, is very important. In light of the widely observed current environmental changes exerting high pressure on habitat properties (e.g., lowering of groundwater levels), control—monitoring of mineral content to avoid mineral deficiency or excess [4,30] is very important. Grasses are one of the basic components of the sward of meadow and pasture communities; however, as mentioned, they contain fewer micro and macro elements in the sward than, for example, the so-called herbs and plants of the *Fabaceae* family. Our research has shown that the analyzed sedges have similar levels of individual minerals to grasses. This also applies to the comparable silicon contents of the aboveground organs. In spite of this, some studies, e.g., Metson et al. [37], treat sedges as a factor that reduces the economic value of the sward.

As the content of the minerals tested was comparable to that recorded in some grasses used in meadow management, attention should be paid to the potential of sedges, as they can be a valuable component of meadow communities and increase their forage value. The results of our study suggest a wide range of possibilities for their use in practice, for example, by reseeding species with the most desirable traits. Thus, they can be used to model the retention of various elements in plant biomass and modify the composition of plant communities, which can enrich their forage value, which can be translated into use in animal diet supplementation. This applies to different types of grassland, including those associated with organic farming.

Results obtained by other authors indicate that sedges also appear to be a plant material with probable therapeutic potential, due to the presence of bioactive substances, both in the rhizomes, leaves and in the fruit and follicles. In their generative organs and in their leaves, including in the *C. spicata* analyzed in this study, the presence of unsaturated fatty acids has been demonstrated, substances essential for normal metabolism that animals are unable to synthesize on their own Ayaz and Olgun [38], Bogucka-Kocka and Janyszek [39]. The aboveground biomass of sedges also showed the occurrence of polyphenols, including phenolic acids, substances with strong antioxidant and free radical-fighting properties, e.g., caffeic acid and p-coumaric acid, as well as synaptic acid, which is very rare in plants. These substances were also detected in *C. muricata*, *C. disticha*, *C. remota* and *C. sylvatica* Van de Staaij [40], Bogucka-Kocka et al. [41], Rajak and Grosh [42], and described by us. Also noteworthy is the occurrence in some species of resveratrol and other polyphenols and secondary metabolites—stilbenes, in particular a novel stilbene oligomer carexinol-A, a substance with antioxidant properties as well as substances with potential anticancer properties Arraki et al. [43], David et al. [44], David et al. [45], Triska et al. [46].

The presented properties of sedges are generating interest in these plants as a potential and attractive food additive, e.g., *C. hirta* presented in Arraki et al. [43] and analyzed in our study. An undoubted advantage of sedges as a potential supplement, as well as in animal nutrition, is the fact that most species are common plants. The taxonomic richness of the Carex genus (about 100 species in Poland), their habitat diversity, especially in terms of substrate moisture—from dry to swampy habitats, their high evolutionary and survival potential, also in the soil seed bank, thanks to the development of a characteristic and specific organ, the bladderwort, offer a wide range of possibilities for their use in practice.

4. Conclusions

1. The difference in micronutrient content between May and June harvest dates in the dry weight of all sedge species analyzed was statistically confirmed only for copper.
2. The timing of harvesting, which is also a reflection of the specific phase of plant development, had a statistically significant effect on the change in the macronutrient content of the dry matter of all the sedge species analyzed and was associated with a

decrease in phosphorus, magnesium and calcium, while in the case of silicon, a delay in mowing resulted in an increase in the content of this element.

3. The mineral value of sedges, like many other plant species, at the beginning of the growing season is higher compared to the plant material analyzed at the end of the growing season. Species differing in physiognomy and habit were selected for the study. C. *spicata*, *C. muricata* and *C. remota*, are dense-clumped plants, *C. sylvatica* forms a loose clump. In contrast, *C. hirta*, *C. disticha* and *C. praecox* are plants, with crawling rhizome-producing upright stems at intervals. Additionally, in *C. disticha* and *C. hirta*, in contrast to the other species analyzed, usually the leaves begin to die back after the vesicles mature. However, as the analyses showed, these traits generally had no effect on the concentration levels of the individual elements. The only significant exception was *C. remota* with regard to iron content.
4. The results showed that sedge sward is a good and, in most cases, sufficient source of the micro and macronutrients studied in forage, particularly in comparison with the content observed in grass species desirable in meadow communities.
5. Sedges appear to be a potentially good source of compounds with beneficial effects on animal organisms, including compounds of a therapeutic nature. They are rich in essential fatty acids, and contained in hair follicles and leaves, making them a good source of supplements. Low-sedge floodplain meadows may be a potential source of macro and micronutrient supplementation, but their nutritional value may depend on a number of environmental factors. The results of our study indicate variation in the mineral content of the dry matter of all analyzed sedge species depending on the harvest date.
6. However, it should be noted that the study had some limitations. Firstly, the meadows analyzed represent specific habitat conditions, which may make it difficult to extrapolate the results to other regions. Secondly, the influence of seasonal and hydrological factors on the mineral composition of plants requires further research in a multi-year perspective. Finally, the bioavailability of nutrients to animals was not assessed, which is an important aspect of the practical application of the results.

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