MINERAL CONTENT IN *SPHAGNUM* MOSSES FROM OMBROTROPHIC BOGS OF SOUTHWESTERN POLAND: PATTERN IN SPECIES AND ELEMENTS

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ABSTRACT

Major elements (N, P, K, Ca, Mg, Na, Fe) were analyzed in 11 Sphagnum species from ombrotrophic bogs in southwestern Poland. The material included species from wet to dry microsites. The highest levels of elements were recorded for *S. lindbergii*, whereas *S. balticum* and *S. cuspidatum* were poorest in elements. The microhabitat gradient from hummock to hollow species is clearly reflected by decreasing concentrations of Ca and Mg, and increasing concentration of Na. Phosphorus, K and N were much more enriched into moss tissues than the remaining elements. These three nutrients were also accumulated in the upper green parts of mosses, while the concentrations of Na and Fe were higher in the bottom brown parts. There were no differences in Ca and Mg between the green and brown segments.

KEY WORDS: major elements, *Sphagnum* mosses, ombrotrophic bogs, southwestern Poland

INTRODUCTION

Ombrotrophic bogs receive elements largely from atmospheric precipitation and dust fall. Thus, these ecosystems have practically a uniform nutrient status. In such conditions the mineral economy of *Sphagnum* mosses is chiefly determined by physico-chemical factors of microsites and depends also on the moss species (Aulio 1980, 1982, Damman 1978, Malmer 1988, Malmer and Sjörs 1955, Pakarinen 1978, Pakarinen and Tolonen 1977). Therefore, the nutrient-poor ombrotrophic *Sphagnum* bogs are ideal sites for various comparative studies.

This paper summarizes the major element concentrations of N, P, K, Ca, Mg, Na and Fe in 11 *Sphagnum* species. The main objectives are to compare both (1) species from various microhabitats and (2) the behaviour of elements.

MATERIAL AND METHODS

Study sites – The sampling was performed on two obrotrophic bogs located in the Sudeten Mts., southwestern Poland (Fig. 1). The study bog in Karkonosze Mts., situated at 1450 m a.s.l., is an oligotrophic mire with ombrotrophic and poor minerotrophic areas. Drier ombrotrophic parts are dominated by *Scirpus cespitosus*, *Vaccinium uliginosum*, *Sphagnum compactum*, *S. lindbergii* and *S. russowii* on hummocks. Wet depressions are dominated by *Carex rostrata*, *Carex limosa* and *Drepanocladus fluitans* (Fabiszewski 1978, Matuła and Wojtuń 1981).

The second bog is located in Bystrzyckie Mts. at 750 m a.s.l. and form a bog-fen complex. The ombrotrophic bog is dominated by *Eriophorum vaginatum*, *Andromeda polifolia* and several *Sphagnum* species. *Sphagnum cuspidatum*, together with *Carex limosa*, *Sphagnum balticum*, and *S. tenellum* form permanently wet hollows and flarks. *Sphagnum angustifolium*, *S. magellanicum*, *S. papillosum*, *S. russowii* and *S. rubellum* form extensive lawns.

Fig. 1. Location of study sites in Poland;
1 – Karkonosze Mts., 2 – Bystrzyckie Mts.

Sphagnum angustifolium and *S. magellanicum* occur scarcely, together with *Polytrichum strictum*, on low hummocks.

Detailed descriptions of floristic composition and trophic conditions of the studied bogs are given in Wojtuń (1989).

Sampling and laboratory procedures – The material was collected in autumn (September – October) 1986. The *Sphagnum* mosses included species from wet to dry microsites. The samples were collected from stands as pure as possible and transported to the laboratory in 1-2 days.

Moss shoots were cut into two segments from the apex, i.e., the uppermost green one and the bottom brown segment. In most species only the uppermost green segments were taken for analyses, and in a few species (see Fig. 4) the bottom brown segments were analysed too. In most of the species, the boundary between the green and brown segments for most species was determined by change in colour. In *S. compactum, S. fuscum, S. magellanicum* and *S. papillosum* no distinct colour changes were observed. The green/brown limit in these species was determined by the distance between the fascicles of branches (Malmer 1988, Pakarinen 1978). This way of treating the samples ensured that the uppermost green segments were functionally comparable among samples and species. Hence, the comparison between *Sphagnum* species is based on physiologically comparable green phytomass. The lengths of green segments in *S. fuscum, S. compactum, S. balticum* and *S. tenellum* was 1.2 to 1.8 cm from the apex; the green portion of the remaining species ranged from 2.8 to 3.3 cm.

All chemical analyses of moss samples were carried out in the Department of Botany, University of Agriculture in Wrocław. After oven-drying (60°C, 48 h), the analyses of the samples were carried out in a solution obtained by wet digestion (Parkinson and Allen 1975). Total nitrogen and phosphorus were analysed colorimetrically by means of the indophenol blue and ammonium molybdate method, respecively. Flame photometry was used for analyses of K, Na and Ca, and for Mg and Fe the atomic absorption spectrophotometer was used (Allen 1974). For datails, see Wojtuń (1989).

For the statistical elaboration of chemical analyses the t-test of paired samples (differences between green and brown segments) and analysis of variance, the GLM procedure (differences between hummock, lawn and hollow species) were used. In the latter case no transformations were applied. All statistical analyses were made by means of the SAS package (SAS Institute 1988). The nomenclature follows Nyholm (1979) for *Sphagnum* species and Tutin et al. (1964-1980) for vascular plants.

RESULTS

The element concentrations for 11 *Sphagnum* species from two ombrotrophic bogs are presented in Table 1. Tissue element concentrations decreased, on average, in the order N > K Ca > Mg > Na > P, Fe. This sequence was similar for all species. The only notable exceptions to the general trend were that the Fe concentration in *S. compactum* and Na concentrations in *S. lindbergii* and *S. tenellum* exceeded the level of Mg.

The highest element concentrations were recorded for *S. lindbergii*. This species was especially rich in nitrogen and sodium. The poorest in elements were *S. balticum* and *S. cuspidatum*. The differences between the remaining species were, in general, small.

Species profiles of element concentrations (Fig. 2), expressed as percentage deviations from the mean values of all species (Auclair 1979, Aulio 1980, Woodell et al. 1975) clearly demonstrated high species-specific differences. The element levels of *Sphagnum balticum, S. magellanicum, S. rubellum* and *S. papillosum* were near the mean and relatively balanced. The hollow species (*S. cuspidatum, S. tenellum and S. lindbergii*) had the highest concentration of Na, but relatively low Ca. On the contrary, species which often occupied hummocks (S. angustifolium, S. fuscum, S. russowii) demonstrated the highest Ca and Mg levels, but were poor in Na.

The dry-wet microhabitat gradient, e.g. from dry hummocks to wet hollows (Fig. 3) is clearly reflected by the decreasing concentrations of Ca and Mg and increasing concentration of Na. However, the differences were statistically significant only for Ca in hummocks and hollows ($p < 0.01$), and for Mg in hummocks and lawn ($p < 0.001$) and hummock and hollow species ($p < 0.001$). The concentrations of other elements (K, Fe, P, N) revealed only slight changes. When comparing the samples from the same site, the differences in Ca and Mg concentrations between *S. angustifolium* and *S. magellanicum*, colected both from hummock and lawns (cf. Fig. 3), were small. However, there were considerable differences between sites with respect to these cations. In the hummock samples the concentrations of Ca and Mg were 1.63 and 0.78 mg g^{-1} respectively. The corresponding values for the hollow samples were lower, i.e. 1.30 mg g^{-1} and 0.39 mg g^{-1} respectively.

The general distribution pattern of elements (calculated for lawn species) within the mosses was distinct (Fig. 4). Thus, the highest concentrations of N and P were found in green segments. A similar trend was found for K, but the differences between the green and brown parts were not statistically significant. For Fe and Na, the concentration was higher in the lower brown segments and these differences were statistically significant. In the case of Ca and Mg concentrations there were no significant differences between the green and brown parts. These elements were rather evenly distributed. The enrichment ratios (Pakarinen 1978), calculated as the tis-

TABLE 1. Concentration of major elements in green segments of 11 *Sphagnum* species from ombrotrophic bogs of southwestern Poland. Means (mg g^{-1} d. w.) and SD (in parentheses) are given.

Species	n	N	K	Ca	Mg	P	Na	Fe
S. angustifolium	9	11.0 (1.1)	6.4 (1.1)	1.24 (0.3)	0.53 (0.18)	0.44 (0.06)	0.22 (0.10)	0.26 (0.09)
S. balticum	6	10.1 (0.9)	4.7 (0.8)	1.24 (0.3)	0.49 (0.06)	0.34 (0.04)	0.44 (0.19)	0.43 (0.14)
S. compactum	6	12.8 (2.1)	3.8 (0.7)	0.96 (0.1)	0.56 (0.08)	0.39 (0.05)	0.45 (0.10)	1.00 (0.36)
S. cuspidatum	3	9.7 (0.2)	6.1 (0.1)	0.86 (0.1)	0.41 (0.03)	0.36 (0.03)	0.44 (0.06)	0.19 (0.03)
S. fuscum	1	9.8	6.0	1.45	0.46	0.45	0.30	0.35
S. lindbergii	3	15.7 (0.6)	5.1 (0.4)	1.13 (0.2)	0.48 (0.05)	0.39 (0.01)	0.60 (0.18)	0.36 (0.02)
S. magellanicum	10	10.7 (1.3)	4.8 (1.7)	1.35 (0.2)	0.46 (0.12)	0.39 (0.10)	0.43 (0.18)	0.44 (0.15)
S. papillosum	7	11.0 (0.9)	4.8 (1.5)	1.11 (0.3)	0.41 (0.04)	0.36 (0.09)	0.36 (0.08)	0.38 (0.12)
S. rubellum	6	11.6 (0.8)	4.8 (0.7)	1.39 (0.2)	0.47 (0.11)	0.37 (0.03)	0.39 (0.13)	0.34 (0.15)
S. russowii	11	11.8 (1.3)	5.4 (0.8)	1.36 (0.2)	0.48 (0.05)	0.39 (0.07)	0.31 (0.14)	0.26 (0.10)
S. tenellum	3	12.9 (1.4)	4.8 (0.3)	1.09 (0.4)	0.55 (0.03)	0.41 (0.06)	0.60 (0.16)	0.25 (0.01)
mean		11.6 (1.7)	5.2 (0.8)	1.20 (0.19)	0.48 (0.05)	0.39 (0.03)	0.41 (0.12)	0.39 (0.22)

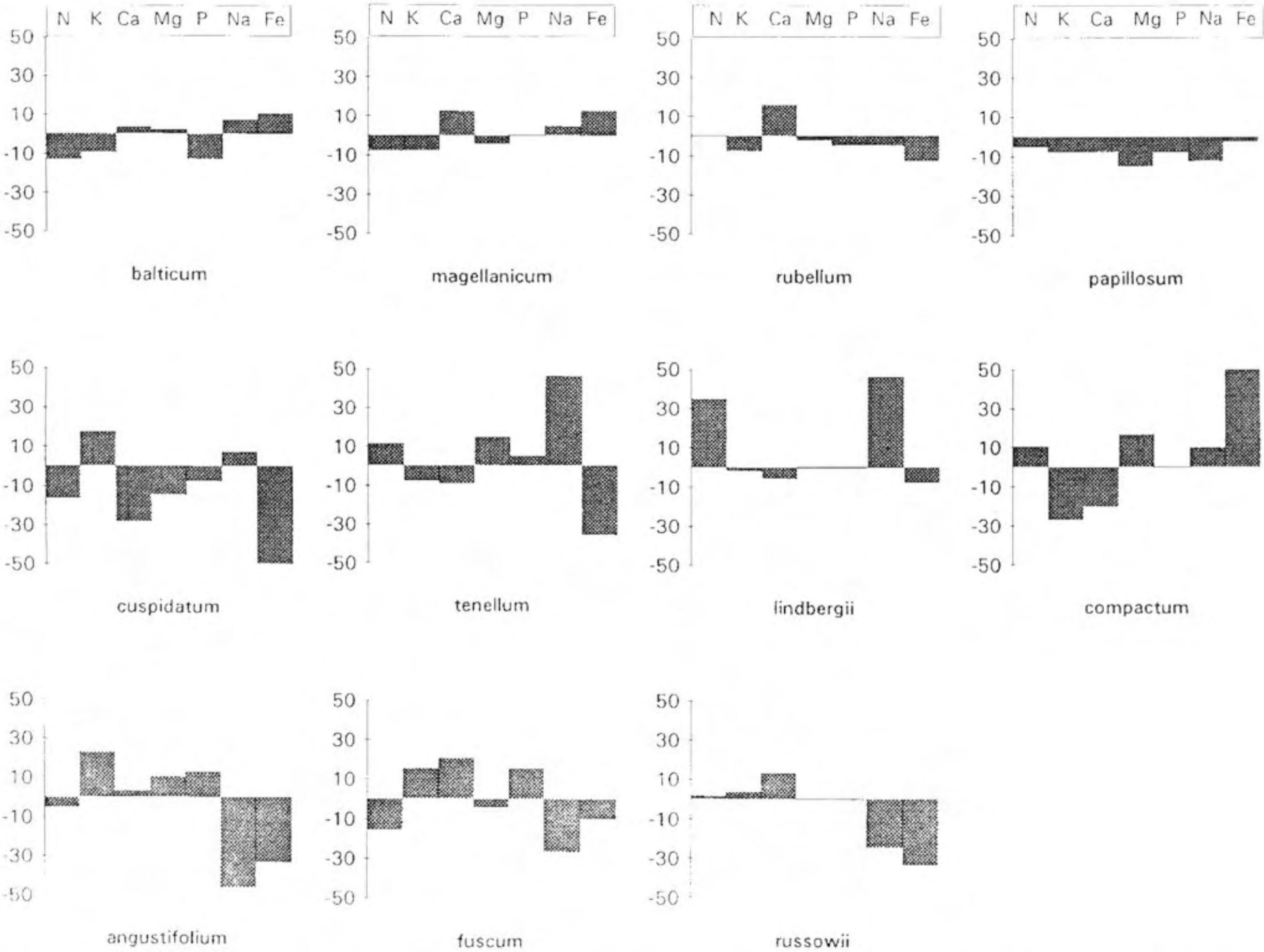

Fig. 2. Mineral element composition of *Sphagnum* species expressed as percent deviations from the means of each element. The histograms give a nutrient profile for each species.

sue element concentration (mg/g^{-1}) in the green segment of mosses divided by the water element concentration (mg/l^{-1}), were highest for K, P and N. The lowest ratios (below 1.0) were found for calcium, sodium and iron (Table 2).

TABLE 2. Mean concentration of major elements in moss and water samples, and enrichment ratio (*Sphagnum*/water). Mean for *Sphagnum* does not include hummock samples (cf. Fig. 3).

Element	*Sphagnum* $mg\ g^{-1}$	Water $mg\ l^{-1}$	Enrichment ratio
N	11.60	1.55[1]	7.5
P	0.39	0.19[2]	20.5
K	5.20	0.40	13.0
Mg	0.48	0.33	1.5
Ca	1.20	1.63	0.7
Na	0.41	0.76	0.5
Fe	0.39	0.49	0.8

1 N-NO3 + N-NH4; 2 P-PO4; Water data from Wojtuń (1989)

DISCUSSION

Species profiles of nutrient concentrations (Fig. 2) indicate that none of the species is alike in nutrient accumulation. This means that the species differ widely in uptake and retention of macro elements. In the present study, the most clear pattern in the mineral element composition of *Sphagnum* mosses within ombrotrophic mire ecosystems was a trend reflecting a gradient in microhabitats, e.g. from hummocks to hollows. This gradient is well reflected by the decreasing concentrations of Ca and Mg, and increasing concentration of Na.

The higher concentrations of Ca and Mg in the hummock species and samples of the same species, i.e. *S. angustifolium* and *S. magellanicum*, support the hypotheses of passive uptake of these cations by exchange processes (Anschütz and Gessner 1954, Brehm 1968, Puustjärvi 1959). Several authors (e.g. Clymo 1963, Clymo and Hayward 1982, Spearing 1975) have shown that species occuring in higher parts of the habitats have a greater exchange ability than those found at lower levels. Further, of the major cations, calcium and magnesium have been shown to be correlated with levels of mire water (Aulio 1982, Pakarinen and Tolonen 1977), and these cations are absorbed mainly through passive exchange processes (Malmer 1988, Malmer et al. 1992, Pakarinen and Tolonen 1977). In the present samples this is reflected in the higher concentration of Ca and Mg in the hummock species, in comparison to lawn and hollow species (Fig. 3). These differences were also visible in the same species from various microhabitats, i.e. *S. angustifolium* and *S. magellanicum* growing on hummock tops and in lawn. Similar differences between hummock and hollow *Sphagnum* species (*S. fuscum* and *S. balticum*) for Ca have been demonstrated by Pakarinen (1978).

In this study, the differences in Na concentration between hummock, lawn and hollow species were not statistically sigi-

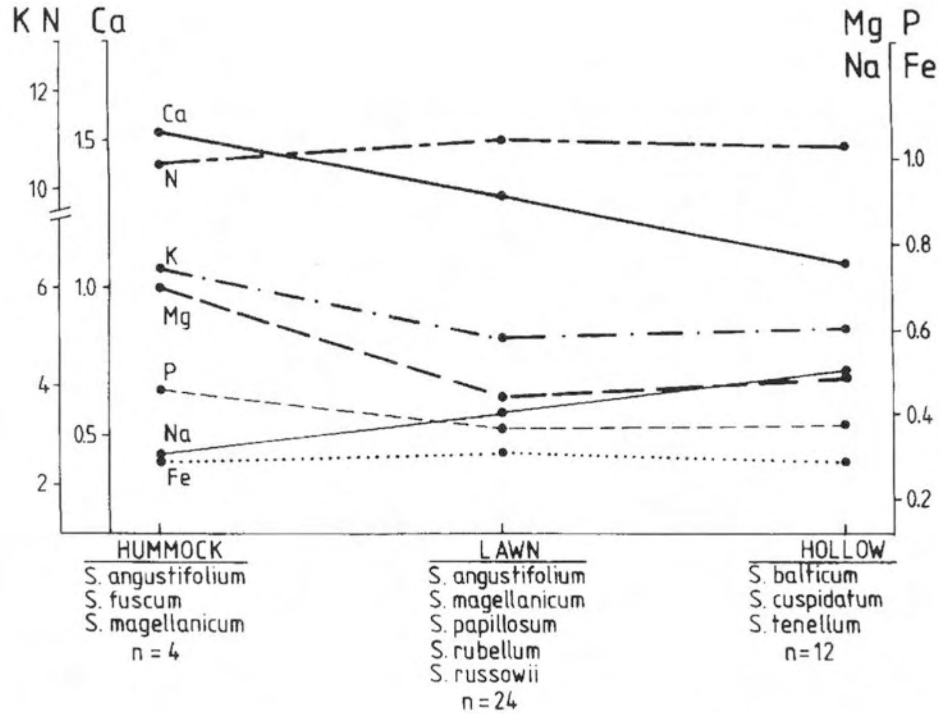

Fig. 3. Changes in the concentration of major elements (mg g-1 d.w.) in green segments of *Sphagnum* species through the microhabitat moisture gradient on the bog in the Bystrzyckie Mts. *Sphagnum* species and number of samples are given below. Note that scales for N and K, and for Ca are different from those for Mg, P, Na and Fe.

ficant. However, there was an evident trend of increase in Na concentration along this gradient (cf. Fig. 3). A very similar trend in Na has been found by Aulio (1982) on an ombrotrophic bog in southern Finland. In another paper (1980) the same author has demonstrated higher concentration of Na in the hollow species *S. majus* than in hummock and lawn species. According to Brehm (1971) and Gignac (1989) sodium is taken up by living cells in relatively small quantities and this element is also the most mobile on the bogs and is easily leached from the hummocks (Brown and Buck 1979, Damman 1978). Thus, the excess of Na that is not taken up by living cells of *Sphagnum* mosses is probably loosely bound to hyaline cells of hollow species. Such process may result in a higher content of Na observed in *S. balticum, S. cuspidatum* and *S. tenellum* dealt with in this study.

The enrichment ratio gives an idea of relative accumulation of elements in *Sphagnum* tissue (Pakarinen 1978). In the present material, consisting of lawn and hollow species, the moss enrichment ratio for the elements (Table 2) decreases in the order. P > K > N > Mg > Fe > Ca > Na. In the southern and northern Finnish material the order of elements was very similar for hollow *Sphagnum* species (Pakarinen 1978, Pakarinen and Tolonen 1977). More recently Malmer (1988) and Malmer et al. (1992) found a fairly similar ranking of the moss enrichment factors (or retention values) calculated as the quotients between the concentration of elements in the hummock *Sphagnum* species and precipitation.

The comparison of green and brown segments of the lawn *Sphagnum* species shows that concentrations of N, P and K were higher in the green parts, whereas the contents of Na and Fe were higher in the brown bottom ones. Magnesium and calcium were rather evenly distributed (cf. Fig. 4). Similar differences between green and brown parts in *S. fuscum* from hummocks, and *S. balticum* and *S. majus* from hollows have been found by Pakarinen (1978). The general trends in distribution of elements within the *Sphagum* mosses were also the same in the present study as those recently demonstrated by Gignac (1989), Malmer (1988), Malmer and Nihlgård (1980), Malmer et al. (1992) for moss plants cut into several segments. The only difference was that these authors found the highest concentration of Na in the middle segments, while the concentrations in the top and distal segments were lower.

Sphagnum mosses accumulate elements in three ways (Clymo and Hayward 1982, Ferguson et al. 1984, Malmer 1988): (1) by direct influx of elements into chlorophyllose cells, (2) by ion uptake into exchange sites of the cell walls and (3) by a less specific accumulation of elements, partly as particles, on the external surface of the plant. For N, P and K the highest enrichment ratios and the highest concentrations in the matabolically most active uppermost green parts of the mosses dealt with in this study suggest an active uptake process of these elements. This process probably takes place mainly by direct influx of nutrients to chlorophyllose cells from external sources (Malmer 1988, Malmer and Nihlgård 1980). These authors suggest also a relocation of these elements from the older to the youngest, most actively growing parts. Rydin and Clymo (1989) recently demonstrated that *Sphagnum* has an effective mechanism for retaining and relocating solutes. They showed that phosphorus compounds are transported vertically almost entirely within the stem. Their results indicate the great importance of translocation of elements from the older to the younger parts of *Sphagnum* stems in mineral nutrition of these mosses.

The low enrichment ratios (Table 2) and uniform concentrations of Ca and Mg in the whole moss plant (Fig. 4) may be interpreted as passive uptake of these elements by the cation exchang reaction on the cell walls of chlorophyllose and hyaline cells (Brehm 1968, Malmer 1988, Malmer et al. 1992, Pakarinen 1978). However, in this study the enrichment ratio calculated for Mg was higher than 1.0 and more than twice

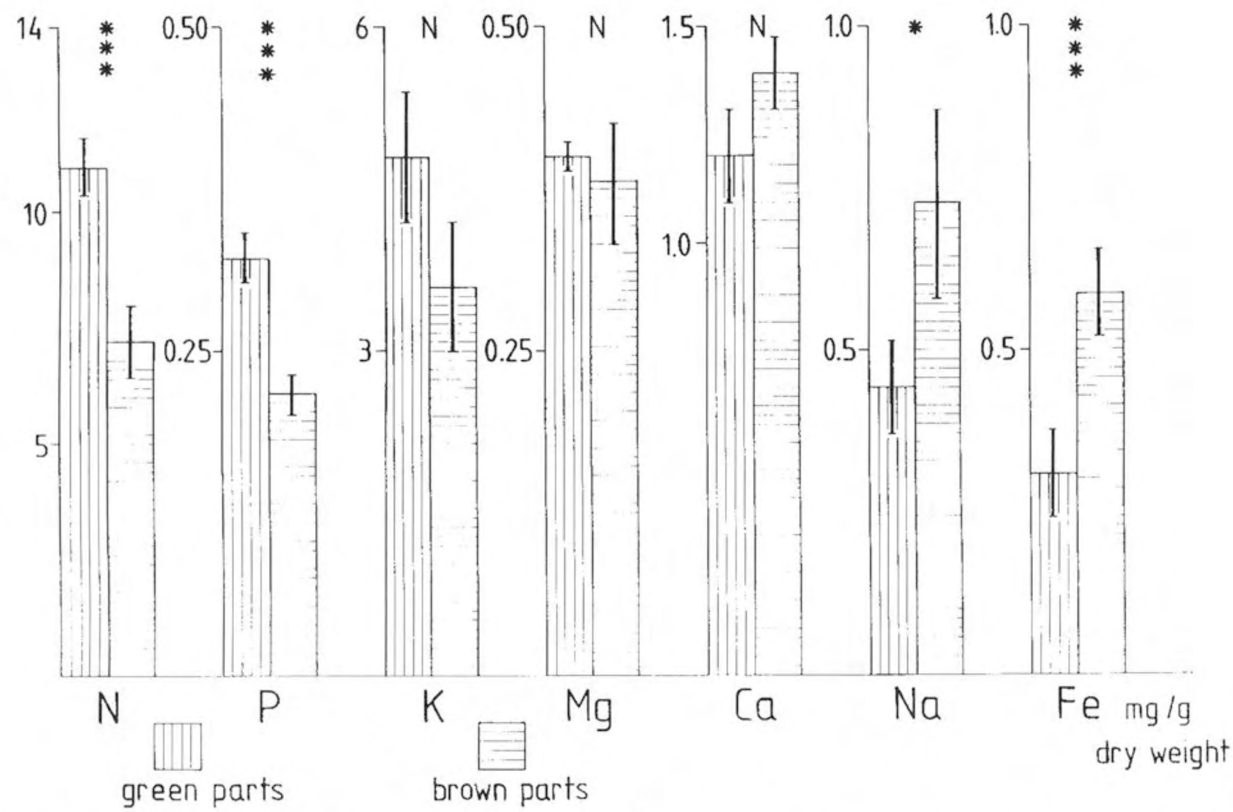

Fig. 4. Concentration of major elements (in mg g-1 d.w.) in green and brown segments of *Sphagnum*. The results are means (n = 6) for five lawn species: *S. angustifolium, S. magellanicum, S. papillosum, S. rubellum* and *S. russowii.* SD is indicated by vertical lines. Note that the scales for each element are different. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; N – not satistically significant.

that of Ca. This can be interpreted as resulting partly from metabolically active accumulation. Such possibility was also suggested by Damman (1986) and Malmer (1988).

The low enrichment ratio (Table 2) and the significantly higher concentration in the lower brown parts (Fig. 4) indicate that Fe is taken up by passive uptake, not necessarily associated with cation exchange processes or metabolic activity. This element is probably less specifically accumulated on the moss surface (Malmer 1988, Malmer et al. 1992).

The present results for Na are not so clear. A low value of the enrichment ratio is similar to that of Fe. However, the weak difference in concentrations of Na between the green and brown parts, as compared with Fe, could suggest a cation exchange process. The mechanism of exchange reactions for Na have been discussed by Clymo (1963), Malmer (1988) and Pakarinen and Tolonen (1977), but the results of the present study seem not to justify such an interpretation.

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ZAWARTOŚĆ SKŁADNIKÓW MINERALNYCH W MCHACH Z RODZAJU *SPHAGNUM* NA TORFOWISKACH POLSKI POŁUDNIOWO-ZACHODNIEJ

STRESZCZENIE

Badano zawartość makroelementów (N, P, K, Ca, Mg, Na, Fe) w 11 gatunkach torfowców (*Sphagnum*) na dwóch torfowiskach ombrotroficznych południowo-zachodniej Polski (Karkonosze i Góry Bystrzyckie). W badaniach uwzględniono gatunki kępowe, dolinkowe oraz występujące na siedliskach umiarkowanie wilgotnych. Najwyższą zawartość makroelementów stwierdzono u *S. lindbergii*, natomiast najniższą u *S. balticum* i *S. cuspidatum*. Gradient wilgotnościowy od mikrosiedlisk kępowych do dolinkowych najlepiej charakteryzują spadek zawartości Ca i Mg oraz wzrost stężenia Na w zielonych częściach torfowców. Najwyższe wartości współczynników pobierania pierwiastków (stosunek zawartości pierwiastka w torfowcach do jego stężenia w wodzie) uzyskano dla N, P i K. Wykazano różnice w składzie mineralnym zielonych, określanych jako żywe, i brązowych, uważanych za martwe, częściach torfowców. Wyższe zawartości N, P i K stwierdzono w częściach zielonych, natomiast części brązowe miały więcej Na i Fe. Obie części nie różniły się zawartościami Ca i Mg. Uzyskane wyniki wskazują na metabolicznie aktywne pobieranie przez torfowce azotu fosforu i potasu. Wapń, magnez i w miejszym stopniu sód, prawdopodobnie pobierane są głównie na zasadzie biernej wymiany tych kationów na jony wodoru. Żelazo może być akumulowane na powierzchni martwych części torfowców.

SŁOWA KLUCZOWE: makroelementy, mchy torfowce, *Sphagnum*, torfowiska ombrotroficzne, Polska południowo-zachodnia