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EFFECT OF GRASS SPECIES AND HARVESTING FREQUENCY ON THE CONTENT OF MACROELEMENTS IN WATERS IN A LYSIMETER EXPERIMENT

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Abstract

The objective of the study was to elucidate correlations between meadow plant species, the content of some biogenic elements in groundwater, sward harvesting frequency and the level of the groundwater table at the beginning and at the end of a growing season. An adequate choice of species grown in organic soil may be of particular significance for nutrient management and prevention of water eutrophication due to biogenic elements. A lysimeter experiment was conducted on peat-muck soil. The chemical composition of groundwater sampled underneath the rhizosphere of *P. pratensis*, *Ph. pratense* and *L. perenne* was assessed in several years. Two fixed levels of the groundwater table were maintained in the lysimeters: 50 and 90 cm below the ground surface. Grass was harvested three or five times during a growing season. The content of nitrate-nitrogen and ammonium-nitrogen, phosphorus, potassium, calcium, sodium and magnesium was determined in the analysed groundwater. The results showed significant variation in the mean (over the research period) content of selected mineral components (except for phosphate ions) in the piezometer water collected under the rhizosphere of specific grass species. The species *L. perenne* absorbed mineral components most effectively. The highest concentration of the majority of the components studied was found in water beneath the rhizosphere of *P. pratensis*. Significantly higher concentrations of calcium, magnesium, sodium, phosphorus, nitrate-nitrogen (but not ammonium-nitrogen) and potassium were found in water in the springtime. The biogenic element content found in objects with a three-cut harvesting regime was lower than in waters underneath grasses harvested five times. Regardless of the species and harvesting frequency, a significantly higher content of specific cations and anions in piezometer water was found in objects with a lower level of the groundwater table.

Keywords: grasses, harvesting frequency, level of groundwater table, biogenic element content in groundwater.

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INTRODUCTION

In areas used for agriculture, unused minerals are stored in the soil or dispersed into the environment, posing a threat to the hydrosphere, including shallow groundwater (TAMPERE et al. 2014, RAFAŁOWSKA 2008). The EU legal regulations increasingly require to reduce excessive fluxes of biogenic elements, particularly nitrogen, from agricultural sources (the Nitrates Directive, the Water Law Act, Code of Good Agricultural Practice, Ordinance of the Minister for the Environment). However, management of mineral components should rely not only on legal restrictions but also, and perhaps more importantly, on rational ways of maintaining an equilibrium between agricultural technologies and the potential capacity of species and their communities (PEYRAUD et al. 2009, KOWALIK et al. 2014). Thus, the pollution of groundwater with biogenic elements should be avoided by limiting the sources of hazardous substances and by creating natural barriers, such as grasslands, that would limit the propagation of contaminants and improve the effectiveness of the environment's self-purification (PIETRZAK 2012, FU et al. 2013).

The aim of the study was to evaluate the content of some biogenic elements in groundwater, depending on meadow plant species, sward harvesting frequency and the ground water level at the beginning and at the end of a growing season.

MATERIAL AND METHODS

The study was conducted at the lysimeter station in Sosnowica, located in a meadow and pasture complex lying within a post-bog habitat (between the Piwonia River and the Wieprz-Krzna canal). Data from the years 2002-2004 were used to estimate the biogenic element content (mean for the study period) in groundwater underneath the rhizosphere of grasses cut five times, whereas the results obtained in 2006-2008 pertain to grasses cut three times. 18 lysimeters set at a depth of 120 cm and over an area of 1600 cm^2 were used in the study. The lysimeters were filled with soil monolith of an undisturbed structure, classified as peat-muck soil (MtIIbb) developed from rushes and sedge peat. Two fixed groundwater table levels were established in the lysimeters: 50 cm below the ground surface – recognised as the maximum acceptable level of groundwater (9 lysimeters) – and 90 cm below the ground surface – the acceptable critical level for peat-muck soils (9 lysimeters). These permanent 50 cm and 90 cm groundwater table levels were maintained in the lysimeters by adding or draining a specific amount of water every day according to the readings on piezometers placed in each lysimeter. The measurements of the groundwater table were carried out with a fox whistle (bell sounder) with an accuracy of ±0.5 cm. The water (obtained from a deep-well pump) was poured into the lysimeters through an upper hole of a piezometer. It was experimentally determined that 170 ml of water changed the groundwater table by 1 cm. An excess (above the calculated values) was drained using a pump specially prepared to extract water from various depths. The measurements began around 15 April and continued until 5-10 October (depending on a year).

The research involved *Poa pratensis* L. (*P. pratensis)* var. Skrzeszowicka, *Phleum pratense* L. (*Ph. pratense*) var. Obra and *Lolium perenne* L. (*L. perenne*) var. Solen, i.e. species characterised by a high use value and intended for permanent grasslands. Each species was sown in monoculture, in three replications. A fixed level of mineral fertiliser was applied in the experiment, i.e. 12 g N, 2.18 g P and 11.6 g K m^{-2} in the form of ammonium nitrate with magnesium, triple superphosphate pellets and 60% potassium salt. In the experiment where the sward was cut five times each year, nitrogen was applied in five equal doses (in the spring, after the first, second, third and fourth harvest), half a dose of potassium was supplied in the spring and a quarter dose after the second and fourth harvest, while phosphorus was given once (in the spring). In the experiment where the sward was cut three times, nitrogen was applied in three equal doses (in the spring and after the first and second harvest), potassium was supplied in half a dose in the spring and after the second harvest, while phosphorus was given once (in the spring). In the growing season, the grass in the lysimeters was cut at 4 cm above the ground (three or five times).

Water samples for analyses were collected (using the pump mentioned above) from the lysimeters (at the depths specified above) prior to and after a growing season, that is depending on the years, at the end of March and the beginning of April, and after cutting the first regrowth, in the first 10 days of October. In the analysed waters, nitrate-nitrogen and ammonium-nitrogen were determined using flow colorimetry, phosphorus was determined colorimetrically using the molybdenum blue method, potassium, calcium and sodium were measured using flame emission spectrometry and magnesium was assessed with the AAS method.

The results were analysed statistically. Multivariate analyses of variance with repeated measurements and the Tukey's multiple comparison tests were conducted using Statistica 6.0 software. The means were divided into statistically uniform groups, and the significance level of $a \leq 0.05$ was adopted. Mean values between which no statistically significant differences occurred are marked with the same letter. Averages for the whole research period period of are given in the diagrams for the interactions: species x measurement date, species x frequency of harvest and species x level of ground water.

RESULTS AND DISCUSSION

The study showed that the K content in water under the rhizosphere of *L. perenne* was lower than in water under *P. pratensis* or *Ph. pratense.* The sampling date had no significant influence on the variation in the K content in water beneath the sward of *P. pratensis* and *L. perenne*, but it affected the water content of potassium under *Ph. pratense*, which was higher in the spring than in the autumn (Figure 1). Similar relationships were also found

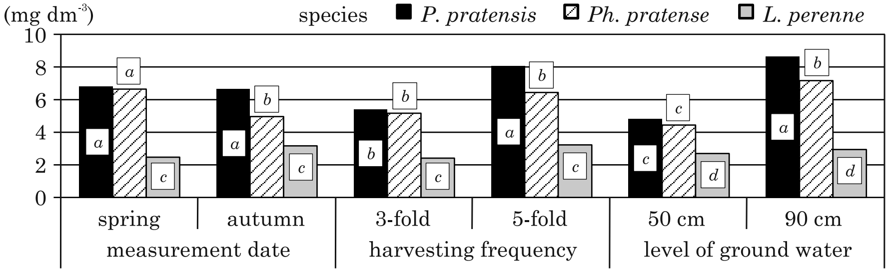

Fig. 1. K content (mg dm^{-3}) in groundwater underneath the rhizosphere of grass

by KAYSER et al. (2007) and TAMPERE et al. (2014). The K content in water was also influenced by the harvesting frequency, particularly in objects with *P. pratensis,* and thus the water from objects harvested three times was characterised by a significantly lower concentration of this element than the water from objects harvested five times. Similar tendencies were also observed in the case of *Ph. pratense* and *L. perenne,* but the differences were not significant. A diverse content of biogenic components in groundwater may result from differences in dry matter yields from objects with three and five cuts. Differences can also be seen in yields between species (LIPIŃSKA 2010*a*,*b*). Compared with meadows, yields from pastures are much lower. According to the Central Statistical Office of Poland (2013), an average harvest hay is estimated at 5.19 t from meadows and at 3.82 t from pasture. At lower yields, lost ingredients can be washed out (LIPIŃSKA 2009, 2010). The groundwater underneath the rhizosphere of all the species studied had a lower potassium content in objects where the groundwater table was maintained at 50 cm below the ground surface. However, the potassium content was significantly lower only in the water from under *P. pratensis* and *Ph. pratense*. Thus, *L. perenne* proved to be a species that limited the migration of potassium into groundwater to a similar extent regardless of the measurement date, harvesting frequency or level of the groundwater table. According to BUČIENE et al. (2014), when provided better soil moisture, plants can use fertilizer components more efficiently, thereby reducing nutrient losses due to leaching out of the root zone.

Groundwater underneath the rhizosphere of the three grass species showed considerable variation in the Ca content (Figure 2). The highest Ca

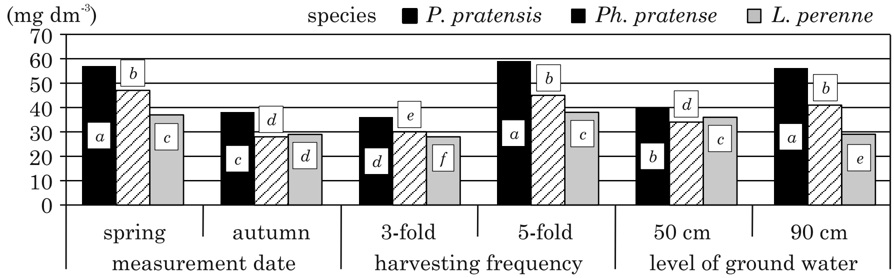

Fig. 2. Ca content (mg dm^{-3}) in groundwater underneath the rhizosphere of grasses

content was found in water underneath the sward of *P. pratensis*, whereas the lowest one appeared in water under *L. perenne.* The calcium content in water from all the objects was significantly higher in the spring and when the sward was harvested five times than in the autumn and when the sward was harvested three times. Lower calcium concentration in water during a growing seasons than after a period of plant growth had been confirmed previously by Koc and Duda (2009). It is believed that higher soil moisture is conducive to calcium intake by plants (Lipińska 2009, Chintala et al. 2012), and this correlation was reflected by the Ca content in water from beneath the rhizosphere of the studied species. Except for *L. perenne,* water collected from objects with a lower groundwater table had a lower Ca content.

Among the grass species studied, *P. pratensis* showed the smallest capacity to limit the leaching of Mg to groundwater because water under the rhizosphere of this species was found to have the highest Mg content. In all the objects, the magnesium content was significantly higher in the spring and when the sward was harvested five times than in the autumn and when a three-cut regime was implemented (Figure 3). According to Tampere et al. (2014), more frequent cutting, which results in a lower height of the sward in the growing season, is conducive to more intensive infiltration. It also results from the limited interception of precipitation water, which reaches the soil surface even during minor rainfall events, and from the limited transpiration process due to a smaller area compared with objects harvested more rarely (Popay, Crush 2010). The loss of magnesium was higher in objects

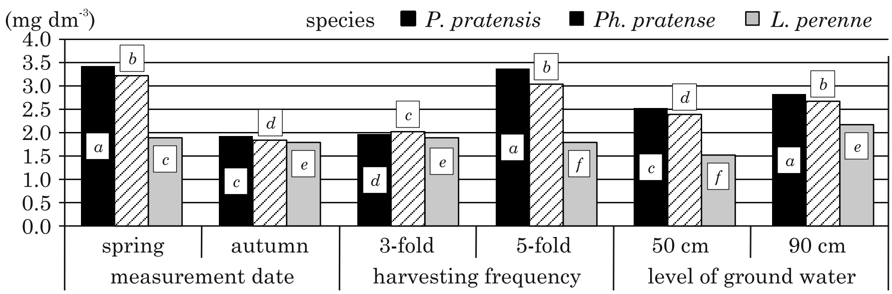

Fig. 3. Mg content (mg dm^{-3}) in groundwater underneath the rhizosphere of grasses

where the groundwater table was maintained at the level of 90 cm below the ground surface than in ones with the grounwater table level of 50 cm. A significantly lower Mg content at the lower groundwater table level was observed only in the case of *L. perenne*. This may be associated with a better magnesium intake by *L. perenne* under such moisture conditions, which has been confirmed earlier by LIPIŃSKA (2009).

The sodium content in water was significantly varied by the experimental factors. The highest sodium content was found in water under the rhizosphere *P. pratensis*, whereas the least sodium was in water under *L. perenne* (Figure 4). According to LIPIŃSKA (2009), this species has a distinctly better

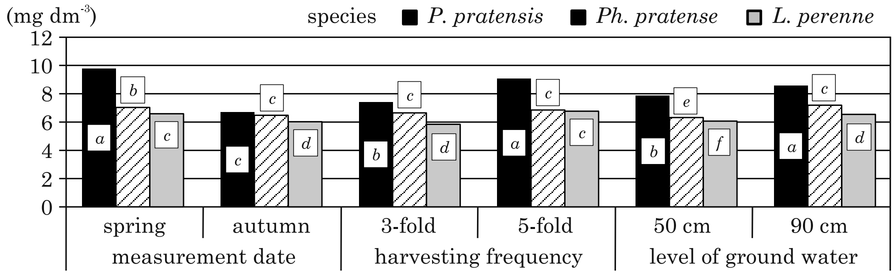

Fig. 4. Na content (mg dm^{-3}) in groundwater underneath the rhizosphere of grasses

capacity to accumulate Na, unlike *P. pratensis* or *Ph. pratense*, and therefore less Na was leached to groundwater. In all the objects, the sodium content in the spring was higher than in the autumn. Harvesting the aerial biomass three times led to a lower sodium content in groundwater. The differences were significant except for the object with *Ph. pratense*. The groundwater table level also determined the sodium content in water from beneath the rhizosphere of the species studied. The sodium content was lower when the groundwater table was maintained at 50 cm rather than 90 cm below the ground surface. This may have resulted from the lower nutrient intake by the plants growing in drier sites, which typically are less rich in nutrients (BUČIENE et al. 2014).

The content of phosphate ions in the water samples analysed was similar and did not vary significantly (Figure 5). A higher concentration of ions was only found in the water under *L. perenne*. The water under the rhizospheres of *P. pratensis* and *L. perenne* had a higher PO_4^{-3} concentration in the spring than in the autumn, and in objects harvested five times than those harvested three times. Seasonal cyclic fluctuations of the concentrations of P-PO_4 have also been found by SZYMCZYK and GLIŃSKA-LEWCZUK (2007). The P-PO_4 concentrations demonstrated a growing trend from an average 0.26 mg·dm^{-3} in the spring to 0.70 mg dm^{-3} in the summer. The phosphate content in water under *Ph. pratense* was unaffected by the above factors. In nearly all the objects, a higher phosphate concentration was found in

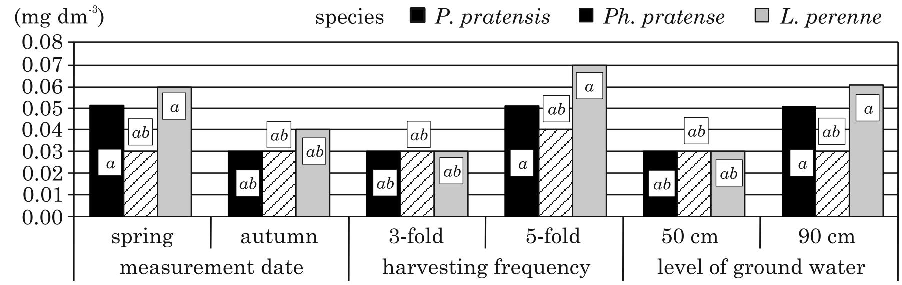

Fig. 5. PO_4^{-3} (mg dm^{-3}) content in groundwater underneath the rhizosphere of grasses

water at the level of 90 cm, particularly under the sward of *L. perenne.* Also, SAPEK. (2008) as well as ŚWITAJSKA and SZYMCZYK (2012) have shown that a seasonal decrease in groundwater leads to a marked increase in the groundwater phosphate concentration, which they have attributed mainly to the release of large amounts of ammonia during ammonification, which prevent phosphates from precipitating. According to OLSZEWSKA (2009), higher soil moisture favours better phosphorus intake by plants, which may contribute to lower phosphate ion concentrations in groundwater.

The mean (for the study period) N-NO_3 content in water under the sward of the grass species studied varied significantly (Figure 6). In the

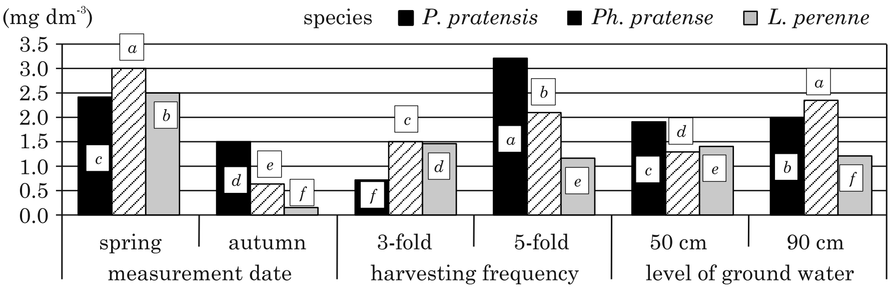

Fig. 6. N-NO_3 (mg dm^{-3}) content in groundwater underneath the rhizosphere of grasses

spring, the highest N-NO_3 concentration was found in water beneath the rhizosphere of *Ph. pratense,* less of N-NO_3 was detected in water under *L. perenne,* and its lowest concentration occurred in water under *P. pratensis*. However, at the end of the growing season, the ion content in water in all the objects was significantly lower, and the correlations were reverse. Seasonal fluctuations in the N-NO_3 content have been found by other authors (RAUBA 2009, RAAVE et al. 2014), who observed significant losses after plant growing seasons. The sward of *L. perenne* protected groundwater from the leaching of N-NO_3, as indicated by its lowest concentration in the groundwater underneath the rhizosphere of this species. Also ERIKSEN et al. (2008) distinguished *L. perenne* as a species characterised by the highest and most efficient absorption of macronutrients, which contributed to a lower concentration of nutrients, especially nitrate ions, in groundwater.

The nitrate ion content also depended on the harvesting frequency. The N-NO_3 content in water beneath *P. pratensis* and *Ph. pratense* was lower in objects harvested three times than in those harvested five times. Jaszczyński et al. (2006) also reported that concentrations of nitrates in groundwater under a meadow were nearly three-fold lower than under a pasture. Jaguś and Twardy (2006) concluded otherwise, stating that N-NO_3 concentrations were associated with more frequent harvests. They confirmed, however, that N-NO_3 concentrations in water beneath *L. perenne* harvested five times were lower than when that grass species was cut three times during a growing period.

A higher N-NO_3 content was found in objects with the lower groundwater table (90 cm), unlike in samples collected under the sward of *L. perenne* from more moist objects (groundwater table at 50 cm). With the groundwater table at 90 cm below the ground surface, the highest content of this ion was found in the water under *Ph. pratense.* A higher content of nitrate-nitrogen at a lower level of the groundwater table has been indicated elsewhere (Schröder et al. 2009, Szymczyk et al. 2010). This may suggest that under poor moisture conditions, plants utilise less nitrate-nitrogen, which results in the increased leaching of nitrogen into groundwater. According to Pawluczuk and Stępień (2010), higher N-NO_3 content in groundwater at a low groundwater table may be caused by more intensive mineralisation of organic matter. Tampere et al. (2014) also noted the considerable variability of nitrogen loss through leaching beyond the rhizosphere of meadow plants under various soil moisture conditions.

In the spring, at the onset of the growing period, the ammonium-nitrate concentration was lower than in the autumn and the differences were always significant (Figure 7). Higher concentrations of ammonium-nitrate in water collected in the summer or autumn than in the spring have been documented by Pawluczuk and Szymczyk (2008) or Szymczyk et al. (2010).

The largest content of ammonium ions in groundwater was found in objects with *Ph. pratense.* A lower content of these ions was found in water

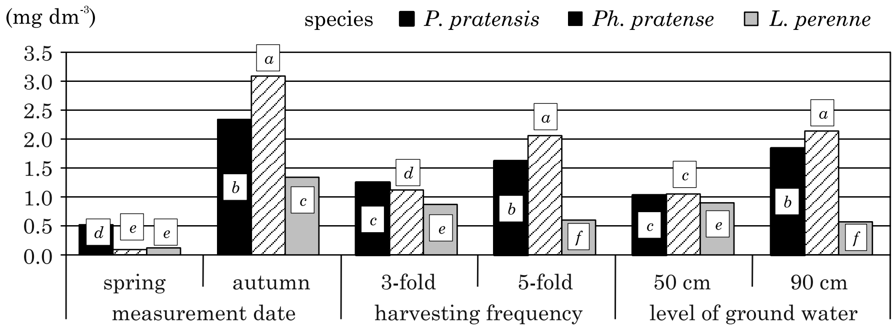

Fig. 7. N-NH_4 (mg dm^{-3}) content in groundwater underneath the rhizosphere of grasses

collected under the sward harvested three times in a growing season, except for the water under *L. perenne* harvested five times. With this management method, *L. perenne*, a species particularly suited for grazing, limited the leaching of N-NH_4 to groundwater much more effectively. According to Kozłowski and Zielewicz (2009) and Bouman et. al. (2010), the capacity to accumulate nitrate nitrogen is a characteristic of cultivated species and varieties, and should be taken into account when selecting species for grassland mixes.

The concentration of ammonium nitrogen ions in groundwater under a particular species of grass sward also depends on the level of water in the soil. A higher concentration of N-NH_4 was found in the water under *P. pratensis* and *Ph. pratense* in the objects with the low groundwater table (90 cm below the ground surface). Higher concentrations of the mineral nitrogen forms induceded by lowering the groundwater level have been observed by Szymczyk et al. (2010). A significantly higher concentration of ammonium ions was found in water beneath the sward of *L. perenne* grown in soil with the groundwater table at 50 cm.

As seen from Figures 6 and 7, water was characterised by a considerably lower N-NH_4 content than N-NO_3, which is confirmed by literature (Raave et al. 2014). However, Kalembasa and Becher (2009) studying peat-muck soils revealed that ammonium forms prevailed over nitrate forms. A higher concentration of N-NO_3 in water may have resulted from the intake of nitrate-nitrogen by plants being lower than that of ammonium-nitrogen; the latter is readily taken in by both microorganisms and plants cultivated on high pH soil (Pawluczuk, Stępień 2010).

CONCLUSIONS

1. *Lolium perenne* was the most effective species preventing biogenic components (except phosphorus) from permeating into groundwater. In turn, *P. pratensis* turned out to be the least effective in this respect.

2. Statistically confirmed higher concentrations of potassium, sodium, calcium, magnesium, phosphorus and nitrate-nitrogen were found in water in the spring. Ammonium-nitrogen was an exception in that its amount was lower in the spring than after a growing season.

3. The presence of mineral components in water significantly depended on the frequency of grass cuts. The biogenic component content found in water from objects cut three times in a growing season was lower than in water underneath grasses cut five times, naturally characterised by a smaller sward height, which stimulates more intensive infiltration.

4. The lower level of groundwater contributed to a higher concentration of particular cations and anions in water underneath the sward, and usually resulted in a lower mineral component intake by plants, therefore stimulating their leaching beyond the rhizosphere.

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