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SEASONAL VARIABILITY OF MINERAL NITROGEN IN GROUNDWATER OF HYDROGENIC SOILS*

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Abstract

Agricultural use of land on hydrogenic soils is associated with lowering the groundwater level, which intensifies the processes of organic matter mineralisation and, in effect, releases large amounts of mineral nitrogen. The aim of the study was to determine the seasonal variability of the concentrations of nitrogen mineral compounds ($N\text{-}NO_2$, $N\text{-}NO_3$ and $N\text{-}NH_4$) in groundwater under extensively managed peat-muck soils, situated in Wrocikowo in the Olsztyn Lakeland and in the Dymerskie Meadows in the Mrągowo Lakeland. Peat-muck soil, found at the study sites, had varied physical properties. The highest content of mineral particles (69.3%) in the muck layer was found in soil marked as MtI 120gy under turf-covered wasteland, and in the peat layer (51.5%) – in soil marked as MtII 60gy under extensively managed meadow. Groundwater taken from piezometers installed in hydrogenic soils was used as the study material. Water for chemical determinations was taken during four seasons: spring – in May, summer – in August, autumn – in November and winter – in January. The concentration of mineral forms of nitrogen in groundwater of peat-muck soil was found to depend on its type, the depth where the groundwater was found and the type of soil use. The highest concentration of mineral nitrogen was found in summer (1.62 mg dm^{-3} on average), and the lowest (1.11 mg dm^{-3} on average) was found in winter. The concentration of mineral nitrogen in groundwater of extensively managed peat-muck soil ranged from 0.81 to 2.27 mg dm^{-3} and was found to be dependent on the type of soil rather than its use. Lowering the level of groundwater in peat-muck soil increases the concentration of mineral forms of nitrogen, especially $N\text{-}NH_4$. Ammonium nitrogen was the dominant form of nitrogen in the groundwater of peat-muck soil (MtII 60gy and MtI 120gy) of non-managed and extensively managed meadows, whe-

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reas nitrate nitrogen was the dominant form of the element in the MtIc 35gy soil under the meadow and the MtII bb under the pasture.

Key words: mineral nitrogen, groundwater, meadow, pasture, biogenic substances, peat-muck soil.

SEZONOWA ZMIENNOŚĆ STĘŻENIA MINERALNYCH FORM AZOTU W WODACH GRUNTOWYCH GLEB HYDROGENICZNYCH

Abstrakt

Zagospodarowanie rolnicze terenów położonych na glebach hydrogenicznych wiąże się z obniżeniem poziomu wody gruntowej, co powoduje nasilenie procesów mineralizacji substancji organicznej, a w efekcie uwalnianie dużych ilości azotu mineralnego. Celem badań było określenie zmienności sezonowej stężenia mineralnych związków azotu ($N-NO_2$, $N-NO_3$ i $N-NH_4$) w wodzie gruntowej pod ekstensywnie zagospodarowanymi glebami torfowo-murszowymi położonymi na obiektach Wrocikowo – Pojezierze Olsztyńskie i Łąki Dymerskie – Pojezierze Mrągowskie. Występujące na obiektach badań gleby torfowo-murszowe charakteryzowały się zróżnicowanymi właściwościami fizycznymi. Największą zawartość części mineralnych (69,3%) w warstwie murszowej stwierdzono w glebie MtI 120gy pod zadarnionym nieużytkiem, a w warstwie torfowej (51,5%) – w glebie MtII 60gy pod ekstensywnie zagospodarowaną łąką. Materiał badań stanowiła woda gruntowa pobierana z piezometrów zainstalowanych w glebach hydrogenicznych. Wodę do oznaczeń chemicznych pobierano w czterech porach roku: wiosną – maj, latem – sierpień, jesienią – listopad i zimą – styczeń. Wykazano, że stężenie mineralnych form azotu w wodzie gruntowej gleb torfowo-murszowych jest uzależnione od ich rodzaju, głębokości występowania wód gruntowych oraz sposobu zagospodarowania gleb. Największe stężenie azotu mineralnego stwierdzono latem (średnio 1,62 mg dm^{-3}), a najmniejsze (średnio 1,11 mg dm^{-3}) zimą. W wodzie gruntowej gleb torfowo-murszowych zagospodarowanych ekstensywnie zawartość azotu mineralnego wahała się od 0,81 do 2,27 mg dm^{-3} i była bardziej uzależniona od rodzaju gleby niż sposobu jej użytkowania. Obniżenie poziomu wody gruntowej w glebach torfowo-murszowych powoduje w niej zwiększenie stężenia mineralnych związków azotu, szczególnie $N-NH_4$. W wodzie gruntowej gleb torfowo-murszowych (MtII 60gy i MtI 120gy) nieużytkowanych i ekstensywnie użytkowanych łąk, dominującą formą azotu mineralnego był $N-NH_4$, a w glebach MtIc 35gy pod łąką i MtII bb pod pastwiskiem $N-NO_3$.

Słowa kluczowe: azot mineralny, woda gruntowa, łąka, pastwisko, składniki biogenne, gleby torfowo-murszowe.

INTRODUCTION

There are many marshes and swamps in the young glacial areas of northeastern Poland (Kiryluk 2004, Piaścik et al. 2000, Szymczyk, Glińska-Lewczuk 2007). Peatlands are a dominant form among hydrogenic habitats. They are not only natural reservoirs of water in the environment but also places where organic matter accumulates. Owing to these properties, peat retards the flow of biogenic substances in the environment, including nitrogen compounds, released in the process of mineralisation of organic matter

(BRANDYK et al. 1996, SAPEK, SAPEK 2004). Mineral nitrogen compounds, which are formed in the processes of organic matter decomposition, are a very important element of nutrient circulation, especially in marshy ecosystems. Released in the process of mineralisation of organic nitrogen compounds, ammonium nitrogen, followed by nitrate nitrogen, form the available supply of mineral nitrogen, whose amount determines the abundance of the nutrient in soil. Released from hydrogenic soils, mineral nitrogen can be taken up by plants, migrate down the soil profile to groundwater or become denitrified. The amount of mineral nitrogen leached from hydrogenic soil to groundwater depends mainly on the dynamics of its release from soil and may vary from year to year; its intensity may be different in different seasons (PAWLUCZUK, GOTKIEWICZ 2003, SAPEK, SAPEK 2004). The organic matter mineralisation rate and, in consequence, the concentration of mineral forms of nitrogen in water depend mainly on soil humidity, on the genetic type of organic matter in which decomposition processes take place, and on the weather conditions and the manner of soil use (PAWLUCZUK, SZYMCZYK 2008). Much of the peatlands in Poland have been drained and are used agriculturally, which has precipitated water and the outflow biogenic substances, including considerable amounts of mineral nitrogen compounds (KOC, SZYMCZYK 2003, KOC et al. 2005, SAPEK, SAPEK 2004).The aim of the study was to determine the seasonal variability (four seasons of the year) of concentration of mineral compounds of nitrogen ($N-NO_2$, $N-NO_3$ and $N-NH_4$) in groundwater of peat-muck soil depending on their use (meadow, pasture, turf-covered wasteland) against the background of habitat conditions.

MATERIAL AND METHODS

Seasonal variability in concentration of mineral compounds of nitrogen ($N-NO_2$, $N-NO_3$ and $N-NH_4$) in groundwater of peat-muck soil was examined in 2004-2008 at the following sites: Wrocikowo (2004-2006), a village situated in the Olsztyn Lakeland, and the Dymerskie Meadows (2006-2008) in the Mrągowo Lakeland. The study on the concentrations of $N-NO_2$, $N-NO_3$ and $N-NH_4$, presented in this paper is a continuation of our earlier research into the dynamics of mineralisation of organic matter of peat soil at the same sites (PAWLUCZUK 2006, PAWLUCZUK, SZYMCZYK 2008, SZYMCZYK, SZYPEREK 2005). The peat bog in Wrocikowo was formed at the site of a former kettle lake. The 142.66 ha drainage basin which feeds the peat bog has been reclaimed and is used as agricultural land. The water which drained off from the upper areas flows into the peat bog, from which it is channelled off by a drainage ditch. Only part of the peat bog (extensively managed meadow – MtI 120gy soil) was used agriculturally during the study period, while the other (MtII 60gy soil) was turf-covered wasteland, an ecological site (SZYMCZYK, SZYPEREK 2005). Hydrogenic soils of the Dymerskie

Meadows were put to agricultural use by draining Dymer Lake (242 ha) in 1876. This also drained the peat soil (*ca* 111 ha), situated on the lake's edge. Currently, only part of the muck soil in the Dymerskie Meadows is under extensively managed grassland (meadow and pasture), where the air-water balance is not properly regulated due to negligence in the maintenance of the drainage system (PAWLUCZUK 2006, PAWLUCZUK, SZYMCZYK 2008). The physical properties of the peat-muck soil at the study sites varied (Table 1). The highest concentration of minerals (69.3%) in the muck layer was found in MtI 120gy soil, and in the peat layer (51.5%) – in MtII 60gy soil in Wrocikowo. The hydrogenic soils – MtIc35gy under the extensively managed meadow and MtIIbb under the heavily exploited pasture in the Dymerskie Meadows – were less depelted. Lower concentrations of mineral substances were determined both in the upper muck layers (37.9% and 58.9%, respectively) and in peat (25.8% and 32.1%, respectively). Ash content in the analyzed soils decreased in deeper organic layers. Hydrogenic soils in Wrocikowo and the Dymerskie Meadows were slightly acidic (Table 1).

Table 1

Physicochemical properties of hydrogenic soils in Wrocikowo and in the Dymerskie Meadows

Soil	Layer (cm)	Level	Ash content (%)	Volumetric density (g cm^{-3})	pH_{KCl}
MtII 60gy	do 20	Mt	67.3	0.65	6.7
	20-60	Otnitu	51.5	0.33	6.5
MtI 120gy	do 20	Mt	69.3	0.46	6.2
	20-120	Otnitu	41.6	0.23	6.1
MtIc 35gy	do 20	Mt	37.9	0.27	5.7
	20-35	Otnitu	25.8	0.15	6.0
MtII bb	do 20	Mt	58.9	0.39	5.9
	20-60	Otnitu	32.1	0.26	5.9

Two piezometers were placed at the depth of 150 cm in organic soil near the pits at each study site, with their filtration part at the depth of 120-150 cm below the surface. The groundwater level in the piezometers was measured once a month. Water samples for chemical determinations were taken in four seasons (spring – in May, summer – in August, autumn – in November, winter – January). The following were determined in the water samples: $N\text{-}NO_2$ – colorimetrically with sulphanilic acid, $N\text{-}NO_3$ – colorimetrically with disulphonic acid, $N\text{-}NH_4$ – colorimetrically with Nessler's reagent. Subsequently, the concentration of mineral nitrogen ($N\text{-}NO_2$ + $N\text{-}NO_3$ + $N\text{-}NH_4$) was calculated. The results were analysed statistically.

Analysis of variance was performed (test *F*) and variability coefficients (*V*%) were calculated, taking into account entire sets of data for each soil.

RESULTS AND DISCUSSION

The use of each of the study sites depended mainly on the soil humidity, which was in turn determined by the groundwater level. Typical seasonal variability of groundwater levels was recorded at both the study sites – the minimum in summer (July-September) and the maximum in winter (January-March. The highest levels of groundwater were recorded in peat soils with underlying organic gyttja MtIc 35gy – the Dymerskie Meadows (average – 38 cm below the surface) and in MtI 120gy – Wrocikowo (average - 42 cm below the surface), where they were significantly higher compared to the other two types of soil (Figure 1).

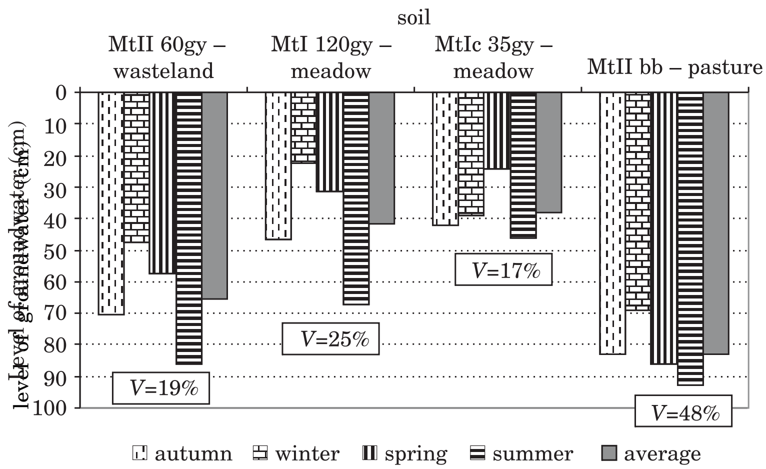

Fig. 1. Seasonal average levels of groundwater in hydrogenic soils

Where gyttja was found in shallower layers (MtIc 35gy soil), a clear tendency for the ground level to remain high with low variability was found throughout the study period ($V = 17\%$). This was the consequence of of the meadow being situated in the vicinity of gyttja-containing soil and the lack of proper maintenance of the draining ditch. The lowest levels of groundwater with the highest variability during the study period ($V = 48\%$) were recorded under extensively managed pasture, in MtIIbb soil. Such high variability of the groundwater surface level as compared to the other study sites was due to atmospheric precipitations in the consecutive years of study.

It could also be of some importance that the grassland was used as pasture, where higher biomass production resulted in greater evapotranspiration.

Higher concentration of $N\text{-}NO_3$ was found in groundwater in the Dymerskie Meadows (0.54 and 0.43 mg dm^{-3} on average – Figure 2); the values found in the peat-muck soil in Wrocikowo were much more variable (MtI 120gy soil – $V = 76\%$, MtII 60gy soil – $V = 45\%$).

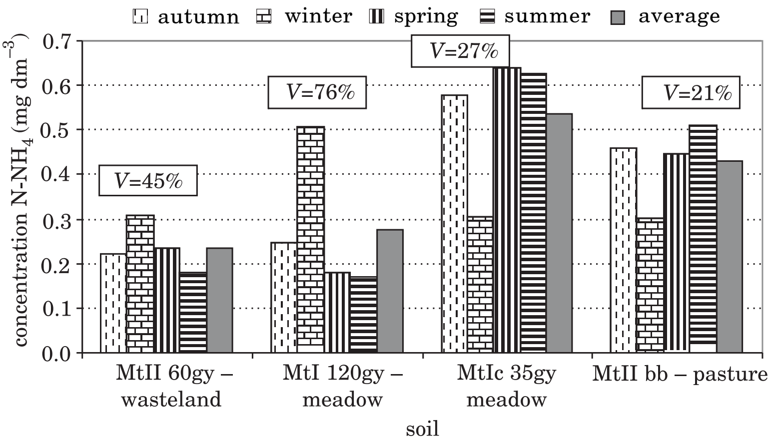

Fig. 2. Seasonal average concentrations of $N\text{-}NO_3$ in groundwater of hydrogenic soils

The highest concentration of $N\text{-}NO_3$ (0.54 mg dm^{-3} on average) was found in groundwater under the extensively managed meadow in peat-muck soil (MtIc 35gy), formed on shallow organic gyttja, whereas the lowest values (0.24 mg dm^{-3} on average) were found in peat-muck soil (MtII 60gy) formed on carbonate gyttja under wasteland meadow (Figure 2). This was associated both with the type of substratum and with the groundwater stagnation depth. As compared to the results reported by other authors, these values are up to several dozen times lower (SAPEK, SAPEK 2004). Over 20-fold higher variability was recorded when the results attained in this study were compared with the values found in groundwater under intensively managed grassland (meadows and pastures) (JASZCZYŃSKI et al. 2006).

Lowering the groundwater level in peat soils favours an increase in organic matter mineralisation rate, with increasing nitrogen concentration as a result (PAWLUCZUK, GOTKIEWICZ 2003, SAPEK, SAPEK 2004). The correlations calculated for the results (from $R = 0.13$ in MtII bb soil to $R = 0.51$ in MtII 60gy soil) have shown that the lowering of the groundwater level at the study sites was accompanied by a decrease in nitrate(V) concentrations, which increased when the groundwater level rose (Table 2). This may be attributed to more intensive mineralisation of organic nitrogen compounds, and, in effect, releasing higher amounts of nitrates(V) in the upper layer of peat-muck soils when the groundwater level lowers, which then migrate to groundwater after it rises.

Table 2

Correlation between the groundwater level and mineral nitrogen compounds

Nitrogen form	Soil			
	MtII 60gy	MtI 120gy	MtIc 35gy	MtII bb
$N\text{-}NO_3$	0.51	0.40	0.32	0.13
$N\text{-}NO_2$	0.28	-0.52	0.61*	0.06
$N\text{-}NH_4$	-0.68*	-0.44	0.11	0.04

* correlation significant at $p< 0.05$

Seasonal variability in the soil humidity level, which depends on the depth of the groundwater level, resulted in a considerable variability of $N\text{-}NO_3$ concentrations groundwater (V from 21 to 76%). The concentration of $N\text{-}NO_3$ in groundwater of MtII 60gy and MtI 120gy soils decreased from spring to summer and subsequently started to increase in autumn, attaining the highest values in winter, whereas the lowest concentrations in MtIc 35gy and MtII bb soils were found in winter, and the highest were in spring and summer, respectively.

As compared to the extensively-managed meadows on MtI 120gy and MtII 60gy soils (Wrocikowo), significantly higher concentrations of $N\text{-}NO_3$ were found in groundwater in MtII bb and MtIc 35gy soils (the Dymerskie Meadows). However, the groundwater in MtIc 35gy soil under the extensively-managed meadow contained more nitrates (15% more on average) than that under pasture in MtII bb soil. This may have been caused by less intensive nitrate uptake by the vegetation covering the more humid meadow habitat.

The concentration of $N\text{-}NO_2$ in the analyzed groundwater varied (from 0.008 to 0.067 mg dm^{-3}); it was particularly high in Wrocikowo (MtI 120gy soil – V=143% and MtII 60gy soil – V = 138%), which may be attributed both to the nature of the substratum and to the variability of groundwater levels (Figure 3).

They were also significantly higher than in the Dymerskie Meadows. Low and the least varied concentrations of $N\text{-}NO_2$ in groundwater in MtIc 35gy soil may be attributed to high and stable levels of groundwater. Extensive management of the pasture on MtII bb soil, formed from low rush peat, resulted in a nearly twofold increase in the concentration of $N\text{-}NO_2$ in groundwater as compared to MtIc 35gy soil, formed on shallow organic gyttja. Except for MtI 120gy soil (R = -0.52), a similar tendency to increase with rising groundwater levels was observed for concentrations of $N\text{-}NO_2$ and $N\text{-}NO_3$. In MtIc 35gy soil, the concentration of MtIc 35gy was found to decrease significantly with increasing saturation of the soil profile with water (R = 0.61).

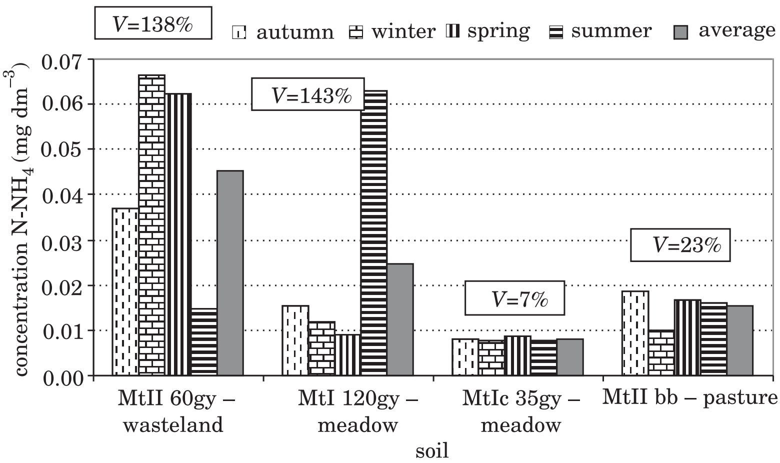

Fig. 3. Seasonal average concentration of N-NO_2 in groundwater of hydrogenic soils

The concentration of ammonium nitrogen in groundwater of turf-covered hydrogenic soils depended on their type and was subject to high seasonal variability. A considerably higher load of N-NH_4 in groundwater in MtII 60gy soil was recorded in summer (2.49 mg dm^{-3}) and in autumn (2.47 mg dm^{-3}), in MtI 120gy soil – mainly in summer (1.52 mg dm^{-3}), and in MtIc 35gy soils (0.53 mg dm^{-3}) and MtII bb (0.52 mg dm^{-3}) – in autumn. However, it was significantly higher in groundwater in Wrocikowo than in the Dymerskie Meadows (Figure 4).

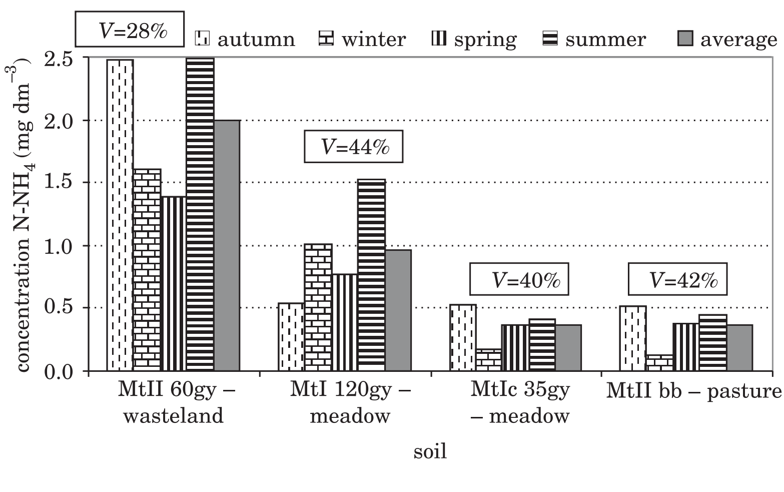

Fig. 4. Seasonal average concentration of N-NH_4 in groundwater of hydrogenic soils

This may have been associated with higher variability of water levels, especially with a clear minimum during the summer, which favoured more intensive mineralisation of organic matter, especially in MtII 60gy. This is confirmed by high correlation coefficients (R=-0.68) of N-NH_4 concentrations with water levels (Table 2). Very low correlations between these features were determined in the Dymerskie Meadows.

It should be stressed that the concentrations of N-NH_4 (from 0.37 to 1.99 mg dm^{-3} on average) in groundwater under extensively-managed or unused hydrogenic soils were 2- to 8-fold lower than those determined by JASZCZYŃSKI et al. (2006) for intensive meadow or pasture use of peat-muck soils.

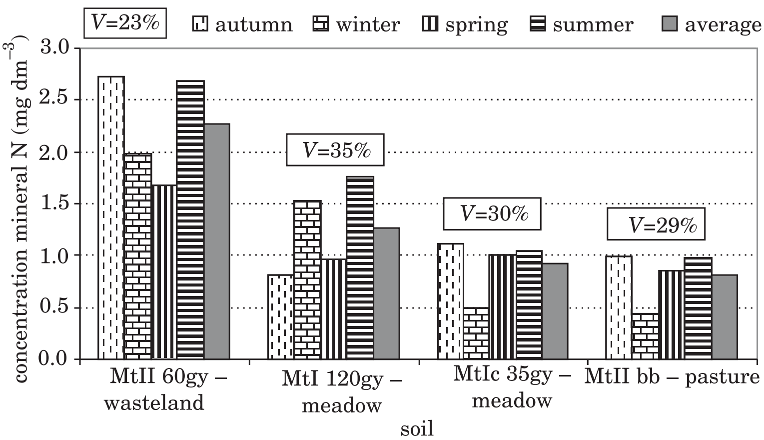

Fig. 5. Average seasonal concentration of mineral nitrogen in groundwater of hydrogenic soils

The concentration of mineral nitrogen (from 0.81 to 2.27 mg dm^{-3} on average) in groundwater of muck soils (total N-NO_3, N-NO_2 and N-NH_4) was more dependent on the type of soil than on its use (Table 5). Significantly higher concentrations of mineral nitrogen were found in groundwater in Wrocikowo, where they were 4-fold higher (MtII 60gy) and twice higher (MtI 120gy) than in the Dymerskie Meadows. Ammonium nitrogen dominated the total mineral nitrogen in groundwater in Wrocikowo. This indicates higher mineralisation of organic matter at the site, which may result from more intensive draining than in the Dymerskie Meadows. Extensive use of hydrogenic soils for meadows (MtI 120gy soil) as well as fallowing (MtII 60gy) results in loading groundwater with mineral nitrogen compounds, especially the ammonium species. Unlike Wrocikowo, N-NO_3 dominated over N-NH_4 in groundwater in the Dymerskie Meadows. The difference between these two compounds varied considerably from season to season. The concentration of N-NO_3 in groundwater of MtIc 35gy soil was 49% higher on average, and only 8% higher in MtII bb soil, which was mainly affected by the concentrations in winter. Despite better conditions for mineralisation of organic matter, which resulted from lower levels of groundwater and oxygenation of the soil profile, which facilitates more intensive nitrification of ammonium nitrogen, the ammonium form accounted for a greater portion of the total mineral nitrogen in groundwater under the pasture than in that under the extensively-managed meadow. This may have resulted from more intensive bioaccumulation of N-NO_3 by vegetation, which grows more intensely on the pasture than on the meadow. The highest concentration of mineral nitrogen in groundwater of peat-muck soil is found in summer (1.62 mg dm^{-3} on average), and the lowest (1.11 mg dm^{-3} on average) is found in winter.

CONCLUSIONS

1. Concentration of mineral forms of nitrogen in groundwater of peat-muck soils depends on their type, the depth at which groundwater is found and the soil use; the highest concentration of mineral nitrogen is found in summer and the lowest is found in winter.

2. The concentration of mineral nitrogen (total N-NO_3, N-NO_2 and N-NH_4) in groundwater of peat-muck soil under meadow, pasture of turf-covered wasteland ranges from 0.81 to 2.27 mg dm^{-3} and depends more on the type of soil than on its use.

3. Ammonium species is the dominant form of nitrogen in groundwater of unused peat-muck soil (MtII 60gy soil) and extensively-managed meadow (MtI 120gy soil) – 1.52 and 2.49 mg dm^{-3}, respectively – whereas nitrates were the dominant form of nitrogen in MtIc 35gy soil under meadows and in MtII bb soil under pasture – 0.64 and 0.51 mg dm^{-3}, respectively.

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