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MINERALIZATION OF NITROGEN ORGANIC COMPOUNDS IN MEADOW POST-BOGGY SOILS

A. Łachacz

Department of Soil Science and Soil Protection, University of Warmia and Mazury
Plac Łódzki 3, 10-957 Olsztyn, Poland

A b s t r a c t. The mineralization of nitrogen in post-boggy soils with a wide range of soil organic matter - SOM (from 3% to over 80%) was studied. Laboratory aerobic incubation of soil samples taken volumetrically in the autumn period was carried out. According to $N\text{-}NO_3$ content after incubation one can state that moorshous formations have medium levels of available nitrogen, moorshes - medium to high, and peats - low. The relationship between $N\text{-}NO_3$ content and soil moisture (%, v/v) is parabolic. The highest nitrate content was found in samples with water content of 40-70%, v/v. The relationship between the quotient $N\text{-}NO_3 : N\text{-}NH_4$ and the water content displays a similar pattern. The rate of nitrogen transformation is higher in post-boggy soils with lower content of SOM than in soils having more organic matter. In moorshous soils mineral nitrogen after incubation constitutes 0.71% of total nitrogen, whereas in moorsh soils only 0.31%.

K e y w o r d s: nitrogen, mineralization, aerobic incubation, post-boggy soils, nitrogen availability.

INTRODUCTION

Transformation of nitrogen compounds in organic soils concentrates attention for several reasons. Hydrogenic soils contain substantial amounts of nitrogen as a part of soil organic matter (SOM). Nitrogen released due to mineralization can be taken up and utilized by plants, or it can undergo unfavourable transformations leading to environmental degradation [5,7,11,20,22]. Mineralization of nitrogen compounds contributes to the general process of mineralization of SOM, which leads to reduction of organic matter content and decline of organogenic soil formations in dewatered (reclaimed) hydrogenic soils.

The paper is focused on the effect of site conditions, mainly soil moisture, on the rate of nitrogen mineralization in post-boggy soils with a wide rage of SOM content. Because the momentary content of mineral nitrogen (N_{min}) shows considerable seasonal variation [1,14,18], in this research the laboratory aerobic incubation of soil samples taken volumetrically in the autumn period was applied [4, 7]. This method was developed for nitrogen availability assessment in meadow organic soils. One can presume that this analytical approach reflects in an appropriate way the processes taking place in the soil [1]. This method was successfully employed in studies on nitrogen transformation in hydrogenic soils of large peatland areas in Poland, e.g. the Biebrza Wetland, but there is a lack of results describing moorshous soils (3-10% of SOM), which are the terminal stage of evolution of dewatered hydrogenic soils. Therefore one of the most important aims of the investigations undertaken here was to compare nitrogen transformation in moorshous soils with hydrogenic soils which have higher levels of SOM.

MATERIALS AND METHODS

Investigations were carried out in three inner-forest meadows in Pisz Primeval Forest (NE Poland). Post-boggy soils with a wide range of SOM (from 3% to over 80%) are present in the meadows studied. Substantial parts of the meadow areas are covered by sandy humous soils (3-10% SOM), which are described as moorshous soils in the Systematics of Polish Soils. Places lower in elevation are covered by mineral-moorsh soils (a layer of moorsh of a thickness less than 30 cm, underlain by sand), and the lowest places are covered by shallow peat-moorsh soils developed from strongly decomposed alder-wood peats. Site conditions and soil properties are described in more detail in previous papers [12,13].

Soils were sampled in the autumn period after ca. 7 days without precipitation, from the layers of 5-10 cm; 15-20 cm, and in the case of peat-moorsh soils also from the deeper layers of 25-30 cm; 45-50 and 55-60 cm. In these soil samples, loss on ignition at a temperature of 550 °C was determined, regarded as soil organic matter content (SOM). Organic carbon was determined by sulphochromic oxidation [2]. Total nitrogen was determined by Kjeldahl digestion.

Incubation was carried out in steel cylinders of capacity of 100 cm^3 (4-6 repetitions), according to the method developed by Gotkiewicz [4]. Briefly, this method consists in incubation of soil samples with preserved structure in bacteriological thermostats for 14 days at a temperature of 28 °C. During incubation the initial soil moisture (sample-time moisture) was maintained by periodic addition of distilled water. After incubation, the live roots were removed, and after extracting soil using 1% K_2SO_4, $N\text{-}NH_4$ content was determined by means of the distillation method with the Nessler reagent, and $N\text{-}NO_3$ content was determined by means of the phenoldisulphonic acid technique. At the same time, dry soil bulk density as well as water retention characteristics (pF curves) were determined [25].

The results of mineral nitrogen (N_{min}) content were calculated on the basis of volume (mg N/dm^3 of soil DM) in order to compare soils with a wide range of SOM content and bulk densities. Threshold values based on $N\text{-}NO_3$ content after incubation were employed for evaluation of nitrogen availability for meadow plants [7]:

$N\text{-}NO_3$ content (mg/dm^3 of soil DM)	Nitrogen availability
0-5	very low
5-10	low
10-20	medium
20-40	high
>40	very high

RESULTS

The soil formations investigated were divided into four groups according to SOM content and the nature of soil material: three of them are in the upper (top) layer formations, and the fourth - peats underlying the peat-moorsh soils (Table 1).

The C:N ratio is lower in upper layers, and within top-layer formations it decreased as SOM content decreased. The C:N ratio is calculated in order to assess the susceptibility of soil material to microbiological decomposition [10,11,15]. The moorshous soils have lower pH levels (pH_{KCl} 4.9) in comparison with the other soils. This is caused by the fact that a leaching type of water budget dominates in these sandy soils. Acid reaction is considered as a factor inhibiting the nitrifying process [11,24]. The soils studied have a wide range of total porosity, which is strongly correlated with SOM content (Table 1).

The moisture conditions during incubation are depicted in the form of 5 parameters (Table 1). Volumetric water content was the lowest in moorshous formations (average 17.3%, v/v), and the highest in peats (average 81.1%, v/v). In contrast, the highest air content was in moorshous formations, and the lowest in peats. It should be noted that air content in all upper-layer formations exceeded 15%, v/v. This means that they were well aerated, but in peats the air content was very low (average 5.6%, v/v). The most reliable index of soil air-water conditions is matrix pressure, which describes water availability for vascular plants as well as for microorganisms. The matrix pressure during incubation in moorshous formations was around 35 kPa (2.5 pF). Both groups of moorshes had similar average

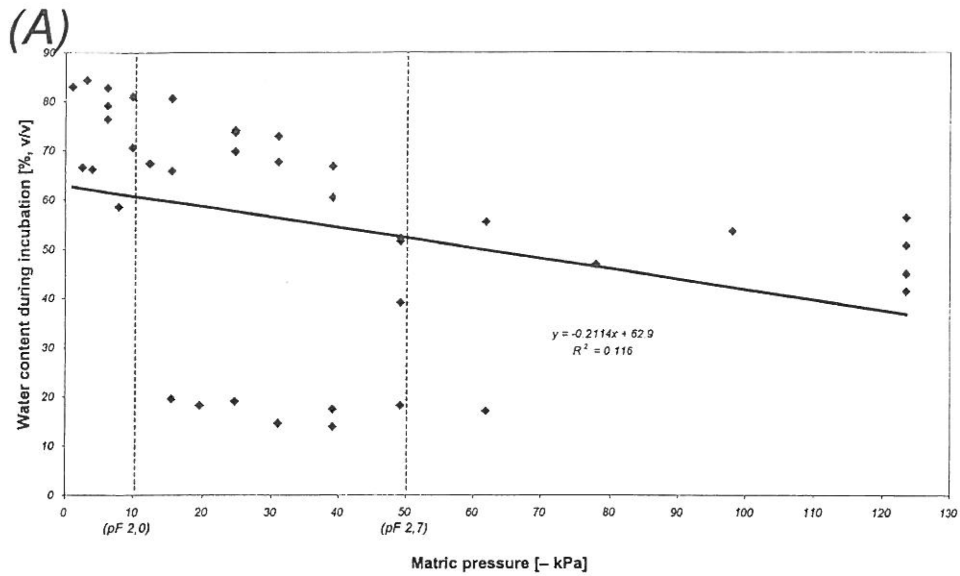
Table 1. Statistical description of investigated properties

Properties	Moorshous formations n=8	Moorsh formations of mineral-moorsh soils n=8	Moorsh formations of peat-moorsh soils n=15	Peats
SOM (%)	5.1±1.1*	41.9±7.6	73.7±6.4	75.3±9.8
Org. C (%)	2.36±0.74	23.39±3.76	39.75±2.80	40.83±7.08
Total N (%)	0.23±0.04	1.54±0.29	2.68±0.32	2.35±7.08
C:N ratio	9.9±1.7	1.54±1.7	15.2±1.4	2.35±0.37
pH in H_2O	6.9±0.4	6.4±0.2	6.3±0.3	17.4±2.2
pH in 1 M KCl	4.9±0.3	5.7±0.3	5.8±0.3	6.5±0.7
Total porosity (%, v/v)	43.8±2.5	72.1±4.3	80.4±1.1	86.7±2.7
Conditions during incubation:				
Water (%, v/v)	17.3±1.7	54.6±8.6	62.4±5.6	81.1±2.4
Air (%, v/v)	26.6±2.3	17.5±4.8	18.0±5.1	5.6±1.8
Moisture in % of TP	39.8±3.3	75.2±7.7	77.5±6.5	93.5±1.9
Matric pressure (kPa)	−35.0±13.0	-50.9±24.9	-49.1±26.2	-6.8±4.2
pF value	2.5±0.2	2.6±0.3	2.5±0.3	1.7±±0.4
Content after incubation:				
N-NH_4 (mg dm^{-3} of soil DM)	9.9±1.2	7.6±1.6	8.0±1.0	7.4±2.4
N-NO_3 (mg dm^{-3} of soil DM)	12.6±1.1	19.5±8.5	21.8±6.0	7.5±3.0
N-NH_4 + N-NO_3 (mg dm^{-3} of soil DM)	22.5±2.1	27.2±9.3	29.8±6.4	14.9±3.8
N-NO_3:N-NH_4 ratio	1.3±0.1	2.6±0.9	2.7±0.8	1.1±0.4
N_{min} as % of total N	0.71±0.12	0.31±0.08	0.32±0.05	0.30±0.11

*arithmetic mean ad 95% confidence interval.

matrix pressure (50 kPa) but individual soil samples showed significant differences in this respect (Fig. 1A). The highest moisture was in peat samples, where it was well above the field capacity. Generally, it can be stated that soil moisture of top-layer formations was close to the lower limit of easily available water (Fig. 1A), and the soil moisture was not a stress factor for microorganisms [10,21,23].

The N-NO_3 content as well as the sum of N_{min} increased in top-layer formations as SOM content increased (Table 1, Fig. 1B). Based on nitrate content, moorshous formations have medium levels of available nitrogen, moorshes - medium to high, and peats - low. It is interesting that nitrate content is highly variable among moorshes, but has a tendency to remain at a similar level in moorshous formations (Fig. 1B). The N_{min} content increased as total N content increased (Fig. 1C). From this figure it is clear that in the investigated soils it is difficult to assess the susceptibility of organic nitrogen compounds to mineralization solely by determining the total N content. From both these figures (Fig. 1B and 1C) it is visible



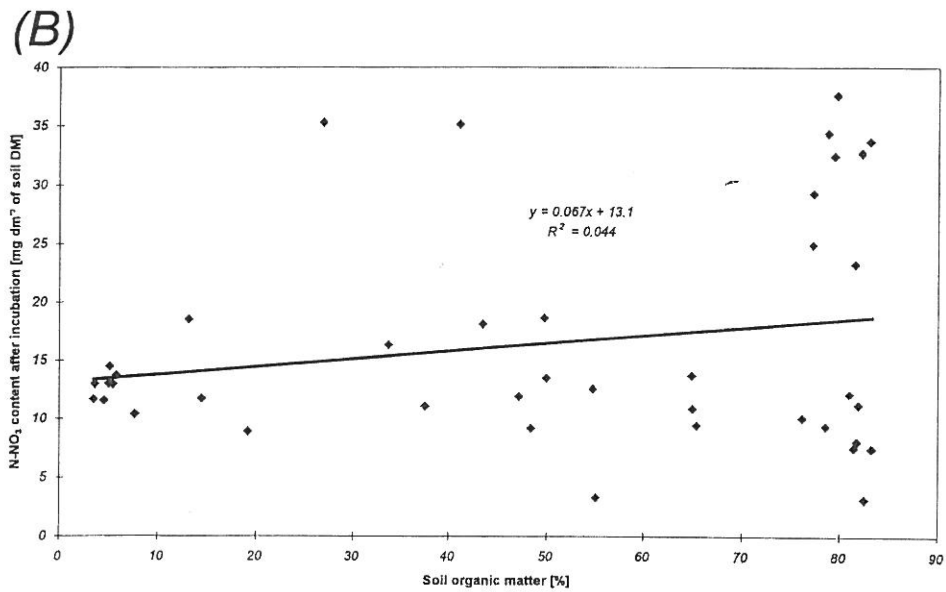
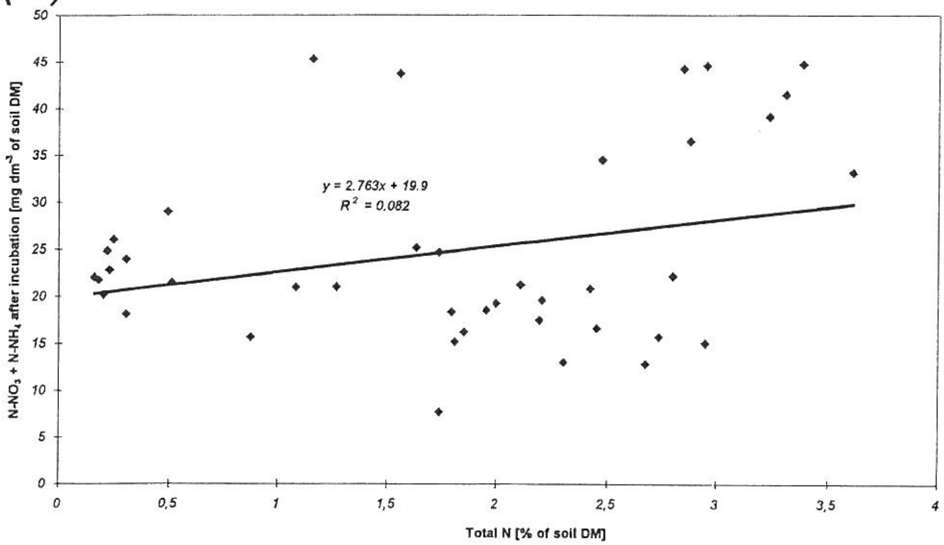


Fig. 1 A-F. Some regressional relationships between investigated properties.

(C)



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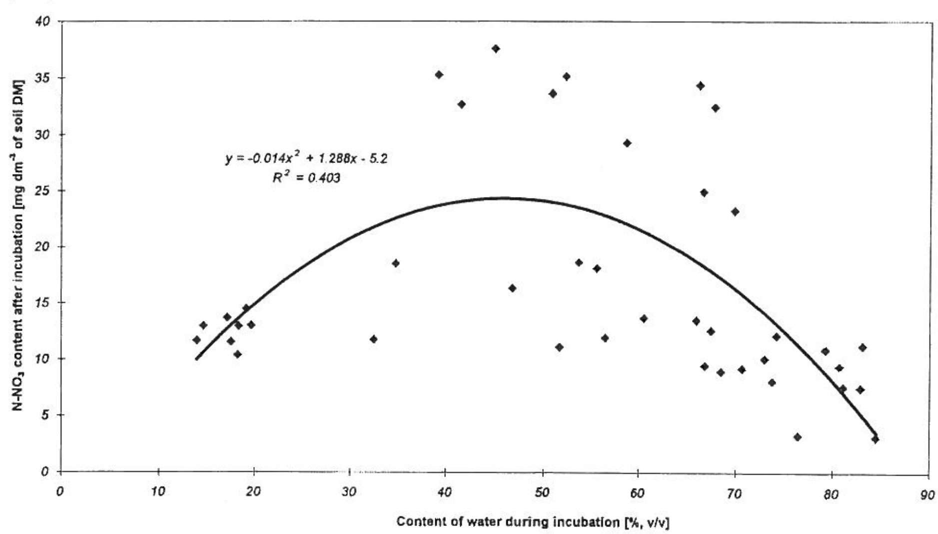

Fig. 1 A-F. Some regressional relationships between investigated properties.

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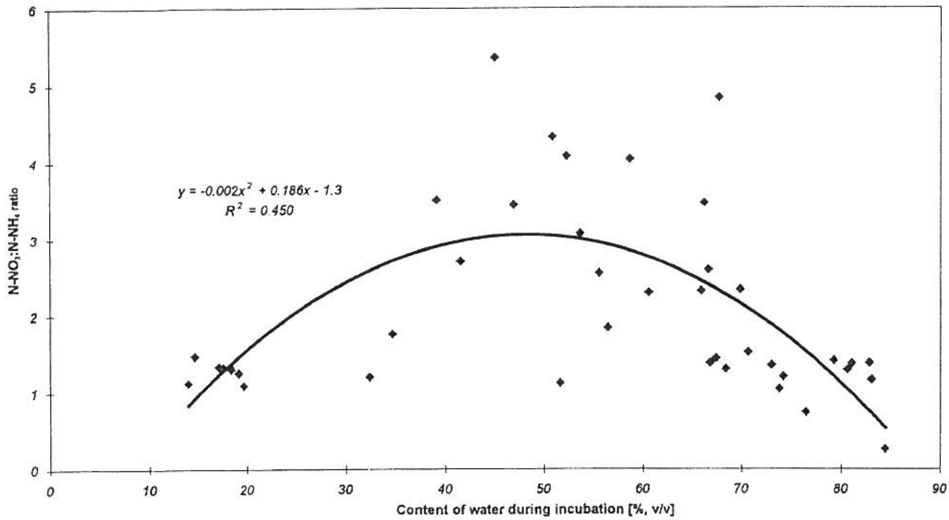

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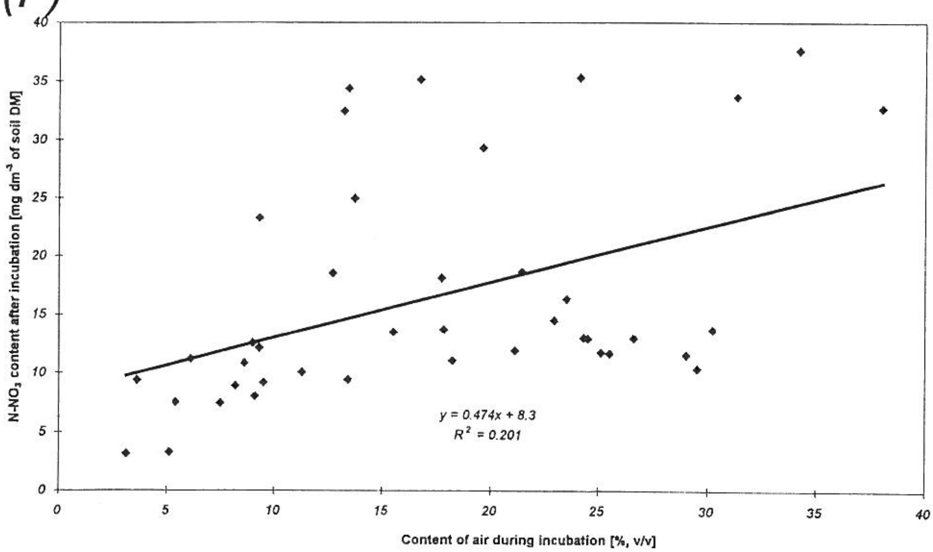

Fig. 1 A-F. Some regressional relationships between investigated properties.

that moorshous formations showed a relatively high content of N_{min} compared to soil formations richer in SOM and total N. It should also be noted (Table 1) that moorshous formations accumulated the highest amounts of ammonium nitrogen (average 9.9 mg dm^{-3}). As a result the sum of N_{min} in these formations amounted to 22.5 mg dm^{-3}, and N_{min} levels were only slightly lower than this sum for moorshes. It can be concluded that the post-boggy soils investigated do not require nitrogen fertilization when utilized as meadows. This statement is also valid for moorshous soils.

It is worthy of note that the rate of nitrogen mineralization is high in moorshous soils, which accumulated comparable amounts of N_{min} to moorshes, although they have several times less SOM and total N (Table 1). This is clearly visible when N_{min} content is calculated as a percentage of total N. On average, during incubation of moorshous formations, as much as 0.71% of total N was mineralized, whereas in the other soil formations only 0.30%. On the grounds of the above mentioned results, we can state that the rate of nitrogen mineralization in moorshous soils is twice as high as in moorsh soils. Because nitrogen transformations are closely related to the carbon cycle, this is evidence of intensive mineralization of SOM in moorshous soils. In agriculturally utilized hydrogenic soils one should take into consideration this constant reduction in SOM.

When analysing the relationship between nitrate content and soil moisture (Fig. 1D), one can state that this relationship has a parabolic shape and it is well described by second-degree equation. The highest rate of nitrification was found at moisture levels of 40-70%, v/v. When moisture content was above 75-80%, v/v, the production of nitrate nitrogen decreased markedly, but it was still considerable - around 10 mg dm^{-3}. The relation between the $N\text{-}NO_3$:$N\text{-}NH_4$ ratio and moisture content showed a similar parabolic shape (Fig. 1E). This quotient represents the relation between oxidized and reduced forms of nitrogen, and at the same time this describes the air-water conditions in soil. According to Gotkiewicz [3,7] this quotient fluctuates from below 1 to about 20. In investigated upper-layer formations, the $N\text{-}NO_3$:$N\text{-}NH_4$ ratio was above 1 (Table 1). However in peats it was considerably, lower. The $N\text{-}NO_3$:$N\text{-}NH_4$ ratio regularly decreased with depth in all soil profiles (Table 2). In peat-moorsh soils the quotient was lower than 1 only at the depth of 55-60 cm. This means that the aerobic zone of microbiological processes reaches the deep layer of peat-moorsh soils under study. The $N\text{-}NO_3$:$N\text{-}NH_4$ ratio was relatively low in moorshous soils (average 1.3). The lower rate of nitrification in moorshous soils, in comparison to moorshes, may be caused by nutritional conditions (scarcity of Ca, Mg, K, Ca) and soil acidity (Table 1).

T a b l e 2. Comparison of N-NO3:N-NH4 ratios at various depths, for the three types of soils investigated

Depth (cm)	Moorshous soils	Mineral-moorsh soils	Peat-moorsh soils
5-10	1.34*	3.40	3.47
15-20	1.21	1.79	2.00
25-30	n.d.	n.d.	1.39
45-50	n.d.	n.d.	1.32
55-60	n.d.	n.d.	0.72

*-arithmetic mean, n.d. - not determined.

From data presented in Fig. 1F, one can conclude that air content below 10%, v/v may restrain the nitrification process, which is exclusively an aerobic process. Soils rich in SOM, especially the upper moorsh horizons, show a tendency towards natural scarification (loose crumb structure), and they have a high capacity of air-filled pores (macropores), which contain air at very low values of matrix pressure. Therefore, in order to restrict nitrification and at the same time excessive mineralization of SOM, in conjunction with maintenance of high moisture, the soil porosity should be limited by means of e.g. rolling and maintenance of dense sod.

DISCUSSION

Production of N_{min} after incubation by the peat-moorsh soils studied was similar to production in organic soils from other regions of Poland [5-7]. The ability to mineralize organic compounds of nitrogen is extremely variable and depends on the nature of the soil substratum and site conditions, chiefly the air-water conditions [5,7]. As an example it can be cited that nitrate content after incubation can exceed 100 mg dm^{-3}, as was recorded for the Wizna Fen soils [5]. The relatively low content of N_{min} found in some mineral-moorsh soils (Fig. 1B and 1C) could be caused by the great transformation (advanced moorsh-forming process) of these formations. The mineral-moorsh soils under study were dewatered and reclaimed in the last century. It is considered [8,16,17,20] that in such soils nitrogen and carbon are both bound in cyclic humic compounds, which are less prone to mineralization.

The constant predominance, found in top-layer formations, of the nitrate form over ammonium is consistent with other investigations, which underline the tendency of dewatered organic soils to accumulate substantial amounts of nitrates [3,5,6,9,19, 22-24]. This indicates that there is a predominance of aerobic conditions and generally high microbiological efficiency of soil processes in the investigated soils

[3,7]. The restraining effect of high moisture on mineralization of nitrogen, and especially on nitrification, is widely known [5-7,19,20,22].

It seems to be of interest that the $N\text{-}NO_3 : N\text{-}NH_4$ ratio increased as organic matter content increased in upper soil formations (Table 1). The relatively low $N\text{-}NO_3 : N\text{-}NH_4$ ratio in moorshous soils (average 1.3) indicates some inhibition of nitrification. It appears that this is not caused by the air-water conditions, but rather is determined by the nature of soil material. The moorshous soils contain lower levels of organic colloids (as they have less organic matter) and they contain virtually no mineral clay colloids (because they developed on loose sands). It is believed [21] that nitrifying bacteria in soils live mostly in film water surrounding colloidal particles. This can explain, in conjunction with the nutritional conditions, the differences found between the moorshous and moorsh soils. It is worthy of note in this place that the moorshous soils showed a constant predominance of ammonium nitrogen over nitrate during repeated measurements of momentary content of mineral nitrogen. On average, the $N\text{-}NO_3 : N\text{-}NH_4$ ratio in momentary mineral nitrogen amounted to 0.84 in moorshous soils, whereas in moorsh soils it was around 2.0. In this respect the moorshous soils display similar nitrification conditions as acid sandy soils from temperate areas [18].

CONCLUSIONS

1. The investigated upper soil formations of post-boggy soils with organic matter content ranging from 3% to over 80% showed relatively high levels of production of N_{min} during aerobic incubation. Within mineral nitrogen, there was a constant dominance of nitrate forms. Their content of available nitrogen is moderate to high, so these soils do not require additional nitrogen fertilization.

2. The air-water conditions influence the rate of nitrogen mineralization. High moisture content (over 75-80%, v/v), and low air content (below 10%, v/v) can, to some extent, inhibit this process, but complete restriction of nitrogen mineralization is impossible in agriculturally utilized soils.

3. The moorshous formations (3-10% SOM) show intensive nitrogen mineralization. During incubation they mineralized twice as much nitrogen, in relation to total nitrogen, than moorshes. This indicates a high rate of organic matter mineralization in post-boggy soils which have the lowest levels of SOM.

4. The relatively low rate of nitrification in moorshous soils, when compare to moorshes, could be caused by their nutritional status (acidity) and lower content of soil colloids (mineral and organic).

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