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Phosphorus release from peat soils under flooded conditions of the Łęczyńsko-Włodawskie Lake District

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Abstract. The aim of this paper was to study the process of phosphorus release from peat soils under flooded conditions and to specify the time and conditions in which this process takes place. Studies were conducted on samples of peat soils collected in the Łęczyńsko-Włodawskie Lake District, from high-moor peat and from low-moor peat. The peat soil samples (from depths of 0-20, 20-40 and 40-60 cm) was placed in plastic containers. 500 ml of water was added to each sample and the containers were tightly closed. The incubation was conducted in darkness for 126 days, at room temperature. The Eh and pH of peat soils were measured each week and filtrate was collected for determination of the $P\text{-}PO_4^{3-}$ and Fe^{2+} concentrations. Phosphorus release was the highest in the surface layer (depth of 0-20 cm) of both sites in the high-moor and in the low-moor peat. The maximum phosphorus released (50.5 mg $P\text{-}PO_4^{3-}dm^{-3}$) from low-moor peat was 7.5 times higher than the maximum phosphorus released from low-moor peat.

Keywords: high-moor peat, low-moor pet, phosphorus release

INTRODUCTION

High phosphorus input to the aquatic environment, resulting in eutrophication of lakes, rivers and reservoirs, is still the major problem of water management in most European countries (Olila, 1996; Gelbrecht *et al*., 2005). Generally, concentrations of phosphates are considered low if they do not exceed 32 μg P dm^{-3} for rivers and ponds, and 8 μg P dm^{-3} for lakes. They are considered as high if they exceed 163 and 32 μg P dm^{-3}, respectively. In Poland the process of eutrophication is at an advanced stage. About 95% of the lakes are in the state of eutrophy. Eutrophication is arguably the biggest pollution problem facing estuaries globally, with extensive consequences including anoxic and hypoxic waters, reduced fishery harvests, toxic algal blooms, and loss of biotic diversity (Howarth *et al*., 2000).

The drying and re-wetting of fen peat soils causes anaerobic soil conditions, low redox potentials, the reduction of Fe(III)-compounds, and therefore enhances the mobilisation of phosphorus from peat soils, especially in the case of long drying periods, deep water table drawdown or repeated drying/rewetting circles which are common in disturbed fen systems (Tiemeyer *et al*., 2005).

The presence of organic matter also contributes to phosphorus release, but it happens due to mineralization rather than acceleration of Fe (III) reduction. The quantity of released phosphorus may also increase because of the desorption of phosphates from organic anions or the complexing of aluminium and iron from complexes which can adsorb phosphates (Welp *et al*., 1983).

The factors which may regulate phosphorus reactivity in inundated soils include redox potential and pH (Kirk and Saleque, 1995; Shahahandeh *et al*., 1994; Gardolinski *et al*., 2004). According to Holford and Patrick's (1979) studies the level of pH determines the dissolution and precipitation of Fe complexes and, consequently, the sorption-desorption of phosphorus in inundated soils. The influence of Eh on the changes of P is not direct, but its solubility is connected with changes of Eh through phosphorus precipitation with elements such as Fe and Mn ions (Engels *et al*., 1995; Kirk and Saleque, 1995; Olila, 1996; Moore and Reddy, 1994).

Gotoh and Patrick (1974) found out that Eh critical values corresponding to iron reduction depend on pH. In soils with pH 5 the Eh critical value fostering iron reduction is +300 mV, and in soils with pH 8, between +300 and +100 mV.

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Therefore, the projects of renaturalization in former marshlands should be based on appropriate recognition of possibilities of stimulating the activity of phosphorus compounds and the threats resulting from that.

The aim of this paper was to study the process of phosphorus release from high-moor and low-moor peat soils under flooded conditions and to specify the time and redox conditions in which this process takes place.

MATERIALS

The following peat soils were collected in June 1999 on the territory of the Łęczyńsko-Włodawskie Lake District:

High-moor peat. The natural peat soils from which the samples were collected are situated on the territory of Poleski National Park, in the vicinity of the reserve of 'Lake Moszne'. It is a high-bog peat with organic matter layer up to 2.5 m thick. The ground water level was at a depth of 20 cm. The gravimetric water content was 81%. The bottom of layers profile constitutes a thin layer of peated gyttja which passes to sedge-moss peat. The surface of the peat-bog, abundant in peat holes, is covered by pine wood with birches, black alders and trembling poplars.

Low-moor peat. The low-moor peat samples were collected near the village Pieszowola. Drained hydrogenic soils were the experimental material of the research. The peat soils were meliorated in 1968 and used as meadows. Melioration work considerably changed the bog characteristics of the region. The peat soils were transformed by the moorshing process and, as a result, the water level declined. In June, the ground water level was at the depth of 60 cm. The gravimetric water content was 70%.

Peat profiles were sampled from each site by digging pits and removing oriented blocks cut from the pit side. The blocks were bagged in plastic sampling bags. The peat soil samples were immediately transported to the laboratory and placed in 5 dm^3 plastic containers. Scheme of the incubation containers is presented in Fig. 1. In each container three platinum electrodes were installed to measure redox potential, an agar bridge closing the circuit during Eh measurements, as well as a ceramic filter for sampling the soil solutions. 500 ml of distilled water was added to each container to cover the soil surface slightly with about 1 cm of stagnant water. The containers were tightly closed. The incubation was conducted in darkness for 126 days at room temperature. Redox potential (Eh), P-PO_4^{3-} and Fe^{2+} concentrations as well as the pH of collected solutions were measured each week. Every time, 5 ml of soil solution was sampled. No water was added to the samples during the incubation experiment. The following methods were used to analyse the soil solution:

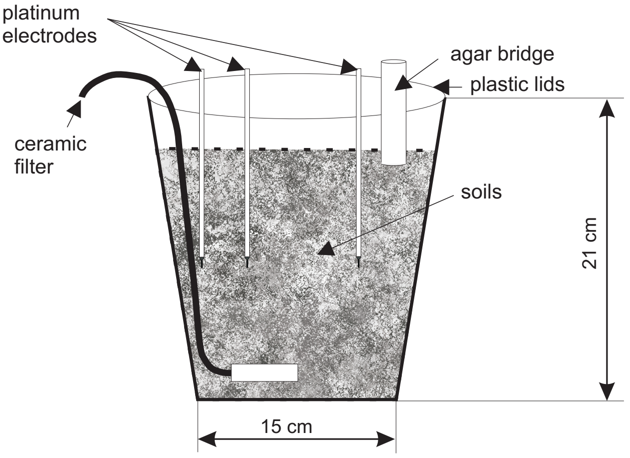


Fig. 1. Scheme of the incubation containers.

- redox potential measurements were made using a calomel electrode as the reference electrode with constant non-zero potential, well tested and accurately calibrated with relation to the standard hydrogen electrode (Gliński and Stępniewski, 1985). Redox measurements were taken using an 'pIONneer 10' Radiometer portable apparatus;
- pH measurement was performed by a combined electrode using Radiometer pH Meter;
- determination of P-PO_4^{3-} concentration was performed with the help of the FIA-Star 5010 flow-through spectrophotometric analyser made by Foss Tecator (Application Note ASN 60-01/83).
- concentration of Fe(II) was determined by the spectrophotometry method following the addition of $\alpha\alpha$'-dipyridyl and acetate buffer (Aleksandrova and Naidenova, 1967).

RESULTS

At the beginning of the incubation the reaction of the soil solutions studied oscillated on the mean levels of pH 4.6 and pH 7.4 for high-moor and low-moor peat, respectively. In the course of the study slight fluctuations in the reaction were observed with a declining tendency to around 1 at the end of the incubation.

In the variant high-moor peat during the first several days of incubation the values of the potential decreased from about 140 to about -35 mV and for the rest of the period remained on that level (Fig. 2). Only in peat samples from 0-20 cm depth, the Eh decreased gradually for the whole incubation period.

In the low-moor peat the value of the potential decreased gradually for the whole period of the experiment. On the last day of incubation Eh was on the levels of -173, -178, and -118 mV (for 0-20, 20-40, 40-60 cm, respectively) (Fig. 2) and these values were lower than the values of the redox potential in high-moor peat.

At the beginning of the incubation in the 'high-moor peat' and in the low-moor peat Fe(II) concentration oscillated in the range of 0.74-1.34 mg $Fe^{2+}dm^{-3}$ (Fig. 3) and in the range of 0.16-0.32 mg $Fe^{2+}dm^{-3}$ (Fig. 4), respectively. During the time of incubation the iron (II) concentration was

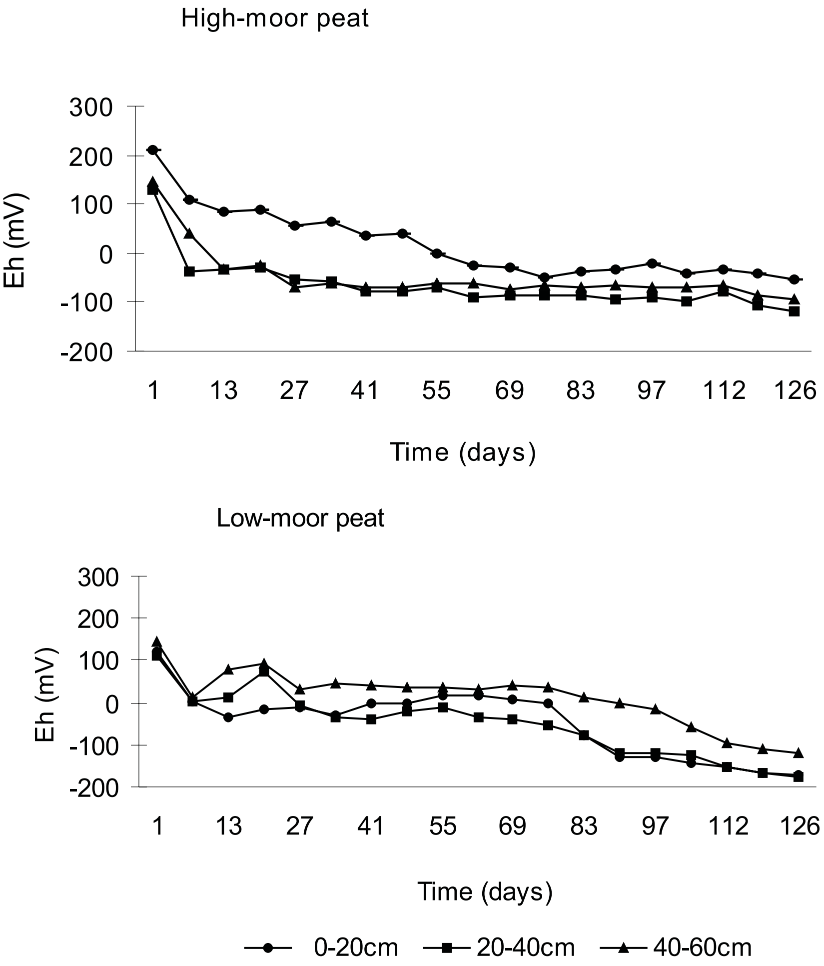


Fig. 2. Dynamics of changes in Eh in high-moor and low-moor peat at different depths.

quantity increased. The highest concentrations of iron (II) dissolved in soil solutions were observed in low-moor peat from the depth of 0-20 cm.

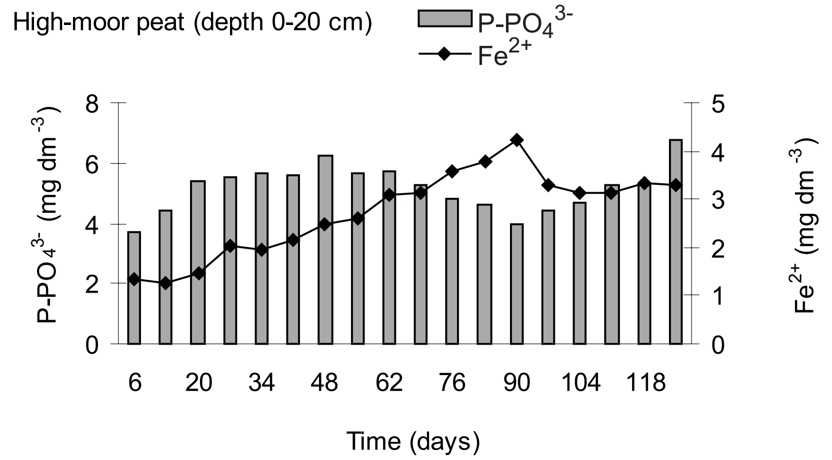
The P-PO_4^{3-} concentration in the high-moor peat is shown in Fig. 3 and that in low-moor peat in Fig. 4. The concentration of phosphorus measured on the 6th day for the high-moor peat varied from 0 to 0.32 mg P-PO_4^{3-}dm^{-3} at the depths of 20-40 and 0-20 cm, respectively. During subsequent days of incubation the average amount of phosphorus released for the high-moor-peat from the depth of 0-20 cm was 5.18 mg P-PO_4^{3-}dm^{-3}. The phosphorus concentrations in the samples from the depth of 20-40 cm varied from 0.09 to 1.37 mg P-PO_4^{3-}dm^{-3}. In the high-moor peat from the depth of 40-60 cm, phosphorus release was observed after the 76th day of incubation on the level of 0.02 mg P-PO_4^{3-}dm^{-3}.

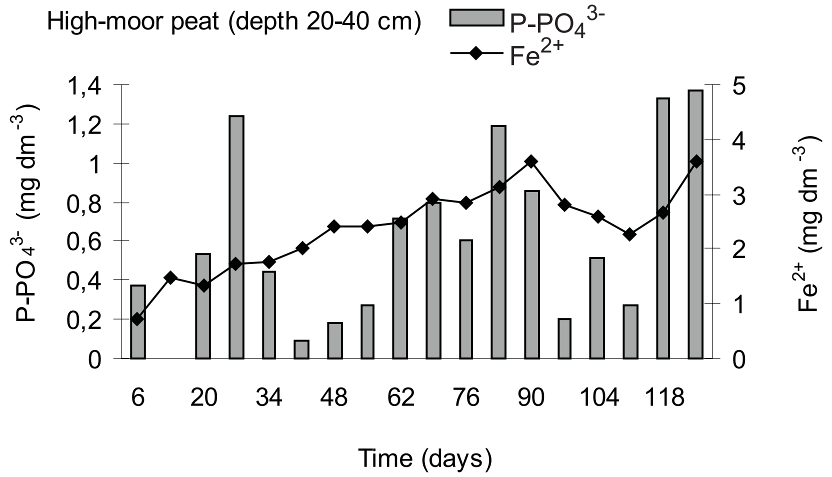
Concentration of phosphorus at the beginning of the experiment in the low-moor peat varied from 0 (depth of 20-40 cm) to 0.32 mg P-PO_4^{3-}dm^{-3} (depth of 0-20 cm). During subsequent days of incubation the amount of released phosphorus increased. The maximum phosphorus concentration for the low-moor peat (50.5 mg P-PO_4^{3-}dm^{-3}) was measured after 126 days of incubation from the depth of 0-20 cm.

Highest rates of phosphorus release were found in the soil surface layer (0-20 cm) of both sites in the high-moor (Fig. 3) and in the low-moor peat (Fig. 4). In low-moor peat surface layer 5 times more P-PO_4^{3-} ions were released than from layer of 20-40 cm, and 55 times more than from layer of 40-60 cm. In high-moor peat these differences were even larger. Thus, it can be stated that the quantity of released phosphorus decreased with the decrease of depth, showing the highest concentration of P-PO_4^{3-} ions in the surface layer, then at the depth of 20-40 cm, and the lowest at the depth of 40-60 cm.

DISCUSSION

A well-oxidized soil has a redox potential range up to +400 to +700 mV. Flooded soils may reach redox potential values lower than –300 mV due to the absence of O_2 and the activity of facultative and obligate anaerobic bacteria (Yu *et*





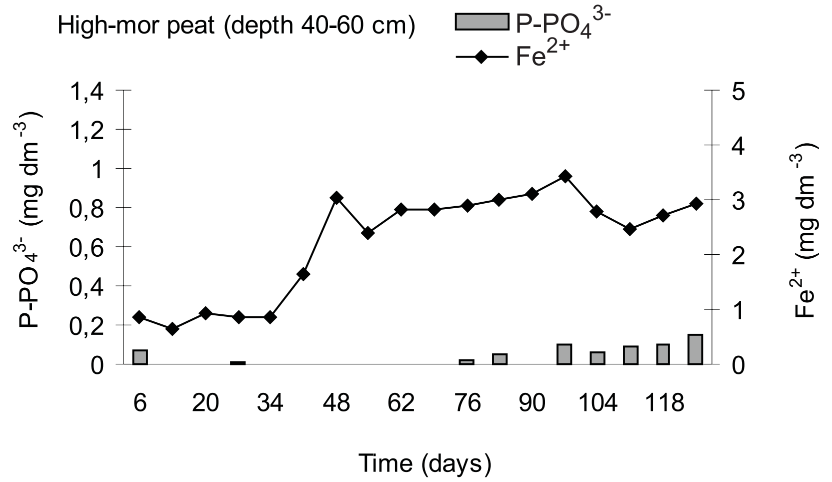


Fig. 3. Concentration of P-PO_4^{3-} and Fe^{2+} in high-moor peat during incubation.

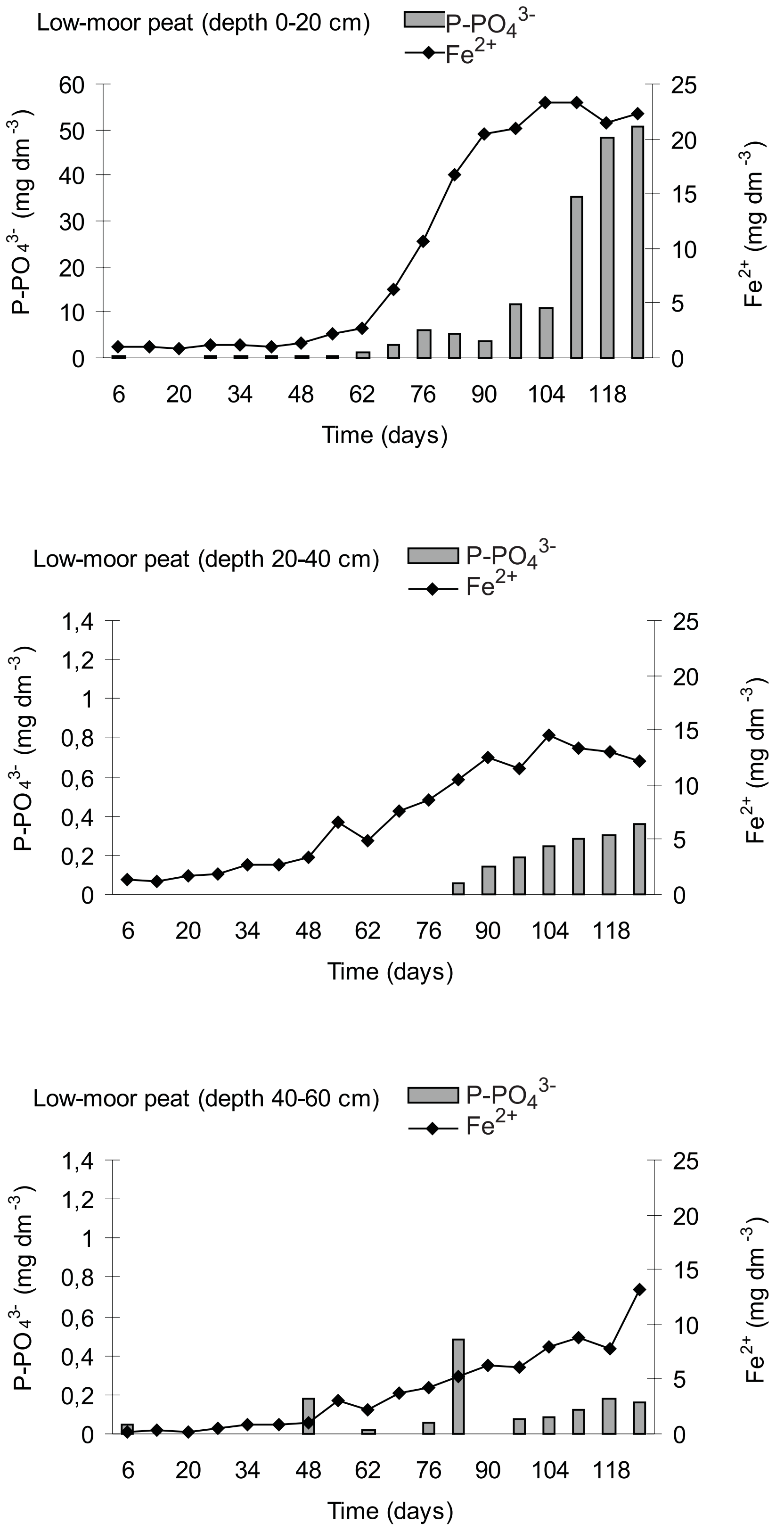


Fig. 4. Concentration of P-PO$_4^{3-}$ and Fe^{2+} in low-moor peat during incubation.

al., 2001). Redox potential decreased from 162 to –89 mV (high-moor peat) and from 125 to –156 mV (low-moor peat) during the incubation of peat soil under flooded conditions. Stępniewska *et al.* (2003) observed soil redox potential decrease from about +400 mV down to about 100 mV during the first two days of incubation of flooded loess soil.

The comparison of concentrations of $P\text{-}PO_4^{3-}$ ions in solutions studied shows that the largest quantity of phosphorus was released from the inundated surface layer of peat previously low. Here the maximum concentration of phosphorus was observed (50.5 mg $P\text{-}PO_4^{3-}dm^{-3}$), which was 7.5 times higher than the maximum (6.77 mg $P\text{-}PO_4^{3-}dm^{-3}$) concentration of phosphorus released from high-moor peat.

In studies conducted in Finland in 1995 and 1996 on the territory of a peat mine just after the redrainage of the area (the first drainage took place in 1970), the quantities of determined $P\text{-}PO_4$ were much lower. The average concentration of released phosphorus was on the level of 0.0158 mg kg^{-1} in water from melioration trench and 0.338 mg kg^{-1} in ground water, and the maximum concentrations were: 0.055 and 0.67 mg kg^{-1}, respectively (Kløve, 2001). Studies on the washing out of biogenes from peat lands were conducted also on a low peat-bog in Docksmyren, in central Sweden, drained for the purpose of forest production and peat exploitation. From July to August, 1989, from 1 m^2 of this peat-bog only 0.004 mg of P_{org} was washed out (Lundin, 1992). And on a low peat-bog in Rhinluch, Brandenburg, in the years 1995-1996, the average quantities of total phosphorus determined in water flowing in and out were 0.24 and 0.31 mg dm^{-3}, respectively (Balla *et al.*, 2000).

Phosphorus release from the peat soils examined was the fastest in the surface layer of the peat soils (0-20 cm). This remains in accordance with the statement made by Kirk and Saleque (1995) who maintain that the surface layer of boggy peat soil contains 3 to 5 times more accumulated phosphorus than deeper layers.

In our experiment this ratio was much higher, because phosphorus released from high-moor peat was 8.5 and 140 times higher in surface layer than in the 20-40 and 40-60 cm layers, respectively. In low-moor peat these differences were also high (113 and 126, respectively). The re-wetting of peatlands can have deteriorating side effects on the water quality of adjacent surface water bodies. Our experiment showed that phosphorus release from peat soils under flooding conditions is the highest in surface layer. Increase of the water level to the surface layer of the peat soil is thus especially dangerous. That is a very important aspect of peat protection strategy.

CONCLUSIONS

1. The process of phosphorus release during incubation of peat soils after flooding in laboratory conditions was the highest in the soil surface layer (depth of 0-20 cm).

2. The maximum phosphorus release (50.5 mg $P\text{-}PO_4^{3-}dm^{-3}$) was observed in the low-moor peat from the depth of 0-20 cm, after 126 days of incubation, at the Eh value of –173 mV and concentration of reduced iron of 22.18 mg dm^{-3}.

3. The maximum phosphorus released from high-moor peat was 7.5 times lower than the maximum phosphorus released from low-moor peat.

4. Activating of phosphates occurred in clearly negative oxidoreducing conditions at Eh <100 mV and intensified with deepening anaerobiosis.

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