

http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2014.19.3.171

Interaction of Peat Soil and Sulphidic Material Substratum: Role of Peat Layer and Groundwater Level Fluctuations on Phosphorus Concentration

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Received 24 April 2014 / accepted 30 August 2014

ABSTRACT

Phosphorus (P) often becomes limiting factor for plants growth. Phosphorus geochemistry in peatland soil is associated with the presence of peat layer and groundwater level fluctuations. The research was conducted to study the role of peat layer and groundwater level fluctuations on P concentration in peatland. The research was conducted on deep, moderate and shallow peat with sulphidic material as substratum, peaty acid sulphate soil, and potential acid sulphate soil. While P concentration was observed in wet season, in transition from wet to dry season, and in dry season. Soil samples were collected by using peat borer according to interlayer and soil horizon. The results showed that peat layer might act as the main source of P in peatland with sulphidic material substratum. The upper peat layer on sulphidic material caused by groundwater level fluctuations had no directly effect on P concentration in the peat layers. Increased of P concentration in the lowest sulphidic layer might relate to redox reaction of iron in the sulphidic layer and precipitation process. Phosphorus concentration in peatland with sulphidic material as substratum was not influenced by peat thickness. However, depletion or disappearance of peat layer decreased P concentration in soil solution. Disappearance of peat layer means loss of a natural source of P for peatland with sulphidic material as substratum, therefore peat layer must be kept in order to maintain of peatlands.

Keywords : Groundwater level, peat soil, phosphorus, soil chemical properties, sulphidic material

INTRODUCTION

Phosphorus (P) is an essential plant macronutrient required for adequate growth and development of roots and shoots as well as many biochemical processes. Function of P within plants includes energy storage, energy transfer as well as a building block for deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) (Barker and Pilbeam 2007). Phosphorus is often limiting to both wetland and upland plants because of its low solubility in water and its low mobility in the soil. In acidic wetland soils P solubility is restricted by reactions with metal ions especially iron (Fe) oxides/hydroxides, while aluminium dominate in acidic upland soils.

About 3% of earth surface is covered by peatlands (Limpens *et al.* 2008) and about 14.9 million ha of peatlands are found in Indonesia

(BBSDLP 2011). Most of peatlands in Indonesia are formed in low altitude coastal and sub-coastal situations, and based on geografic condition of peat formation, apart of peatland in Indonesia is developed above on sulphidic material. The majority of peatlands in Borneo are in dome form, this convex shape causes varying groundwater fluctuation. The fluctuation of groundwater level in ombrogenous peat depends mainly on rainfall. Page *et al.* (2006) summarized that between wet dan dry season, groundwater level fluctuations in ombrogenous peatland reach 0.2–0.6 m or even 1.0 m. Groundwater level fluctuations in peatlands may influence nutrient and metal ions concentrations in peatland (Koretsky *et al.* 2007; Kaczorek *et al.* 2009; Sapek *et al.* 2009).

Peat soils are classified as highly organic soil that mainly composed of organic matters such as leaves, branches and stem which are partly decomposed. Peat mainly consists of large plants residues that are decomposed under anaerob condition. Peat soil have very low pH, this condition may be lead low P availability (Yonebayashi *et al.* 1997). Kurnain *et al.* (2001) found P contents of

tropical peat soil at Kalamangan in Central Kalimantan range from 0.4 to 0.7 g kg⁻¹, whereas Sajarwan *et al.* (2002) reported P contents of tropical peat soil at Sebangau catchment area range from 0.3 to 0.9 g kg⁻¹. Generally, P geochemistry in wetland soil is associated with Fe oxides and hydroxides (Litaor *et al.* 2004). Phosphorus sorption in organic soils is affected by poorly crystalline Fe (Meissner *et al.* 2008; Forsmann and Kjaergaard, 2014). While solubility of Fe in wetlands soil is generally affected by groundwater level fluctuation.

Flooding may lead increase Fe²⁺ solubility due to reduction reaction and *vice versa* (Reddy and DeLaune 2008). In Fe³⁺ reduction process, P is released to the soil solution and soil pH increases (Morris and Hesterberg 2010). However, Fe solubility in peat soil was low due to fixation or chelation by humic substances. Karlsson and Persson (2010) stated that more than 50% of Fe in peatland are chelated by humic substances, and especially chelated by humic acid (Sarzynska and Sokolowska 2002). Based on these facts, therefore a better understanding of the role of peat layer and groundwater level on P concentration in peatland with sulphidic material substratum is necessary for a better management of peatland.

The research was conducted to study the role of groundwater level fluctuations on P concentration of peatland with sulphidic material substratum.

MATERIALS AND METHODS

Site Description

The research was conducted on deep, moderate and shallow peat with sulphidic material as substratum, peaty acid sulphate soil and potential acid sulphate soil. Each study site was spread in one area and each of them is separated by tertiary

channels. The extent of each study site was determined at least 1 to 2 ha which is located at Pangkoh IX, Pulang Pisau District, Central Kalimantan, Indonesia, with 8 m elevation and geografic positions at South (S) : 2° 52.240 and East (E) : 114° 05.409 for deep peat, S: 2° 52.372 and E: 114° 05.811 for moderate peat, S: 2° 52.609 and E: 114° 06.088 for shallow peat and S: 2° 52.369 and E: 114° 06.034 for peaty acid sulphate soil, respectively. It was about 10 km west of Kahayan river and 20 km east of Sebangau river. The site was covered mainly by mixed of shrubs and rubber plants.

Soil Sampling Points

Soil samples were collected by using peat borer according to interlayer (the border layer of peat and mineral layer) and soil horizon (thickness and humification stage). The sampling depths were (in cm) 20 and 55 for acid sulphate soil (ASS); 25, 50 and 75 for peaty acid sulphate soil (PASS); 45, 70 and 120 for shallow peat which partially of peat layers were removed (SP 0,5); and 85 and 120 for shallow peat which all of peat layers were removed (SP 0), 25, 50, 75, 95, 115 and 135 for shallow peat (SP); 50, 100, 120, 135 and 155 for moderate peat (MP); 50, 150, 200, 225, 245 and 265 for deep peat (DP), respectively (Figure 2). At each study site, sampling points were replicated three times.

There was found only sapric peat material on the shallow peat, whereas sapric and hemic peat material in moderate and deep peat. The humification stage of peat material was determined in the field using a von post method. Soil samples were air dried to a constant mass and homogenized in a stainless steel mill (sieve mesh diameter 2 mm). Phosphorus (P) concentrations (using Bray I analysis) in ASS, PASS, SP 0.5, and SP 0 were observed on June of

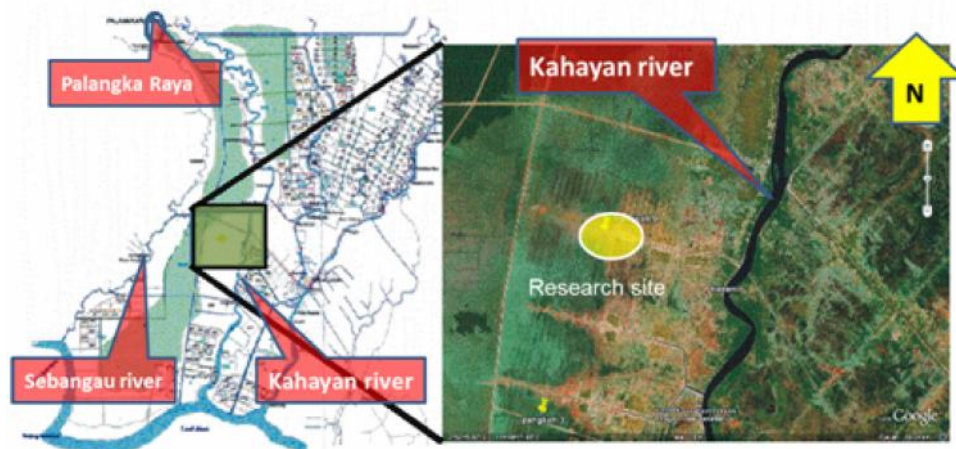


Figure 1. Research site at Pangkoh IX, Pulang Pisau District, Central Kalimantan, Indonesia.

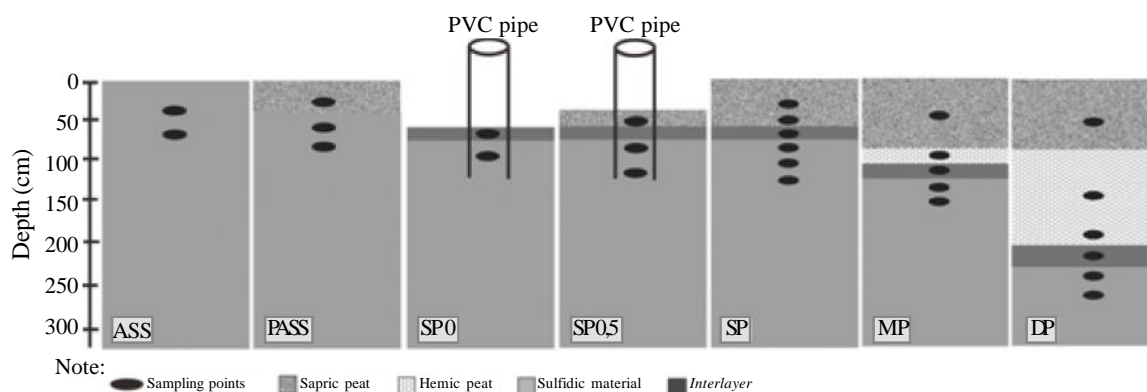


Figure 2. Soil profile and sampling points in potential acid sulphate soil (ASS), peaty acid sulphate soil (PASS), shallow peat which all of peat layers were removed (SP 0) and shallow peat which partially of peat layers were removed (SP 0.5), shallow peat (SP), moderate peat (MP) and deep peat (DP).

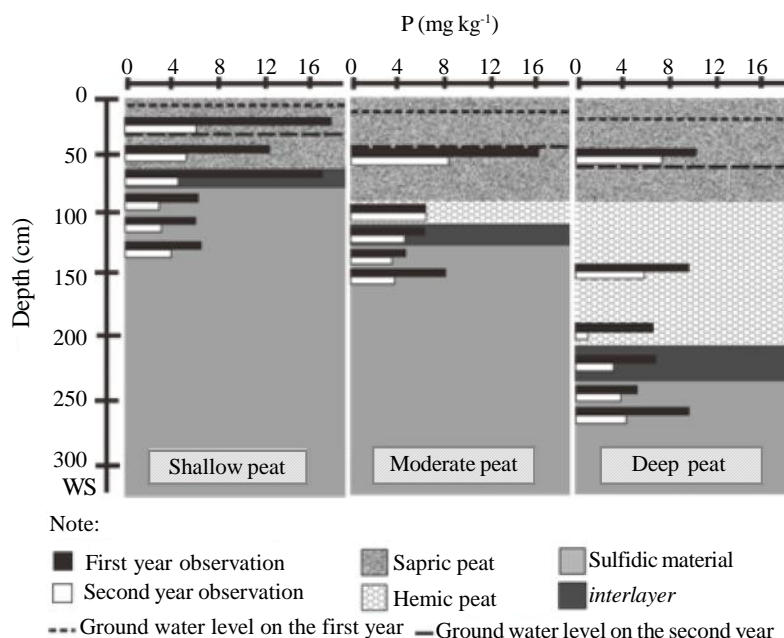


Figure 3. Phosphorus concentration at shallow (SP), moderate (MP) and deep peat (DP) that observed at wet season (WS).

2010 (transition from wet to dry season), September 2010 (peak of dry season) and January of 2011 (peak of wet season), whereas P concentration in SP, MP and DP research site were observed on June of 2009 and 2010 for transition from wet to dry season (T), September of 2009 and 2010 for peak of dry season (DS) and January of 2010 and 2011 for peak of wet season (WS).

The influence of season on P concentration in peatland was approached with comparing data of P which based on groundwater level that measured at observation times. In addition, data logger DCX

22 SG from *Keller* was installed to record daily average of groundwater level around the research site (Figure 4).

RESULTS AND DISCUSSION

Phosphorus in peat layer (average 7.91 mg kg⁻¹) was higher than sulfidic material layer (average 4.84 mg kg⁻¹), with concentration pattern was gradually decreased, and tend to return increased in the lowest layer of peat (Figure 3, 4 and 5). Previously, Stępniewska *et al.* (2006); Sapek (2008);

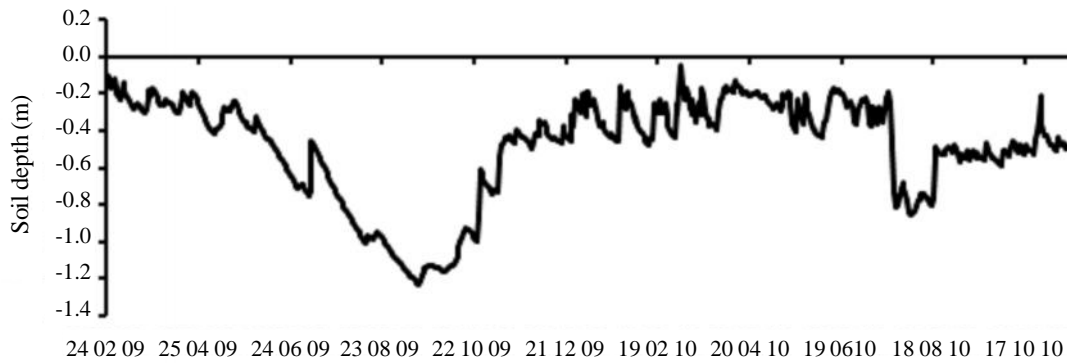


Figure 4. Daily average of groundwater level on research site from February of 2009 to November of 2010.

Wright and Mylavarapu (2010) also reported total P concentration in upper peat layer was higher than lower layer of peatland. This result indicated role of peat layer as the main source of P in peatland with sulphidic material substratum. The presence of P in surface layer was mainly supplied through mineralization process of peat. Koretsky *et al.* (2007) and Geurts *et al.* (2010) also reported that peat mineralization process enhance P concentration in the soil surface of peatland. Three mechanisms that may increase P concentration in the peat soil are organic matter mineralization and transformation of $\text{Fe}^{3+}\text{-P}$ to $\text{Fe}^{2+}\text{-P}$ (Sapek 2008; Kjaergaard *et al.* 2012; Forsmann and Kjaergaard 2014), as well as competition of P with SO_4^{2-} on the surface site sorption (Dierberg *et al.* 2011). According to Yonebayashi *et al.* (1997). Phosphorus tends to accumulated in the upper layer due to the relatively

rapid decomposition processes in forest soil ecosystems. Stone and Plante (2014) concluded that low P concentrations in subsurface of mineral soil are correlated with microbial communities and substrate concentrations.

Generally, solubility of P in wetland soils are affected by groundwater level fluctuation, soil flooding leads to increase P concentration and *vice versa* (Sapek 2008; Fahmi *et al.* 2009; Banach *et al.* 2011; Obour *et al.* 2011). Forsmann and Kjaergaard (2014) concluded that P released from peat soil at anoxic conditions was caused by reductive Fe (III) dissolution. In addition, the influence of groundwater level on P concentration is related to lowering of groundwater level that enhance P concentration through mineralization process of peat (Mezbahuddin *et al.* 2014). Conversely, present study showed that the presence

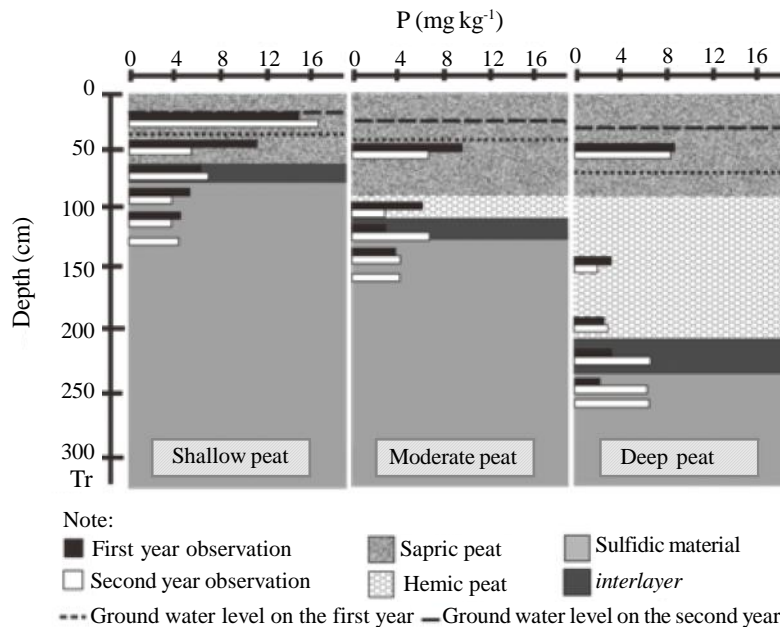


Figure 5. Phosphorus concentration at shallow (SP), moderate (MP) and deep peat (DP) that observed at transition from wet to dry season (T).

of upper peat layer on sulphidic material due to groundwater level fluctuations had no direct effect on P concentrations in the peat layers (Figure 3, 4 and 5). These differences are occurred due to low concentration of Fe in the peat layer in which Fe may be chelated by humic substances. It means there is no P released to the soil solution through Fe^{3+} reduction processes in the peat layer. Previously, Kieckbusch and Schrautzer (2007) also reported that rewetting of phosphorus-rich eutrophic fen soils does not automatically result in an increased of P concentration. According to Jordan *et al.* (2007) that dissolution of P in peat was related to high Fe(III)-oxyhydroxide contents, and Fuss *et al.* (2011) demonstrated that Fe^{3+} reduction is restricted by complex formation of organic compounds with Fe, thereby reducing amount of P that is released to the soil solution when groundwater level is rising. On the other hands, fixation of P by complex of Fe-humic substances may continue both in reduced or oxidized soil conditions (Morris and Hesterberg 2012). This fact was reinforced by Grunth *et al.* (2008) who concluded that dissolution of P due to inundation of the peat soil can not be predicted based on inundation as typically on mineral soil.

Phosphorus concentration in the lowest layer of sulphidic material at several observations time was increased (Figure 3, 4 and 5). This might be related to reduction of Fe^{3+} to Fe^{2+} , and this fact was supported by data of Eh and Fe^{2+} on these observations as reported by Fahmi *et al.* (2009 and 2010). Data of Eh on these observation was in

reduced condition and Fe^{2+} was in large concentration. Niedermeier and Robinson (2007); Banach *et al.* (2011) and Morris (2011) also reported there are an association between P and Fe concentrations in the peat soil. According to Zak *et al.* (2010) concentration magnitude of P that released from the soil depends on the amount of P which sensitive to changes of soil redox condition or ratio between Fe and P in the soil solution.

In addition, increased P concentration in the lowest layer of sulphidic material (Figure 3, 4 and 5) might be caused by leaching process as reported by Gorham and Janssens (2005). According to Waldron *et al.* (2009) there was a significant relationship between the loss of dissolved P and the amount of carbon lost from soils. Banach *et al.* (2009a and b) stated that soil flooding increased nutrients concentration, and they might be leached and transported to the surrounding areas due to moved of groundwater table. Phosphorus is an element that readily leached if it has high concentrations in the soil solution (Sapek *et al.* 2009), and according to Kurnain (2005) and Andersen *et al.* (2010) that peat soils did not have sufficiently and strong absorbtion site for P, therefore P was easily to be leached.

Plant and organism residues are indirectly as a renewal source of peat material and peat layer. Organic materials that continues to be added from the plant and organism residue is the main source of P in the peatland with sulphidic material substratum. The majority of P residue in plant litter

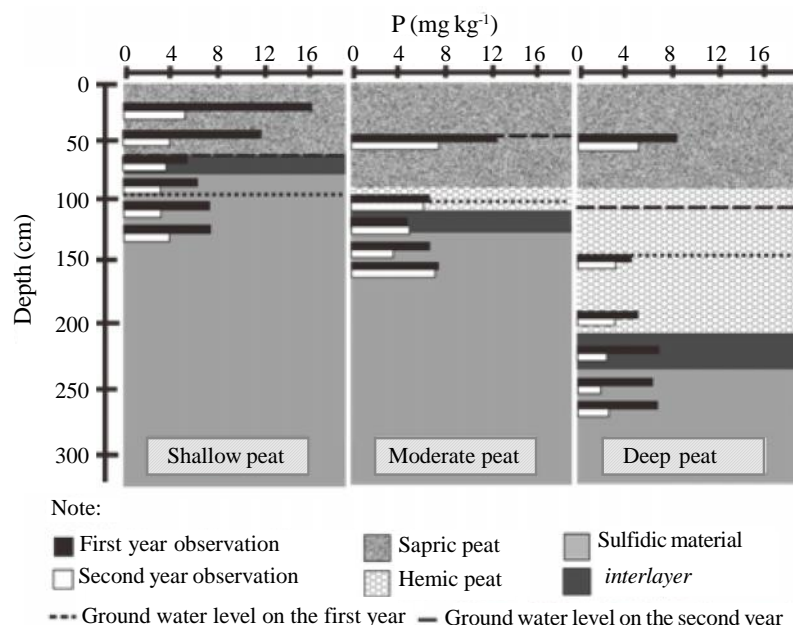


Figure 6. Phosphorus concentration at shallow (SP), moderate (MP) and deep peat (DP) that observed at dry season (DS).

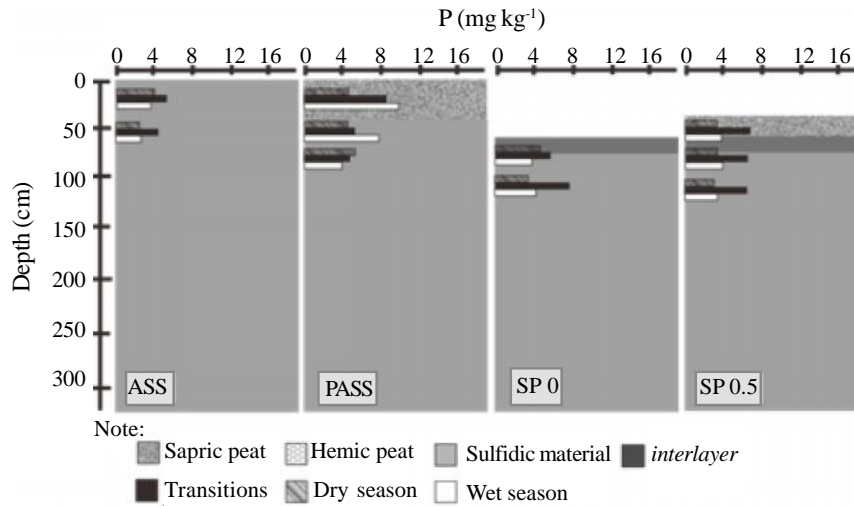


Figure 7. Phosphorus concentration in potential acid sulphate soil (ASS), peaty acid sulphate soil (PASS), shallow peat which all of peat layers were removed (SP 0) and shallow peat which peat layer was partially removed (SP 0,5) that observed on wet season (WS), transition from wet to dry season (T) and dry season (DS).

that lies aboveground has the potential to be delivered to soil in a form readily available to plants and soil microorganisms (Noack *et al.* 2012). Weedon *et al.* (2014) demonstrated the important role of substrate input from organic material on nutrient cycling on the peatland.

Sulphidic material layer below the peat layer also has a positive role on P concentration in the soil through the reaction of P fixation by Fe and reduction of Fe^{3+} -P, so reduce the potential lost of P from peatland and enhance its availability for plants. Wang and Li (2010) concluded high capacities of sediments from estuary and wetland to retain P may play a critical role in buffering some chemical and ecological changes and benefit aquatic eco-environments by preventing P rapid release to the surrounding environment. In peatland, water management or groundwater level fluctuations are a key role in P management. In addition, peat thickness can be maintained by managing groundwater level, furthermore leaching of P and reduction of Fe^{3+} -P is also influenced by the groundwater movement and groundwater level (Sapek *et al.* 2007).

Peat as organic material is continued to be decomposed or mineralized slowly even in anaerob condition. The presence of upper peat layer on sulphidic material increased P concentration, peat as organic material supplies P to soil solution through mineralization process. Organic matter that highly humified or poorly decomposed provides a small but constant source of nutrients which may favour the formation of organic P (Malik *et al.* 2012) and

according to Geurts *et al.* (2010) and Mezbahuddin *et al.* (2014) peat mineralization increases P concentration in soil. Indication of P that was supplied from peat mineralization showed by data of P concentration at three observation times in SP (5.23 – 16.89 mg kg^{-1}) and PASS (4.29 – 9.35 mg kg^{-1}) that were higher than ASS (3.30 – 5.34 mg kg^{-1}) (Figure 6).

Based on peat thickness, P concentrations observed in all observation points were not influenced by peat thickness (Figure 3, 4 and 5). This fact was strong related to peat soil properties, contribution of P from organism residue, rate of decomposition processes and dissolution of P, and redox reaction. This mean the hydrological factor becomes more dominant than peat thickness factor, because the hydrological factor is more dynamic and progressively in the certain environmental condition than peat thickness that seen as more static factor.

Phosphorus concentrations on ASS, PASS, SP 0.5 and SP 0 that observed at transition time tended to higher than others (Figure 6). This fact might related to soil pH on these observation time that was higher than others (data not shown). According to Kirk (2004) increasing concentration of P was due to increasing pH of soil with variable charge mineral.

Depletion or disappearance of peat layer due to excavation decreased P concentration in soil solution. Phosphorus concentration observed on three observation times ranged from 3.30 – 5.33 mg kg^{-1} in SP 0,5 and 2.97 – 5.37 mg kg^{-1} in SP 0

(Figure 6). These data were lower compared to P concentration at shallow peat (5.26 – 16.89 mg kg⁻¹) (Figure 3, 4 and 5). This condition showed that disappearance of peat layer means loss of a natural sources of P for peat soil. According to Bhadha *et al.* (2010) all materials on soil surface that contains P can be a source of P for soil.

Distribution pattern of P in soil that formed is an indication that P dynamic and concentration in peatland is influenced by peat layer. According to Sjoegersten *et al.* (2011) peat soil fertility depended on organic material that supplied from plant and organism residue that alive above it. Peat layer and organic material to be main source of soil nutrients for peatland through decomposition process, in which rate of mineralization or dissolution, distribution and concentration of P were influenced by fluctuation of groundwater level, peat thickness and peatland properties.

CONCLUSIONS

The presence of upper peat layer on sulphidic material due to groundwater level fluctuations had no directly effect on P concentration in the peat layers. Low Fe³⁺ concentration in the peat layer was due to P be chelated by humic substances lead no P released to soil solution from reduction proses of Fe³⁺ that typically occurs on wetland soils. Whereas increased of P concentration in the lowest sulphidic layer might relate to redox reaction of Fe in the sulphidic layer and accumulation process due to leaching process from upper layer.

In general, P concentration in peatland with sulphidic material as substratum was not influenced by peat thickness. This condition might relate to peat soil properties, P contribution from organism residue that alive above it through decomposition processes.

Depletion or disappearance of peat layer due to excavation might decrease P concentration in soil solution, disappearance of peat layer mean loss of a natural sources of P for peatland with sulphidic material substratum. Therefore peat layer must be kept in order to maintain peat soil fertility.

ACKNOWLEDGEMENTS

This Study was funded as part of the Tropical Peat Biochemical Interaction with Acid Sulphate Soils (TROPEASS) Project. The authors would like to thank to Dr. Eko Hanudin (Gadjah Mada University), Prof. Harri Vasander and Dr. Jyrki Jauhainen (University of Helsinki, Finland), Dr. Suwido Limin and Mr. Kitso Kusin (CIMTROP) for their assistance.

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