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ENZYME ACTIVITIES IN RELATION TO TOTAL NUTRIENTS OF K, Ca, Mg, Fe, Cu, AND Zn IN OIL PALM RHIZOSPHERE OF TROPICAL PEATLAND IN RIAU, INDONESIA

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ABSTRACT

Enzyme activity could be used as a peat decomposition indicator in oil palm rhizosphere of peatland. Oil palm plantation management requires fertilization into the rhizosphere as nutrient for oil palm growth. The state of total nutrient in rhizosphere can influence enzyme activities. This research was aimed to study the enzyme activities in relationship to nutrient of oil palm rhizospheres in peat. The research was conducted by using the explorative method in tropical peatland of Riau. The research sites chosen were in oil palm plantation as the main site, and a degraded forest and a shrub land, for comparison. In the oil palm plantation, peat samples were taken from the adhered peats on oil palm roots at the peat depths of 0−25 and 25−50 cm and the distances of 0−1, 1−2, 2−3, and 3−4 m from the tree. In the degraded forest and shrub, those samples were taken from selected plant roots at the depth of 0-25 and 25-50 cm. The triplicate peat samples were composited for analysis of enzyme activities and the content of total nutrients. The results showed that enzyme (urease, phosphatase, β-glucosidase, and laccase) activities in oil palm rhizosphere decreased with increasing distance from the tree and the depth of rhizosphere. The decrease of enzyme activities were caused by the low of peat pH and the increase of water content and organic carbon content. Enzyme activities increased with increasing oil palm age and ash content. The content of total nutrients K and Zn showed no correlation with enzyme activities. However, total nutrient of Ca and Mg showed positively correlation only with β-glucosidase activity. The total Fe and Cu contents showed significantly negatively correlation with enzyme activities (urease, phosphatase, β-glucosidase, and laccase). Enzyme activities in the rhizosphere of degraded forest and shrubs was mostly lower than in oil palm rhizosphere.

Keywords: rhizosphere, total nutrients, enzyme activities, oil palm, peatland.

INTRODUCTION

The clearance of peatlands for oil palm plantations has reached 1.7 million ha of the total peatland area of 14.9 million ha in Indonesia (Tropenbos International Indonesia 2012 & Ritung *et al.* 2011). The change in peat land use due to oil palm cultivation has become a spotlight because it is considered as a source of CO_2 emissions due to land drainage and hence accelerated peat decomposition and during the long dry periode, peat fire. The relationship of accelerated of peat land decomposition due to land drainage and the development of oil palm cultivation is still debatable.

The influence of oil palm cultivation can be traced by studying enzyme activities in the root or rhizosphere. Fertilizer application for supporting oil palm growth could be influenced by peat properties like pH. The change of pH can influence some biochemical reaction like enzyme activity in peatland. Rhizosphere is one of environment that influenced by interaction between plant roots and peat matter. All enzyme activities in the rhizosphere resulting changes on the properties and processes in the soil that

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determine nutrient *availability* which is determined by enzyme release by roots and microorganisms (Gianfreda 2015). Enzyme activities are highly responsive to environmental changes due to changes in CO_2 concentration in atmosphere and the rainfall pattern which in turn impacts to ecosystem functions, such as decomposition, nutrient cycle, and plant-microbial interactions (Burns *et al.* 2013).

Several enzymes, such as urease, phosphatase, ß-glucosidase, and laccase can be used as indicators of organic matter decomposition processes in peatlands. The enzyme that is often used as an indicator of organic carbon mineralization in soil is β-glucosidase activity (Stott *et al.* 2010). Common enzymes which hydrolyse the molecules, such as hydrolase activity (urease, phosphatase) and phenol oxidase (involved in the synthesis of secondary compounds, decomposition, and humification), need to be given great attention because these enzyme activities are essential in nutrient release (Nannipieri *et al.* 2012). It is known that the soil K, Ca, Mg, Fe, Cu, Zn are the nutrients involved as enzyme cofactors that those were applied by fertilizer mostly. Enzymes require metal ions as catalysts in biochemical reactions. The requirement of transition metal ions for biochemical functions is essential as evidenced by the fact that metalloproteins represent about one third of all structurally characterized proteins with a biological activity (Finney & O'Halloran 2003). The aim of this study was to assess the enzyme activity in relation to the total nutrients in the oil palm rizosphere of peatlands in Riau Province, Indonesia.

MATERIALS AND METHODS

The research was conducted on peatland in Oil Palm Plantation in Pangkalan Pisang Village, Koto Gasib, Siak District, Riau Province Indonesia (0.74 - 0.77 N and 101.77 - 101.74 E). This peatland has a groundwater table in the range of 40 cm in the rainy season and 80 cm in the dry season.

The peat material analysis was carried out at the Laboratory of Soil Chemistry and Fertility, Department of Soil Science of Land Resources, Bogor Agricultural University (IPB), Bogor. The research was an explorative study in the form of observation activity (observational exploratory research). Sites were selected based on the peat thicknesses of <3 and >3 m and oil palm age of < 6, 6-15, and >15 years. The observations were done on six transects in oil palm plantation and one transect in the respective degraded forest and shrub, in which each transects perpendicular to the drainage channel (collection drainage system).

The rhizosphere observation and peat sampling were done by dismantling the root zone of the selected oil palm tree on the frond windrow, space between two rows of plants. Samples were taken two times in wetter month (January-February 2015) and dryer month (July-August 2015). Peat samples was composited from the adhered peat at root surface. Peat samples was digged at the peat layers of 0-25 and 25-50 cm depth, at the distances of 0-1, 1-2, 2-3, 3-4 m from the tree within a quarter circle area (¼ circle of canopy). The application of macro and micro nutrient fertilizers (K, Ca, Mg, Fe, Cu, Zn) and mineral-soil dressing in the oil palm circle at distance 1-2 m about 30 cm wides became the benchmark changes that occurred in the rhizosphere of oil palm on peatlands (Figure 1 and Table 1). Fertilizer application was done in every 4 month and mineral-soil dressing that containing 6.1% Fe or 610 mg/kg (Hartatik 2012) as an ameliorant was given one time (±100 kg/tree) in the periode between rainy season and dry season. As a comparison, samples also was collected from root zones of the degraded forest and shrub vegetation. The samples was taken at the distance 50 and 100 m from the collection drain (drainage canal) in the depth 0-25 and 25-50 cm from peat surface. The adhered samples was collected from the selected plant roots.

Determination of peat water content was done by volumetric water content, for which the water content was corrected by bulk density of peat in each peat depth (Table 2). The ash content was done by ashing method using furnace at temperature 550°C. The pH (1:2) measurement of peat material (10 g of peat material: 20 ml of ion free water) was performed by using a pH meter (pH 2700 Autech Instrument). The determination of total macro nutrients (K, Ca, Mg) and micro nutrients (Fe, Cu, Zn) was performed by the wet destruction (extracting 60% $HClO_4$ and HNO_3) method, and the extracts were measured by Atomic Absorption Spectrophotometer (AAS) Shimadzu AA-6300

Table 1. The total content of K, Ca, Mg, Fe, Cu and Zn (kg/tree) that applied by oil palm plantation management[a].

Oil palm age (years)			Oil palm age (years)		
<6	6-15	>15	<6	6-15	>15
2 (K) ; 0.8 (Ca) and 0.2 (Mg)	-	-	-	-	-
nd[b]	11(K); 2(Ca) and 0.7(Mg)	-	nd	0.04(Fe);0.04(Cu) and 0.04 (Zn)	-
nd	nd	10(K); 3(Ca) dan 1 (Mg)	nd	nd	0.04(Fe);0.04(Cu) and 0.04 (Zn)

Note:
[a]The total nutrients (K, Ca, Mg, Fe, Cu and Zn) were given by using fertilizers (compound fertilizers, Kieserit, NK, Dolomite, Calcite, MgSO,$FeSO_4$, $CuSO_4$, $ZnSO_4$) for oil palm having the age of <6, 6-15, >15 years; the fertilizers were used at reasonable rates as plantation recommendation, and applied by the plantation management during the period of 2002-2015 (K, Ca, Mg) and 2011-2012 (Fe, Cu, Zn). [b]nd = no data; the fertilizers were also given by plantation management at reasonable rate during the period before 2002. However, the information of fertilizer application was not documented.

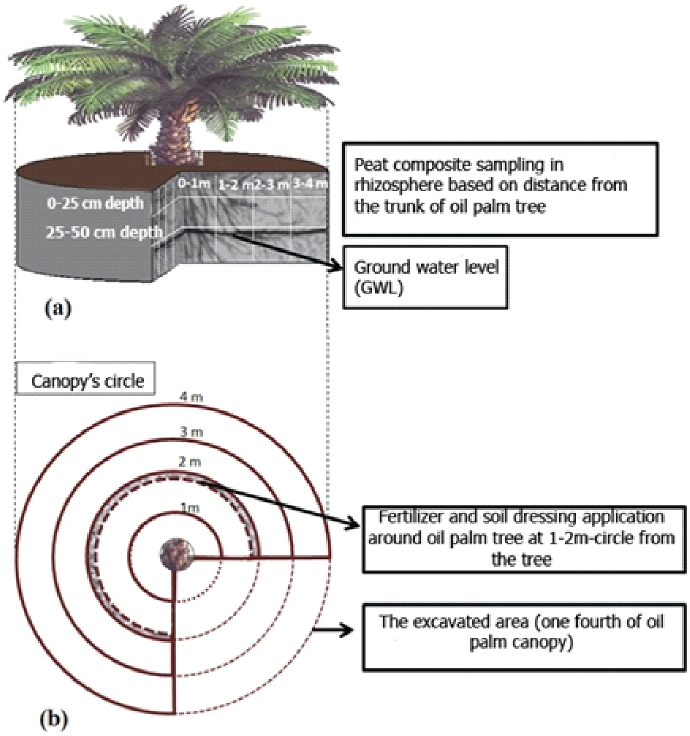

Figure 1. Peat composite sampling in rhizosphere based on distance from the trunk of oil palm (a); fertilizer and mineral-soil dressing applications around of oil palm tree (b).

Table 2. Bulk density (g/cm^3) of peat in oil palm rhizosphere based on peat thicknesses <3 and >3m, peat depth and plant age, and in the rhizosphere of degraded peat forest and peat shrub.

Peat depth (cm)	Peat Thickness <3 m Oil palm age (years)			Peat Thickness >3 m Oil palm age (years)			Degraded Forest	Shrub
	<6	6-15	>15	<6	6-15	>15		
0-25	0.1	0.26	0.11	0.09	0.11	0.1	0.17	0.17
25-50	0.09	0.09	0.1	0.09	0.09	0.09	0.11	0.16

for Ca, Mg, Fe, Cu, and Zn, whereas K was measured by Flamephotometer Corning Flower 405r (Indonesian Soil Research Institute 2005).

The measured enzyme-activities included urease, phosphatase, β-glucosidase, and laccase activities. The determination of the urease activity was performed by the measure of ammonium releasing by the non-buffered method, while the determination of phosphatase activity was conducted to measure the release of phosphorous (P) from organic (P) by the p-nitrophenyl buffer method. Determination of β-glucosidase activity to measure the breakdown of cellulose into glucose was done by using a β-glucosido-saligenin (salicin) method developed by Schinner *et al.* (1996). The determination of laccase activity to measure lignin degradation activity was done by the 2.2-azinobis 3-ethyl-benzothiazoline-6-sulphonate (ABTS) method (Eichlerová *et al.* 2012). All data was analysed by MS Excel for descriptif analysis.

RESULTS AND DISCUSSION

pH Level and Water Content

The pH level and water content affect biochemical reactions in the rhizosphere of peatlands. The water content of the peat around the rhizosphere of oil palm ranged from 10-120% (v/v) (Figure 2). The water content of peat increased with increasing root depth and distances from the tree, regardless of oil palm age (< 6, 6-15, and >15 years) on the peat thicknesses (<3 and >3m) (Figure 2). This presumably occured because the loss of water in the deeper of the root zone was low due to the shallow water table while the water absorption in the root zone near the tree was rapid. The increase of water content was indicated by solubilization of organic acids in peatland that it would be impact on peat pH. It can be seen from Table 3 that the pH was significant negatively correlated with water content. According to Neumann *et al.* (2000), the plant roots secrete a number of organic acids such as citric acid to acidify the rhizosphere in mature plants.

The low of pH in higher water content decreased activities of enzyme. As can be seen in Figure 2, that peat pH was in the range of 3.0−4.0 in the rhizosphere and it was positively correlated with enzyme activities particularly phosphatase, β-glucosidase, and laccase (Table 3). The same result was observed by Blonska (2010) that enzyme activity increased with increasing the pH level in peatlands. The pH value decreased with increasing distance from oil palm tree, both in the peat layer of 0−25 and 25−50 cm. This indicates that the low of pH as a consequence increasing of water content in the deeper root zone.

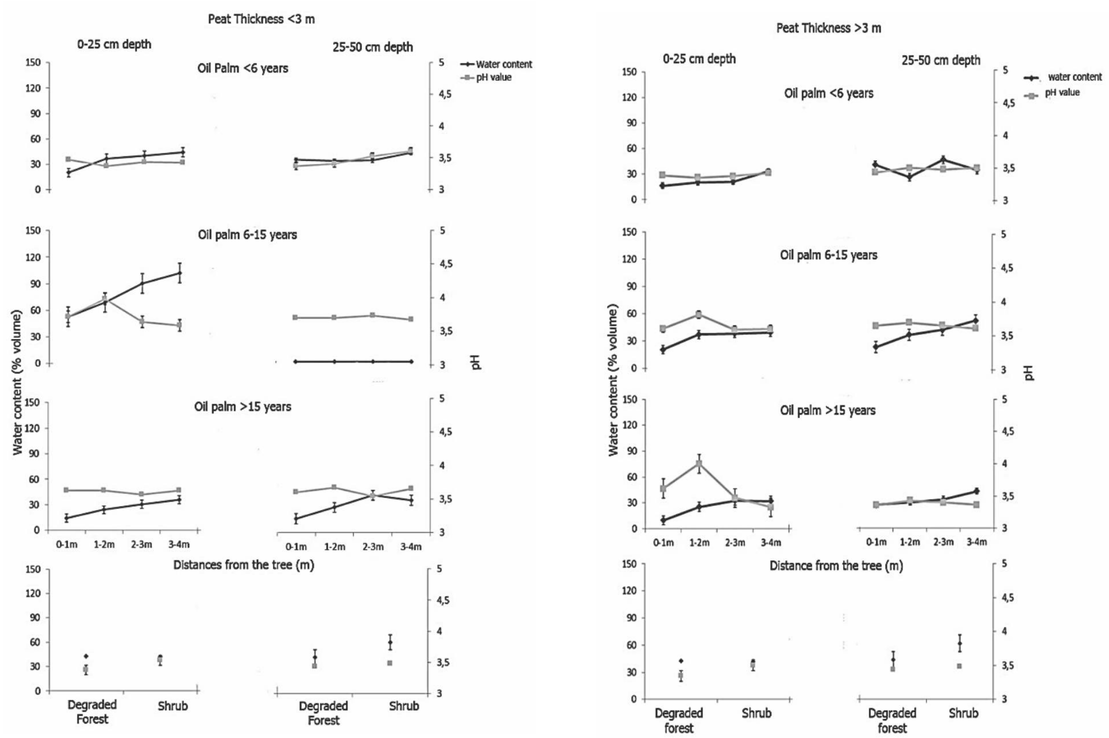

Figure 2. Volumetric water content and pH of oil palm rhizospheres in peat thicknesses <3 m and >3m by peat depth, the distances from the tree and plant age, and in the rhizosphere of degraded peat forest and peat shrub.

Table 3. Pearson's correlation coefficient test between the rhizospheres enzyme activities, water content,pH, ash content, organic C, and total nutrients in Riau's peatland.

	Urease	Phosphatase	β-glucosidase	Laccase	Water content	pH	Ash content	Organic Carbon	K	Ca	Mg	Fe	Cu	Zn
Urease	1	0.231	**0.243***	**0.361****	-0.222	-0.200	0.213	-0.198	0.005	0.019	-0.084	**-0.242***	**-0.276***	-0.156
Phosphatase		1	**0.532****	**0.469****	**-0.619****	**0.318****	**0.584****	**-0.483****	-0.127	0.108	-0.012	**-0.487****	**-0.588****	-0.053
β-glucosidase			1	**0.815****	**-0.731****	**0.294***	**0.342****	**-0.307****	0.167	**0.397****	**0.286***	**-0.394****	**-0.540****	-0.231
Laccase				1	**-0.804****	**0.261***	**0.528****	**-0.452****	0.012	0.193	0.077	**-0.467****	**-0.618****	-0.121
Water content					1	**-0.387****	**-0.632****	**0.558****	0.020	**-0.263***	-0.150	**0.537****	**0.798****	0.125
pH						1	**.233***	-0.228	**-0.268***	**0.311****	0.042	**-0.254***	**-0.433****	-0.116
Ash content							1	**-0.723****	-0.076	-0.061	-0.164	**-0.294***	**-0.515****	**0.368****
Organic Carbon								1	-0.046	-0.037	0.106	**0.335****	**0.601****	-0.187
K									1	**0.556****	0.162	0.105	**0.537****	**0.337****
Ca										1	**0.734****	-0.059	-0.201	-0.196
Mg											1	0.052	0.005	-0.196
Fe												1	**0.678****	**0.489****
Cu													1	0.226
Zn														1

*.Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Rhizosphere of degraded forest and shrub vegetation have lower water content (41-42% v/v) in the peat layer of 0□ 25 cm than that in the peat layer of 25-50 cm (43-61% v/v). The peat layer of 25-50 cm have a higher ability in retaining water. It has higher moisture due to the lower evaporation as well as the presence of capillary action that came from the peat water table. The pH level in the degraded forest and shrub vegetation tended to be the same ranging from 3 to 3.5. However, it lower than the pH in the oil palm rhizosphere. This occurred because there was addition of fertilizer in oil palm rhizosphere can be seen in Figure 2, that the pH of peat tended increasing at the distance 1-2m from the tree.

Organic carbon and ash contents

Organic carbon contents in the oil palm rhizosphere in peat thicknesses of <3 and >3 m was not difference with organic carbon contents in the degraded forest and shrub (50-60%) (Figure 3). This indicated that organic carbon contents in peat after it was open into the plantation not changed much. The ash content in the oil palm rhizospheres in peat thickness of <3m was not difference with that in peat thickness >3m. There was an increase of ash content with increasing plant age in peat thickness <3 m, and this might be due to high nutrient was absorbed by plant with increasing age and fertilizer applications continuously.

The organic carbon was significant negatively correlated with enzyme activities (Table 3). The higher organic carbon was support the deceleration of decomposition processes in peatland, and resulting lower emmision of carbon. It was associates with the increase of C/N content of peat that it could reduced enzyme activities. Almeida *et al.* (2015) stated that the higher organic carbon content and the lower N content in organic matter were caused by lower

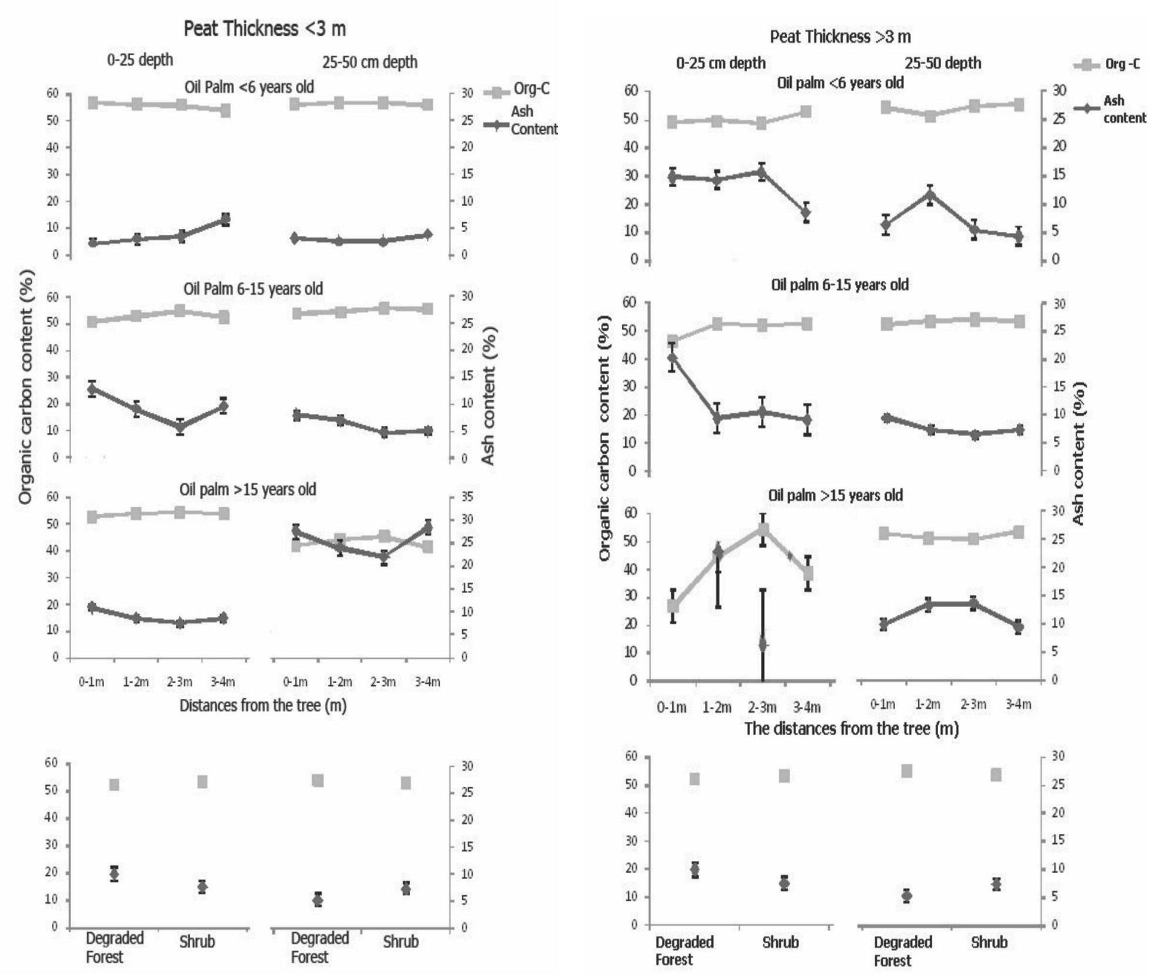

Figure 3. The content of organic carbon and ash of oil palm rhizospheres by peat thicknesses (<3 m and >3m) by peat soil depth, by the distances from the tree and by plant age, as well as in the rhizosphere of degraded forest and shrubs.

enzyme activities, it resulted the lower decomposition processes.

Ash content in the rhizosphere of oil palm >15 years was higher than that of oil palm <6 and 6-15 years. The increase of ash content might be caused by the increase of the plant age. The other way, ash content was decreased by increasing the distance from the tree. This might occured because there was fertilizer application and the higher root density in the distance near of the tree, so that those caused higher organic matter decomposition and increasing of ash content. The increasing of ash content was increase enzyme activities. The ash content showed significant positive correlation with enzyme activities. This indicates that enzyme activity was increase peat decomposition which it has higher ash content. Based on Boguta and Sokolowska (2014) the higher ash content had showed higher mineralization processes in peatland.

Total K, Ca, Mg contents

The total nutrient content of K (30-150 mg/kg) and Mg (76-350 mg/kg) in the rhizosphere of oil palm plantation for the peat with thicknesses of <3 m and >3 m was not different from that in the rhizosphere of degraded forest and shrubs vegetation. The nutrients in the rhizosphere of oil palm plantation tended to decrease with the distance from the oil palm trees. In contrast, the content of total Ca 100-3000 mg/kg in oil palm rhizosphere was higher than that in the rhizosphere of degraded forest and shrubs vegetation. The content of K and Mg were lower than the Ca content. The contents of K and Mg in the peat layer of 0-25 cm were not different from the peat layer of 25-50 cm. Total Ca content decreased with the increasing distance from the oil palm tree, particularly in oil palm ages of <6 and >15 years (Figure 4).

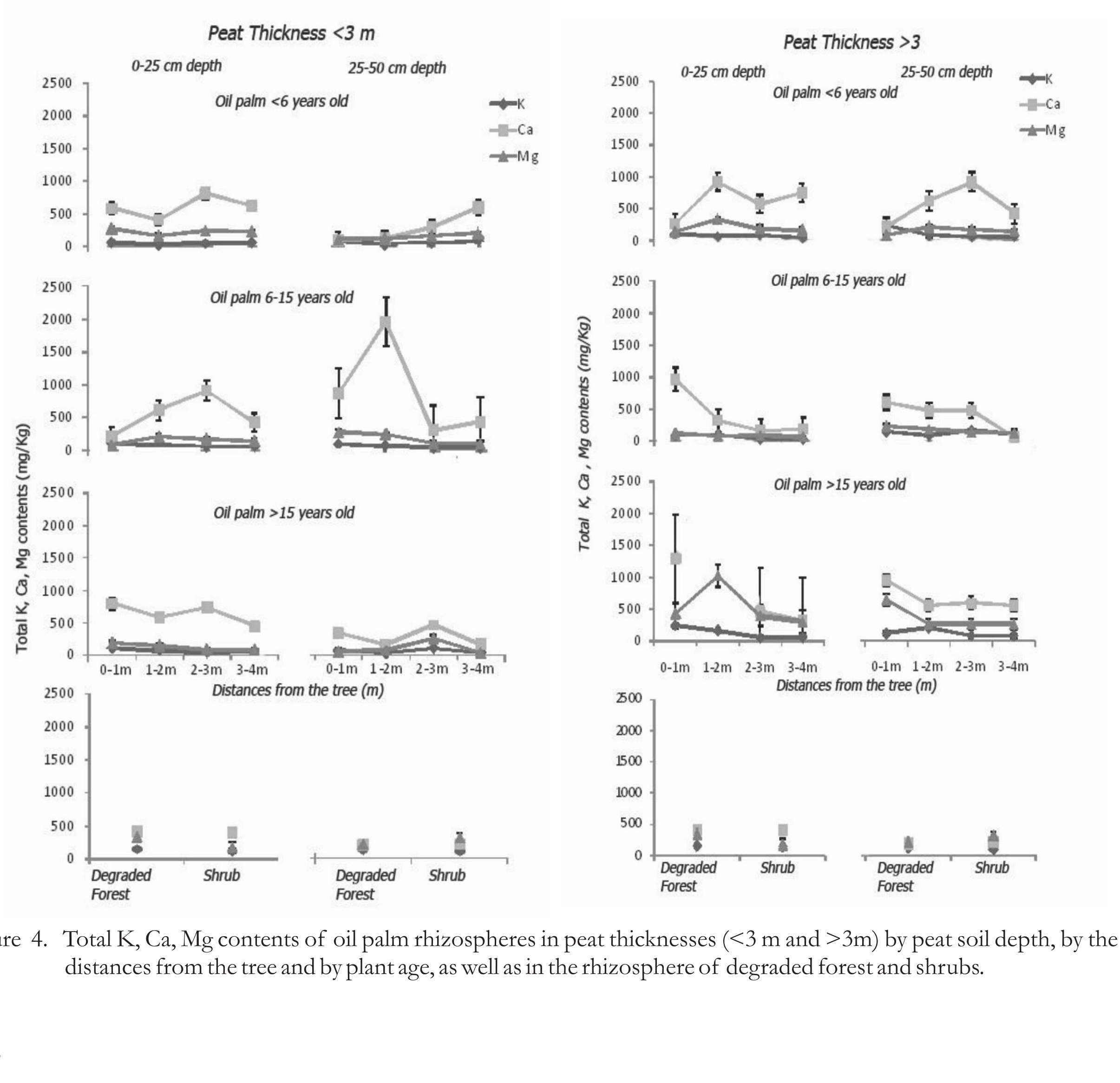

Figure 4. Total K, Ca, Mg contents of oil palm rhizospheres in peat thicknesses (<3 m and >3m) by peat soil depth, by the distances from the tree and by plant age, as well as in the rhizosphere of degraded forest and shrubs.

However, the different result obtained in oil palm ages <6 years in the layer of 25-50 cm in which there was an increase in Ca content at a distance of 3−4 m from the tree. It was caused by the limited extent of roots in this age which there was concentration of root extent in the 0-1 and 1-2m from the tree. So that, the absorbtion of Ca was minimized. In contrast to oil palm of 6-15 years, it was show an increase of Ca content at a distance of 1−2 and 2−3 m from the tree. This occurred due to the application of fertilizer continually at the distance of 1−2 m from the tree (Table 1 and Figure 1). Total Ca and Mg contents in peatlands were positively correlated with β-glucosidase, whereas total K content did not show any correlation with enzyme activities (Table 3). The treatment of Ca and Mg through dolomite-liming applications to oil palm plantation *have* potential to increase peat pH which is resulting the increase of enzyme activities. Szajdak *et al.* (2007) stated that the treatment of active mineral materials could accelerate the decomposition of the organic materials.

Total Fe, Cu, Zn contents

The total Fe content in the oil palm rizosphere in peat thickness of <3m was ranging 300-700 mg/kg, whereas the total Fe in peat thickness of >3 m level was ranging 350-2200 mg/kg (Figure 5). Total Fe content in oil palm rhizosphere was higher than total Fe in rhizosphere of forest and shrub vegetation (100-350 mg/kg). The high level of total Fe allegedly came from the addition of mineral-soil dressings containing high Fe. High content of Fe might suppress enzyme activities as can be seen in Table 3 that the total Fe content was negatively correlated with enzyme activities (urease, phosphatase, β-glucosidase, and laccase). The increase of total Fe was caused by the addition of Fe from mineral-soil dressing. Cation of Fe is the most reactive metals with organic acids to form the stable metal-organo complex (Hartatik 2012).

The Cu content was ranging 9-52 mg/kg in the peat depth 0-25 and 25-50 cm on the peat thicknesses of <3 m and >3 m and it was very low due to the increase of plant age. Thus, it was

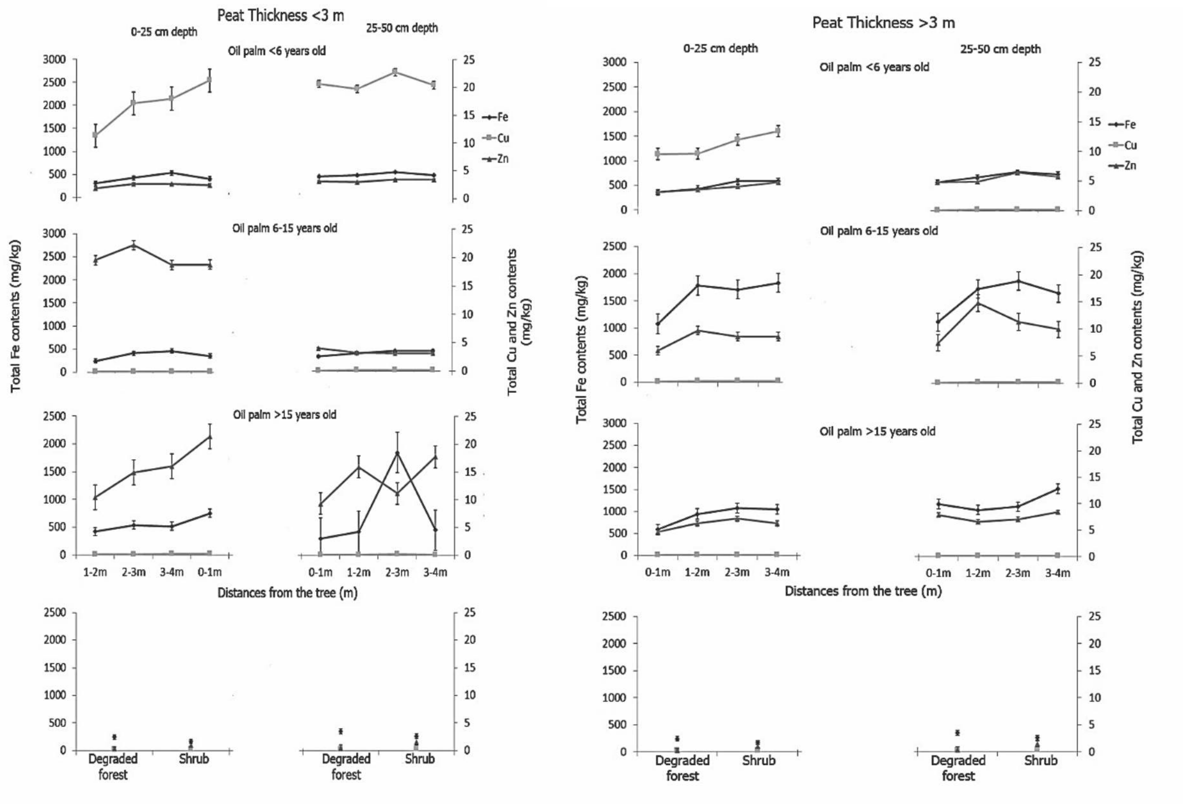

Figure 5. Total Fe, Cu, Zn contents of oil palm rhizospheres in peat thicknesses (<3 m and >3m) by peat soil depth, by the distances from the tree and by plant age, as well as in the rhizosphere of degraded forest and shrubs.

increased Cu absorbtions by oil palm roots. The Zn contents (1.5-22 mg/kg) was lower than Fe and Cu in oil palm rhizosphere. There were an increase of total Fe, Cu and Zn in 1-2m distance from the oil palm tree (Figure 5). The contents of Fe, Cu, and Zn in degraded forest peat and shrubs rhizosphere were lower than those in oil palm rhizosphere. The total of Fe, Cu, Zn content in oil palm rhizosphere was caused by the addition of Fe, Cu, and Zn from micro-nutrient fertilizers (Table 1) and mineral-soil dressing in distance 1-2m from the tree (Figure 1). Cation of Fe, Cu and Zn are reactive metal to form metal organo-complex with organic acids which is hard to decompose (Tan 1993). Therefore, a high Fe content may suppress enzyme activities in decomposition processes, although Fe is one of the enzyme activators.

According to Ruggiero *et al.* (1996) in Stotzky and Bollag (1996) that Cu and Fe have a function as catalytic centers of oxidoreductase enzymes (such as laccase, phenoloxidase, dehydrogenase) involved in redox reactions due to oxygen and hydrogen peroxide as an electron acceptor. Meanwhile, Zn content showed a significantly negative correlation to enzyme activities (urease, phosphatase, β-glucosidase, and laccase) because Zn is not a metal activator for such enzymes. However, Singh and Tabatabai (1978) stated that Zn significantly affects rhodanase activity.

Enzyme Activities

Enzyme activities is related to microbial activities of decomposing organic matter. The enzyme activities in peat thicknesses of <3 m and >3 m did not show any difference (Figure 6). However, the increase of the plant age could increase enzyme activities as well. In contrast, the farther distance from the tree, enzyme activities tended to decrease, particularly in the distance 1-2m from the tree. As known, fertilizer application was done in 1-2m from the tree continuously (Figure 1), which that indicated the increase of nutrient (Figure 4 and 5) which it was not increasing the enzyme activities and

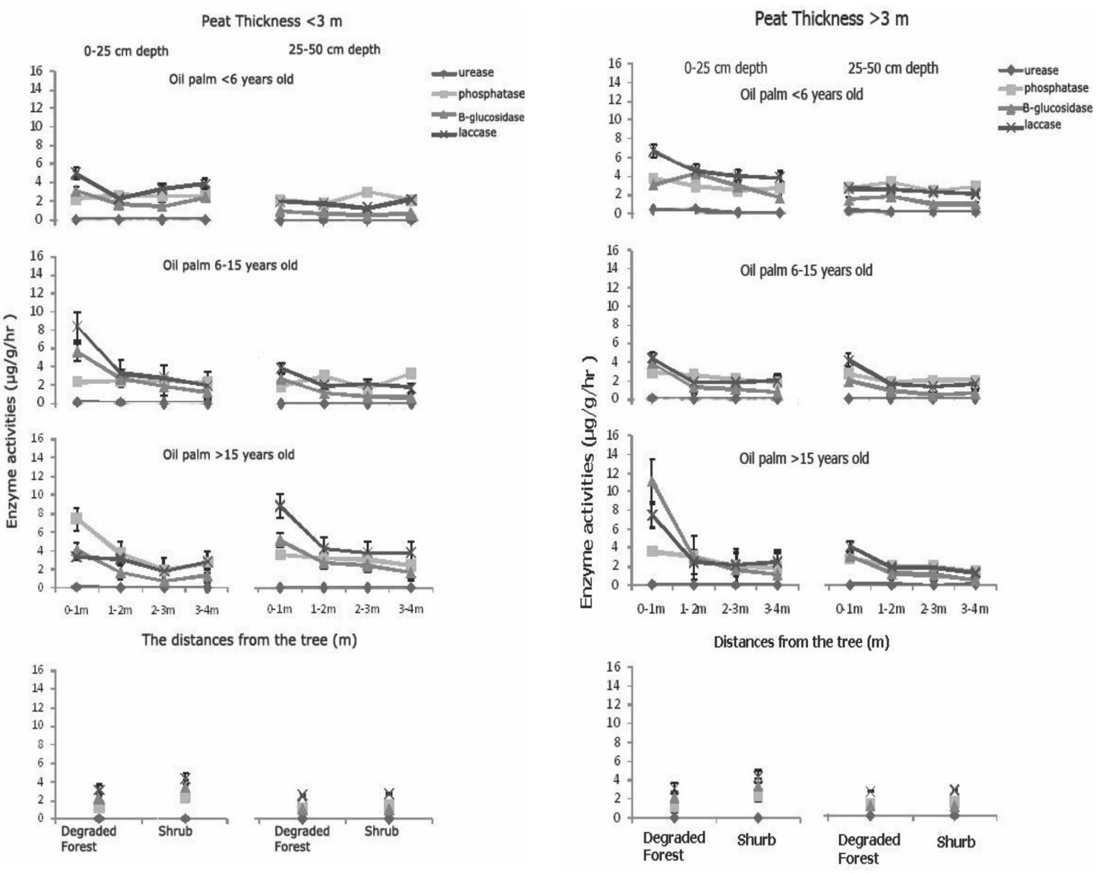

Figure 6. Enzyme activities of oil palm rhizospheres in peat thicknesses (<3 m and >3m), by peat soil depth, by the distances from the tree and by plant age, as well as in the rhizosphere of degraded forest and shrubs.

decomposition prosesses. In the peat layer of 0-25 cm, enzyme activities were higher than those in the peat layer of 25-50 cm, because the top layer of the peat is more oxidized so that it triggers the increase of microbial activities in producing the enzymes. The enzyme activities in the rhizosphere of the degraded forest and shrub vegetation were lower than that of enzyme activities in oil palm rhizosphere. Laccase and β-glucosidase activities were higher than that of urease and phosphatase which indicates that peat decomposition from lignocellulolytic still occurs eventhough land is not utilized.

Urease activity in oil palm rhizosphere was very low (0.01- 0.5 µg/g/hr) compared to phosphatase, β-glucosidase, and laccase in peat thicknesses of both < 3 m and > 3 m at the different ages of oil palm in the different peat layers (Figure 6). The measured phosphatase activity ranged from 2-6 µg/g/hr. It showed that oil palm requires a high phosphate as shown in peat thickness of <3 m in which phosphatase activity was lower than that in peat thickness of >3 m and tended to increase as the age of oil palm. On the other hand, it tended to decrease with the farther distance from the tree. Oil palm can withstand to grow at a low P condition by secreting phosphohydrolase (phosphatase) from its roots into rhizosphere. The phosphohydrolase can convert organic phosphate into soluble inorganic phosphate such as acid phosphatase as a response to P deficiency (Lefebvre *et al.* 1990; Duff *et al.* 1994).

Urease and phosphatase activities were significantly positively correlated with β-glucosidase and laccase activities. However, urease and phosphatase activities were significant negatively correlated with total Fe and Cu contents. In addition, phosphatase activity was significantly positively correlated with peat pH and ash content. Otherwise, it was significantly negatively correlated with water content and organic carbon (Table 3). These enzyme activities indicated that peat decomposition can be suppressed by increasing water content and organic carbon. According to Parham and Deng (2000) the increasing of water content, the low of pH, fertilizer and pesticide applications, heavy metal and industrial waste as a part of soil and plant management hampered enzyme activities.

The high content of Ca and Fe derived from fertilizer application and peat decomposition. Fertilizer application indirectly influenced peat characteristic, particularly peat soil pH. However, application of fertilizer (K, Ca, Mg Fe, Cu and Zn) was not able to increase peat pH because there were higher water content and organic carbon. In the case of maintaining peat stability in oil palm rhizosphere, it can be done by maintaining soil water with a high water content of peat. According to Zhang *et al.* (2011), soil water is a factor that determines the biochemical processes in C-transformations catalyzed by β-glucosidase.

The presence of β-glucosidase and laccase activities indicated that decomposition of peat derived from cellulose-hemicellulose and lignin has occured. The laccase activity was higher than the β-glucosidase activity in the peat layers of 0-25cm and 25-50 cm depth, which indicated that peat decomposition of lignin was greater than that of cellulose and hemicellulose. β-glucosidase and laccase activities in the oil palm rhizosphere tended to decrease with the farther distance from the tree. β-glucosidase and laccase activities at 0-1 m distance from the tree were higher due to a high root activity and low peat water level causing a more oxidative peat environment, thus triggering an increase in microbial activity in the rhizosphere. The decrease of enzyme activities at a distance of 3-4 m and in the peat layer of 25 -50 cm depth was caused by the increase of peat water level and low pH. Otherwise, pH value of peat was ranging 3-4, this indicated that environment condition in peat was not support the increasing enzyme activities for organic matter decomposition. In addition, the higher content of organic carbon was suppress enzyme activities. This fact related to optimum pH for enzyme activity. β-glucosidase activity was optimum in pH 5.5 and urease was optimum in pH 6-7 (Parham & Deng 2000).

The treatment of lime and fertilizers containing Ca and Mg in oil palm plantation can trigger an increase in enzyme activities. In contrast, the treatment of materials containing Fe and Cu in large quantities such as the addition of mineral-soil dressings can suppress the enzyme activities, although the availability of Fe and Cu serves as an enzyme activator. Enzyme activities in the rhizosphere of degraded forest and shrub vegetation did not show any difference from enzyme activities in oil palm rhizosphere particularly for urease and phosphatase activities. Laccase and β-glucosidase activities in the degraded forest and shrub vegetation were higher than urease and phosphatase activities. This shows that peat decomposition can still occur, eventhough peatlands are not used.

CONCLUSIONS

Enzyme activities as an indicator of peat decomposition processes tended to decrease with increasing distance from the tree and root depth. Enzyme activities in rhizosphere of oil palm plantation increased with the increasing oil palm age and ash content in peat. The total K content did not show any correlation with enzyme activities, however the total Ca and Mg contents are positively correlated with β-glucosidase activity. Total Fe and Cu contents of peat are negatively correlated with enzyme activities, while Zn contents was not correlated with enzyme activities. The enzyme activities in the rhizosphere of degraded forests and shrubs are generally lower than in oil palm rhizosphere. Fertilizer application and mineral-soil dressing had increased the content of nutrient in peat, but those were decreasing enzyme activities. Particularly, the decreasing of enzyme activities was influenced by the low of peat pH and the content of Fe and Cu. The decreasing of enzyme activities interpreted the low of decomposition processes in peat.

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