Peatland characterization and laccase activity on smallholder oil palm plantation in Padang Pariaman and West Pasaman, West Sumatra

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Abstract. The purpose of this research was studying peat characteristics and laccase activity as a bioindicator for decomposition processes. Studied peatlands were managed by private land farmers or smallholders with minimum tillage. Peatland characteristics in topsoil Ketaping Padang Pariaman and Pasaman had pH value of more than 4, ash content was higher than 10-60%, a low water content (150<WC≤500% w/w), total Fe and Cu content >5%. Peat water level fluctuated, but not exceeding 80 cm in both locations. Peatlands in Ketaping Padang Pariaman possessed high laccase activity, ranging from 1.8-562 πmol/g, while in Pasaman was about 200 πmol/g. Laccase activity was decreased with distance from channel due to an increase of water content. Peatlands in both locations had a high enzyme activity, mainly in topsoil. It indicated that peatlands have undergone decomposition processes.

1. Introduction

Land use change over peatlands into agricultural land, particularly for oil palm plantations, is performed by constructing drainage canals. They remove excess water from peatlands to allow a better root development. Disproportionate drainage accelerates peatland degradation that triggers decomposition of organic matters. Peatlands are vulnerable as their main material is easily decomposed. Wosten et al. [1] explained that water loss causes maturation of peat materials, resulting in material shrinkage and air inclusion into peat layer (more aerobic). Decomposition and subsidence rate of peatlands are influenced by water maintenance (drainage depth) [2]. Low groundwater table increases subsidence rate on peatlands [3].

Peatland carrying capacity is determined by stability of organic substances related to material constituent. Tropical peatland in Indonesia is generally derived from woody peat material [3]. Sabiham and Ismangan [4] discovered chemical composition of Sumatera and Kalimantan peatlands, which contained high lignin compound around 57.38-73.67%, as well as protein, cellulose, hemicellulose, and other compounds with <10%. Harianti [5] found lignin levels in oil palm rhizosphere, forest vegetation, and shrub rhizosphere around 3.14-17.4%. This result was almost identical with lignin level found in Pesisir Selatan peat of West Sumatra of ±17% [6]. Most peatlands used as oil palm plantation has been decomposed, therefore lignin levels are low. Lignin degradation by white mold fungus or white rot Fungi (WRF) is accelerated along with peroxidase, manganese peroxidase, lignin peroxidase, and laccase enzyme activities. They catalyzes biological oxidation of lignin with free radical oxygen as lignin degradation and is performed under oxidation reactions [7].

Laccase activity is one of enzymes used as tropical peatland decomposition bioindicator. Laccase activity correlates negatively with peat water and micronutrient level (Fe and Cu). This indicates that induced peat water and total peat and Cu levels can suppress enzyme activities [5], inhibiting decomposition rate and causing improved peat stability. Cu level in Pesisir Selatan peatlands was

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more than 20 mg/L, higher than total Cu in Riau soils. However, management of oil palm plantations requires land drainage, suggesting a more aerobic peat layer. This results peat oxidative layer, which triggers a rise of enzyme activity such as laccase.

Oil palm plantation in West Sumatra in 2008 covered around 310,281 ha, mostly situated in Pasaman Barat Regency. Oil palm plantations in this regency were mostly maintained as core-and-plasma plantation management. Out of 102,000 ha oil palm plantations in this regency, about 62% was located in Pasaman District, while the rest is scattered throughout Lembah Melintang, Kinali, and Sungai Beremas Districts [8]. There have been no studies on environmental impacts of oil palm plantations based on peatland changes, heterotrophic decomposition, and enzyme activity associated with CO₂ emissions from peat ecosystem. Peat characteristics and environmental factors determine peat stability level against decomposition factors. Biological indicators in the form of enzyme activity is important for a better understanding on their role to the environment. Increasing plantation extent potentially triggers peatland decomposition, in which characterization by increased lignin enzyme activity is required. The purpose of this study was to evaluate bioindicator of peat decomposition through enzyme activity in oil palm plantation.

2. Methodology

2.1. Location

Peat observation and sampling were performed on oil palm plantations over chosen locations in Ketaping, Padang Pariaman and Pasaman Regency, specifically on farmer-owned plantations using transect method. Transects were arranged perpendicularly against drainage canal (collection drain), considering stand age and peat thickness. Observation points were then determined in-situ, and marked at 5, 25, 50, 75, 100, 150 m distance from canal bank. Peat sampling outside oil palm canopy/non-rhizosphere areas was performed to minimize the influence of roots as C contributor to peat degraded microbial biomass. We observed 0-20 and 20-40 cm root layer depending on peat water height. Sampling was performed using a peat auger.

Subsamples were taken at approximately 200-300 g and prepared for laboratory analysis. Peat subsamples were stored in plastic (polyethylene) bag to maintain water content and were housed in a cool box to avoid drastic temperature changes and potentially damage peat samples, then stored in refrigerators. At the laboratory, peat samples were prepared under maintained room temperature for 1-2 days. Subsamples for physico-chemistry analysis were stored at room temperature. Hence, peat water content correction was required.

2.2. Peat material analysis

2.2.1. Chemical analysis

Peat water content was analyzed using gravimetric method, while ash content was measured using dry ignition method [9]. In this research, pH H₂O was acquired with 1:2 peat material (10 g material: 20 ml non-ionic water) exploiting the 2700 Autech Instrument pH meter. Total micronutrients (Fe, Cu) were analyzed using wet destruction method (60% HClO₄ and HNO₃ extraction) and measured using Shimadzu AA-6300 atomic absorption spectrophotometer (AAS).

2.2.2. Enzyme activity

Enzyme activity was specifically studied at 0-20 and 20-40 cm peat layer depth through measuring laccase activity with ABTS method (2.2-Azinobis (3-ethyl-benzothiazoline-6-sulphonate). Activity of laccase extracellular enzyme was evaluated using spectrophotometer with 0.5 mM ABTS substrate. Oxidation of ABTS was monitored by setting a spectrophotometer at 420 nm wavelength. Precisely 7.5 ml of 100 mM sodium acetate pH 5 buffer was added to 5 g peat material, while the subsequent of 7.5 ml 0.5 mM ABTS were added and whipped slowly at 25°C for 15 minutes. The suspension was filtered and measured using Spectrophotometer UV-Vis 1280 at 420 nm wavelength. A unit of enzyme activity was described as the number of enzymes that oxidize 1Mm ABTS per minute at 25°C.
2.3. **Data processing**

Peat characteristics and enzyme activity datasets were descriptively analyzed. Averaged value of each parameter was presented based on peat layer depth. Graphical analysis was used to determine each parameter given with 5% standard deviation. Data processing was performed using Microsoft Excel.

3. **Result and discussion**

3.1. **Environmental conditions**

Peat thickness in Ketaping was less than < 1m (thin peat), while in Pasaman, thicker peat was observed (more than 3m). Frequent flood happened on both locations, carrying sand deposits or sediment into peat layer from nearby rivers. Ground water observation on peatlands is presented in Figure 1.

![Figure 1](image-url)

**Figure 1.** Peat ground water level in Ketaping, Padang Pariaman and Pasaman

Ground water level in studied peatlands fluctuated, but not exceeding 80 cm. Away from canals, increasing water depth was observed, which was reaching 30 cm. Previous research [10] assumed that averaged depth of peatland under oil palm plantations was around 60 cm; nonetheless, peatlands under oil palm plantation in Padang Pariaman was 40cm, while in Pasaman Barat was 5.5 cm.

Oil palm plantations on both locations were managed with minimum drainage, causing frequent flood and making the peat become more puddle. This was due to the lack of farmer capital. Peatland management in smallholder plantation is very different from private plantations, especially drainage problems. Smallholder oil palm plantation in peatlands is usually natural, without regular drainage and without restricted water management unlike private companies. They have paid much attention to oil palm productivity in their land caused by low CPO price.

3.2. **Peat characteristics on oil palm plantation**

Peat physicochemical characteristics determine peat stability against decomposition. Important peat characteristics to determine the peat stability include:

- **Peat water content**

  Water content determines peatland stability against degradation. In addition, biochemical reactions in peat materials are driven by peat water content. Figure 2 displays peat water content in upper and lower peat layers. Peat water content at 0-20cm (31-142%) layer was lower than 20-40cm (68-387%) layer, while water content increased away from the canal. Water content at 25 and 75 m distance were lower than areas closer and farther from canals, both at 0-20 and 20-40 cm layer. This indicated that water moved laterally.
Figure 2. Peat water content of oil palm plantation in Ketaping, Padang Pariaman

Figure 3 represents lower peat water content of oil palm plantation in Pasaman at 0-20cm (142-209%) layer than 20-40cm (146-498%) layer. Based on the distance from the canal, peat water content at 0-20cm layer was slightly varied, while 20-40cm layer showed fluctuating water content. Fluctuation of ground water was found around 0-30cm, therefore peat water content can be maintained especially at 20-40cm layer. In general, peat water content in oil palm plantation belonged to farmers in Pasaman was higher than Ketaping, Padang Pariaman; however, water content at 0-20cm layer with 31-146% was lower than private oil palm plantations with > 200% w/w [6].

Figure 3. Peat water content of oil palm plantation in Pasaman
Figure 2 and 3 presents peat water content in both locations were much lower than Pesisir Selatan (200-600%) [6], triggering acceleration of peat degradation as water held by peat began to decrease. Although peat water depth is higher than 0cm in certain condition, it cannot guarantee that peat has high water content. This means that water in peat material is immediately lost with peat water change; to add the effect of uncertain climate change. Level of peat stability is determined by holding power of peat against water. Minimum drainage efforts in farmer’s land did not make the peat more stable, as water movements are more uncontrollable when there is no water management effort. Unlike peatlands in well-controlled private plantation, water streams and reservoir are to be held continuously by peat materials.

b. Peat ash content and pH value

Peat ash content was in range of 18-70%, whereas in Ketaping area it was very high with >10%. Based on the distance from canal, ash content decreased with peat layer depth. Ash content indicates peat and mineral decomposition. Figure 4 shows pH reduction trend along decreasing ash content. Peat pH value in Ketaping area was around 4.2-5.2. This pH value was very high for peatland; peat pH layer at 0-20cm was lower than for 20-40cm layer. Averaged 0-20cm layer ash content was higher than of 20-40cm layer. Lower pH value in upper layer means that upper layer has been highly decomposed as low pH value indicates peat decomposition of organic matter into more soluble organic acid. This statement was supported by low water content on peat layer. Averaged pH value in bottom layer was due to high mineral in peatlands. High ash content is in line with high decomposition level occurred along with increased mineral soil mixture [11].

Figure 4. Ash content and pH value of the peat in oil palm plantation of Padang Pariaman based on the distance from the canal.

Peat ash content in Pasaman ranged 5-60%, lower than in Ketaping, Pariaman. As seen in Figure 4, peat ash content at 0-20 cm layer was higher than the one observed at 20-40cm. Based on the distance from the canal, ash level increased in upper layer. Peat pH value at 0-20cm later was lower than of 20-40cm layer, ranged 4.7-5.3; while at lower layer, it was averagely above 5. Similarly, pH value of peat upper layer in Ketaping had undergone further decomposition process, causing high organic acid solubility, although ash content was very high. Ash content and pH in Ketaping, Padang Pariaman and Pasaman were similar to the one investigated on Pesisir Selatan with ash content of >40%. Mineral enrichment determines peat characteristics associated with peat degradation. High ash content will
lower CO₂ emission from peat; however, it depends on large grain size of mineral. Smoother size shows significant effect of lowering emission [11].

![Graph showing ash content and pH value of peat in oil palm plantation of Pasaman based on the distance from the canal.](image1)

**Figure 5.** Ash content and pH value of the peat in oil palm plantation of Pasaman based on the distance from the canal

### 3.3. Peat degradation bioindicator based on laccase activity

**a. Laccase activity in Ketaping, Padang Pariaman**

Peat degradation indicator observes high activity of peat-degrading microorganisms. Tropical peat material is sourced from wood material, especially lignin. Its degradation is catalyzed by laccase enzyme (one of oxidase enzymes) to oxidize aromatic and non-aromatic compounds into phenol and CO₂, therefore it is also utilized as CO₂ emission indicator. High laccase activity indicates a more susceptible to peat degradation. As seen in Figure 6, laccase activity on oil palm plantation in Ketaping area ranged 1.8 - 562 μmol/g, higher than Pesisir Selatan peat with < 0.5 μmol/g. This was due to low peat water content of < 400%; even upper peat layer showed lower water content. Figure 6 also presents enzyme activity on upper peat layer higher than the bottom due to upper water content was lower than bottom layer, followed with decreasing laccase activity and further distance from drainage, especially the bottom layer.

![Graph showing laccase activity and water content in oil palm plantation in Ketaping, Padang Pariaman.](image2)

**Figure 6.** Peat laccase activity on oil palm plantation in Ketaping, Padang Pariaman
b. Laccase activity in Pasaman

Peat laccase activity on oil palm plantation in Pasaman is presented in Figure 7. Laccase activity was <200 μmol/g, lower than in Ketaping. This occurs as the water content of Pasaman was higher than in Ketaping with >200% (w/w). However, enzyme activity level in Pasaman was still higher than in Pesisir Selatan with <0.5 μmol/g [6]. Enzyme activity in upper peat layer was higher than the bottom. Peat decomposition level in upper layer was much higher, as characterized by higher ash content along with mineral enrichment, triggering low pH in upper layer. The activity in the bottom layer was decreased based on the distance from canal, while upper layer was not very different, triggered by fluctuating peat water content in bottom layer to more than 500% (w/w).

Figure 7. Peat laccase activity on oil palm plantation in Pasaman.

c. Total Fe and Cu

Total Fe and Cu were determined by peat ash content. Ash content comes from mineral enrichment. Total Fe in Ketaping was 2,499-45,415 ppm or 0.3-5% of peat total Fe, higher than in Pasaman with <6,544ppm or <0.6% (Figure 8). Fe level decreased along with increasing distance from canals; further distance from canal causes decreasing flood deposits. Total Fe content in upper layer was higher than the bottom (Figure 8a and b), due to material enrichment from nearby river carrying flood deposits containing high Fe level. Averaged ash content in upper layer was higher than the bottom triggering an increased level of laccase activity in upper layer on both locations (Figure 6 and 7). Based on ash content, peatland in Ketaping had relatively higher ash content. Total Fe enrichment was likely obtained from high ash content. A previous research [12] found that median solubility of Fe from mineral soil was 13%. The presence of large Fe cation in peat should increase peat stability; however, peat decomposition process characterized by high enzyme activity had already leads to peat degradation. Total Fe level in Ketaping was very high, causing peatland became almost mineralized. Large Ketaping peatland would be soon depleted when unmanaged in terms of water content maintenance.
Figure 8. Peat total Fe on oil palm plantation in Padang Pariaman (a) and Pasaman (b) based on the distance from the canal.
Total Cu level in Ketaping was higher than in Pasaman with above 10,000 ppm (> 1%) (Figure 9a and b). High ash, Fe, and Cu levels in Ketaping and Pasaman peatlands should have a positive impact on peat stability, when managed properly. Addition of high Fe mineral is a form of peat amelioration to reduce phenolic acid concentration and increases crop productivity [12], along with good drainage management. This means that peat should be moist with water content should not be less than 400%, suppressing laccase activity. Ketaping and Pasaman peatlands had average water content of < 300% (w/w), showing higher peat degradation rate than Pesisir Selatan, as characterized by high lignin degradation enzyme activity level. Relatively poor management of oil palm plantation at farmer’s level in Ketaping, Padang Pariaman and Pasaman can accelerate peat degradation.
4. Conclusion

Peatland on oil palm plantations managed by farmers in Ketaping, Padang Pariaman had high laccase activity ranged 1.8-562 μmol/g compared to Pasaman with < 200 μmol/g, and was higher than Pesisir Selatan peat. Enzyme activity as the bioindicator of peatland degradation has shown peatland in both locations had undergone decomposition, leading to degraded peat when unmanaged. This was also supported by peat characteristics with high pH >4, high ash content >40%, low moisture content <300% (w/w), and high total Fe and Cu level >5%. Drainage management on both studied peatland was deteriorating and, therefore, accelerating peat degradation.

Good water management is necessary to maintain peat ecosystem that supports oil palm or other crops growth. This is not only increasing sustainable crop productivity, but also maintaining peat environmental condition that is not easily degraded and supporting agricultural business in low emission peatland.

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