Soil physicochemical properties in oil palm plantations impacted to peatland fire

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Abstract. Currently, Indonesia has 1.7 million hectares of oil palm plantations on peatland (12% of the total area of 13.5 million ha Indonesia's peatland). As a consequence, fires on peatland become trending topics. Field observation research that aims to determine the physical and chemical characteristics of peat in oil palm plantations has been carried out on several peat locations in West Aceh District: Suakraya village, Johan Pahlawan district (15 years old), Cot Gajah Mati Village, Arongan Lambalek district (1 year old), and Suakpuntong village, Nagan Raya district (10 years old). Substantial changes in the physicochemical properties of soils from oil palm plantations were observed, then evaluated the impact these characteristics to fires on peatland. The analysis soil showed that peatlands around in West Aceh District have physical characteristic: bulk density (BD) from 0.12 - 0.16 g cm\(^{-3}\); groundwater level of 6 cm (rainy seasons) and 86 cm (dry seasons); moisture or water content in the surface layer (0-20 cm) during the dry season was 505 - 985%. The thickness of peat was 457 cm on deep peat in Suakraya, 157 cm on shallow peat in Suakraya, 243 cm in Cot Gajah Mati, 136 cm in Suakpuntong. The chemical characteristic of peat soil has pH H\(_2\)O 2.9 - 3.9, pH KCl 2.23 - 3.07. The level of maturity of peat in the surface layer in all observation locations is the same, namely hemic. Water content per unit dry weight depends on peatland maturity level (fibric: 540 - 1187%, hemic: 268 - 480% and sapric: 106 - 242%). Ash content per unit dry weight varied from 1.8 - 5.9%, and C-organic content 53.4 - 57.6%. Peat total acidity is 4.2 - 6.4 me g-1, COOH content 0.02 - 0.16 me g-1 and phenolic-OH content 4.2 – 6.2 me g-1. The important result of this study showed that the causes of peatland fires are not caused by the characteristics of peat (occur naturally), but there are triggers of human activities.

1. Introduction

The total area of peatland in Indonesia is about 1.7 million ha with an average yield of oil palm in peatland that can reach 23 tons of Fresh Fruit Bunches (FFB) per year, peatlands have considerable potential for the development on oil palm agribusiness. On the other side, human activity along with the impact of climate change threatens the stability of this large pool of carbon that has been increasing rapidly over the last few decades owing to deforestation, drainage, and fire. Converting primary forest to oil palm plantation decreases the stock of soil organic carbon (SOC) 23% ± 21% [1] and would change the physical, chemical and biological characteristics of the peat. These changes are needed to support the growth and development of oil palm plants, but the newly different characteristics of peatlands would easily cause peat fires.
Peat fires are influenced by many factors among them are rainfall, peat water content, level of peat decomposition and groundwater level [2], the value of bulk density in some depth of peat [3]. Field observations aimed to determine the physical and chemical characteristics of peat on oil palm plantations have been carried out in several peat locations in West Aceh. Hence, the data was used to analyze the possibility of peat fires. Based on the type of fuel and the nature of its combustion, peat fires are grouped into 3 types, namely, ground fire, surface fire, and crown fire.

As a consequence of fires on peatland produces CO₂ emissions. Based on the calculation of the fire emission amount of 0-50 cm layer is 19,850.484 t CO₂ and at layer 50-100 cm is 18,284.371 t CO₂. So total emission of the depth of peat layer 0-100 cm with fire area 6000 hectares is estimated 38,134,855 t CO₂ [3]. Thus, peat management in order to avoid fire is very important, because these ecosystems contribute to greenhouse gas emissions and global warming.

2. Materials and methods
Field observations were conducted in West Aceh and Nagan Raya Districts in which the studied sites located in the oil palm plantations having different plant ages at 1) Suakraya Village of Johan Pahlawan District (15 years old); 2) Cot Gajah Mati Village of Arongan Lambalek District (1 year old); 3) Suakpuntong Village of Nagan Raya District (10 years old), and 4) peatlands forest in Cot Gajah Mati Village (forest without drainage); and, 5) Simpang Village of Kaway XVI Sub-district (peatland forest drainage).

![Figure 1. Observation Fields](image)

Soil samples were collected by a peat auger to measure bulk density, water content, and soil chemical property. The water table inside dipwell was measured every 5 points from the samples site. The peat sampler of Eijkelkamp model can take semi undisturbed samples and its full length of the sample tube has a volume capacity of 500 cm³. The samples were transferred into plastic bags, labeled and sealed to be transported to the laboratory in Bogor City of West Java Province. The samples were dried at 100 °C for 48 hours or until a constant weight has been reached. The dry weight was measured then bulk density and water content by weight was calculated.

The physicochemical analysis was carried out at the Soil Fertility Laboratory, Faculty of Agriculture, Bogor Agricultural University. Peat soil samples were taken from oil palm plantations over a specified transect using a peat drill. The composite soil samples in each transect are grouped
based on the level of maturity of the peat determined by the fast method in the field to be fibric, hemic, and sapric. To determine the effect of peat maturity level on the physical and chemical characteristics of peat, analysis of variance was conducted then proceeded with Duncan’s test at a significant level of 5%.

3. Results and discussion
The average thickness of peat at the forest in Simpang was about 1000 cm, at the oil palm in Suak Raya 457 cm, at the oil palm in Cot Gajah Mati 243 cm, at the forest in Cot Gajah Mati 227 cm, at the oil palm in Suak Raya 157 cm, and at the oil palm in Suak Puntong 136 cm. Bulk density in West Aceh ranges from 0.05–0.26 g cm⁻³ such as shown in the following figure.

![Figure 2. The bulk density of the peat at depth of 0–50 cm in 6 locations](image)

The conversion of forests to oil palm plantations increased bulk density indicating there have been significant compressions of peat pores that could cause peat soil more compact and increase the capacity of peat capillary. Therefore, the water movement from the groundwater table to the surface layer increases that can maintain soil moisture on the surface layer. Furthermore, the compaction of peat soils could reduce oblique plant, soil nutrient leaching, CO₂ emissions and peat risk to fires. [3] in the fire area shows that the bulk density value on the peat surface is higher than the inside part. The differences in bulk density values are due to differences in peat maturity in each soil profile because of both naturally and also human activities.

Table 1 presents the results of the groundwater table measurement showing the groundwater levels on peatlands varied widely both in forests and in oil palm plantations. However, the water content in the peat surface layer as shown in Figure 3 are relatively the same. Therefore, groundwater level is not the best indicator for sustainable peat management especially in the cultivated peatlands, but soil moisture is important to maintain both for the optimum plant growth and fire prevention.

| Table 1. Average groundwater levels at the study site and land use. |
|------------------|--|--|--|--|
| Village/Land use | Water table | | | |
| | Average (cm) | Minimum (cm) | Maximum (cm) | Difference (cm) |
| Suak Raya (Deep peat)/Oil Palm | 40 | 24 | 58 | 34 |
| Suak Raya (Shallow peat)/Oil Palm | 45 | 33 | 53 | 20 |
| Suak Puntong/Oil Palm | 73 | 63 | 86 | 24 |
| Cot Gajah Mati/Oil Palm | 35 | 6 | 65 | 60 |
| Simpang/Forest drainage | 53 | 32 | 70 | 38 |
| Cot Gajah Mati /Forest without drainage | 13 | 8 | 17 | 9 |
Soil moisture can be a rational criterion if it is associated with the risk of fires on peatlands. According to [4] and [5], more than fifty percent of peat fires are on the soil moisture content of 100-125%. For this reason, efforts to maintain peat soil moisture are needed so that fire incidents can be avoided.

Figure 3. Soil moisture in surface soil (0-50 cm) in August 2009

Figure 3 shows the average soil moisture on the surface of the peat is relatively high above 500%. The risk of a peat fire in this condition is very small. Rainfall pattern has 2 peaks in the wet and dry seasons in a year, and the rainfall in the dry season is relatively high (Figure 4).

Figure 4. Rainfall patterns in the studied site (Source: Badan Pusat Statistik (BPS) West Aceh, 2007)

Peatlands in Meulaboh have pH H₂O 2.9–3.9 and pH KCl 2.23–3.07. Based on the level of peat maturity, the average of pH H₂O was 3.52 for peat fibric, 3.45 for hemic peat, and 3.08 for peat sapric. While the average of pH KCl was 2.73 for peat fibric, 2.62 for hemic peat, and 2.55 for peat sapric. The results of the variance analysis showed that pH H₂O was significantly different on the level of peat maturity, while the pH KCl was not significantly different. With Duncan's test, the pH H₂O on fibric is the same as hemic, but sapric is the lowest.

In this study, the water content of peat was depending on the level of maturity of the peat. Fibric peat has the highest water content, followed by hemic and sapric. The range of water content fibric: 540–1187%, hemic: 268–480% and sapric: 106–242%. Peat in Cot Gajah Mati area which is a peat forest that has just been opened and cultivated for oil palm cultivation has an average water content
higher than peat in Suak Puntong and Suak Raya villages, so Cot Gajah Mati including in the fibrich peat, it has not decomposed. Decomposition process tends slowly at low pH. This indicates that subsidence has occurred in peat which has long been used for oil palm cultivation such as in Suak Puntong and Suak Raya villages.

Peat subsidence was caused by changes in water level due to the position of compaction and oxidation. When the water level is low, the peat structure cannot support the above material and the pores of the structure are destroyed so that the peat material on the surface of the peatland decreases. While subsidence occurring, bulk density increases and hydraulic conductivity decreases, due to the compaction of peat soil pores. The consequences of changing the volume on the hydraulic properties will directly influence to the changes of water storage and flow of penetrates water to the subsoil [6] and lead to changes in the biogeochemical processes of peat [7].

The accelerated peat decomposition in Suak Puntong and Suak Raya villages have led to an increase in ash content per unit dry weight varied from 1.8–5.9%, and organic C content 53.4–57.6%. [8] showed that the ash content in fibrich is lower than hemich and saprich and [9] reported that poor peat has lower ash content than rich peat. The increase in the content of organic matter from 0.1 to 57.4% caused BD to decrease from 1.86 to 0.33 g cm⁻³ and the total porosity increase from 38 to 90%. In addition, the pore size distribution in the peat soil is determined by the degree of decomposition of peat, the peat decomposes will further (saprich) have a pore size distribution more uniform [10].

Total acidity of peat represents the total of carboxylic acid (-COOH) and a phenolic acid (-OH) which shows the magnitude of the cation exchange capacity of peat soil. Dissociation of a carboxylic group (COOH) and phenolic -OH may result in the formation of a negative charge, thereby increasing the adsorption of water and cations. The results of measurements of total acidity of peat, carboxylic acid (-COOH) and a phenolic acid (-OH) of peat were presented in Figure 5.

![Figure 5. Average total acidity, -COOH, and -OH base on the peat maturity level](image)

Peat fires are influenced by several peat characteristics such as peat water level, peat decomposition rate, and water level. In this study, water content based on the maturity level of peat ranges for fibrich: 540–1187%, hemich: 268–480% and saprich: 106–242% and in the surface layer (0–20 cm) during the dry season was 505–985%. The higher the water content the lower the rate of combustion of peat. Peat fires can still occur at 119% which is a critical value triggering peat fire [2].

The groundwater level in the forest was 11 cm in the rainy season and 70 cm in dry season while in the oil palm plantations was 6 cm in the rainy season and 86 cm in the dry season. The water content of peat on the surface layer (0–20 cm) during the dry season was 717–978% in the forest, and 505–985% in the oil palm plantations. Thus, the conversion of the forests to the oil palm plantation has no significant impact on peat fires.

The maturity level of peat on the surface layer at all locations is hemich. The level of peat decomposition also affects peat fires, the more mature the peat (saprich type) the more difficult to burn compared to the immature peat type such as fibrich and hemich types. The average bulk density in the forest (0.04 g.cm⁻³–0.06 g.cm⁻³) was lower than in the oil palm plantation (0.12 g.cm⁻³–0.16 g.cm⁻³).

Therefore, the incidence of peat fires could potentially occur in all conditions of land cover (forest and plantation), or in other words, the cause of the fire peatlands is not caused by the characteristic peat (naturally occurring), but there must be a trigger that human activity (whether intentional or accidental). Peat Fires usually begin with the ignition of fire above ground level. The fire will move in...
all directions, below the surface, above the surface, left, right, front and back. Fire will move up to the surface affected by wind speed and direction as the surface fire and when it reaches the tree canopy will be as crown fire.

4. Conclusion
Result in this study showed that the causes of peat fires were not caused by the characteristics of peat (occur naturally), but there are triggers of human activities. Maintaining soil moisture on peat soil is more important to avoid peat fires and must be used as a major variable over groundwater levels in peat management.

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