Excessive amount of rainfall decreases oil palm yield on well-drained peatland

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Abstract. Low inputs of smallholder plantation in drained peatland causes the low oil palm yield. Extreme environmental factors in tropics, such as excessive rainfall, may also reduce the yield. The research objective was to evaluate the effect of the amount of rainfall on oil palm fresh fruit bunch (FFB) yield. Two study sites with different drainage condition of well (WD) and fair (FD) drained oil palm plantations on peatland was carried out from 2018 to 2019 in Jambi Province, Indonesia. The daily rainfall was monitored using a manual rain gauge. FFB yield was monitored every two weeks, following the farmer’s practice. This study showed that the excessive amount of rainfall in WD plantation site decreased FFB yield in the subsequent weeks after the rainfall events. The higher the amount of rainfall the longer the recovery of FFB yield occurs. The lowering FFB yield was possibly affected by nutrient deficiency due to nutrient transportation through water movement during the event of high rainfall amount. The FFB yield in the FD site was not affected by rainfall, reflected the higher nutrient availability of FD compared to that of WD. Based on these findings, it is confirmed that well-drained agricultural peatland is a fragile ecosystem in terms of nutrient loss.

1. Introduction
The primary source of vegetable oil, fats, and biodiesel in the world is palm oil [1-3], while the global demand for palm oil increased in line with the population growth. Indonesia is an important supplier of crude oil palm in the world, where Sumatra and Kalimantan Islands are the basis of palm oil production. The massive expansion of oil palm plantation occurs in both islands to address the world’s demand for palm oil. The growth of the oil palm industry contributes significantly to the national economic growth and increase the rural household income of Indonesia [4]. In the year 2018, the oil palm plantation area in Indonesia was 14.4 M ha which of 40.6% occupied by smallholder farmers [5].

Peatland has low nutrient content, low pH, low bulk density, low bearing capacity, and wet, which is considerably less favorable for oil palm cultivation [6-8]. However, water drainage, ameliorations, and fertilization have been applied to reclaim peatland including to increase the productivity of peatland [9]. Currently, Indonesia has 13.4 M ha of peatland [10] in which around 1.7 M ha of Indonesia peatland are used for oil palm plantation [11].

Tropical peatland had an important role in the carbon, water and biogeochemical cycles but considered as a fragile ecosystem [12, 13]. Soil surface of drained peatland under mature oil palm plantation in Sumatra Island was considerably recalcitrant and did not act as the source of C emission anymore but sub soils potentially become the new source of such emission [14]. Moreover, water
movement occurs in drained peatland of Kalimantan Island, in the preliminary of the wet season has caused the huge nutrient loss persisted for three months [15]. The nutrient availability to the roots is crucial to crop life and their productivity. Currently, there is no published report on the relationship between rainfall amount and crop productivity in tropical drained peatland. The objective of this study was to evaluate the effect of rainfall amount on the yield of oil palm which had been conducted in smallholder plantation for two consecutive years.

2. Materials and methods
This study was conducted in smallholder oil palm plantation in Pandan Lagan Village, Tanjung Jabung District, Jambi Province from January 2018 to December 2019. Two study sites were established in peatland. The first site was 15 years old of oil palm plantation which never experienced water inundation even in the wet season, namely well-drained (WD) site. While the second site was 14 years oil palm plantation which has been waterlogged for two months in the wet season of March and April 2018, indicating the water drainage in this site was in fair condition, then it is so-called fair-drained (FD) site. The distance between WD and FD sites is 4.5 km, which similarly located next to the secondary canal and near the road and secondary forest. The water table measurement through 20 perforated pipes had been conducted for two consecutive years for every two weeks, although this data was not presented in this paper.

2.1. Field investigation
Two manual rain gauges were installed in WD and FD sites for measuring daily rainfall amounts. The cone-shaped at the top part of the rain gauge was to catch the rainwater then collect it into the below measuring cup. The rain gauge was placed 1.5 m height from the ground and no objects around a radius of 10 m that possibly hinder the rain from entering the gauge. The rain was monitored in the daily base. FFB was yielding fortnightly by farmers, following the farmer’s practice. The weight of the FFB yield was monitored continuously.

2.2. Data analysis
Analysis of interconnecting data between rainfall amount and FFB yield was conducted by the cumulative sum method. This cumulative sum method is used to present the graph of total sum of rainfall and yield as it grows with time. The first day of rain gauge installation is the benchmark of the data collection. For example, the rainfall data in day 3 is presented to be the total sum of rainfall in days 1, 2, and 3. Based on this interconnection of cumulative sum graph between rainfall amount and FFB yield, the simple model was qualitatively built with the logic mechanism explaining in the discussion chapter.

3. Results and discussion

3.1. Results
Research results from WD site showed that cumulative rainfall amount during the two-year research period was 4,440 mm, while the cumulative FFB yield was 35,248 kg ha⁻¹ (figure 1). The cumulative rainfall increased quickly in two periods of March to May 2018 and November 2018 to May 2019. The cumulative rainfall graph was flattened followed by the increased cumulative graph of FFB yield in those two research periods (figure 1). The fluctuation graph of cumulative rainfall and FFB yield was like two ovals shape during this research.
Figure 1. Cumulative rainfall (mm) and FFB yield (kg ha\(^{-1}\)) in WD site during two-year field research period from 1 January 2018 to 31 December 2019. Black arrows indicate the peak of increasing cumulative rainfall while white arrows indicate the peak of decreasing cumulative FFB yield.

Field research in FD site for two years showed that cumulative rainfall amount was 5,031 mm, while cumulative FFB yield was 50,265 kg ha\(^{-1}\) (figure 2). Please note that the maximum number of cumulative yields between figure 1 and 2 is different, adjusting the graph to be understandable. There were two peaks of cumulative rainfall in the similar period with WD site. However, the cumulative FFB yield increased linear without any fluctuation. The graph of cumulative rainfall and FFB yield was like two half-ovals shape during this research.

Figure 2. Cumulative rainfall (mm) and FFB yield (kg ha\(^{-1}\)) in FD site during two-year field research period from 1 January 2018 to 31 December 2019. Black arrows indicate the peak of increasing cumulative rainfall.
3.2. Discussion

3.2.1. Fluctuation of the cumulative rainfall amount and FFB yield. The different amount of cumulative rainfall between WD (4,440 mm) and FD (5,031 mm), although only 4.5 km separated each other, reflected the high variation of environmental factor in this study site. However, these two sites have similar trend of rainfall fluctuation over the time. The graph of cumulative rainfall quickly increased during March to May 2018 and November 2018 to May 2019 (figure 1 and 2), caused by the rainfall in wet season. The decreased graph of cumulative rainfall marks the lowering rainfall amount, while dry season affected the cumulative graph was flattening.

The graph of cumulative FFB yield was fluctuated twice during this research period, following the pattern of cumulative rainfall fluctuation. The increased rainfall cumulatively followed by the decreased FFB yield; it indicated the relationship between those variables. The response of FFB yield to the rainfall was not instant but having a lag time, which indicated that the mechanism inside the trees tissue needs a certain time [16]. Figure 3 left showed a model of rainfall as the function of FFB yield in WD site. The higher cumulative rainfall, the longer FFB yield was recovered. However, such model did not work in FD site, where the FFB yield was stable and not affected by rainfall.

3.2.2. Effects of rainfall to FFB yield. FFB yield from WD and FD sites was 35,248 and 50,265 kg ha\(^{-1}\) during this research period, respectively. It means that the FFB yield from WD and FD sites was 17.1 and 25.1 t ha\(^{-1}\) y\(^{-1}\), respectively. The large gap between two sites is possibly because of different management on water and nutrient, and the complex interaction among those factors.

In well drained peatland of WD site, the additional rainfall water coming inside the farm possibly caused nutrient dilution, transportation, and flowage outside the farm [1]. Based on the fortnightly soil solution measurement from 50 and 200 cm deep showed that extreme rainfall easily removes nutrients to the below ecosystem. This published report was conducted in similar well drained peatland in West Kalimantan Province, Indonesia, where the water inundation was never experienced during study period [15]. In the wet season, nutrient was lost due to the extreme rainfall once after long dry season. The almost zero nutrient condition of peat water was persisted for three months. The nutrient was lost from soil and might not be available for roots of oil palm trees, indicated that the nutrient supply for generative growth of FFB was interfered. The frequent loss of nutrients possibly caused the lower FFB yield of WD site (17.1 kg ha\(^{-1}\)) than that of FD site (25.1 kg ha\(^{-1}\)). Moreover, average FFB of oil palm yield in Indonesia is 18 t ha\(^{-1}\) y\(^{-1}\) [5] means that the high water and nutrient retention of FD site was beneficial compare to national yield circumstances.

Moreover, the waterlogged condition for more than five weeks in FD site reflected that excessive water coming to FD site was not easily transported outside the farm. The excessive water of rainfall
caused dilution of nutrient concentration, while nutrient transportation and flowage were limited. The water inundation caused the peat nutrient retained better than that of WD site.

3.2.3. The gap of this study. This study succeeds to reveal the new insight of relationship between rainfall amount and its effects on FFB yield, but study of nutrient loss study vs rainfall was conducted in different location and time. Because both study sites having a similar characteristic regarding water pertaining, the logic of rainfall-nutrient-FFB yield relationship might be understandable. However, within the different location and time measurement, some detailed relationship mechanism of those three variables possibly missed out to be monitored such as the influence of rainfall quality and intensity, inherent physicochemical characteristic of peat and mineral substratum, landform and geology, soil-water-crop and pest management. A comprehensive study is very important to undertake in order to understand the mechanism behind this interconnection among variables.

3.2.4. The possibility management in the future. The water should be collected in the farm as long as possible to ensure the nutrient availability for roots. This should consider the high evapotranspiration of oil palm plantation during dry season [17] which easily reduces the water storage in peatland. Moreover, the excessive water during wet season which possibly goes out the farm should be avoided. Water inundation for several weeks might impede soil aeration for short period which is very important condition for root respiration and roots-nutrient exchange [18]. However, this study showed that water inundation was not harmful for oil palm productivity. It seems that oil palm trees are tolerant species of wetland, although this assumption need scientific proof.

4. Conclusions
FFB yield of WD site was lower than that of FD, it indicated that the well-drained peatland was prone to nutrients loss due to extreme rainfall amount. Nutrients were transported to the lower ecosystem through water flowage during wet season. This study implies that water management is the key to increase agriculture productivity in peatland. The water shortage capacity of peatland should be increased to retain the nutrient availability for oil palm roots.

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