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Temporal Variations in Soil Water Profiles During Discharged Periods Under Oil Palm and Rubber Plantations in Bengkulu, Indonesia

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ABSTRACT

The conversion of forestland to cultivation land such as oil palm plantation has been reported to cause a shortage of water resources in Indonesia. However, it was not clearly understood whether the decrease in water resources was related to a specific crop type like oil palm following deforestation or to the disappearance of forest covers regardless of successive crop types. The present study aimed to analyse the temporal variations in soil water profiles under two crop plantations and to compare soil wetness between two crops. Two soil profiles were described at the adjacent mature oil palm and rubber plantations, fifteen cable sensors were inserted into the depths of 5-cm intervals up to the depth of 75 cm for the weekly determinations of the in-situ soil water. Undisturbed soil samples were then taken from corresponding layers at each plantation site for the soil bulk density and water retention analyses. Measurements of in-situ soil water and sampling for the water retention analyses were repeated at two other adjacent plantations of oil palm and rubber. Results showed that gravimetric and volumetric values of soil water content were consistently higher under oil palm compared to under rubber sites during the May-to-August measurements. The findings suggested that any deterioration of soil water resources after deforestation in the study area could be caused by the shift of land cover from forest to cultivated land rather than to a specific type of successive vegetation like oil palm.

Keywords: *deforestation, oil palm, rubber, soil water profile*

1. INTRODUCTION

In the last few decades, there have been massive land use changes in Indonesia particularly from the forest to cultivated land such oil palm plantations. The conversions of natural ecosystem to extensive oil palm plantations are believed by researchers to be the reasons for the environmental degradation as indicated by decreasing water level in wells during the dry period and increasing levels in stream during the rainy season [1]. Similar changes in land covers during the same period also occur in Bengkulu Province. For example, about 80.000 ha of forestland has been lost and, at the same time, about 86.000 ha of plantations grew in the northern part of Bengkulu. The conversion of forestland to cultivation land such as oil palm plantation has been reported to cause the land degradation and a shortage of water resources in Bengkulu regions as reported by Mujiono *et al.* [2]. Tarigan *et al.* studied the minimum proportion of forestland required to protect watershed in the rapid expansion areas of monoculture oil palm plantations [3]. They found that at least 30% of forestland should be available in the oil palm areas in order to maintain a hydrological-based ecosystem function.

Many assumptions have been made to correlate changes in eco-hydrological processes with the conversions of rain-forest ecosystem to oil palm plantations. The assumptions are made due to the increase of water scarcity in the world including in the oil palm producing countries [4]. However, it was not clearly explained whether a shortage of water resources was related to a specific crop types like oil palm after deforestation or caused by the disappearance of forest covers regardless of successive vegetation types. A study by Muhammad-Muaz and Marlia showed that green water footprint or water availability to crops from the oil palm plantations were more different between locations rather than among the vegetation types, therefore, the calculation of water footprint should also consider the local water stress index [5].

In Bengkulu Province, oil palm is not the only dominant plantations established by the company and people. Rubber is the second largest area of plantations in Bengkulu Province after oil palm. In 2019, areas of people's plantations in Bengkulu Province are 208,627.11 ha and 100,946.38 ha for oil palm and rubber plantations, respectively [6]. Both commodities become major sources of economic growth in the province. Therefore, oil palm plantation is not the only massive expanse of agricultural activities after the forest disappearance in the region. It is necessary to compare the possibilities in water scarcity under both oil palm and rubber sites.

The present study aimed to analyse the temporal variations in soil water profiles under two crop plantations and to develop a model of predicting the temporal soil water status in relation to daily rainfall. We assume that both types of plantations had similar temporal status of soil water profiles and decreasing quality of watershed was associated more with disappearance in forest covers rather than with plantation types after deforestations.

2. MATERIAL AND METHODS

2.1. Sites Description

The study was conducted during a discharged period of May to August 2020 in Mukomuko Regency, Bengkulu Province, Indonesia. The regency was about 270 km to the north from the capital of the province, Bengkulu City. Study sites were at adjacent mature oil palm and rubber farms to minimize the effects of non-vegetation factors to the dependent variables. The three adjacent sites were located in three different villages of Pondok Tengah, Pondok Kopi and Selagan Jaya and functioned as experimental replicates. The measurement points were chosen in a flat land in the middle between two oil palm or rubber stands.

Some characteristics of study soils at topsoil and subsoil layers are presented in Table 1. In both plantations, B horizon had finer textures than A horizons as indicated by higher clay content of 9-to-20%. This textural condition was normal since the finer particles such as clay migrated to the lower depths following water percolation processes during rain events. On the other hand, soil compaction levels were relatively similar under oil palm and rubber plantations throughout the profiles. The bulk density values ranging from 0.77 to 0.86 g.cm^{-3} indicated that the study soils were very loose probably due to less compacting agents working on these sites. Soil compaction could be assumed equal under oil palm and rubber stands, therefore, would not interrupt the effects of vegetation types on the soil water profiles.

Table 1. Particle-size distribution and bulk density of study soils

Plantations	**Horizons**	**Particles-size Distribution (%)**			**Bulk Density (g.cm^{-3})**
		Sand	***Silt***	***Clay***	
Oil Palm	A	15	59	26	0.81
	B	18	47	35	0.85
Rubber	A	15	55	30	0.77
	B	10	40	50	0.86

2.2. Soil Water Measurements

A couple of sensor cables were inserted into the soil profile under oil palm trees at 5 cm depth intervals up to a total of 75 cm. Therefore, there were fifteen couples of cables were inserted in this site (Figure 1). The lowest 5-cm parts of cable were left uncovered by rubber and functioned as cathode-anode transmitting the electric current through the soil media. The cable installation was also made at the adjacent mature rubber site, and the two installations were repeated at two other locations. The sensor cables were left in the field for temporal measurements of water profiles during the research period. Soil water content was measured weekly at 5-cm depth increments by connecting the upper parts of sensor couples to a newly developed device called dielectrometer [7]. When switch was on, the device transmitted the electrical current and the electrical impedance of measured depth appeared on the LED screen. The measurement was conducted in all installed cables in three locations. The instrument was regularly calibrated using the free water and air media prior to measurements.

The dielectrometer instrument determined soil water content indirectly by reading the electrical impedance of soils. The measured electrical impedance values (Z in k.ohm) were then converted to the gravimetric water content (θ_g in g.g^{-1}) using equation

$$\theta_g = a.b^Z \quad (1)$$

The device was calibrated to soils with various water content to calculate constants *a* dan *b*. Constants *a* and *b* for this device were 0.87 and -0.32, respectively [8], and Equation (1) were then written as

$$\theta_g = 0.87.b^{-0.32} \quad (2)$$

Soil bulk density values (ρ_v in g.cm^{-3}) were also determined at corresponding depths to calculate the volumetric water content ($\theta_v$in cm^3.cm^{-3}) using the following equation

$$\theta_v = \theta_g \times \rho_v \quad (3)$$

Soil water profiles ($W_p$in mm) were then calculated using the following equation

$$W_p = (\text{average } \theta_v) \times D \quad (4)$$

Average θ_v referred to the average values of volumetric water content throughout the profile, while *D* (in mm) was total soil depth.

Figure 1 The 3x5 pairs of sensor cables inserted at depths of 5 cm increments to a total of 75 cm for temporal measurements of water profiles.

2.3. Supporting Variables

Ecological and climatical variables were determined in order to explain the temporal variations in the soil water profiles. The canopy and root systems were observed in the mature oil palm and rubber sites, while weekly rain event histories were recorded at the time of measurements. Some basic soil properties such as texture and organic carbon were also determined in each location.

2.4. Data Analysis and Presentation

Data of soil water profiles collected from different vegetation types were analysed descriptively to evaluate the effects of stands. Temporal differences in soil water between oil palm and rubber sites were presented in graphs.

3. RESULTS AND DISCUSSION

3.1. Spatiotemporal Variations

Spatial and temporal changes in gravimetric water content, i.e. the weight comparison between water and dry soils, under oil palm and rubber trees were presented graphically in Figure 2. During a water discharged period from rainy to the end of dry seasons (May to August 2020), the uppermost 10 cm soil layers were consistently wetter for mature oil palm than mature rubber plantations. Soil water content at the 0-10 cm layers were up to 0.05 g.g^{-1} higher compared to that at the lower depths. On the other hand, soils in the rubber plantations were wetter at the 10-20 cm layers than those in the oil palm sites. The differences in gravimetric water content between two vegetation types at the 10-20 cm soil depth were also about 0.05 g.g^{-1}.

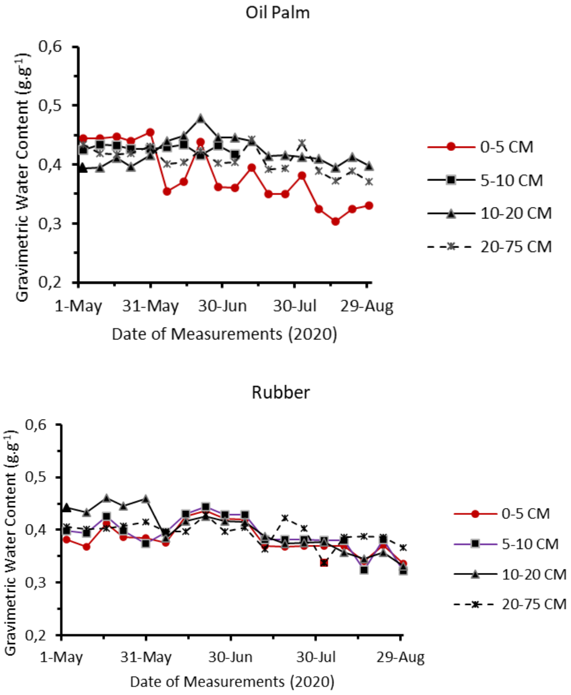

Figure 2. Temporal variations in gravimetric water content at various depths for oil palm and rubber plantations during the May-August measurements

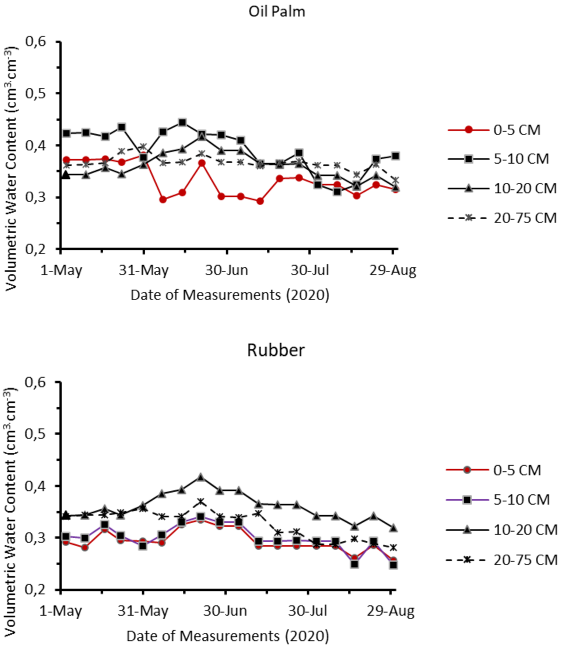

Figure 3 Temporal variations in volumetric water content at various depths for oil palm and rubber plantations during the May-August measurements

The expression of soil water profiles referred to the accumulation of volumetric water content at various depths of soil. Values of gravimetric soil water content presented in Figure 2 were multiplied by soil bulk density values of study soils at corresponding depths (Table 1) in order to get the volumetric soil water content at corresponding depth of interest. Soils at the study sites were relatively loose and had bulk density values of less than 1.0 g.cm^{3}and, therefore, had lower volumetric than gravimetric water. However, trends of vegetation effects were similar between the two status of water content. As shown in Figure 3, oil palm-maintained soil water content at the uppermost 10 cm depth while rubber at the lower depths consistently during the measurement periods.

3.2. Temporal Soil Water Profiles

Soil water profiles were calculated from the summation of the volumetric water fraction in a volume of soil body or a comparison between a depth of water in a given depth of soil profiles. During a discharged period, soil water profiles under oil palm and rubber plantations decreased from about 0.39 to 0.28 and from 0.35 to 0.26 cm^3.cm^{-3}, respectively, during the period of May to August (Figure 4). Results from the current study suggested that soil water profiles at the 75 cm depth were consistently higher under mature oil palm than under rubber although the difference was smaller in the dry season.

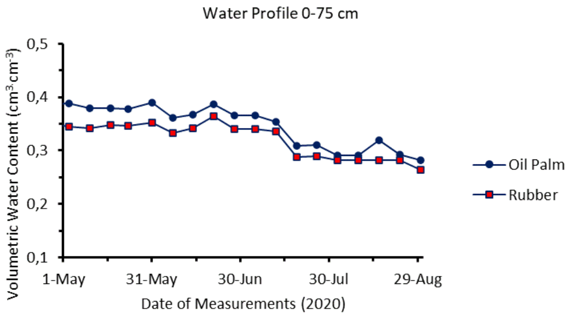

Figure 4. Temporal variations in volumetric water content at various depths for oil palm and rubber plantations during the May-August measurements

Findings in this study proved that the massive expanse of oil palm plantations in Bengkulu Region could not solely be appointed as the reason for a shortage of water resources. The cultivation of rubber after deforestation could decrease hydrological characteristics more severe compared to oil palm. This assumption agrees with the work by Lang *et al.* [9] that forest-converted rubber monoculture had negative effects on soil hydrology and carbon sink, therefore, they suggested the implementation of rubber agroforestry instead. On the contrary, oil palm plantations can be managed in such a way to retain hydrological properties such as by applying the empty fruit bunch on the soil surface [10].

4. CONCLUSION

There were about 28 and 26 percent of soil water loss from the 75-cm profiles in the oil palm and rubber plantations, respectively, during a four-month period of water discharge. However, soils under oil palm were consistently wetter than under rubber during the measurement period. The findings suggested that any deterioration of soil water resources after deforestation in the study area could be caused by the shift of land cover from forest to cultivated land rather than to a specific type of successive vegetation like oil palm.

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