The role of oil palm biomass recycling on soil health in oil palm plantations

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Abstract. Oil palm cultivation produces a massive amount of biomass (e.g., empty fruit bunches (EFB), frond and trunk) which could be recycled directly in the plantation to maintain/improve the quality of soils. The impact of this biomass recycling, i.e., EFB and frond, - in term of chemical, physical and biological characteristics, will be analyzed. The fresh application of the EFB could alternate most of the soil parameters in line with the kinetics of the decomposition of the EFB and the release of nutrients. For example, the pH of the soil after the EFB application was higher during more than 18 months compared to the initial situation. Soil exchangeable potassium increased dramatically within a few days after EFB spreading. Frond recycling, at harvesting and pruning, modifies the chemical and physical characteristics of soils whether they were applied on heaps between palms in dedicated inter-rows, or spread on harvesting paths where they could reduce run-off and erosion. The systematic distribution of fronds in inter-rows reduced rainwater run-off by more than 30%, even on 5% gentle slopes. Subsequently, soil loss through erosion was reduced by 65% depending on the slope intensity of the terrain. Consequently, the loss of nutrients was considerably reduced, resulting in higher fertilizer efficiency. Similar measurements have been done when applying fresh EFB to the soil. The impact on soil physical fertility, i.e., rainwater infiltration rate and subsequently soil humidity are improved. We have also recorded a reduction of the soil resistance to penetration, as well as an improvement of the soil aggregate stability. Several representative parameters of soil biological activity, i.e., soil fauna feeding activity using bait-lamina test system and earthworm’ population showed the positive impact of EFB applications as well as frond spreading in inter-rows.

1. Introduction

Thousands of years ago, before the development of agriculture, the soil was considered merely physical support for crops. With the development of modern agriculture, a wider role for soil has emerged. A greater interest in soil has been associated with the discovery of the role nutrients and water play in growth and development, and subsequently their intensive use as part of the development of intensive agriculture in the middle of the 20th century, required to meet exponential population growth. This transformation, later called ‘the Green Revolution’ in agriculture after the Second World War, was based on extensive use of ploughing of soil, an-organic fertilizers and irrigation, combined with the high-yielding cultivars. Concerns to reduce a perceived over-reliance on fertilizers lead to a new interest in soil health. This new understanding of the role and importance of soil has led to the development of new soil management systems required to achieve sustainable agriculture. It is not surprising that the Food
and Agriculture Organization of the United Nations (FAO) declared 2016 the year of soils, and 2015-24 the decade of soils [1].

Soils contribute to disease and pest control, as well as carbon sequestration and storage. They are home to microorganisms that contribute to plant health and regulate nutrient availability and to the decomposition and mineralization of organic residues and waste. Soil fertility was recognized as a key factor for plant growth, while soil degradation, such as erosion, undermines ecosystem services and biomes [2], [3].

The oil palm is a heavy feeder and requires a quite large quantity of fertilizers to achieve its potential yield [4]. Every tonne of crude palm oil produced generates by way of by-product, one tonne of empty fruit bunches (EFB). In the last decade, an increasing number of planters have been considering the utilization of EFB as a means of reducing mineral fertilizer inputs while improving soil fertility [5]. The decomposition of EFB in the soil is facilitated by soil faunas and microorganisms [6].

An important way of reducing costs in the industry is to improve the efficiency of use of the fertilizer applied. Part of the loss cannot be regained if it is in run-off, erosion, leaching and volatilisation, and this must be minimized [7]. Land cover crops play an important role in influencing erosion. Cover crops provide protection against the destruction of soil aggregates by rain and run-off. The soil conservation techniques in oil palm cultivation can reduce the rate of surface run-off, soil erosion and nutrient loss [8].

The objectives of this study were to study and quantify the impact of biomass recycling (e.g., EFB and frond) on soil health (chemical, physical and biological characteristics) under oil palm plantation.

2. Materials and methods

The experiment was conducted in a mature oil palm plantation planted in 1989, located in Riau (Sumatra-Indonesia). The soil type was a typic dystropept, with a sandy loam texture. There are several methods to observe the impact of biomass recycling to maintain the quality of soils:

2.1. Physical characteristics

In this study, we used a penetrometer to measure the soil compaction (presented in penetration resistance value) until ± 80 cm of soil depth. The distribution of water content (humidity) in the soil were measured every 10 cm soil depth until 20 cm soil depth using Gravimetry method. These observations carried out in with and without EFB application. To quantify the volume of water run-off and soil erosion, we were installed erosion plot. Each plot covered 18 m x 18 m of the area and included four palms. Each plot was isolated from outside water run-off intrusion by a 20-cm high wall built with bricks. The amounts of run-off water and soil eroded were collected in a series of 200-liter plastic drums after each rainfall event.

2.2. Chemical characteristics

In this study, we collected water and soil eroded samples from erosion plot to quantify the impact of biomass recycling on nutrient losses (e.g., Nitrogen, Phosphorus, Potassium, Total organic carbon and soil C-organic). The impact of EFB application to maintain the soil quality was observed with soil sampling until ± 60 cm soil depth for soil pH (using H2O method), soil K-exchangeable and soil Al-exchangeable. While, for soil C-organic and soil base saturation, the soil sampling until ± 160 cm soil depth.

2.3. Biological characteristics

In this study, we used bait-lamina method and soil macrofauna samplings (earthworm and soil insect) for assessing the soil fauna feeding activity and macrofauna abundance in the soil as the impact of various slopes and agriculture practices to the biological soil properties. Bait-lamina stick is thin PVC strips (1 mm x 6 mm x 160 mm) with 16 apertures (1.5 mm diameter) bored at 3 mm intervals. The apertures filled with standard bait, containing cellulose powder, bran flakes and activated carbon (70:27:3). The test was based on visual assessment of the feeding portion of laminated bait substrate.
exposed (empty holes indicate some biological activities in the soil). A matrix of six baits lamina sticks inserted vertically and randomly into the soil on three management zones (circle, harvesting path, and windrow) each sticks about 20 cm apart. The sticks were inserted until the top aperture was just below the soil surface (± 1 mm) and baits exposed for 6 days. Each aperture was recorded as zero (without perforation) and one (partial or complete perforation). To calculate the rate of feeding activity per bait, the number of holes (partial or complete hole) counted then divided by 16 (the total number of holes per bait). Therefore the minimum score will be 0%, and the maximum will be 100%. A Tropical Soil Biology and Fertility (TSBF) method used to assess the macrofauna abundance in the soil. A square of 25 cm x 25 cm x 10 cm randomly placed in the soil, then dig the soil in 10 cm depth and put the soil into closed bag. The macro-invertebrates defined as the fauna larger than 2 mm in body length, were collected by hand sorting. The major taxa of macrofauna such as Formicidae, earthworms, Diptera, Dermaptera, Coleoptera, Isopoda, Myriapoda, Chilopoda, Diplopoda, Blattaria, Aranea extracted from the soil using grips and stored in tubes containing 70% alcohol.

Statistical analysis: The analysis of variance was used to compare the effect of each treatment; whereas treatment means were compared, using Tukey test at P ≤ 0.05 with SPSS software.

3. Results and discussion

The results on the impact of this biomass recycling, mainly the EFB, applied fresh from the mill or after composting, but also of the fronds, on several components of soil health, i.e. the chemical, physical and biological characteristics.

EFB fresh applications modify most of the soil parameters with specific patterns in line with the kinetics of the decomposition of the EFB and the release of nutrients. For example, the pH of the soil after the EFB application was higher during more than 18 months compared to the initial situation. Soil exchangeable potassium increased dramatically within a few days after EFB spreading. Figure 1 indicates that the application of EFB tends to increase pH mainly in the upper layer of soil. The impact of EFB on soil pH is observed until about 30 cm of soil depth. The application of EFB increases soil pH from 5.0 (acid) to 7.0 (neutral) after 21 days of application in 0-5 cm soil upper layer and becomes 7.2 after 90 days application. The rise soil pH is observed until 120 days after application and tends to decrease after this period. The application of EFB also increases the soil K-exchangeable significantly, mainly in the upper layer of soil (0-6 cm) and reduces the soil Al-exchangeable during decomposition.

![Figure 1](image1.png)

**Figure 1.** Dynamic of soil pH (H₂O method), K\textsubscript{exch}, and Al\textsubscript{exch} during EFB decomposition according to soil depth under EFB

The application of EFB gives slightly higher on soil C-organic content mainly in the upper soil layer. The observation also indicates that the concentration of C-organic in upper layer soil is higher than in the lower layer, which may relate with the relatively high organic source in this area (root, leaf, etc.). The application of EFB increases the average of soil base saturation significantly mainly in the soil upper layer until about 75 cm depth. The increase of this value may relate with the release of basic cations such as K, Mg, and Ca from EFB during its decomposition (figure 2).

![Figure 2](image2.png)
The impact on soil physical fertility, for example, rainwater infiltration rate and subsequently soil humidity are improved. We have also recorded a reduction of the soil resistance to penetration, as well as an improvement of the soil aggregate stability. The observation indicates that the application of EFB affects the distribution of water content (humidity) mainly in the upper soil layer. In an area with EFB application, the distribution of soil water content is relatively continuous along soil depth; while in soil without EFB application (control site), the distribution of water content is discontinuous. In an area with EFB application, the humidity of soil in the upper layer tends to decrease smoothly with soil depth. During wet condition (after rainfall), the difference of humidity between upper and lower soil layer increases; and this gap of difference decreases during dry condition, but the humidity of soil in the upper layer is still higher than the lower layer (figure 3).

The soil compaction (presented in penetration resistance value) is relatively equal in area with and without EFB application during the initial condition (before EFB application). The application of EFB tends to reduce the value of soil compaction. This decrease is more intense in the upper soil layer. Our observation indicates that the ratio value between soil compaction with EFB application compared to control after 1-month application decreases on 0-10 cm soil depth. After 3 months of application, the decrease of soil compaction increases until 40 cm soil depth. The decrease of penetration resistance observed in the area with EFB application may mainly relate to the higher soil humidity in the soil as mentioned earlier. This decrease is more intense in the upper layer since the humidity is higher. In fact, the value of soil compaction (penetration resistance) is a physical characteristic of soil relating to other physical soil characteristics such as moisture content, bulk density, soil structure, soil texture and
organic matter content. The application of EFB may increase soil moisture content, reduces bulk density, improves soil structure and increases organic matter content. Hence, the application of this organic matter may undoubtedly reduce the soil compaction and facilitates the development of root mainly in the upper soil layer (figure 4).

Figure 4. Soil penetration resistance in initial condition (A), after 32 days (B) and after 115 days of EFB application (C)

Frond recycling, at harvesting and pruning, modifies the chemical and physical characteristics of soils whether they were applied on heaps between palms in dedicated inter-rows, or whether they were spread on harvesting paths where they could reduce run-off and erosion. These impacts have also been quantified in our field experiment: the systematic distribution of fronds in inter-rows reduced rainwater run-off by more than 30%, even on 5% gentle slopes. Subsequently, soil loss through erosion was reduced by 65% depending on the slope intensity of the terrain (figure 5). This shows the importance of ground cover because it can furnish run-off and erosion protection in several ways such as: protection of soil surface against disruptive action of falling raindrops, offer resistance to moving water and slows down its rate of run-off, the plant roots also help to hold the soil in place. The plant roots and crop residues help to improve soil structure which makes it more porous and better able to absorb rainfall [9]. Land cover crops play an important role in influencing erosion. Cover crops provide protection against the destruction of soil aggregates by rain and run-off.

Figure 5. Soil Ground Cover Management Effect of Biomass Recycling on Water Run-off and Soil Erosion

Nutrient losses can be expressed as concentration in the soil solution that lost as dissolved forms in water run-off, or the sediment carried in run-off water, and these losses are affected by soil type, cover and fertility; slope of the terrain; amount, method and time of fertilizers application; intensity, amount
and moment of occurrence of rainfall [10]; as well as by soil management practices [11]. Consequently, the loss of nutrients was considerably reduced, resulting in higher fertilizer efficiency. The effect of biomass recycling such as fronds can reduce the nutrient losses for nitrogen about 72% and 70%, for phosphorus about 54% and 48%, for potassium about 58% and 70% for 5% and 15% respectively compared to the standard soil cover. Similar measurements have been done when applying fresh EFB to the soil (figure 6). The result also indicated that the average of total net nutrient losses increased with the slope and the impact of the slope is more intense in bare soil (BS) than the others treatment.

**Figure 6.** Soil Ground Cover Management Effect of Biomass Recycling on Nitrogen, Phosphorus and Potassium Losses

Besides nitrogen, phosphorus and potassium; fronds and EFB can reduce the total organic carbon from water run-off and soil eroded about 57% and 24% for 5% and 15% respectively compared to the standard soil cover as shown in figure 7.

**Figure 7.** Soil Ground Cover Management Effect of Biomass Recycling on Total organic carbon losses, Organic carbon in soil eroded and Total organic carbon in water run-off

Several representative parameters of soil biological activity have been recorded. Soil fauna feeding activity using bait-lamina test system, insect and earthworm’ population showed the positive impact of EFB applications as well as frond spreading in inter-rows (figure 8). The feeding activity, soil insect and earthworm abundance in harvesting path, in the soil under applied organic material, showed a higher result compared to the bare soil and standard soil cover. In this study, we found that the addition of organic material has an impact on soil biological property (soil fauna feeding activity as one of the biological soil indicator). The soil fauna was dominantly found in the upper soil layer; this might affect the depth distribution of soil fauna feeding activity [12].
Figure 8. Effect of Biomass Recycling on Harvesting Path to Soil Fauna Feeding Activity, Soil Insect and Earthworm Abundance

This result showed that there might be a relationship between the organic material and soil macrofauna abundance, this result expected that the organic material provides food for the soil macrofauna, for example, earthworm. The earthworm is one of the examples of soil macrofauna, which affects the dynamics of changes of organic matter in the soil, as they decomposed the bigger fragments of organic material and turned in to cast (smaller fragments). Soil fauna feeding activity has a positive correlation with the earthworm and soil insect abundance. This result was linked with the observations made by reference [12] that bait perforation was not found when only mesofauna (such as collembolans) was present but seemed to be dependent on medium and large fauna like earthworms.

4. Conclusion
In this study, we found that the application of EFB gives a significant effect on chemical soil characteristic such as soil pH mainly in 0-30 cm layer, C-organic, K-exchangeable, Al-exchangeable and base saturation. The increase of base saturation was observed until 75 cm soil depth. The existence of EFB can maintain soil moisture content and reduce soil compaction mainly in the upper layer. The effect of slope on water run-off, soil erosion and nutrient losses could be minimized using addition application EFB or Frond on the surface of the soil. The addition organic material such as EFB and frond increased the value of soil fauna feeding activity, the earthworm, and soil insect abundance.

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