Research Article

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Shifting of microbial biodiversity and soil health in rhizomicrobiome of natural forest and agricultural soil

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Abstract: Intensive agricultural practices and heavy use of inorganic fertilizers have significantly accelerated soil degradation. Mineralization of the organic matter of soil affects soil health and the abundance of soil beneficial microbes (SBMs) and its dynamics in the soil. The research to investigate the shifting of microbial population and the soil health was conducted in natural forest, agricultural, and degraded ecosystems. The research setting involved randomized block design consisting of six ecosystems, namely, natural forest, agricultural soil (oil palm: 10, 9, 8, and 7 years old), and degraded soils. The soil samples were taken with four replications from rhizomicrobiome of each land use. In the soil health analysis, it was understood that soil beneficial microbes (SBMs) consist of total bacteria, phosphate-solubilizing bacteria, nitrogen-fixing bacteria, total actinomycetes, and total fungi. The results showed that natural forest, oil palm plantation, and degraded land demonstrated a significant effect on the changes in biodiversity of SBM in rhizomicrobiome. The highest population of SBMs was in natural forest followed by the 10-year-old oil palm plantations and the lowest was recorded in degraded soils. These results confirm that the shift of forest ecosystems to agricultural soils will accelerate the degradation and decline of soil health.

Keywords: degraded ecosystem, microbial biodiversity, natural forest, oil palm plantation, soil health

1 Introduction

Natural forest areas in Indonesia are in critical condition and decreasing continually as a consequence of land conversion to agricultural soils and other uses. Natural forest can be defined as a land of more than 6.25 ha with vegetation height above 5 m and canopies more than 30% (Sasaki and Putz 2009). In Indonesia, the natural forest areas decreased from 98.7 million ha in 2011 to become 93.52 million ha in 2018 (Central Bureau of Statistics Indonesia 2019). However, oil palm plantation increased from 8.57 million ha in 2015 with a total production of 31.07 million ton to 8.83 million ha in 2016, with a total production of 33.23 million ton (Austin et al. 2017). Agricultural practice in oil palm plantation might decrease the soil quality and the abundance of SBMs. Oil palms require higher nutrients such as 1,162 kg Nitrogen ha−1, 124 Phosphor kg ha−1, and 1,673 kg Potassium ha−1, compared to rubber plantation 60 kg Nitrogen ha−1, 60 kg Phosphor ha−1, and 40 kg Potassium ha−1 (Tarmizi and Tayeb 2006; Mandal et al. 2015). Consequently, this condition makes oil palm plantation highly depend on inorganic fertilizer. Intensive use of inorganic fertilizer accelerates the carbon mineralization and disturbs soil nutrient cycle which in turn decreases soil chemical
quality (Kanchan et al. 2018). It also decreases soil physical quality due to soil compaction that alters the soil structure by combining aggregates into larger units, increasing bulk density, and decreasing the number of coarse pores that hamper root growth (García-Tomillo et al. 2017) and also soil microbial growth (Florin and Allen 2019).

Most of the land in East Kalimantan are dominated by Ultisol with low soil fertility, which is used for oil palm with various limiting factors such as poor content of organic material that decreases soil health (Sudaryono 2016). The decrease in soil health indicates the decreasing soil microbial biodiversity in rhizomicrobiome. Rhizomicrobiome consists of SBMs that interact with the vegetation and forms an external digestive system, and it has a great role in the nutrient cycle to support vegetation growth in the ecosystem (Lemanceau et al. 2007; Mendes et al. 2013; Zeh et al. 2019). Soil microbial biodiversity in rhizomicrobiome consists of bacteria, fungi, and actinomycetes (Zeh et al. 2019). Fungi has ability to decompose complex organic matter into simple organic matter, that would be process further by bacteria become mineral (nutrients for the plant). Meanwhile, actinomycetes can degrade solid polymers such as cellulose to disaccharides and monosaccharides, which function as the sources of energy for bacteria (Bonfante and Anca 2009). This study focused to evaluate the soil health and the richness of soil microbial population due to the conversion of natural forest to oil palm plantation (agriculture soil).

2 Materials and methods

This research was conducted at the Kalianusa Oil Palm Plantation, with a natural forest close to it, and degraded land is also located near the oil palm plantation in North Sangatta, East Kalimantan. The study was conducted from August 2018 to January 2019 (Table 1). Natural forest is defined as a mature natural humid tropical forest that has not been completely cleared and regrown in the recent history, with most vegetation taller than 5 m in height with 30% minimum tree cover density excluding tree cover within the mapped tree plantations. Oil palm plantation (consisting of 10-, 9-, 8-, and 7-year-old plantations) is defined as an area converted from natural forest. Degraded land is defined as an area that has been left after shifting cultivation with less vegetation fractional coverage ([VFC] < 46%). The altitude of the research location was around 100 m above sea level (masl) with B-type climate based on Schmidt and Ferguson (Irfan 2006; Sasminto et al. 2014) with a Q value of 14.3–33.3% and an annual rainfall of 2,488 mm/year. Based on 2014 USDA soil taxonomy (Soil Survey Staff 2014) compared to soil field and laboratory analysis all ecosystem soil are categorized as Ultisols (argillic horizon with cation exchange capacity of less than 35% and B horizon slightly acidic). Soil samples were collected from rhizosphere (0–10 cm), palm oil plantation (four plantations), degraded land, and natural forest with a soil auger and stored in a cool box (Novitasari et al. 2014).

Soil health was determined using soil health assessment based on Simarmata et al. (2019), which consists of soil physics (texture, aggregates stability, soil infiltration, soil color, soil strength, and effective depth); soil chemistry (soil organic matter [SOM], soil pH, salinity) and soil biology (VFC, amount of root, and earthworm populations). Six ecosystems were categorized into unhealthy (10–30), moderate (31–60), and healthy (61–90) ecosystems based on the soil quality (Table 2).

Soil health analysis was achieved using soil physics indicators such as texture, soil aggregate stability, soil infiltration, soil color, soil strength, and effective depth. Soil texture analysis was performed using the jar method by mixing soil and water 1:1, then shacked for 60 min, and scored based on the layer thickness. The stability of aggregates was measured by soaking soil aggregates in a glass of water and scored based on dispersion. Soil infiltration was analyzed by immersing 2 cm ring (5.08 cm diameter and 4 cm high) from topsoil, then the rings were filled with water, and scored based on infiltration time. Soil color measurement was done by using soil Munsell color chart. The effective depth of the soil was measured by detecting the presence of roots.

Chemical indicators such as SOM, soil pH, and soil salinity were also used in this research. SOM was analyzed by destruction method using 10% hydrogen peroxide in 1:1 ratio and then scored by using foaming time as an indicator. Soil pH was analyzed by using a pH meter. Soil salinity was analyzed using an EC meter which is inserted into the suspension of soil and water in 1:5 ratio.

### Table 1: Ecosystems location

| Ecosystem location | Coordinates       |
|--------------------|-------------------|
| Natural forest     | 0°68′59.4″N 117°E28.2″ |
| 10-year-old plantation | 0°66′78.7″N 117°E27′35.5″ |
| 9-year-old plantation | 0°67′35.8″N 117°E24′47.3″ |
| 8-year-old plantation | 0°67′95.1″N 117°E22′62.0″ |
| 7-year-old plantation | 0°69′24.4″N 117°E21′71.2″ |
| Degraded land      | 0°69′98.0″N 117°E27′24.1″ |
Biological indicators of soil health analysis consist of VFC, large roots, and earthworm populations. VFC was analyzed using $15 \times 15$ cm$^2$ quadrant thrown randomly and then calculated based on the percentage of quadrant that was covered up by plants. Earthworm population was calculated by counting the total earthworm inside the soil sample that was taken by the same quadrant and scored based on soil health field analysis.

Isolation of soil microbes for SBM biodiversity was carried out using the total plate count (TPC) technique. Soil sample of 20 g was added to a test tube containing 180 mL of physiological NaCl (0.85%) and diluted until $1 \times 10^{-8}$ and then 0.2 mL solution was taken out from $10^{-5}$, $10^{-6}$, and $10^{-7}$ dilution, respectively, for phosphate-solubilizing bacteria (PSB), nitrogen-fixing bacteria (NFB), and total microbial and then cultured using Pikovskaya, Ashby, and NA; 0.5 mL solution was taken from $10^{-3}$ to $10^{-4}$ dilution for total fungi and then cultured using PDA; and 0.2 mL solution was taken from $10^{-5}$ and $10^{-6}$ dilution for actinomycetes and then cultured using yeast extract media, which is a medium with sufficiently low nutrient content and is ideal for the isolation of actinomycetes (Crawford et al. 1993). That isolation process was performed in four replications. After obtaining the culture results of each sample from all replications, the samples were then observed 7 days after dilution for fungi and bacteria and 3–10 days after dilution for actinomycetes (Kanti 2005). TPC results are processed into data in the form of colony-forming unit per gram.

Soil field was analyzed and scored based on the criteria of soil health field analysis. While the SBMs were analyzed using two-way analysis of variance, the analysis was continued using Duncan multiple range test with $\alpha = 0.05$ using SPSS 25. The data of SBMs were normalized by logarithmic transformation before the analysis.

### 3 Results

#### 3.1 Soil health analysis

Tables 2–4 showed that natural forests, oil palm plants, and degraded lands have different soil health categories based on the soil health analysis method (Simarmata et al. 2019). The entire ecosystem has a silty clay texture and is following the results of the initial soil laboratory analysis. Natural forest ecosystems have dark brown soil, oil palm plantations have brown soil, except for the 9-year-old plantations, whose soil are of bright brown, and the
degraded land possesses brown soil which indicate the difference in SOM visually for each ecosystem. Table 5 demonstrates that different land use might cause changes in soil health.

### 3.2 Soil beneficial microbial biodiversity

Table 6 shows that the natural forest ecosystem has the highest rhizobiome. Natural forest has 4.7 times higher total bacteria, 6 times higher PSB, 2.3 times NFB, 7.9 times total actinomycetes, and 7.3 times total fungi compared to the degraded land. While the 10-year-old plantations have 2.7 times higher total bacteria, 6.1 times higher PSB, 17 times higher NFB, 5.6 times higher total actinomycetes, and 4 times higher total fungi compared to the degraded land. Table 6 shows an increasing trend of rhizobiome abundance along with increased oil palm plantation age.

### 4 Discussion

#### 4.1 Soil health analysis

Ecosystem difference such as natural forest and cultivated land affects the level of soil strength. The level of soil strength ranges from 1 to 5 categorized as unhealthy to moderate, soils with high soil strength or small scores will be more difficult to be penetrated by plant roots. This condition accordance with an effective depth of plant roots with a score of 1–9 which is categorized as unhealthy to healthy and (Simarmata et al. 2019).

The highest organic matter content is found in natural forest ecosystems and the lowest is in 9-year-old plantation categorized as unhealthy to healthy. The difference in land use such as natural forests and oil palm plantations affects soil pH, with the highest pH of 6.38 found in natural forest ecosystems and the lowest pH of 5.2 in 7-year-old oil palm plantations with a value of. The soil pH analysis demonstrated different values in the field and the laboratory results because the tools used in the laboratory have a higher degree of accuracy. Salinity in natural forest ecosystems, oil palms, and degraded lands was between 0.018 and 0.089 µS/cm which is categorized as healthy and nonsaline. VFC in the analyzed land is between 20 and 87.5%, which directly influences the distribution of SOM and soil microbial activity (Paul 2016).
Natural forest has a healthy soil quality score of 86.11 because it has a sustainable nutrient cycle performed by rhizomicrobiome that plays an important role in the nutrient cycle (Mendes et al. 2013). Land use for oil palm plantations with intensive use of inorganic fertilizers might result in decreased soil health compared to the soil health in natural forest because the lack of organic matter input and the use of inorganic nitrogen fertilizer could accelerate SOM decomposition which is important as a carbon source for rhizomicrobiome (Phillips et al. 2011). Also, the continuous application of inorganic fertilizers can cause a decrease in soil fertility due to the accumulation of residues, which causes the soil to become saturated (Rakhmawati et al. 2017). In addition to residues, years of intensive land use for crop cultivation can reduce the chemical and biological fertility of soils (Van Bruggen and Termorshuizen 2003). The decline in chemical and biological fertility is due to the decrease in SOM, which can reduce rhizomicrobiome (Cardoso et al. 2013). The oil palm plantation has moderate soil health score of between 42.2 and 51.1.

Degraded land was categorized as unhealthy with a soil score of 30.00. Degraded land is defined as the land that has several limiting factors if it is used for agricultural purpose (Sohng et al. 2017). Degraded land in Kalimantan is formed by shifting cultivation and parent material that has already decomposed (Husnain et al. 2014). Low nutrient reserves in degraded soils cause lack of vegetation coverage by only 20%. The lack of vegetation coverage in degraded land compared to natural forest which has 85% vegetation coverage lead to the lack of organic matter which is a source of carbon for SBMs.

### 4.2 Soil beneficial microbial biodiversity

The natural forest ecosystem possesses the highest rhizomicrobiome because natural forests have the highest SOM and also higher diversity and dense vegetation compared to other ecosystems. Therefore, plant residues and exudate might be higher than oil palm plantation and degrade land as they possess carbon sources for rhizomicrobiome microbes. The increasing content of organic matter as a food supply or energy in the soil will increase the growth of microbial populations which will then increase the microbial activity in the soil (Murphy 2014). Increased soil microbial activity will also increase the decomposition and reactions that require microbial assistance, for example, phosphate dissolution and nitrogen fixation (Mori et al. 2018).

Rhizomicrobiome in natural forests is also affected by dense vegetation and vegetation age. Vegetation in natural forests is dominated by Dipterocarpaceae which is a family of plants including wood-producing trees. This condition results in higher root exudates compared to oil palm ecosystem which has lower density plant population because of planting distance. This is related because the plant age correlates with the root exudate content produced by plants as a source of carbon for soil microbes. Increased plant age will result in increased root exudate produced by plant roots (Chaparro et al. 2014). Degraded land has the lowest rhizomicrobiome microbial population compared to other ecosystems. This is caused by the lack of vegetation on degraded soils which have the lowest organic content.

The population of NFB decreased in 7- to 9-year-old oil palm plantation but increased again in 10-year-old oil palm plantations. The decline in the population of NFB occurred due to the intensive input of urea fertilizer. Excess inorganic fertilizer with the main content of nitrogen in the soil will cause NFB to be inactive in nitrogen fixing (Chhogyel et al. 2015). Plantations of 10-year-old had the highest total actinomycetes population, while the total actinomycetes population in 7- to 9-year-old declines. This condition is influenced by the amount of oil palm residues such as empty fruit bunches, oil palm fronds, and oil palm flowers that contain lignin.
Organic matter containing lignin will affect actinomycetes population in the soil because actinomycetes can degrade lignin and cellulose into simple compounds in the form of glucose which are useful for other soil organisms (Widyatyi 2013). Oil palm plantations of 7- to 9-year-old had a qualitatively less residual litter in the canopy area compared to the 10-year-old plantation, as a result of the cultivation process, therefore, affecting the availability of lignin and also affecting the total abundance of actinomycetes.

5 Conclusion

The change in land use of forest soils from natural ecosystem to agricultural land affected the soil health and biodiversity of beneficial microbes in rhizomicrobiome. The lowest soil health and abundance of soil microbe population resulted in degraded ecosystem (unhealthy soils). Natural forest has the highest rhizomicrobiome abundance followed by oil palm plantation. Natural forest has about 4.7 times higher total bacteria, 6 times higher PSB, 2.3 times NFB, 7.9 times total actinomycetes, and 7.3 times total fungi compared to degraded land. While the 10-year-old plantation has 2.7 times higher total bacteria, 6.1 times higher PSB, 17 times higher NFB, 5.6 times higher total actinomycetes, and 4 times higher total fungi compared to degraded land. In addition, the increasing trend of microbial abundance in rhizomicrobiome is in line with increased oil palm age. This result showed that the change of natural forest ecosystem into agricultural soils could affect soil health and the abundance of SBMs in soils.

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Data availability statement: All data generated or analyzed during this study are included in this published article.

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