Oil palm plantation in ex-coal mined site: A case study in East Kalimantan, Indonesia

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Abstract. The oil palm plantation in the ex-coal area is new hope for renewable energy. Oil palm is also known as an important source of raw material for many products and the plantation area is expanding. Mine reclamation area may be suitable for oil palm but there are challenges for its development. This study aims to determine the land suitability of the ex-coal mined site for oil palm and evaluate the growth and yield compared to the plantation in commercial cultivation from the previous studies. The study in a coal mine company in Indonesia used soil quality, rainfall, vegetation growth and yield production data in 4, 5, 6 and 7-year-old plantations. The result showed that the ex-coal mined site referred to S2 or suitable with limited factors in the 7-year-old plantation area, while S3 or marginal soil in other areas. The soil mostly had low nitrogen content and cation exchange capacity as if the initial condition before mining and required additional manure and nitrogen fertilizer. Water management was required due to the sandy loam texture in the 4-year-old plantation area to protect water availability by the silt pit or cover crops, especially in the dry season. The plant height showed a positive correlation to the land suitability, although the plant height was far lower than in commercial cultivation. The yield production also confirmed a rapid increase after castration in 2019 for 4, 5 and 7-year-old plantation areas. The findings are useful for considering potential plant species of choice in the ex-coal area.

1. Introduction
A high demand of coal mine reclamation management has been an issue for a decade. Large disturbed area is expected to be productive land after mine-out. Therefore, some models have been developed and proposed for the mine closure plan considering protecting local conditions including natural and social conditions. Coal mine land had potential to be a new resource of economy for the long term after closure such as cultivation [1]. Many products have been planted regarding the stakeholder’s demand mainly from community around the site as well as rubber (Hevea brasiliensis), cajuput (Melaleuca cajuputi) crops, and even for biofuel product such as oil palm (Elaeis guineensis) and Ricinus communis.

As renewable energy has been expanded to achieve the national energy mixture target, oil palm becomes popular and continues to thrive in Sumatera, Kalimantan and Papua. Although there was a shifting of new oil palm growing in 2010-2015 in non-forest areas, deforestation may occur in the future especially in Kalimantan and Papua [2]. This business not only attracts in the company scale but also
small-scale farmers who planted more than 42% area of oil palm in 2013 [3]. Moreover, small scale farmers impacted the increasing open land for oil palm independently [4].

The ex-mined reclamation and oil palm catch stakeholders’ interest. Some communities around the mine site propose its plantation in an ex-coal mined area with the expectation to establish the sustainability for local economy and decrease the new direct clearing of forest. Nevertheless, this concept requires soil improvement since the ex-mined land is degraded. The soil in the ex-coal mine site had lower pH and nutrients such as organic carbon and total nitrogen [5]. Therefore, cultivation requires strategy to achieve maximum yield by land suitability evaluation and growth monitoring. This study aims to determine the land suitability of ex-coal mined sites for oil palm plantation and evaluate the growth and yield compared to plantation in undisturbed land, especially mining from the previous studies.

2. Material and Methods

2.1. Study area
This study was performed in PT Gunungbayan Pratama Coal, East Kalimantan Province, Indonesia. The concession of the coal mining site is in a non-forest area which has a suitable model of mine closure to develop regarding the local spatial plan. Open-pit mining was used to extract the coal and left a large disturbed area. The stakeholders proposed oil palm cultivation for the reclamation program considering the farmers’ willingness. The oil palm plantation started planting in 2014 to 2019 in 300 ha. As part of the mine reclamation program, oil palm is required to meet the reclamation success based on regulation before being handled by farmers.

2.2. Data and methods
This study used the monitoring data of oil palm growth from 2017-2021. The blocks were classified by planting year: 2014, 2015, 2016 and 2017. The land suitability analysis used the soil quality and rainfall data. The soil quality data was taken before planting in 5 plots for planting year: 2014 (1 plot), 2015 (1 plot), 2016 (1 plots), and 2017 (2 plots) which measured texture, total nitrogen, organic carbon, pH, CEC and base saturation. The rainfall data was taken from 2016 to 2020. The soil quality data was compared to the land suitability assessment guideline provided by the Indonesian Ministry of Agriculture [6, 7].

The vegetation growth monitoring was measured in 11 plots: 2014 (3 plots), 2015 (2 plots), 2016 (1 plots) and 2017 (5 plots). The plot design was square plot with radius 50 m in each point and the plant spacing of 8 m x 9 m. The growth parameters were diameter, height and fruit bunch weight. The vegetation growth monitoring was analysed by statistic descriptive using Statistica 13 to determine the correlation between each parameter and time.

3. Result and Discussion

3.1. Land suitability
The expansion of ex-mined reclamation for agriculture has been implemented in Indonesia regarding the sustainable land [8] despite the barren land. Open pit mining impacts the soil characteristic alteration and decreases the fertility. Topsoil of ex-coal mined land in South Kalimantan tends to have low to very low chemical properties such as pH, organic carbon, cation exchange capacity (CEC) and base saturation [9]. The land clearing causes the decline of chemical characteristics such as organic carbon [10]. Soil management in surface mining is a key for revegetation success after post mining.

The initial pH and CEC in the study area were low to very low (pH of 4.14 – 5.24; CEC of 2.35 – 8.91 meq/100 g) before land clearing [11]. The soil was treated to avoid the mixture with the overburden from the soil stripping and spread directly in the reclamation area or dumped in the soil bank.

For mine reclamation purposes, soil quality tests were conducted to measure the characteristics of soil. The soil quality data was taken in 5 random plots for planting year: 2014 (1 plot), 2015 (1 plot),
2016 (1 plots), and 2017 (2 plots). The land suitability assessment consists of 4 classifications: S1 (very suitable), S2 (suitable), S3 (marginal), and N (not suitable). In general, water availability in oil palm plantations was adequate (S1) since the average rainfall was 2,930 mm per year and the average dry month was 1 month per year (table 1). Therefore, the water conservation had to be prepared approximately during the dry month in July to September. The implementation of bund terrace and retarded-water hole was not only succeeded to provide the water but also to increase the yield [12].

Plot 2014 was classified as suitable (S2na.nr) and had potential to upgrade the classification to S1 through strategy to improve total nitrogen and CEC. Nitrogen has an important role in the growth and production [13]. The addition of chicken manure escalated the nitrogen in ex-mined land [14]. In the oil palm case, the effect of nitrogen fertilizer amendment increased the height, frond length, leaf area and stem circumference for 1 to 3 year after plantation (YAP) which the dosage of amendment was required to increase due to the age [15]. Besides nitrogen, CEC has a positive correlation to bunch production per oil palm plant [16]. Application of organic matter amendment increases CEC [17]. Its application in clay soil in Plot 2014 tends to succeed to increase CEC since clay content also influences the CEC [18]. Plot 2015 and 2016 had similar soil characteristics (S3.na.nr), a condition under Plot 2014 with the same problems. Those extensification strategies may upgrade the land suitability status one class upper, Plot 2014 can be elevated to S1 while Plot 2015 and 2016 can be elevated to S2.

**Table 1.** Soil quality assessment based on criteria for oil palm.

| Parameter                        | 2014 | 2015 | Planting Year | 2016 | 2017 | 2017 |
|----------------------------------|------|------|---------------|------|------|------|
| Water availability (wa)          |      |      |               |      |      |      |
| Rainfall                         | S1   | S1   | S1            | S1   | S1   |      |
| Dry month                        | S1   | S1   | S1            | S1   | S1   |      |
| Root characteristic (rc)         |      |      |               |      |      |      |
| Texture                          | S1   | S1   | S2            | S3   | S3   |      |
| Nutrient availability (na)       |      |      |               |      |      |      |
| Total nitrogen                   | S2   | S3   | S3            | S3   | S3   |      |
| Nutrient retention (nr)          |      |      |               |      |      |      |
| Organic carbon                   | S1   | S2   | S2            | S2   | S2   |      |
| pH H2O                           | S1   | S1   | S1            | S2   | S2   |      |
| CEC                              | S2   | S3   | S3            | S3   | S3   | S2   |
| Base saturation                  | S1   | S1   | S1            | S2   | S2   | S2   |
| Result                           | S2na.nr | S3na.nr | S3na.nr | S3rc.na.nr | S3rc.na |

Plot 2017 had additional problems in soil texture (S3rc), sandy loam. The nutrient availability and retention may be improved but the soil texture is a limited factor. The additional 50 ton per ha per month of manure in oil palm plants resulted in an insignificant effect to CEC increment in sandy soil [19]. The soil chemical properties had no impact on bunch weight in sandy soil [16].

3.2. *Vegetation growth*

The height of oil palm showed increment every year (figure 1) with the mean plant height growth of all plots was 23 cm per year. The plant height increases 25-100 cm per year with the maximum height being 18 m in the plantation [20]. The growth of oil palm on ex-mined land came up the standard in the plantation from undisturbed land. The ex-mined land showed the opportunity to be expanded as the oil palm plantation as renewable energy farming and deforestation reduction.
Figure 1. The plant height of all plots in different monitoring period (a) Plot 2014; (b) Plot 2015; (c) Plot 2016; (d) Plot 2017.

Plot 2014 showed the highest annual increment among all plots. The soil quality may impact the growth because the land suitability achieved by S1 excludes total nitrogen and CEC. The total nitrogen and CEC were also available to be enriched by the organic matter amendment such as manure and nitrogen fertilizer [14, 15, 17]. The addition of compost and phosphorus fertilizer impacted the plant height of oil palm seedling [21, 22]. Moreover, the compost from the empty fruit bunch was available to elevate the nitrogen content [23]. Otherwise, Plot 2014 also had the highest increase in 2021 (29 cm in 7 YAP). The plant height grew more rapidly after 6 YAP but it was still lower than plantation in the cultivated areas at the same age [24].

For comparison on the same plant age (4 YAP), Plot 2014 was still the highest among all plots (1.54 m) and Plot 2017 had the lowest plant height of 0.91 m. The sandy loam in Plot 2017 became the limited factor that was unable to be altered. Silt pit is suggested to manage the water both in the rainy and dry season [25]. They also recommended enhancing the nutrient content by adding 100 kg compost per tree. These recommendations can be implemented since there was no addition of organic matter in the study area since the start of planting. The fertilizer used in the study area referred to NPK fertilizer with the purpose to enrich the nutrient content.
Figure 2. The comparison of stem and trunk diameter and fruit bunch weight of all plots; (a) Plot 2014; (b) Plot 2015.

In addition, the implementation of cover crops such as *Mucuna bracteata* affected the moisture content to avoid the water loss and enrich the organic matter in soil [26]. Therefore, *Brachiaria decumbens*, *Chloris gayana*, *Mucuna bracteata*, *Pueraria javanica* and *Centrosema pubescens* were planted in the study area. Furthermore, the use of cover crops such as *Axonopus compressus* prevents the growth of herbicides [27].

The information of the trunk occurs in 3 YAP and ranges 25-50 cm per year [28]. The trunk diameter had positive correlation with the yield production [16]. This occurred in Plot 2014 and 2015 (figure 2) in which the trunk diameter and yield production increased through the plant age. However, in this research, we found that the yield production was not impacted by the growth of the trunk diameter in Plot 2016 and Plot 2017 (figure 3) while the yield production in Plot 2016 and Plot 2017 dropped in 2021. Based on the soil texture, Plot 2016 and 2017 may require more treatment in fertilizer.
Figure 3. The comparison of stem and trunk diameter and fruit bunch weight of all plots; (a) Plot 2016; (b) Plot 2017.

Generally, the first harvest of young fruit in the study area was in 2-3 YAP producing 5.31-7.53 ton per ha. The young fruit production occurred for 2 years. In other research, the first yield was generally 10-15 ton per ha [29] with the peak of yield in 9-12 YAP [30]. Therefore, the production in the study area was still lower than in the commercial plantation. The first production was also in accordance with the land suitability assessment in which Plot 2014 (S2) had the highest production and Plot 2017 was the lowest production (S3) in the first production.

Moreover, the castration is required to obtain the productivity of fresh fruit bunch (FFB) [31]. Because the success criteria of mine reclamation excluded the castration process, the young fruit was unmanaged. The oil palm in mine reclamation needs the specific criteria in order to achieve the maximum production including the castration procedure as maintenance.

FFB of Plot 2014 and Plot 2015 was in the 4 YAP with the production of Plot 2014 was 13.37 ton per ha and Plot 2015 was 15.34 ton per ha. One of the factors which influenced was soil nutrient such as organic carbon, nitrogen content and P_2O_5 [32]. In fact, Plot 2015 had higher FFB production than Plot 2014 in 4 YAP although the initial soil quality was lower. In 2019, castration began in all plots and resulted in the production in Plot 2015 also increased than 2014.

Furthermore, unlike the plant height, diameter of oil palm may decrease through plant age [33] which is also shown in Fig. 3b for Plot 2017 in 2018. It may occur because of the difference of measurement technique or person. However, this result was found before the trunk was formed (under 3 YAP) [28].
The alternative of palm oil plantation in ex-coal mined areas can be implemented for commercial production. Not only for the renewable energy farm, the oil plantation is able to enrich the soil's physical and chemical properties [34]. The case of the study area, the commercial production is managed by the small-scale farmers around the mine site for a new economic source. However, the plantation needs to match the land use spatial plan since only available to develop in non-forestry areas in ex-mined land. Moreover, palm oil also requires maintenance action and cost to achieve the production since the real harvest occurs after the young fruit period.

4. Conclusion
Palm oil plantation in an ex-coal mine site is a new hope for reducing deforestation and also a new source of energy and economy. As disturbed land, the soil requires treatment and strategy to achieve the production. Understanding the land suitability helps to define the limitation and arrange the plan such as the amendment requirement and water management. Compost is required to enrich the organic matter and CEC while the manure and N fertilizer is also important to enhance sufficient nitrogen in soil. The application of silt pit and cover crop are also recommended protecting the water availability and moisture content in the dry season in marginal like sandy soil. In terms of production achievement, the castration plays a significant role to speed up the FFB production and can be included in the mine reclamation guideline for oil palm. Generally, the production of FFB in ex-mined land was close to the commercial plan which is a good start for palm oil production in disturbed land.

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