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Suitability of Oil Palm Plantation on Tunjung Plateau´s Volcanic Parent Material in West Kutai Districts, East Kalimantan, Indonesia

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Authors' contributions

This work was carried out in collaboration among all authors. 'All authors read and approved the final manuscript.

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Short Research Article

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Abstract

The study of Oil Palm plantation suitability on Tunjung Plateau Vulcanic parent materials in Wast Kutai Districts of East Kalimantan, Indonesia, has been done. The soil profile on two different physiographic, i.e.,on almost flate and undulating/hilly topography, was selected. The climate used from available data as close as possible by location, where both climatic data (rainfall, temperature, and relative humidity) and soil profile, laboratory data (routine analyses) used to land evaluation according to FAO soil evaluation system modified by Sys and Van Ranst (1993) and the soil classified using Key to soil taxonomy (USDA, 2022). The suitability classification of Soil with a flat soil topography according to land characteristics (climate, soils, and landscape) of the study area, with the requirements for growing oil palm plants gives the result that flat slope is classified as suitable (S1) and moderately suitable (S2t) by topographic limiting factor. Soil of the study area has highly developed and show low activity clay (CEC clay less than 16 C mol (+), classified as Humic

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Kandiperox (flat area/slope 0%) due to the soil has 17.39 % organic carbon content between the mineral soil surface and a depth of 100 cm and Andic Kandiperox on slope 11 % (undulating/hilly) which mean that the soil has Isohyperthermic temperature regime and perudic soil moisture regime, Ochric epipedon, Oxic and Kandic subsurface Horizon which have ECEC of less than 1.50 cmol (+) per kg clay, pH (1N KCl) of 5 or more on undulating topography and pH (1N KCl) of less than 5 on plate area.

Keywords: Clay; palm oil; soil taxonomy; pH.

1. Introduction

Oil palm is aflex crop that can be used as food, feed, fuel, or as an industrial material. The cultivation systemof oil palm is more efficient, making it have a higher competitive andvavntage than other commodities such as soybeans and rapeseed. Its high productivity and lower cost of cultivation bring substansial and attractive benefits either at micro business unit or at macro-economic system. (Dharmawan,. et al., 2021).

Oil palm plantations become a strategic sector in the Indonesian economy, especially in the Kalimantan region. Although its contribution to economic growth is undeniable, its impact on poverty alleviation is still debatable. (Barkah and Muhammad, 2024).

The expansion of oil palm plantations is one of most prominent examples. The total oil palm area expanded from 6.1 to 20.3 million ha between 1990 and 2015. Although oil palm is grown in 43 countries, Malaysia and Indonesia are by far the largest producers, refresenting over 80 percent of the global production (Yuliani et al., 2020). Palm productivity is determined by two main factors that are interrelated, namely, the application of technical cutureand land suitability (Anwar et al., 2014. The soil formed in West Kutai, especially the Tunjung plateau, originates from the weathering of Old Volcanic Parent material, but the soil has developed further due to soil-forming factors such as climate, topography, living being, parent material and the one that plays the most role in soil formation in Barongtongkok is time (Mulyadi, 2022; Jaroenkietkajorn & Gheewala, 2021). Buol et.al., (2003), stated that soil formation is influenced by climate, parent materials, vegetation, topography, and time.

According to atlas, East Kalimantan, Indonesia by *Frithjof Vos,* the geology of the area is dominated by Neogene Volcanic Rock, belongs to the physiographic region of West Kutai Volcanic Region, and the area divided into three major geomorphological unit; the 1st unit is lava fiield area, the 2nd is volcanic shield and 3rd is extinct Volcano. The elevation of lava field ranges from some 80 to 230 masl, the volcano shield ranges from 180 to 350 masl and, the extinct volcano ranges from 320 to 550 masl (Aksa, 2000; Zhao et al., 2024).

In the study of soil development, topographic factors are the most important factors in assessing and determining soil properties; slope position also affects the weathering process, development, and leaching (Molina et. al., 2019). Jimoh et al., (2020) stated that topography plays an active role in influencing soil properties, especially in sequential units (toposequences), where toposequency is a conceptual framework for changes in soil properties driven by differences in elevation.

Based on visual observations of the area and growth of smallholder oil palm plantations, which can also improve the welfare of the Tunjung Plateau, West Kutai community, it is necessary to carry out a more in-depth study of oil palm lands in this area using a pedogenesis and land suitability approach. Based on this study, it is hoped that it will provide an understanding of the area's potential for the development of even larger oil palm plantations.

The rate of land degradation can be measured through the morphological characteristics of the soil and landscape (Aji et al., 2020), Haidar et al., (2020), stated that the information on soil characteristics and morphological properties can be determined by observing soil profiles. A soil profile is a historic record of all the soil-forming factors and processes, providing a snapshot of soil development. Knowing soil characteristics and classification would also help identify management and land use properties.

2. Materials and Methods

Soil samples were taken during soil survey activities in Barong Tongkok, East Kalimantan. Eighteen pedons were identified for soil characteristics developed on volcanic parent materials in Barong Tongkok Area, East Kalimantan, Indonesia, and classified according to FAO Systems.

In the laboratory, all the soil samples (more than 100) were extracted from the 18 pedon i.e. particle size distribution, bulk density, water permeability, soil chemical property. The area of Barong Tongkok located in the middle course of Mahakam River at south latitude between $0^{o}08'$ and $0^{o}20'$ and east longitude between $115^{o}31'$ and $115^{o}47'$ (Fig.1). It belong to administrative district of West Kutai County, Province of Est Kalimantan< Indonesia. It is about 170 km west by west of Samarinda City.

Based on the two selected pedon data above, the soil is then classified, using the key to soil taxonomy (USDA, 2022) and land suitability classification for rubber plantations using the FAO system modified by Sys and Van Rants (1993).

3. Results and Discussion

3.1 Genesis and Classification

From pedon data by Jica Expert (Daksa, 2000), the soil description shows that on the plate area by slope (0%) has an Umbric epipedon by using, namely brownish black to dark brown in color with color value and chroma 2-3 (moist) to a depth of 42 cm from the soil surface, with base saturation ranging from 16.7 - 19.8% (NH_4OAc pH 7). Texture: clay loam to clay, fine granular to strong, very fine blocky to moderate very fine and fine subangular blocky, friable to moist consistency, and abruptly smooth soil boundary.

Soil analysis of the subsurface horizon, which also uses the same key to soil taxonomy in layers Bw2 (42-100 cm) and Bw3 (100-150 cm), shows that the soil in this flat area has an Umbric Epipedon covering the kandic subsurface horizon to a depth of 150 cm. Meanwhile, based on initial field observations, the soil profile description described Bw1, Bw2, and Bw3 indicated that they have a Kambic horizon. However, based from soil chemistry data, especially CECclay on that layers, the CECclay is less than 16 cmol (+) per 100 grams (6.67 in the Bw2 layer and 10.4 in the Bw2 layer Bw4) clay is classified as low activity clay so it is classified as a kandic horizon because there is also an increase in clay from the eluvial to the illuvial horizon as required of the kandic horizon in key to soil taxonomy.

An epipedon is a diagnostic horizon that formed on the surface of the soil (Epidermis, skin, and pedon) whose rock structure has been destroyed. Epipedons are quite dark in color due to the decomposition of organic matter. Epipedon is not always limited to horizon A; it can also include horizon B if the soil remains dark in color due to organic matter content (Soil Survey Staff, 2014).

In soils with undulating to hilly topography and a concave shape of the lava fields, the soil still has an Umbric epipedon with a color value of 3 and chroma 3 to a depth of 45 cm, with a Base Saturation (NH_4OAc pH 7) ranging from 23.8 to 43.6 %. This epipedon also has soil texture clay, moderate to very fine and fine granular, and blocky to weak fine and medium subangular blocky; friable consistency; and a clear, smooth boundary.

Fig. 1. Map of Barong Tongkok (researched area)

Table 1. Pedon depth, Soil colors, Texture, properties

Pedon	Horizon symbol	Depth(cm)	Soil color moist	Particle size			Texture class *	Chemical properties					
				Sand	silt	clay		pH H_20	KCl	CEC	BS	C	N
1 Slope 0%	Ah	0 - 9	7.5 YR 2/2	43.7	16.5	39.8	Clay loam	4.9	4.00	24.65	18.9	6.42	34.3
	Ah2	9 - 20	7.5 YR 2/2	28.2	14.2	57.6	Clay	4.96	4.02	23.18	19.8	6.07	25.9
	Bw1	20 - 42	10 YR 3/3	33.7	18.5	47.8	Clay	4.99	4.36	14.19	16.7	2.92	13.8
	Bw2	42- 100	1o YR 4/4	19.0	9.0	72.0	Clay loam	5.14	4.80	5.25	67.2	0.97	11.5
	Bw3	100 - 150	10 YR 4/4	45.6	11	43.4	Clay	5.20	4.96	4.53	93.6	0.65	7.7
2 Slope 11%	Ah	0 - 10	10 YR 3/3	40.8	6.6	52.6	Clay	4.99	3.99	18.69	23.8	6.05	6.9
	B1	10 - 45	10 YR 3/3	33.8	5.7	60.5	Clay	5.12	4.29	7.42	43.6	2.21	0.9
	B2	45 - 81	10 YR 3/4	31.0	4.3	64.7	Clay	5.05	4.30	5.24	23.0	0.79	1.1
	B3	81 - 123	10 YR 3/3	28.8	5.2	66.0	Clay	5.32	4.41	2.47	18.7	0.59	1.6
	B4	123 - 164	10 YR 3/5	28.4	5.9	65.7	Clay	5.38	4.46	3.71	24.6	0.50	0.4
	BC	164 - 200	10 YR 3/5	26.9	6.9	66.2	clay	5.34	4.41	5.90	60.2	0.52	0.2

** Field identification*

Diagnostic subsurface horizons are horizons that form below the soil surface. However, some are formed directly below the leaf litter layer, composed of mineral materials, and may be exposed to the soil surface due to being cut by erosion; some of these horizons are considered B horizons, but not all Pedology experts and other experts determine them as A or E horizons (Soil Survey Staff, 2022).

Observing and analyzing soil profiles and analyses in undulating to hilly areas shows that the soil has undergone further development from the top layer of the subsurface horizon (B1) to the deeper layers (B4) with a characteristic increase in clay of more than 8%. CEC clay calculated in this layer gives varying values, i.e, between 3.74 cmol (+) in the B3 horizon to 12.26 cmol (+) in the B1 horizon, but all subsurface horizons are classified as low activity clay (CECclay < 16 cmol (+).

From the results of observations of the diagnostic horizon, it can be seen that in the B1 layer there has been a change in the diagnostic horizon from a kandic horizon to an oxic horizon due to topographic factors and increasing time in the same climate, even though the destruction/change is still at the beginning with indications that the clay content has not increased until it reaches 8%. The next horizon is still classified as a kandic horizon (B2-BC).

The characteristics of the study of these two soil profiles (flat and undulating/hilly) in the Barong Tongkok area show that there is a change/destruction of the diagnostic horizon from Cambic horizon to Candic horizon (flat area) on the lava field parent material to Oxic horizon over time, even in only the upper subsurface horizon B2. The climatic factor significantly influences pedogenesis in this area, driven by high rainfall and elevated temperatures resulting from the region’s topography.

The high rainfall and PET, which produce an annual effective rainfall (R-PET) of around 1000 mm/year, significantly increase the leaching rain process. Likewise with temperature, according to the law of "t Hoff', every 10°C increase in temperature will accelerate chemical reactions in the rock by 2-3 times, causing rock minerals to integrate and dissociate more quickly (Mulyadi, 2022).

Based on climate data in Barong Tongkok, it has an isohyperthermic soil temperature regime and perudic soil moisture regime, with an annual average rainfall of 3134 mm, a mean monthly air temperature of 26°C, and an annual PET of 1545 mm, resulting in a surplus of around 1589 mm. This means that a large amount of rainfall reaches the ground surface, and some of it evaporates through transpiration. The amount of rainfall that reaches the soil surface will enter the soil through infiltration, some of which moves on the surface (runoff) or moves laterally (seepage) in the soil when the soil has been saturated with water (impermeable layers). The amount of water that enters the soil (infiltration) depends on how much water is lost in the soil (seepage), and this process continues until the rain stops.

On the land with relatively flat topography, water infiltration will be greater than in areas with undulating/hilly topography. This is because in areas with undulating/hilly topography, the runoff process and lateral water movement are greater due to the slope. As a result, the large amount of water infiltration in flat areas will be able to increase the kinetic energy of leached out weathering results, such as texture and dissolved bases or other weathering products, into deeper layers and even dissolve the silica content of the soil into deeper layers compared to areas with undulating/hilly topography.

The effect of water infiltration on both soil profiles (flat and undulating/hilly) has changed the diagnostic horizon from cambic to kandic without the formation of an argillic horizon. Likewise, on soil with undulating/hilly topography, there has been a change in the kandic horizon in the upper layer of the subsurface horizon to become an oxic horizon. This means that over time, the pedogenetic destruction process will continue until the soil finally develops into older soil, namely soil with a positive charge (pH H_20 - pH KCl).

Table 2. Climatic Records of Barong Tongkok

Station: Barong Tongkok	**Latitude:** -0.2332°
Station ID: BRT	**Longitude:** 115.6861°
Period of Record: 1980 – 2012	**Elevation:** 90 m
Period Type: normal	**Waterholding Capacity:** 200 mm
Mean Annual Precipitation: 3134 mm	**Soil Moisture Regime:** Perudic
Soil Temperature Regime: Isohyperthemic	

Table 3. Soil climate regime—Newhall Simulation Model (MAST – MAAT + 2.5 °C ; Amplitudo 0.66)

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
Mean Monthly Air Temperature (°C)												
25.70	25.80	26.10	26.10	26.30	26.10	25.80	26.10	26.10	26.30	26.10	26.00	26.00
Mean Monthly Precipitation (mm)												
263.00	274.00	320.00	324.00	277.00	201.00	172.00	177.00	230.00	259.00	306.00	332.00	3134.00
Modeled Estimate of Monthly Total Potential Evapotranspiration (mm)												
125.11	114.61	132.07	128.21	135.60	128.15	126.63	132.02	128.21	135.78	128.38	130.40	1545.17
Modeled Estimate of Monthly Total Water Balance (mm)												
137.09	159.39	107.93	195.79	141.40	72.85	45.37	44.98	101.79	122.22	177.52	201.60	1588.83

Source: Makhrawie, 2019

3.2 Soil Classification (USDA, 2022)

Based on the pedogenetic analysis above, the soil is classified as an **Oxisol,** since it contains surface clay (eluvial) with a thickness of 18 cm from the surface greater than 45%, and suborder **Perox** because it has a perudic soil moisture regime (PET > R throughout the year). Great group **Kandiperox** (other perox that has a kandic horizon within 150 cm of the mineral soil surface) and subgroup **Humic Kandiperox** because the soil has 17.39 % organic carbon (kg/m^2) between the mineral soil surface and a depth of 100 cm.

3.3 Land Suitability for Oil Palm Plantation

The land suitability process was used to determine the degree of suitability of a given area for a specific use. The land suitability of one area may differ depending on the specific land utilization type required. Area can be considered suitable, actually or potentially. When the area is considered potentially suitable, suitability can become reality after addressing limiting factors. The land suitability classification is the systematic evaluation of an area and its grouping into categories based on land characteristics (Physical environment) as limiting factors.

In evaluating the fertility of an area, several factors must be considered, such as the quality and characteristics of the land. Based on the quality and characteristics of the land, the land suitability of an area is determined in the Orders, Classes, or even subclass levels.

3.3.1 Land suitability orders and classes

In general, land suitability can be divided into two orders, and five classes were defined, namely:

1. Order suitable (S): use only three classes: S1 (Suitable), S2 (Moderately Suitable), and S3 (Marginally Suitable).
2. Order Unsuitable (N); use only two subclasses: N1 (Actually unsuitable but potentially suitable), and N2 (Actually and potentially unsuitable).

3.3.2 The land suitability subclasses

The subclasses reflect limitations or the main types of improvement measures required within each class. They are indicated in the symbol using lower-cased letters, with mnemonic significance. The following subclasses have been defined: **c** (climatic limitations), **t** (topographic limitations), **w** (wetness limitations), **s** (physical soil limitations/influencing soil or water relationship and management), **f** (soil fertility limitations not readily corrected), **n** (salinity and/or alkalinity limitations). (Sys et al., 1991).

3.3.3 Evaluation of land suitability classification of survey area

Based on the land characteristics (climate, soil, and landscape) of the surveyed area, the degree of land suitability classification for oil palm plantation in each soil mapping unit is considered as a specific land use.

3.3.3.1 Climate

The optimum mean daily temperature for oil palm is 22-30 °C, with the mean minimum temperature being at least 18 °C (Sys et al., 1993). Oil palm performs well in regions with total annual precipitation of over 1700 mm/year, evenly distributed throughout the growing period, and with two or fewer consecutive dry months. Excessive rainfall reduces both pollen density and mesocarp oil content. To get high yields, the annual number of sunshine hours should exceed 1300 hours/year (Sys et al., 1991).

The methodology suggests that, to achieve our aim of determining the climatic rating, climate evaluation should be incorporated into the overall evaluation. For this reason, the climatic characteristics are grouped into three categories: rainfall, temperature, and radiation. For the calculation of the climatic index (Sys et al., 1993), the lowest characteristics rating of each group is used. This is because there is always a strong interaction between characteristics of the same climatic group and because they do not act together. The climatic evaluations of the surveyed area show that the climatic characteristics, such as annual rainfall, length of the dry season, mean annual maximum, average daily minimum of the coldest month, and mean annual temperature, have the highest values for oil palm. The mean annual sunshine hours (n/N) have a moderate value, but the overall climatic characteristics have an optimum rating of 96. Due to sunshine hours (4.99 hours). This climatic index was transferred into a climatic rating that will be used in the total land evaluation by the formula 1:

$$\text{Climatic rating} = 16.67 + 0.9\ (96) = 100 \quad (1)$$

Table 4. Landsuitability subclasses (actual) for rubber plantation

Profile/Land form	Soil Taxonomy	Land suitability	Limiting Factors	Conclusion
Flat area	Humic Kandiperox	S1	-	Very suitable
Undulating/Hilly area	Andic Kandiperox	S2t	- Topography	Moderately suitable

3.3.3.2 Soil

Deep, permeable, well-structured soils are most suitable for the Oil palm cropping system. The required effective soil depth is > 1.00 m, and the maximum rooting depth is 2.00 m. Oil palm is sensitive to waterlogging; a groundwater table below 0.9 m from the surface for more than 14 days should be avoided. If the land floods for 1 week in 10 years, it is considered unsuitable. Clay and clay-loam textures are optimal for oil palm. Soil on alluvial deposits is preferred. Poorly drained soil with ironstone gravel, sandy coastal soil, and deep (>0.50 m) peats are unsuitable (Sys et al., 1993).

3.3.3.3 Suitability classification for oil palm plantation

The suitability classification for oil palm plantation using the Storie method by formula 2:

$$A = B/100 \times C/100 \times D/100 \qquad (2)$$

where: B, C, D: rating

4. Conclusion

Soil profile observations were carried out by JICA Experts in the Barong Tongkok area and were selected to study which are believed to represent flat and undulating to hilly topography conditions on volcanic parent materials, as well as collected climatic data as close to soil profile data. Using soil morphology, chemical, and other data, soil taxonomy (USDA, 2022) was applied to the subgroup level, and it was found that land with flat topography produced a Humic Kandiperox, while areas with undulating, hilly topography produced an Andic Kandiperox.

The results of observations on the climate rating using a table of rubber growing requirements, such as rainfall, temperature, and solar radiation, obtained a rating of ninety-five (95). After processing with the formula, an Index rating of 100 was obtained. It means the climate is very suitable for oil palm plantations.

Based on the climate index obtained, combined with soil and landscape requirements such as topography, wetness (flooding, drainage), physical soil characteristics, soil fertility characteristics, salinity, and alkalinity, it is obtained that land with flat topography is classified as very suitable (S1). In contrast, lands with undulating/hilly topography are quite suitable (S2t) with topographical constraints (11%). These two limiting factors do not need improvement because they only affect workability when managed on a large commercial scale; if managed on a smallholder oil palm plantation scale, they will have little effect.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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