Research Article

Analysis of Soil Fertility in Oil Palm Plantation (*Elaeis guineensis* Jacq) Smallholder Farmers in East Luwuk District, Banggai Regency

Analisis Kesuburan Tanah Perkebunan Kelapa Sawit (**Elaeis guineensis** Jacq) *Petani Rakyat di Kecamatan Luwuk Timur Kabupaten Banggai*

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Abstract: One of the factors that influence the production of oil palm plantations is the condition of the land favorable for their growth and development, especially regarding the physical and chemical properties of the soil and the status of soil fertility. The purpose of this study was to determine soil's physical and chemical properties, as well as its fertility status on smallholder oil palm plantations. Soil sampling was conducted through a descriptive exploratory survey method, involving six sampling points and representing three oil palm ages (11, 16, and 22 years old). The soil chemical and fertility status were analysed using National Criteria of Soil Chemical Properties developed by Soil Research Institute and Five Major Soil Chemical Properties approach developed by Soil Research Center. All observed soil exhibited clay textures and varying soil color matrix. The soil had neutral acidity, medium to high base saturation/BS and cation exchange capacity/CEC, moderate P_2O_5, as well as low organic C and K_2O. Soil fertility status on the entire sites were classified as low, which primarily caused by low soil organic C and K contents. In order to improve soil condition favorably for oil palm growth and development, further studies must be conducted using more direct approach, relating the oil palm requirement with current state of soil and land conditions.

Keywords: Soil fertility, smallholder oil palm plantation, soil physical and chemical properties

Abstract: Salah satu faktor yang mempengaruhi produksi perkebunan kelapa sawit adalah kondisi tanah yang menguntungkan bagi pertumbuhan dan perkembangannya, terutama mengenai sifat fisik dan kimia tanah serta status kesuburan tanah. Tujuan dari penelitian ini adalah untuk mengetahui sifat fisik dan kimia tanah, serta status kesuburannya pada perkebunan kelapa sawit rakyat. Pengambilan sampel tanah dilakukan melalui metode survei deskriptif eksploratif, melibatkan enam titik pengambilan sampel dan mewakili tiga umur kelapa sawit (11, 16, dan 22 tahun). Kondisi kimia tanah dan status kesuburan dianalisis menggunakan Kriteria Nasional Sifat Kimia Tanah yang dikembangkan oleh Balai Penelitian Tanah dan pendekatan Lima Sifat Kimia Tanah yang dikembangkan oleh Pusat Penelitian Tanah. Semua contoh tanah yang diamati menunjukkan tekstur liat dan matriks warna tanah yang bervariasi. Tanah tersebut memiliki kemasaman netral, kejenuhan basa/BS dan kapasitas tukar kation/KTK sedang sampai tinggi, P_2O_5 sedang, serta C organik dan K_2O rendah. Status kesuburan tanah di seluruh lokasi tergolong rendah, terutama disebabkan oleh rendahnya kandungan C dan K organik tanah. Untuk memperbaiki kondisi tanah yang menguntungkan bagi pertumbuhan dan perkembangan kelapa sawit, studi lebih lanjut harus dilakukan dengan menggunakan pendekatan yang lebih langsung, menghubungkan kebutuhan kelapa sawit dengan keadaan tanah dan kondisi lahan saat ini.

Keywords: Kesuburan tanah, petani kelapa sawit rakyat, sifat fisik dan kimia tanah

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INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) plays an essential role in the global market for producing edible oil, as well as other abilities such as industrial oil and biofuel. Oil palm is a plant with a wide distribution and very efficient production (Dislich et al., 2016). It can grow and produces well in diverse agroecosystems, from dry land and upland mineral soils to peat soils that develop in the tidal swamp (Firmansyah, 2014). In Indonesia, oil palm plantations have developed extensively. They are currently the highest agricultural contributor to the Indonesian economy (BPS, 2022), contributing 83% of the total global palm oil production (Shigetomi et al., 2020). Oil palm plantations involve the community as farming actors in the form of smallholder farmers (Siswati, 2017), which account for 34.62% of the entire oil palm plantation in Indonesia (BPS, 2020).

One of the determining factors for sustaining optimal oil palm production is soil fertility (Darlita et al., 2017). Proper soil management is essential in maintaining the appropriate fertility of the soil, hence, the growth and yield of oil palm (Harahap et al., 2020), which is often considered missing, inadequate, or imbalanced by smallholder farmers (Woittiez et al., 2018). Plant growth depends not only on the availability of adequate and balanced nutrients but also on suitable physical and chemical soil conditions. This property will also affect the potential of the soil to produce optimally. According to Bahendra (2016), changes in soil's physical and chemical properties occur due to oil palm planting and the increase in planting age. According to Adiwiganda (2005), the soil commonly found in oil palm plantations was yellow podzolic with a high clay fraction, which contained moderate organic C in the upper layer and low in the lower layer. Nitrogen (N) content was rather low in all layers as well as phosphorus (P) was low and had acidic soil reaction. Furthermore, exchange capacity cation, and base saturation were low in all layers. Besides many published reports on Sumatran and Bornean oil palm plantations soils, we found very limited reports of the soil's physical and chemical characteristics and soil fertility cultivated by oil palm smallholder plantations, particularly in our study area.

Based on the information above, this research is aimed to determine soil physical and chemical characteristics, as well as soil fertility in smallholder oil palm plantations (*Elaeis Guineensis* Jacq.), Luwuk Timur District, Banggai Regency.

MATERIALS AND METHODS

Research Location, Soil Sampling, and Laboratory Analysis

Soil sampling was carried out on the land of the smallholder oil palm plantation in East Luwuk district, Banggai regency, as presented in Figure 1. Field sampling was carried out in July 2021 using the Exploratory-Descriptive Survey Method. Soil material (± 1.5 kg) was taken using the mini pit technique. The soil samples represented three phases of the oil palm plants in the plantation based on different planting ages (11, 16, and 22 years old) at two depths (0-20 and 20-40 cm). Furthermore, laboratory determination was carried out in the Laboratory of Soil Chemistry and Fertility, Faculty of Agriculture, Hasanudin University. The entire physical and chemical properties analyzed in this study were summarized in Table 1.

Data Analysis and Interpretation

The soil's physical and chemical data were firstly interpreted according to Technical Guidelines for Chemical Analyses of Soil, Plants, and Fertilizers; Soil Research Institute (Eviati and Sulaeman, 2009). Secondly, the soil fertility status was evaluated using the Five Major Soil Chemical Properties approach developed by Soil Research Center (Soil Research Center, 1995).

The approach involves several soil chemical parameters as benchmarks, namely cation exchange capacity (CEC), base saturation (BS), P_2O_5, K_2O, and organic C. Based on the combination of these chemical parameters, the status of soil fertility can be determined. The classified ranges vary from very low to very high, as presented in Table 2.

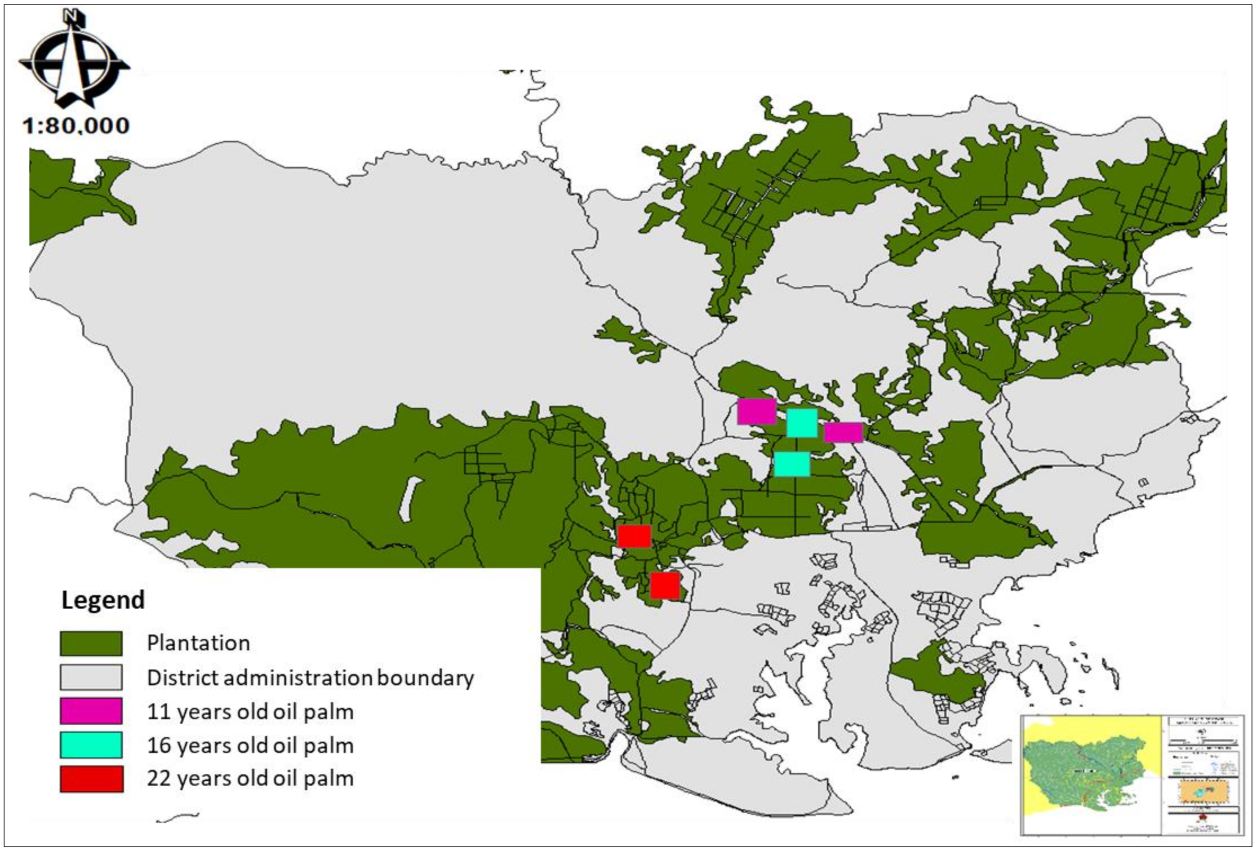

Figure 1. Research locations depicting six sampling point observed in this study

Table 1. The soil characteristics analyzed in this study

No	Parameter	Method
1	Soil texture	Pipette
2	Soil Color	Munsell soil color chart
3	Organic C	Walkley and Black
4	Total N	Kjeldahl
5	P_2O_5	Olsen
6	K_2O	HCl 25%
7	Soil pH	H_2O 1:2.5
8	CEC (me/100 g)	NH_4 Acetate 1N, pH7
9	K (me/100 g)	NH_4 Acetate 1N, pH7
10	Na (me/100 g)	NH_4 Acetate 1N, pH7
11	Mg (me/100 g)	NH_4 Acetate 1N, pH7
12	Ca (me/100 g)	NH_4 Acetate 1N, pH7

Table 2. The Five Major Soil Chemical Properties approach for the soil fertility assessment

CEC	BS	P_2O_5, K_2O, Organic-C	Fertility Status
H	H	>2H without L	H
		>2H with L	M
		>2M Without L	H
		>2M With L	M
		HML	M
		>2L With T	M
		>2L With S	L
H	M	>2H Without L	H
		>2H With L	M
		2M	M
		Other combination	L
H	L	>2H Without L	H
		>2H With L	L
		Other combination	L
M	H	>2H Without L	M
		>2M Without L	M
		Other combination	L
M	M	>2H Without L	M
		>2M Without L	M
		Other combination	L
M	L	3H	M
		Other combination	L
L	M	>2H Without L	M
L	H	>2L With L	L
		>2M Without M	M
		Other combination	L
L	M	>2H Without L	M
		Other combination	L
L	L	All combination	L
M.L	H.M.L	All combination	VL

Note: VL: very low, L: low, M: moderate, H: high

RESULTS AND DISCUSSION

Soil Physical Properties

Based on the soil physical characteristics analysis determined from the field and laboratory, as summarized in Table 3, it was observed that the soil color matrices at the study site had relatively dark colors at their surface, particularly for the 11 and 12 years old oil palm. Furthermore, the dark intensities decreased along with the increasing depth. The dark color on the surface layers is mostly caused by the high organic C content. Meanwhile, the light colors are often the result of intensive leaching of iron and lower organic matter content, which generally coincides with the loss of various nutrients. Hence, light-colored soils are often associated with low productivity (Hanafiah, 2005). Moreover, the darker color of the lower layers of a 22-year-old oil palm compared to its surface layers is possibly owing to a buried horizon resulting from repeated volcanic eruptions (Ferdeanty et al., 2019).

Soil texture is part of the physical properties of the fine earth fraction of soils, constituted of a relative proportion of sand, silt, and clay fractions. The results found in this study (Table 3) revealed that the research site entirely consisted of clay textures (more than 60% clay) within 0-40 cm depth. Clay particle has a higher affinity to water than sand or silt particles (Foley, 1999), which corresponds to a higher water-holding capacity of clay textured soils (Andalusia et al., 2016; Suleman et al., 2016) as observed in this study. High clay content in the soil at the study site also partially explained the darker soil color at the surface, possibly due to higher content of organic material and water content, since clay particles can retain more organic matter and suppress their decomposition (Totsche et al., 2017; Witzgall et al., 2021). In addition, higher organic material combined with high clay content can hold more water, preventing excessive evapotranspiration from the soil surface (Ankenbauer and Loheide, 2016; Lal, 2020).

Table 3. Analysis of Soil Physical Properties

Age	Depth	Texture (%)			Texture Class	Soil Color	
Year	cm	Sand	Silt	Clay			
11	0-20	11	22	67	clay	2.5 Y 3/2	Very Dark Grayish Brown
11	20-40	6	34	60	clay	10 YR 4/3	Brown
16	0-20	6	28	66	clay	2.5 Y 4/2	Dark Grayish Brown
16	20-40	12	20	68	clay	2.5 Y 3/3	Dark Olive Brown
22	0-20	14	11	75	clay	10 YR 4/3	Brown
22	20-40	8	10	82	clay	10 YR 3/2	Very Dark Grayish Brown

Soil Chemical Properties

The soil's chemical characteristics determined in this study are presented in Table 4. The soil CEC were classified as medium and high, respectively, are possibly due to the influences of the clay content possessed by the studied soils (Table 3). According to Rukmi et al. (2017), the high clay fraction in the soil highly affects soil cation exchange because it has a large surface area. Suarjana et al. (2015) mentioned medium cation exchange capacity because soils dominated by clay and humus fractions have sufficient cation exchange capacity and water holding capacity. Therefore, soils dominated by clay fractions have high aggregate stability due to higher bonds between the clay and organic matter particles (Sukisno et al., 2011).

Table 4. The chemical characteristics of the soils determined in this study

Age	Depth	CEC	BS	Organic C	P_2O_5	K_2O
Year	cm	cmol(+)/kg	------------ %	------------	------------ ppm	------------
11	0-20	23.58 (M)	57 (M)	1.43 (L)	14.20 (M)	12.63 (L)
11	20-40	32.05 (H)	38 (M)	1.73 (L)	15.36 (M)	20.14 (L)
16	0-20	21.39 (M)	69 (H)	1.86 (L)	16.33 (M)	22.15 (M)
16	20-40	30.43 (H)	42 (M)	1.43 (L)	13.98 (M)	19.32 (L)
22	0-20	33.91 (H)	41 (M)	1.58 (L)	18.27 (M)	18.63 (L)
22	20-40	25,72 (H)	62 (H)	1.99 (L)	19.95 (M)	13.25 (L)

Note: VL: very low, L: low, M: moderate, H: high

BS plays a vital role in soil fertility, where base saturation represents the plant-available quantity of base cations the soil could supply. Table 4 exhibited that the value of base saturation in 11 years of oil palm plantations is classified as medium status. Meanwhile, the base saturation value at the older planting ages was classified as medium to high. Given the fertilization and amelioration that is rarely or minimally conducted by the farmers (Woittiez et al., 2018), the value of base saturation at the study site reflects the abundance of available bases in the soil (Widyantari et al., 2015), which in contrast with other reports conducted in smallholder oil palm plantations (Woittiez et al., 2018; Woittiez et al., 2019). Therefore, the status of BS found in the studied soils was possibly derived from the natural occurrence of cations in the parent materials.

The laboratory results in Table 4 showed that the organic C content in oil palm plantations during the entire oil palm ages is classified as low. It is presumably because organic fertilizers are rarely added to cultivating oil palm in the research location. Only inorganic fertilizers are given. According to Rahmi & Maya (2014), most sources of soil organic matter is originated from plant tissues. Rahman et al. (2021) reported that the management practised in smallholders resulted in lower soil organic matter compared to best management practices/BMPs and standard/current management practices/CMPs conducted in large-scale oil palm companies.

Based on the soil analysis results (Table 4), P_2O_5 for different planting ages in oil palm plantations in East Luwuk District were classified as moderate. This condition is seeming because of the soil reaction in the study area. Soil acidity influences soil P availability. At the research location, the pH value ranged from 6.6 to 7.0, which was classified as neutral and considered relatively high compared to the soil developed in humid tropical regions (*e.g.,* Adiwiganda, 2005; Rahman et al., 2021). At neutral pH conditions, the P content is usually also in high or moderate, and this is because the solubility of P is optimal at this range of pH (Prabowo and Subantoro 2018). Therefore, in line with Widyantari et al. (2015), inorganic P and organic P fertilizers such as compost and green manure are needed for these land units.

The analysis of K_2O content in oil palm plantations for younger and older than 16 years were low (Table 4). Therefore, the low K content in the soil possibly resulted from high K uptake by plants older than 16 years. Meanwhile, soil erosion might become the primary causative factor for low soil K content in the first year after planting has less ground coverage. However, young plantations typically have a dense ground cover, which can minimize soil erosion. Thus, low fertilizer addition is a possible explanation for lower soil C content in the oil palm age younger than 16 years. Furthermore, the nature of K ions in the soil solution also provokes K leaching. Compared to other cations, K ion is very mobile; hence, they are easily exchanged from the soil exchange complex and washed out from the soil system (Barber 1985: Al Mu'min et al., 2016; Afandi et al., 2017; da Silva et al., 2018).

Soil Fertility Status

Based on soil fertility determination guidelines (Soil Research Center, 1995), soil fertility status at the study site is classified as low status (Table 5). Soil fertility is the ability of a soil to provide nutrients at a certain dose and balance to support the growth of a type of plant in the environment with other growth factors in favorable conditions (Lubis and Siregar, 2019). The research location is marginally capable of sustaining plant growth and development.

The low soil fertility at the study site was primarily caused by low organic C and K contents. Soil organic matter greatly affects soil's ability to maintain fertility levels through the activity of soil microorganisms and the behavior of its material. The role of organic matter in soil is to form granulation and is very important in forming stable soil aggregates, hence, preventing soil erosion. In addition, organic colloidal fractions have higher CEC than inorganic fractions, which can hold more cations, thereby limiting cation leaching (Bot and Benites, 2005; Anwar and Sudadi, 2013; Tolaka, 2013).

Table 5. Results of Analysis of Soil Fertility Status in Oil Palm Plantations

Age	Depth	CEC	BS	P_2O_5, K_2O, and Organic C	Soil Fertility Status
Year	cm				
11	0-20	M	M	Other Combinations	L
11	20-40	H	M	Other Combinations	L
16	0-20	M	H	Other Combinations	L
16	20-40	H	M	Other Combinations	L
22	0-20	H	M	Other Combinations	L
22	20-40	H	H	Other Combinations	L

Note: M = Medium, H= High, L = Low

Therefore, particularly for oil palm plantations, the analysis must be continued by assessing oil palm requirements and comparing them with the current state of soils. This technique is widely known as soil/land suitability analysis. Through this approach, the farmers can directly assess and measure whether their soils are suitable for oil palm cultivation or less, by looking for its limiting factors that can hamper optimum oil palm growth and development.

CONCLUSIONS

The selected sites on the smallholder oil palm plantations in the East Luwuk district had clay textures and varying ranges of soil color at the entire depths and oil palm ages. The soils also exhibited moderate P, as well as moderate to high BS and CEC. However, all observed sites showed low soil fertility, which are mainly caused by low soil organic matter and K contents. Hence, it provides marginal conditions for plant growth and development. Therefore, to improve soil fertility in the study area, it is necessary to add sufficient organic and inorganic K fertilizers and conduct appropriate soil management. Furthermore, the soil fertility analysis used in this study is considered an initial approach to assessing how the soil in the study area supplies nutrients and provides favorable conditions for plants. Thus, matching the soil condition with oil palm requirements is needed to obtain more direct management actions for improving soil conditions to be more suitable for oil palm growth and development.

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