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Importance of Soil and Mineral Characteristics in Supporting Sustainable Agriculture

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Abstract: Soil consists of four main components: Minerals, organic matter, air, and water, which are arranged in the space to form the soil body. Inorganic minerals in the soil come from rock fragments and other primary minerals. Sustainable soil fertility is supported by the nutrient content contained in the minerals. The research objectives were: 1) to observe the physical and chemical properties of soil in the upper (0-50 cm) and lower layer (>50-112.5 cm); 2) to observe microscopically the upper and lower layer. Microscopic observations of the topsoil and subsoil of the samples included The material composition of the topsoil and subsoil matrix, identifying the type of nutrient-bearing minerals for sustainable crop development. The research was carried out in early 2024; the research location and sampling were carried out in Pepalang District, Mamuju Regency, West Sulawesi. The research used survey methods and analysis of soil physical properties. Soil mineral analysis included making thin sections of Kubina box samples and micromorphological analysis using a polarizing microscope. The analysis of the physical properties of soil samples was carried out at the Soil Laboratory, Faculty of Agriculture, Hasanuddin University Makassar. For the analysis of clay mineralogy, an X-ray diffractometer was used at the Laboratory of Optics and Petrography, Faculty of Engineering, Hasanuddin University. The results showed that there are seven types of minerals found in the three profiles in the study area: Quartz, biotite, muscovite, K-feldspar, plagioclase, opaque and clay minerals. The chemical properties, texture, clay content and minerals that are easily weathered indicate that the soil has the potential to be developed crops because there is still potential for K, Ca, Mg and Na nutrients. High rainfall and intensive weathering require inputs such as improved drainage and the use of balanced fertilizers. This is necessary to support sustainable agricultural land productivity.

Keywords: Chemical Properties, Soil Mineral, Sustainable Agriculture

Introduction

Soil consists of four main components: Minerals, organics, air and water, which are arranged in the space forming the soil body. Inorganic minerals in the soil come from rock fragments and various other primary minerals. Commonly sustainable soil fertility is supported by the content of nutrients in minerals (Manna *et al.*, 2007; Tamfuh *et al.*, 2018; Ali *et al.*, 2020). According to Ahmad *et al.* (2020); Rosati *et al.* (2021); Suryani *et al.* (2021), in determining the level of nutrient reserves of a soil type, it is necessary to analyze the composition of the main soil minerals (Jiao *et al.*, 2020; Mahapatra *et al.*, 2022; Li *et al.*, 2022). It is very important to know the amount of soil that contains weathered minerals in the soil in high nutrient reserves supporting agricultural production. Comm, only soil containing dominant resistant minerals will cause oil to have insufficient nutrient sources (Ahmad *et al.*, 2020; Witzgall *et al.*, 2021). These soil properties are closely related to the dynamics of various nutrients in the soil. The type and amount of clay minerals greatly affect the chemical characteristics of the soil, such as Cation Exchange Capacity (CEC) and nutrient fixation (Bissig *et al.*, 2015; Ali *et al.*, 2020; Geisseler and Scow, 2014). Different parent rocks have different mineral compositions and are important in soil formation (Irmak *et al.*, 2007; Sirisokha *et al.*, 2015; Voudouris *et al.*, 2019; Tellen and Yerima, 2018). The speed of the soil formation process is highly dependent on the grain size of the parent material. Generally, small grains are easier to undergo the process of becoming soil (Vermeulen *et al.*, 2012; Bonfatti *et al.*, 2020; Chen *et al.*, 2022; Wu and Tiessen, 2002).

The role of minerals in soil is quite potent in agriculture because minerals derived from rocks contain various essential elements needed by plants and increase plant growth (Caldwell, 2005; Da Silva Fraga and Salcedo, 2004). Fertile soils are potentially used to maintain and improve land productivity related to agricultural production. Various biological, chemical and physical weathering processes can naturally weather rocks into the soil to decompose nutrients for plants and soil microbes. The presence of soil microbes plays an important role in preparing supporting minerals for crops and against plant pathogens. Minerals contained in the soil are quite potent in agriculture because debris and rocks contain essential elements. The material called agrominerals is very useful in increasing agricultural yields. The presence of agrominerals in agricultural land greatly supports the development of crops, and economic improvement comes from the agricultural sector to support sustainable agriculture (Chen *et al.*, 2004; Caldwell, 2005; Kizilkaya and Orhan, 2010). The research objectives were: 1) to observe the physical and chemical properties of soil in the upper (0-50 cm) and lower layer (>50-112.5 cm); 2) to observe microscopically the upper and lower layer. Based on the research results, it is very useful in increasing soil potential in future agricultural productions.

Materials and Methods

Site of Research

The research was conducted in the year 2024. Field research was conducted in three villages: Batu Papan, Pepalang and Batu Ampat, Pepalang District, Mamuju Regency, West Sulawesi, Indonesia. The research was conducted using survey and laboratory observation methods. The stages carried out during the survey were orientation to obtain the facts needed in the field and using the interpreted land cover map as a basis or guide in carrying out the research.

Table 1: Analysis methods used in the research (Umaternate *et al.*, 2014; Hammad *et al*., 2020)

No parameter tool and methods
A chemical analysis
1 Soil pH (H_2O) and (KCl) Extraction (1: 2.5)
2 C-organic Walkley and Black
3 N-total Kjeldahl
4 P_2O_5 Bray and Olsen
5 Cation exchange capacity Ammonium acetate (CEC) extract (pH 7)
6 Alkaline exchanged Ammonium acetate extract (pH 7)
B Physical Analysis
1 Texture Gravimetric
C Soil Mineral
1 Pore and mineral Thin section

Determination of observation and measurement plots in the field was carried out through direct observation with the help of land cover maps, land system maps, slope maps, and other thematic maps. Analysis of the physical properties of soil samples was carried out at the Soil Laboratory, Faculty of Agriculture, Hasanuddin University Makassar. The soil mineral analysis was carried out at the Petrography Laboratory, Faculty of Engineering, Hasanuddin University. The stages of data analysis and interpretation aim to obtain information on soil mineral types.

The Sampling Methods

Collecting soil as the samples of research was conducted randomly in the research location. The soil samples taken were assumed to represent the soil properties of every research area. The whole soil samples used a sample ring and its composite was put in the plastic bag. The composite soil was analyzed for chemical properties. The following procedures were used: The soil sample from the field was air-dried and sieved. Each sample was analyzed for its pH, N-total content, and available phosphorus and potassium.

Analysis

The observation parameters and analysis methods of soil samples are based on Table (1).

Results

Soil Chemistry and Texture

Based on the results of the study, important indicators of top and subsoil quality at the study site ranged from very low to high values. The texture dominant from soil samples contains clay, and the pH ranges from more acidic to acidic. The sample soil showed carbon (C), nitrogen (N), calcium, and base saturation ranging from very low to low. Minerals such as phosphorus, natrium and calcium contents are low, while magnesium and Cation Exchange Capacity range from low to high (Table 2).

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Table 2: Analysis result of chemical and soil structure from research location

No.	Chemical Characteristic	Batu Papan		Batu Ampat		Pepalang	
		Layer (cm)					
		A 0-50 cm	B >50-112.5	A 0-50 cm	B >50-112.5	A 0-50 cm	B >50-112.5
1	pH	4.70 more acidic	4.49 more acidic	5.21 more acidic	4.81 more acidic	4.62 more acidic	4.75 more acidic
2	C (%)	1.60 low	1.77 low	1.07 low	1.62 low	1.33 low	1.77 low
3	N (%)	0.19 low	0.40 medium	0.15 low	0.16 low	0.18 low	0.16 low
4	P (ppm)	15.27 low	15.48 low	14.90 low	13.57 low	15.36 low	14.23 low
5	Cation exchange capacity (cmol/kg)	21.6 medium	15.36 low	24.02 medium	19.72 medium	23.29 medium	19.26 medium
6	Ca (cmol/kg)	2.45 low	2.39 low	3.32 low	2.58 low	2.45 low	2.62 low
7	Mg (cmol/kg)	1.73 medium	1.07 medium	2.78 high	1.09 medium	1.90 medium	1.23 medium
8	Na (cmol/kg)	0.21 low	0.14 low	0.39 medium	0.13 low	0.30 low	0.13 low
9	K (cmol/kg)	0.4 medium	0.12 low	0.19 low	0.13 low	0.11 low	0.18 low
10	Alkaline saturation	20.84 low	17.16 lowest	27.70 low	19.93 lowest	15.57 lowest	21.59 low
11	Texture	clay	clay	clay	clay	clay	clay

Low soil acidity or pH occurs due to the contribution of soil colloidal properties (including clay and organic), base saturation, types of adsorbed cations and other environmental factors. Leaching of bases, hydrolysis of hydrogen and aluminium ions, decomposition of organic matter and oxidation of pyrite compounds are among the causes of soil acidity. Commonly, soils with acid pH have quite the potential to be expanded and able to increase agricultural crop production.

Soil Forming Mineral of Each Profile

Every agricultural area has soil specifications that impact a variety of crops. Based on the results of mineral analysis at the study site, seven types of minerals were identified: Biotite quartz, muscovite, K-feldspar, opaque, plagioclase and clay. The types of minerals contained in the soil profiles of the study research are presented in Table (3).

Based on the result in Table (3), the number of clay dominant and high numbers in soil samples from Pepalang is high. Muscovite was not shown in the Pepalang soil samples. Quartz, biotit and opaque are commonly found in three sample soil areas. K-feldspar and plagioclase are found in specific research areas.

Soil Performing of Batu Papan

The incision of the soil sample was divided into two types: Nicol aligned and crossed form. Commonly, nicol is a method of mineral observation performed using a polarizing microscope. The difference between the use of parallel niches and crossed niches is in the analyzer. The analyzer functions to absorb light in a selected manner (selective absorption); only light that vibrates in certain directions can be forwarded. For parallel niches, the direction of vibration that is forwarded is in the direction of polarizer vibration, while for crossed niches, the direction of vibration that is forwarded is perpendicular to the direction of polarizer vibration (Bissig *et al.*, 2015; Sirisokha *et al.*, 2015; Tun *et al.*, 2015; Voudouris *et al.*, 2019; Zhang and Shangguan, 2016).

Table 3: Mineral from three locations

Type of mineral	Content of the layer (%)					
	Batu papan		Pepalang		Batu ampat	
	Top	Bottom	Top	Bottom	Top	Bottom
Quartz	15	15	10	10	10	10
Biotit	10	15	5	10	10	15
Opaque	5	5	5	5	5	5
Muscovit	10	-	-	-	-	10
K-Feldspar	10	-	10	-	15	5
Plagioklas	-	-	-	5	5	-
Clay	35	55	60	60	45	40

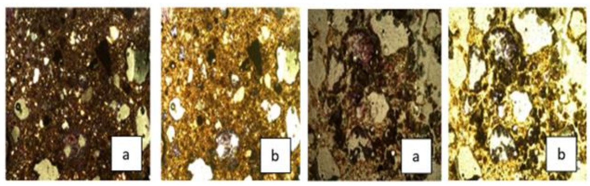

Fig. 1: Batu Papan incisions: top layer (a) Nicol aligned (b) Nicol crossed and bottom layer (a) Nicol aligned (b) Nicol crossed

Microscopic observations showed that the incision results in the upper layer (0-20 cm) were identified in brownish yellow colour in parallel Nicol and brownish grey in cross nicol. Sub rounded grain shape, subangular mineral shape, grain size 0.01-1.4 mm, mineral size 0.1-0.4 mm, inhomogeneous packing (there are dense parts containing granular particles and loose or forming pores) in other parts and Vugh pore type. The results of microscopic observations of incisions made in the lower layers (20-50 cm) showed brownish-yellow colour on parallel nicol, brownish-grey in cross nicol, grain shape brownish yellow colour in parallel nicol, brownish-grey in cross nicol, sub-rounded grain shape, subangular mineral shape, grain size 0.01-0.2 mm, mineral size 0.1-1.4 mm. Packing is not homogeneous due to the presence of solid parts containing loose granular particles (forming pores) in other parts, Vugh pore type (Fig. 1).

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Mineral Formed of Pepalang Soil

Microscopic observations showed that the upper layer incision (0-20 cm) identified a brownish-yellow colour in parallel Nicol and brownish-grey in cross nicol. Subarounded grain shape, subangular mineral shape, grain size 0.01-1.4 mm, mineral size 0.1-0.4 mm, inhomogeneous packing. Some parts are dense with granular particles and loose to form pores in other parts and Vugh pore type. Microscopic observations in the lower layer incision (depth 20-50 cm) are brownish-yellow in Nicol parallel, brownish grey in Nicol cross, brownish yellow grain shape in Nicol parallel, brownish grey in Nicol cross, subrounded grain shape, subangular mineral shape, grain size 0. 01- 0.7 mm, mineral size 0.1-0.7 mm, packing Inhomogeneous; there are dense parts with granular particles and loose (forming pores) in other parts, Vugh pore type (Fig. 2).

Soil-forming Mineral of Batu Ampat

Microscopic observations showed that the incision in the upper layer (0-20 cm) identified brownish yellow colour in parallel Nicol and brownish-grey in cross nicol. Sub rounded grain shape, subangular mineral shape, grain size 0.01-1.2 mm, mineral size 0.05-1.2 mm, inhomogeneous packing. Some parts are dense with grain particles and loose (forming pores) in other parts and Vugh pore type. The results of microscopic observations of the incision in the lower layer (depth of 20-50 cm) brownish yellow colour in parallel niches, brownish-grey in cross niches, grain shape brownish yellow in parallel niches, brownish-grey in cross niches, sub-rounded grain shape, subangular mineral shape, grain size 0. 01-1.3 mm, mineral size 0.06-1.3 mm, packing Inhomogeneous; there are dense parts with granular particles and loose (forming pores) in other parts, Vugh pore type (Fig. 3).

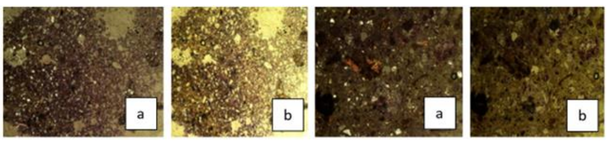

Fig. 2: Pepalang profile incisions: Top layer (a) Nicol aligned (b) Nicol crossed and bottom layer (a) Nicol aligned (b) Nicol crossed

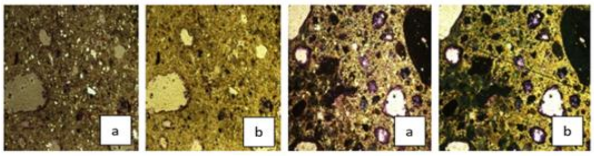

Fig. 3: Batu Ampat profile incisions: Top layer (a) Nicol aligned (b) Nicol crossed and bottom layer (a) Nicol aligned (b) Nicol crossed

Some types of minerals found in the three observation locations commonly are: 1) quartz (SiO_2), which is the primary silicate mineral with characteristics: Stable structural framework and resistance to weathering. The weathering speed of quartz is very slow. Quartz consists of 12% igneous rock and 66.8% sandstone. It was found in the upper and lower layers of all profiles using four transects. The amount of quartz found ranged from 10-15%, measuring 0.01-1.4 mm; 2) Biotite ($K(Mg, Fe)_3(Al, Fe)Si_3O_{10}(OH, F)_2$) is a primary silicate mineral with very high weathering speed. Its nutrient content is K_2O (6-9%) and MgO (2-20%). Biotite is found in all profiles in both the upper and lower layers. The amount of biotite mineral found ranges from 5-15%, measuring 0.05-0.6 mm; 3) Muscovite ($KAl_2(AlSi_3O_8)O_{10}(OH)_2$) is also a primary silicate mineral. Muscovite has low or slow weathering speed with nutrient content of K_2O (8-11%) and MgO (0-3%). Muscovite is found only in the top layer of Batu Papan and the bottom layer of Batu Ampat as much as 10% measuring 0.06-1.3 mm; 4); K-feldspar ($KAlSi_3O_8$) is the primary silicate mineral. Weathering speed is low and slow. Nutrient content of K_2O (9-15%) and CaO (0-3%). The amount of K-Feldspar mineral found ranged from 5-15%, measuring 0.04-0.3 mm in all profiles; 5) Plagioclase ($(Na, Ca)AlSi_3O_8$) is a mineral with medium weathering speed. This mineral is only found in the lower layer of the Pepalang profile and the upper layer of Batu Papan with an amount of 5%, measuring 0.06-1.3 mm; 6) Opaque is an oxide mineral, found in all transects of the upper and lower profiles. Opaque minerals are found in amounts of 5-15% with sizes of 0.01-0.8 mm). Clay has a status of secondary minerals resulting from the alteration of primary minerals found in the amount of 35-60%.

Discussion

The soil type in agricultural plantations is commonly closely related to the mineral content of the soil. Soil minerals greatly influence the infiltration and percolation process from groundwater. Infiltration and percolation of water are slow if the clay mineral content of the soil increases and becomes faster if the resistant mineral content of the soil. Glaser *et al.* (2002); Alzhankiti and Gill (2016); Bi *et al.* (2023) assumed it is necessary to raise the pH and eliminate plant poisoning due to aluminium and the availability of Ca as a soluble nutrient. The result showed that carbon levels were low in all layers of soil profiles. The availability of nutrients that can be used by plants is strongly influenced by the value of Cation Exchange Capacity (CEC). In general, CEC is found in the medium group, commonly in the upper layer and the layer below. Soil with a high number of CEC is able to absorb more nutrients, but it is difficult to release them into solution. Churchman *et al.* (2020); Kum *et al.* (2021); Cao *et al.* (2021) state that CEC makes soil less available to plants and more fertilizer needed to increase crop growth. Conversely, soils with low CEC store few nutrients but easily release them into the solution, and then plants can easily use them. Very low to low base saturation of soil is found around the top-to-bottom layers of soil. A positive correlation between pH and base saturation is seen in the sample profiles used; when the pH is low (acidic), the base saturation is also low, around 20-30%. This indicates that about 1/5-1/3 of the entire Cation Exchange Capacity (CEC) is occupied by base cations od calcium, magnesium, Kalium and natrium. It is estimated that 70-80% or 2/3-3/5 of the Al^{3+} and H^{+} cations are other cations that are easily absorbed, while other cations contribute less to the low pH. These cations are easily replaced by H^{+} ions derived from plant roots, which are highly dependent on the saturation of cations in the sorption complex. The higher the saturation value of the base, the easier it is to replace; on the other hand, if the saturation of the base is low, the more difficult it is to replace.

Karlen *et al*. (2006); Tun *et al*. (2015); Zaher *et al*. (2020) reported that commonly soil minerals consist of easily weathered minerals such as: Pyroxene, biotite, plagioklas and several resistant minerals, such as quartz. The high percentage of minerals in the bottom layers comes from the parent material of the soil, while the high percentage of minerals in the upper layers comes from the transportation of soil from higher elevations. Some of the potential nutrients found in the study area are: Kalium, magnesium, calcium and natrium. Honorine *et al.* (2021); Julian *et al.* (2023); Guo *et al.* (2023) stated that the high rainfall in the study area causes the soil to experience intensive weathering and leaching of nutrients, which is detrimental to crops. This incident can be overcome by applying fertilizer in a balanced manner and improving drainage to remove excess water.

Related to the presence of microbes inside soil content, commonly, soil microbes develop well in the soil with many organic matters. Roles of microbes detected by soil fertility and condition of crops. Few beneficial microbes in the soil are able to increase plant defence against soil-borne pathogens (Martín-Algarra, 2009; Cookson *et al.*, 2007; Rodríguez-Albarracín *et al.*, 2023). Soil microorganisms are important biological indicators for evaluating soil health and play a vital role in carbon-climate feedback. Presence of microbes in the decomposition process in natural ecosystems. The presence of temperature and moisture impacts the biodiversity of soil microbes. The high soil temperature affected the decrease in the population of microbes in the soil. Carbon loss in soil affects the ability of microorganisms to decompose organic resources at high temperatures. The microbial biomass and enzyme activity are crucial factors affecting soil microbial activity in soil (Innocent *et al.*, 2016; Guo *et al.*, 2019; He *et al.*, 2021; Jeljli *et al.*, 2022; Qu *et al.*, 2023).

In general, the development of soil quality in the research area is very feasible for crops as the primary source by looking at the nutrient potential of the soil. Nutrition content in the soil is sufficient to support sustainable agricultural land productivity to achieve the target of strengthening community food security at the individual level. The high rainfall and intensive weathering in the research areas require inputs to improve drainage and the use of balanced fertilizers. This is needed to support sustainable agricultural land productivity in order to achieve the goals of food security and community economy at the individual level. Strategies for achieving sustainable crop production are carried out through several smart strategies such as Increasing productivity, expanding area and optimizing land, reducing rice consumption, developing crop diversification and improving management.

Conclusion

The present study of soil and its minerals showed the chemical properties, texture and clay content of the samples. These, as well as minerals that are quite easy to weather, indicate that the soil has the potential to be more available for crops. They contain the nutritional potential for plant development, such as Kalium, calcium, magnesium and atrium. Our results also indicate the importance of seven types of minerals found in three profiles in the study area: Quartz, biotite, muscovite, K-feldspar, plagioclase, opaque, and clay.

These findings provide valuable insights into the positive impact of soil content on crop development, especially in West Sulawesi areas. However, the challenges of soil plantation contain more clay, and the farmer's technique can increase the function of soil as the growth media of crops. Further research is needed on the presence of specific minerals that affect crop yields related to season.

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Author's Contributions

Ida Suryani: Drafted research design, implementation and data collection.

Marliana Sjuaib Palad: Data analysis, drafted and data collection.

Nur Fitriani and Juni Astuti: Data interpretation and revision.

Roswiyanti Roswiyanti and Sri Nur Aminah: Drafted and revised.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript, and no ethical issue is involved.

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