The Relationship between Lithology and Chemical Characteristics of Soil and Soil Fertility Quality in the Taliabu Island Region, Indonesia

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10.18805/IJARe.AF-902

ABSTRACT

Background: Soil fertility refers to the soil's ability to provide essential nutrients for plant growth. This is largely determined by the process of lithological weathering, which involves the breakdown of parent rock. As the parent rock weathers, it releases different types of minerals into the soil, ultimately shaping the physical and chemical properties of the soil. These characteristics serve as the foundation for effective soil management, which is crucial for supporting a successful agricultural system. Through research on the impact of lithology and soil chemistry on soil quality, we gained a better understand and improve soil fertility.

Methods: The assessment of soil fertility quality is based on two aspects: The type of mineral content in the parent rock and soil chemistry, which includes CEC, BS, pH and elements such as N, P and K. This research was conducted in Taliabu Island Regency, North Maluku Province, Indonesia from May to December 2021. Soil data were obtained through direct observation in the field and by collecting soil samples for laboratory analysis.

Result: The research location's lithology comprised two main groups: Sedimentary and volcanic rocks. Sedimentary rocks included young formations (alluvio-marine and alluvio-colluvium) and old formations (limestone, coral, marl mixtures, sandstone, gneiss and schist). Old volcanic rocks present were breccia, tuff, lapilli tuff, granite and granodiorite. Soil chemical analysis revealed low fertility status. Considering the source rock composition and soil chemical properties, the overall soil fertility status was categorized as low.

Key words: Lithological weathering, Soil chemistry, Soil fertility.

INTRODUCTION

Soil fertility refers to the ability of soil to provide nutrients for plant growth and reproduction. A fertile soil has a balanced amount of water, air and nutrients that are readily available for plants to use (Nadarajah, 2022). However, agricultural land often faces challenges such as low soil fertility due to chemical problems like low soil pH and nutrient availability (Zaheri *et al*., 2024). One of the key factors that affects soil fertility is the lithology, or parent rock, Thakur *et al*. (2021). The weathering of parent rocks releases minerals into the soil, which in turn determines the physical and chemical properties of the soil (da Silva *et al*., 2022). The chemical composition of the soil is inherited from its parent material and this can greatly impact the natural fertility of the soil (Ozren *et al*., 2020). Weathered parent rocks contain easily weathered minerals that contribute to nutrient reserves and soil fertility, while non-weathered minerals like silicate (SiO_2) affect physical qualities such as aeration and drainage (da Silva *et al*., 2022). Understanding the physical and chemical characteristics of soil is crucial for effective soil management in agriculture. This includes evaluating soil fertility to identify limiting factors and determining the type and amount of nutrients needed. The Taliabu Island Regency, with a total area of 1,507.78 km^2 has a significant potential for agricultural development, as seen in its 14 hectares of irrigated rice fields, 1,234 hectares of dry land and 15,810 hectares of plantation land (BPS, 2019). However, there is still room for improvement in optimizing land use. This research aims to provide essential information for identifying technology requirements that can enhance land productivity and agricultural production in Taliabu Island Regency.

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How to cite this article: Aji, H.B., Sudarto, S., Teapon, A., Cahyaningrum, H., Sobari, I., Suwitono, B. and Rokhmah, D.N. (2025). The Relationship between Lithology and Chemical Characteristics of Soil and Soil Fertility Quality in the Taliabu Island Region, Indonesia. Indian Journal of Agricultural Research. 59(4): 643-648. doi: 10.18805/IJARe.AF-902.

Submitted: 24-07-2024 **Accepted:** 07-11-2024 **Online:** 06-01-2025

MATERIALS AND METHODS

This research was conducted in Taliabu Island Regency, North Maluku Province, Indonesia from May to December

2021. The equipment and materials used in the research consisted of: A) A topographic map of Indonesia, GIA scale 1:50,000 from 2018 and a Geological Map of Banggai sheet scale 1:250,000 from 1993; b) Office stationery and computers; c) Field survey equipment, such as: A Belgian-type soil drill 3 meter depth soil sampler kit, an Abney level one gradation arc in slope percentage/degree (two directions, 0° to 60°), an Altimeter and a compass used Celestron Trek Guide 48003, a pH meter used tester ZD-05, a field knife used stainless steel soil knife, a tape measure Krisbow 5 m KW0104086, a loupe GM-10083, and plastic soil sample bags 5 kg.

We created working maps and systematically collected soil samples in the field, using topographic maps (1:50,000) and geological maps (1:250,000) to accurately identify sample points. Soil observations, summarized in Table 1, provided a detailed overview of the distribution and properties of soil across different lithological units. Fig 1 illustrated the sample point distribution, highlighting the relationship between lithological variations and sampling locations. The research involved soil observations and sampling across several lithological units: aluvio-marine sedimentary rock (2 points), alluvium (1 point), limestone (1 point), tuffaceous sandstone (7 points), granite and granodiorite igneous rocks (2 points), and metamorphic rocks (gneiss and schist) with 2 points. Details of sample points, including lithology, administrative locations, and coordinates, were provided in Table 1.

Soil profile descriptions were conducted directly in the field by creating a 100 × 100 cm profile to a depth of 150 cm. If a full profile could not be made, a 50 × 50 cm minipit was dug to a depth of 50 cm, followed by drilling to 150 cm or until hard rock was encountered. Soil chemical properties that could not be measured in the field are obtained through laboratory analysis (Nadporozhskaya *et al*., 2022).

Soil chemical analysis was performed to assess fertility levels in the research area. Composite soil samples were taken from the top layer (0-30 cm) and bottom layer (30-60 cm) at various representative points. Chemical analyses were performed to evaluate key soil properties,

Table 1: Sample locations based on lithology in taliabu islad.

Sample	Lithology	Village/District	South latitude (LS)	East longitude (BT)
P01	Aluvio-Marine	Kilong Village (West Taliabu)	1° 55′ 47.70"	124° 22′ 28.51"
P02	Alluvium	Kilong Village (West Taliabu)	1° 55′ 40.17″	124° 22′ 38.73″
P03	Tufaan Sandstone	Bobong Village (West Taliabu)	1° 56′ 50.07″	124° 23′ 34.11″
P04	Granite, Granidiorite	Wayo Village (West Taliabu)	1° 56′ 56.32″	124° 26′ 41.29″
P05	Tufaan Sandstone	Bobong Village (West Taliabu)	1° 57′ 3.79″	124° 23′ 52.38″
P06	Granite, Granidiorite	Tabona Village (Tabona)	1° 54′ 4.73″	124° 52′ 29.70″
P07	Aluvio-Marine	Kabunu Village (East Taliabu)	1° 55′ 27.76″	124° 53′ 46.12″
P08	Tufaan Sandstone	Lede Village (Lede)	1° 43′ 18.00″	124° 23′ 21.42″
P09	Tufaan Sandstone	Tabona Village (Tabona)	1° 52′ 2.08″	124° 52′ 29.15″
P10	Massive limestone and coral	Kabunu Village (East Taliabu)	1° 55′ 20.90″	124° 53′ 54.63″
P11	Tufaan Sandstone	Tikong Village (Lede)	1° 42′ 57.57″	124° 28′ 24.89″
P12	Tufaan Sandstone	Tikong Village (Lede)	1° 41′ 11.52″	124° 24′ 21.98″
P13	Tufaan Sandstone	Ratahaya Village (West Taliabu)	1° 55′ 59.97″	124° 24′ 36.02″
P14	Gneiss and schists	Wayo Village (West Taliabu)	1° 57′ 57.79″	124° 26′ 21.22″
P15	Gneiss and schists	Wayo Village (West Taliabu)	1° 58′ 4.79″	124° 26′ 23.77″

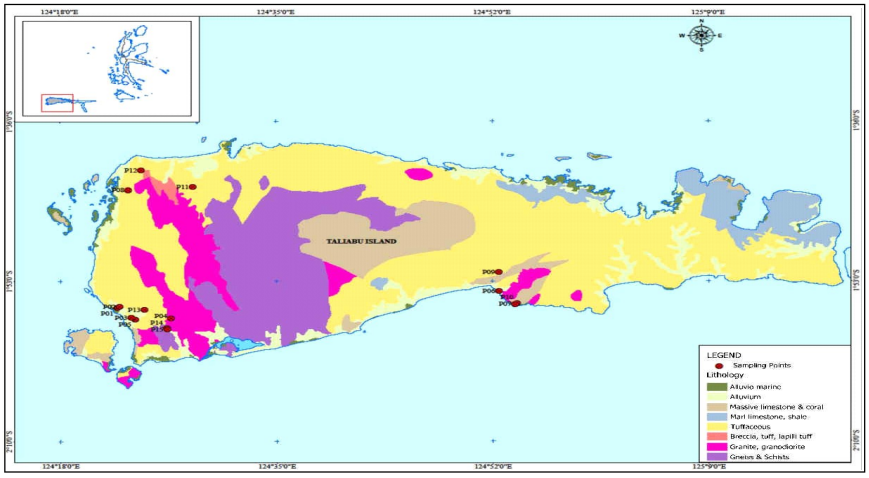


Fig 1: Map of research sample location.

including cation exchange capacity (CEC), base saturation (BS), pH, organic matter and extractable P_2O_5 and K_2O. CEC and BS were measured with 1 M Ammonium Acetate (pH 7), pH in H_2O and KCl and organic matter using the Walkley and Black method. P_2O_5 and K_2O were extracted with 25% HCl. Soil fertility was assessed by combining these parameters, following PPT (1995) guidelines, to obtain a comprehensive understanding of soil fertility status.

Results and Discussion

Description of research location and climate

The Taliabu Island Regency covers an area of 1,507.77 km^2 and is located at coordinates 01°48′00″ - 1,8°48′00″ South Latitude and 124°41′00″ - 104°52′00″ East Longitude. It is bordered by the Maluku Sea to the north, the Capalulu Strait to the east, the Banda Sea to the south and the Banggai Sea Islands to the west (BPS, 2021). The climate of the island plays a crucial role in plant growth and soil processes, with temperature and rainfall being the most influential factors (Luo *et al*., 2017). These climate components affect soil chemical and physical reactions, such as weathering, nutrient leaching, surface flow processes, erosion and sedimentation. The sedimentary stratigraphic formations in the research area are believed to have influenced the characteristics of soil formation. The tropical climate also affects fluvial sediment discharge, sediment type and pigment formation in the sediment (Nomosatryo, 2023). According to the Schmidt and Ferguson (1951) climate classification system, the climate in the research area is classified as slightly wet (SW), with an average of 2.5 dry months (DM < 60 mm) and 7.3 wet months (WM > 100 mm), with a Q value of 33.8%.

Lithology

The lithology (source rock) in Taliabu Regency can be grouped into sedimentary and volcanic rocks (Table 2). The sedimentary rocks found in the area include young sediments such as alluvio-marine and alluvio-colluvium, as well as older sediments such as limestone, coral, marl, shale, sandstone, gneiss and schist. The older volcanic rocks consist of breccia, tuff, lapilli tuff, granite and granodiorite. Based on research data, sedimentary rocks cover 273,323.50 ha (91.00%) of the total area, while volcanic rocks cover 27,017.30 ha (9.00%) (Table 2). Different geologies result in varying physical, chemical and mineralogical properties of the soil, leading to different soil structures (Zinn *et al*., 2020; Wilson, 2019). The chemical and mineralogical composition of the parent material also affects the natural fertility of the soil (Deb *et al*., 2014 and Yang *et al*., 2020). The parent rock that forms the soil determines its fertility, which is assessed based on its physical, chemical and biological properties (Adhikari and Hartemink, 2016). The islands of Taliabu, Sulabesi and Mangoli originated from the northern part of the Australian continent and separated during the Mesozoic to Paleogene period (Kusnama, 2008). The Mangoli

Table 2: Lithology in Taliabu island.

Subdistrict	Lithology (h)								
	Body of water	Aluvio-marine	Alluvium-colluvial	Massive limestone and coral	Marl, limestone, shale	Tuffaceous sandstone	Breccia, tuff, lapilli tuff	Granite, granodiorite	Gneiss and schists
West Taliabu	914.0	2091.2	3,422.4	2,044.3	130.1	15,916.7	-	13,074.8	18,779.4
North West Taliabu	58.3	689.7	923.9	-	-	8,550.0	-	5908.1	3,932.4
Lede	-	721.6	2,556.3	-	364.0	10.232.0	840.6	1,777.8	1,169.9
North Taliabu	8.7	1,089.7	4,025.7	-	3.728.0	47,253.6	-	608.8	21,909.3
South Taliabu	50.6	265.6	2,798.9	2,135.9	-	23,098.8	-	2,449.5	6.153.0
East Taliabu	1.5	1,680.8	4,268.5	-	19,333.5	18,829.9	-	-	-
Southeast Taliabu	12.9	105.1	3,830.0	461.1	-	30,397.9	-	2.254.0	-
Tabona	43.3	-	305.0	-	-	9,039.6	-	103.9	-
Number of Taliabu Islands (Ha)	1,089.3	6,643.7	22,130.7	4,641.3	23,555.6	163,318.5	840.6	26,176.9	51.944.0

Table 3: Soli fertility status in the topsoil layer (0-30 cm) on Taliabu Island.

Soil sample code		Soil chemical properties						Soil fertility status
		pH	CEC (me/100 g)	BS (%)	P_2O_5 (ppm)	K_2O (mg/100 g)	C-organic (%)	
Top layer P1	Aluvio-marine	4.50 (A)	41.12 (VH)	17 (VL)	4.50 (VL)	9.60 (VL)	6.16 (VH)	Low
Top layer P7	Aluvio-marine	4.50 (A)	4.15 (VL)	57 (M)	3.59 (VL)	0.99 (VL)	0.67 (VL)	Very low
Top layer P2	Alluvium	5.40 (A)	4.12 (VL)	95 (VH)	2.14 (VL)	3.16 (VL)	0.59 (VL)	Very low
Top layer P10	Limestone	6.10 (AA)	14.43 (L)	46 (M)	2.14 (VL)	1.56 (VL)	1.01 (L)	Low
P3 top layer	Tufaan sandstone	4.40 (VA)	3.10 (VL)	82 (VH)	2.15 (VL)	2.44 (VL)	0.59 (VL)	Very low
Top layer P5	Tufaan sandstone	4.40 (VA)	4.18 (VL)	54 (M)	2.17 (VL)	1.43 (VL)	0.51 (VL)	Very low
Top layer P8	Tufaan sandstone	4.00 (VA)	7.22 (L)	24 (L)	2.14 (VL)	0.38 (VL)	1.01 (L)	Low
Top layer P9	Tufaan sandstone	4.60 (A)	17.73 (M)	20 (L)	7.95 (L)	8.09 (VL)	3.81 (H)	Low
Top layer P11	Tufaan sandstone	4.00 (VA)	15.64 (L)	17 (VL)	9.39 (L)	2.31 (VL)	1.86 (L)	Low
Top layer P12	Tufaan sandstone	4.30 (VA)	7.23 (L)	35 (L)	6.44 (L)	1.26 (VL)	0.84 (VL)	Low
Top layer P13	Tufaan Sandstone	4.00(VA)	6.20 (L)	36 (L)	1.43 (VL)	1.41 (VL)	0.25 (VL)	Low
Top layer P4	Granite, Granodiorite	4.20 (VA)	6.23 (L)	56 (M)	2.88 (VL)	2.61 (VL)	0.76 (VL)	Low
Top layer P6	Granite, Granodiorite	5.00 (A)	8.32 (L)	35 (L)	2.16 (VL)	2.03 (VL)	0.68 (VL)	Low
Top layer P14	Gneiss and schists	4.00 (VA)	8.23 (L)	27 (L)	1.42 (VL)	1.26 (VL)	0.59 (VL)	Low
Top layer P15	Gneiss and schists	4.00 (VA)	15.74 (L)	15 (VL)	2.91 (VL)	10.94 (L)	0.17 (VL)	Low
Average		4.50 (A)	10.91 (L)	41 (M)	3.56 (VL)	3.30 (VL)	1.30 (L)	Low

Table 4: Soli fertility status in the subsoil layer (0-30 cm) on Taliabu Island.

Soil sample code	Lithology	Soil chemical properties						Soil fertility status
		pH	CEC (me/100 g)	BS (%)	P_2O_5 (ppm)	K_2O (mg/100 g)	C-organic (%)	
P7 bottom layer	Aluvio-marine	4.10 (VA)	3.14 (VL)	75 (H)	1.45 (VL)	0.27 (VL)	0.17 (VL)	Very low
P2 bottom layer	Alluvium	4.90 (A)	5.16 (L)	58 (M)	2.15 (VL)	2.59 (VL)	0.25 (VL)	Low
P3 bottom layer	Tufaan sandstone	4.40 (VA)	5.16 (L)	63 (H)	2.14 (VL)	0.26 (VL)	0.17 (VL)	Low
P5 bottom layer	Tufaan sandstone	4.30 (VA)	3.12 (VL)	70 (H)	1.44 (VL)	0.26 (VL)	0.25 (VL)	Very low
P8 bottom layer	Tufaan sandstone	4.00 (VA)	10.35 (L)	20 (L)	1.43 (VL)	0.39 (VL)	0.50 (VL)	Low
P9 bottom layer	Tufaan sandstone	4.00 (VA)	16.73 (L)	13 (VL)	7.25 (L)	6.33 (VL)	1.62 (R)	Low
P11 bottom layer	Tufaan sandstone	4.00 (VA)	10.36 (L)	22 (L)	1.44 (VL)	1.57 (VL)	0.76 (VL)	Low
P13 bottom layer	Tufaan sandstone	4.50 (A)	6.17 (L)	42 (M)	2.14 (VL)	2.01 (VL)	0.75 (VL)	Low
P4 bottom layer	Granite, Granodiorite	4.20 (VA)	8.29 (L)	42 (M)	6.46 (L)	2.15 (VL)	0.42 (VL)	Low
P6 bottom layer	Granite, Granodiorite	4.20 (VA)	7.28 (L)	34 (L)	2.16 (VL)	0.39 (VL)	0.51 (VL)	Low
P14 bottom layer	Gneiss and schists	4.30 (VA)	13.6 (L)	23 (L)	4.35 (VL)	16.24 (L)	1.19 (L)	Low
Average		4.30 (VA)	8.12 (L)	42 (M)	2.95 (VL)	2.95 (VL)	0.60 (VL)	Low

volcanic rock formations, which cover an area of 3,000 km^2, are believed to have formed during the Tertiary period.

These islands do not have local magma deposition, but rather the magma deposition occurred in the area of origin. According to the 1993 Banggai Sheet Geological Map at a scale of 1:250,000, the rock formations of the Mangoli volcano are estimated to be of upper Carboniferous to Permian age. These rock formations consist of rhyolite, ignimbite, breccia and lapilli tuff, which are all rich in silicate and acidic. The deep igneous rocks on Taliabu Island are known as Banggai Granites and are estimated to be of Permian to Triassic age. These rocks include granite and granodiorite and, along with the metamorphic and volcanic rocks, form the base or crust of the sedimentary rocks found on Taliabu Island. The metamorphic rocks on the island, such as gneiss, schist, amphibole and quartz, are the oldest and are estimated to be of Carboniferous age. All of these rocks are rich in silicate and acidic. According to Mendes *et al*. (2019) and da Silva *et al*. (2022), these rocks have a high silicate content (SiO_2) and low nutrient content, but can still contribute to the physical properties of soil due to their sand content. Liu *et al*. (2021) suggest that the high silicate content is a result of acidic volcanic materials, while Farahnaz *et al*. (2018) mention that the weathering of tuff produces clay minerals with a high silicate content. Additionally, da Silva *et al*. (2022) note that old volcanic rocks, such as breccia, granite, tuff and lapilli tuff, result in sandy, acidic and less fertile soil due to the weathering process.

Soil fertility

Soil fertility is greatly influenced by soil pH in natural environments. The soil on Taliabu Island is derived from a variety of old sedimentary and volcanic rocks, which are all acidic. This is the main reason why the soil on the island tends to be acidic and have low fertility (Table 3 and 4). Soil pH plays a crucial role in determining the availability of nutrients for plants (Thakur *et al*., 2022). Generally, plants can absorb nutrients at a neutral pH, as this is the optimal pH for their metabolism and physiological processes. However, in acidic soil, plants are unable to absorb essential elements such as nitrogen, phosphorus and potassium. The availability of phosphorus in the soil is greatly influenced by soil pH, as it can be present in both organic and inorganic forms. Mujiyo *et al*. (2017) found that in acidic conditions, phosphorus is strongly bound by acidic oxides, making it unavailable to plants. Ramamoorthy and Ariraman, (2023) found that the availability of phosphorus is highest in the pH range of 5.0-7.2. According to Yuan *et al*. (2022) the addition of organic material can increase the availability of phosphorus in the soil sorption complex and raise the pH of the solution.

Furthermore, the lithology of old sedimentary and volcanic rocks, which have undergone extensive weathering, also contributes to a low cation exchange capacity (CEC). This is because these types of rocks dominate the formation of soil structures, compared to clay and organic materials. Soils with high clay content and/or organic matter typically have a higher CEC than sandy soils (Putra and Jalil, 2018). The low CEC in the study area indicates that the soil's ability to retain and exchange cations in the soil solution is limited, which can affect plant growth and development. This is particularly evident in the low potassium (K) content of the soil. A low CEC reduces the soil's ability to hold K, resulting in quick release and leaching (Trinh *et al*., 2023). Trinh *et al*. (2023) explain further that K fixation in the soil can prevent leaching, while continuous K and NH_4 fertilization can reduce K fixation.

Base saturation is a measure of the ratio between the number of base cations and the total number of cations (acids and bases) in the soil adsorption complex. Generally, a higher base saturation indicates a higher pH value, higher CEC and relatively better soil fertility. On the other hand, a low base saturation value indicates a low pH, as part of the adsorption complex is occupied by Al^{3+} and H^+ cations (Baquy *et al*., 2018). Soil organic matter is typically concentrated in the topsoil layer, resulting in a decrease in organic matter levels with soil depth. The low level of soil organic matter in Taliabu Island Regency is due to the advanced source rocks that make up the soil, as well as limited decomposition of plant litter, soil erosion and land burning during agricultural land clearing. Mujiyo *et al*., (2017) suggest that the low organic matter content may be due to a lack of organic matter input in the soil, or an imbalance between the amount of organic matter input and the amount lost through plant transport or erosion.

Conclusion

The quality of soil fertility in Taliabu Island Regency is influenced by its lithological composition, which consists of both sedimentary and volcanic rocks. The dominance of old sedimentary rocks over young sedimentary and volcanic rocks results in sandy soil and low nutrient levels. This is due to the acidic pH, low CEC, low base saturation and low organic matter content. Further research is needed to improve soil fertility through various soil treatments using national strategic commodities.

Acknowledgement

The authors would like to express their gratitude to the Research and Development Agency of the Ministry of Agriculture of the Republic of Indonesia (BPTP North Maluku), the Soil Laboratory of the Faculty of Khaerun University and the Soil Laboratory of the Faculty of Agriculture, Brawijaya University for their valuable contributions to this research.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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