ASSESSMENT OF SOIL QUALITY INDEX FOR TEAK FOREST IN DRY LAND, ACEH BESAR REGENCY

ABDULLAH, U. H.[1*] – AKBAR, Y.[1] – KEUMALASARI, S.[1] – MARTUNIS, L.[1] – KACARIBU, A. A.[2] – WALIS, R.[3]

[1] *Department of Plantation Management, Politeknik Indonesia Venezuela, Aceh Besar, Indonesia.*

[2] *Agricultural Science Program, Universitas Syiah Kuala, Banda Aceh, Indonesia.*

[3] *Department of Agrotechnology, Iskandar Muda University, Banda Aceh, Indonesia.*

**Corresponding author*
e-mail: umarah_1977[at]yahoo.co.id

(Received 18th November 2024; revised 24th February 2025; accepted 03rd March 2025)

Abstract. This research aims to examine the analysis of the soil quality index on land use type specifically on teak forest on dry land of Aceh Besar Regency, Aceh Province. This investigation targeted multiple specific sites where teak forests are established on dry land. Descriptive techniques based on survey data, field observations, and laboratory analysis were used to conduct this study. Field surveys were conducted to gather primary data, including the overall biophysical conditions of the region, the physical and chemical properties of the soil from observations, and indicators of soil quality through laboratory analysis. The findings indicate that the SQI predominantly falls within the medium range. Factors such as low organic carbon levels, elevated bulk density, pH (H_2O), exchangeable potassium (K-exchangeable), phosphorus availability, and reduced total nitrogen content significantly affect these results. To mitigate nutrient leaching and enhance soil organic matter, specific management strategies involving fertilization, pine reforestation, and improved drainage are recommended for these teak forest lands.

Keywords: *dry land, teak forest, physical properties, chemical properties, soil quality index*

Introduction

Teak forests play an essential role in forest ecosystems, particularly in regions like Aceh Besar Regency, where their cultivation contributes significantly to local economies and environmental sustainability. Teak, known for its durable wood, is widely used by local communities for various purposes, including construction and furniture-making. Forest areas are typically divided into land quality classes, known as bonitas, which serve as indicators of land potential. Higher bonitas values reflect better soil and environmental conditions (Almulqu and Renoat, 2021). However, with increasing demand and land use pressures, the sustainability of these teak forests becomes a growing concern. Managing teak forest land effectively is crucial to maintaining not only the forest ecosystem but also the livelihoods that depend on it. The environmental sustainability of teak forest land use is especially important in dryland regions, which are defined by low rainfall and high evapotranspiration rates. Drylands, which account for approximately 41% of the Earth's land surface, are home to about 2.5 billion people, most of whom live in developing countries. These areas are characterized by an aridity index (AI), a ratio of precipitation to potential evapotranspiration (P/PET), which helps classify dry sub-humid, semi-arid, arid, and hyper-arid regions (UNCOD, 1977). Due to their fragile ecosystem, drylands are highly susceptible to degradation,

eISSN: 2716-6341
https://doi.org/10.55197/qjoest.v6i1.205

particularly under human activity and climate change. Degradation in drylands can lead to reduced agricultural productivity, negatively impacting food security, socio-economic development, and biodiversity (Huang et al., 2017; Zhou et al., 2016). Therefore, understanding the soil quality in these regions is essential for formulating strategies for land use and environmental management.

Soil quality, a key factor in land productivity, is influenced by several physical, chemical, and biological properties. One of the most important indicators of soil quality is soil organic matter, which plays a significant role in improving soil structure, water retention, and nutrient availability (Gerke, 2022). Enhancing organic matter in soil not only increases its fertility but also mitigates the effects of erosion and nutrient leaching, which are common in dryland areas. Organic matter decomposition releases organic acids, which are critical for the formation of soil aggregates, improving the soil's physical properties such as porosity and water-holding capacity (Saputra et al., 2018). In teak forest lands, intensive cultivation often results in nutrient leaching, reducing the organic matter content of the soil and threatening long-term sustainability (Lestari, 2023). Sustainable soil management requires a comprehensive understanding of soil quality, including the various indicators that reflect the soil's ability to support plant and animal life. Soil quality assessment involves evaluating these indicators, such as soil organic matter, root depth, and cation exchange capacity, to determine the overall health and productivity of the soil (Bünemann et al., 2018). Inconsistencies in soil quality data can lead to mismanagement, causing issues like landslides, water contamination, and reduced crop yields (Cherubin et al., 2021). This study focuses on evaluating the soil quality index (SQI) of teak forests on dryland in Aceh Besar Regency, where the land use type plays a critical role in determining the soil's fertility and sustainability. Building on previous research on mixed gardens and other land use types (Akbar et al., 2022; Umar et al., 2022), this research aims to provide a detailed analysis of soil quality in teak forests and its implications for land management in dryland environments.

Materials and Methods

Chemicals and equipment

Chemical used were distilled water, and various chemicals including 10N HCl, 10% H_2O_2, and other reagents necessary for laboratory analyses, were purchased from Merck (Malaysia). Field equipment included a handheld GPS (Global Positioning System), soil auger, sample rings, pH meter, tape measure, as well as plastic, rubber, knives, hoes, and an Abney level. Analytical balances, pH meters, ovens, shakers, hot plates, homogenizers, distillation units, burettes, beakers, spectrophotometers, and atomic absorption spectrophotometer (AAS) equipment.

Descriptive techniques and data collection

Descriptive techniques based on survey data, field observations, and laboratory analysis were used to conduct this study. Field surveys were conducted to gather primary data, including the overall biophysical conditions of the region, the physical and chemical properties of the soil from observations, and indicators of soil quality through laboratory analysis. *Figure 1* shows the flow diagram of the study.

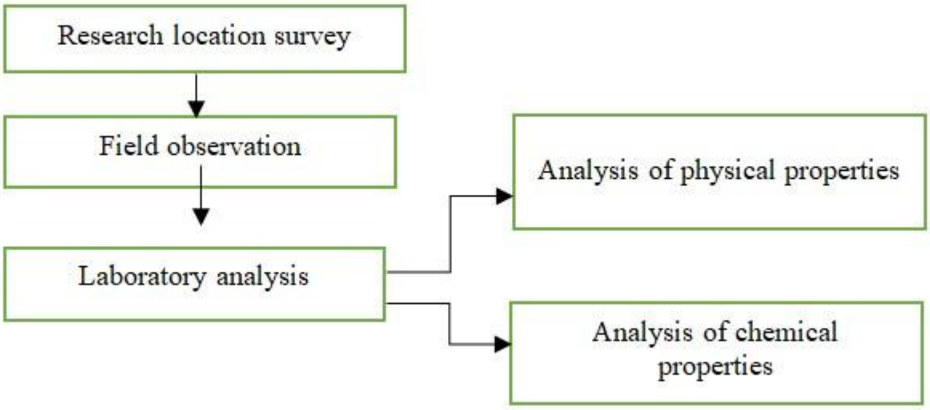

Figure 1. *Flow diagram of the research.*

Soil sampling and analysis procedures

Soil sampling points were selected using purposive sampling at five locations: Jantho 1, Jantho 2, Jantho 3, Uteun Sira 1, and Uteun Sira 2 in Aceh Besar Regency (*Tabel 1* and *Figure 2*). At each location, samples were taken with an average of five repetitions. Soil for chemical analysis was collected via drilling to assess solum thickness, focusing on the top 20 cm of the soil layer. This depth was selected due to its representativeness in reflecting the most biologically active portion of the soil, which is typically richer in organic matter and nutrients. The selection of this depth also aligns with standard practices in soil quality assessments, ensuring the relevance and comparability of the results (Lal et al., 2021). Five to six samples were collected from teak forest areas and analyzed in the lab to determine fertility status. Field observations and sampling were conducted at each Land Use Type (LUT) point in Aceh Besar's teak forests, targeting Entisol and Inceptisol soil types on slopes ranging from 0% to 15%. The field survey was supported by regional maps, Google Maps, soil type maps, and observation point maps (Nurmaya et al., 2022; Panten et al., 2010).

Table 1. *Research location details.*

Location	Sample point coordinates	Code	Forest ages (years)
Jantho 1	95.600343 – 5.302563	S1	10
Jantho 2	95.596966 – 5.304091	S2	20
Jantho 3	95.603445 – 5.301672	S3	20
Uteun Sira 1	95.46971 – 5.507488	S4	20
Uteun Sira 2	95.469424 – 5.507157	S5	40

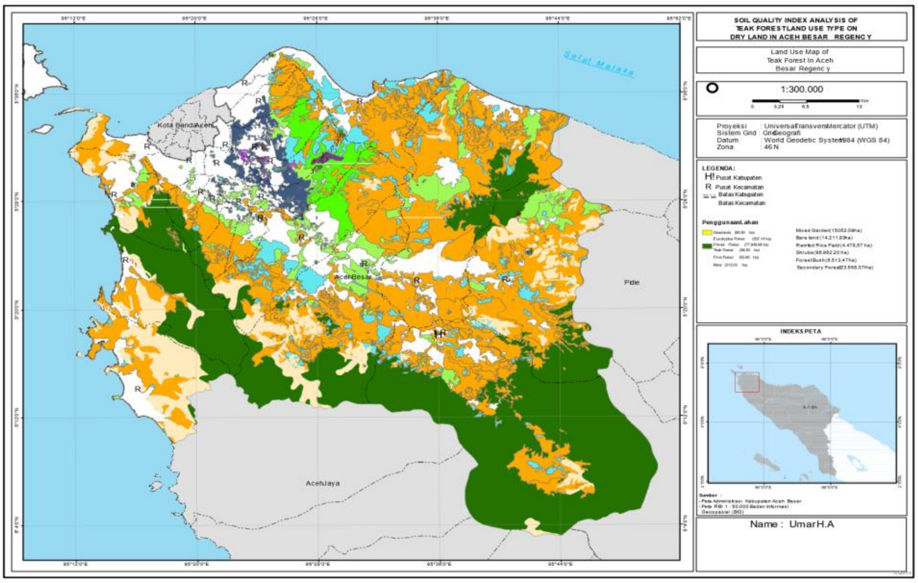

Figure 2. Map of study location in Aceh Besar Regency, Aceh Province, Indonesia.

The study area includes several teak forest plantations with varying ages and histories. Some areas, such as those in Jantho, are the result of government reforestation projects from the 2000s, with teak plantations ranging from 10 to 20 years old. In contrast, teak forests in the Uteun Sira Blang Bintang area have a more varied age distribution, with most of the forests originating from reforestation activities in the 1980s and 1990s. These forests range in age from 20 to 40 years. The age differences in the plantations across the study sites are important for understanding soil dynamics and the specific needs of each forest for sustainable management.

Laboratory analysis

To examine the physical and chemical characteristics of the soil, a soil sample analysis was conducted. The analysis and methods used in this study, including the variables listed in *Table 2*, were utilized. Data on base saturation (BS) and cation exchange capacity (CEC) were also used to support soil classification.

***Table 2**. Soil physical, chemical, and biological properties analyzed in the laboratory.*

No	Aspect analysis	Units	Methods
1	Texture	%	Stokes' Laws pipette method
2	Reaction (pH) of soil : pH (H_2O)*	-	Electrometric
3	C-Organic	g/kg	Walkey and Black
4	N-total	%	Kjeldahl
5	P-available	ppm	Bray and Olsen
6	K-exchangeable	c.mol/kg	Extraction of 1 N NH_4COOH
7	Rooting depth	Cm	Drilling
8	Bulk density	g/m^3	Ring sample (core method)
9	Porosity	%	Complete saturation

*Note: * pH was measured at the soil surface after removing the litter layer (Nisa et al., 2024).*

Soil quality index analysis

The method (Lal, 2020) for analyzing the soil quality index was modified by Arifin (2011) as well as Partoyo (2005) were utilized. The nine soil quality parameters criteria as presented in *Table 2* are used to determine the SQI, while the criteria for soil quality as stated by Partoyo (2005), are shown in *Table 3*. The method of calculating the SQI described as follows (Nisa et al., 2024): (a) The scoring index is calculated by multiplying the weight assigned to soil function (Score I) with the weight of the primary indicator (Score II) and the sub-indicator weight (Score III); (b) The scoring process involves comparing the observed soil indicator data with the assessment criteria. Scores are assigned on a scale from 0 (indicating unfavorable conditions) to 1 (indicating favorable conditions). These scores are obtained through interpolation using a linear equation based on the predefined data range (Eq. (1) and Eq. (2):

$$Y = \frac{x - x_2}{x_1 - x_2} \qquad \text{Eq. (1)}$$

$$Y = 1 - \frac{x - x_2}{x_1 - x_2} \qquad \text{Eq. (2)}$$

where Y is the linear score, x is the value of soil properties, x_1 is the lower limit, and x_2 is the upper limit; and (c) The Soil Quality Index (SQI) is then determined by summing the weighted scores of all indicators (Eq. (3):

$$SQI = \sum wi \times Si \qquad \text{Eq. (3)}$$

where SQI, Wi, and Si=soil quality index, weight index of the soil function, and score of the selected indicator, respectively.

Table 3*. Soil quality criteria based on SQI values.*

No	SQI class boundary	Criteria of soil quality
1	0.80 – 1.00	Very good
2	0.60 – 0.79	Good
3	0.40 – 0.59	Medium
4	0.20 – 0.39	Low
5	0.00 – 0.19	Very Low

Source: Partoyo (2005).

Statistical analysis

Data obtained from the study were processed using descriptive statistical methods. The mean (average) was calculated to represent the central tendency of the data, while the standard deviation (SD) was used to describe the variability and dispersion of the measurements.

Results and Discussion

Soil physical and chemical properties

The soil samples collected from teak forest land use types in Aceh Besar Regency were analyzed for their physical and chemical characteristics. The results, shown in

Table 4, summarize important indicators such as rooting depth, volume weight, porosity, C-organic content, and pH across five different samples.

***Table 4**. Physical, chemical characteristics and rooting depth of teak forest land use types on dryland in Aceh Besar Regency.*

Physcial-chemical properties	S1	S2	S3	S4	S5
Rooting Depth (cm)	195 ± 0.50	185 ± 0.50	210 ± 0.6	175 ± 0.5	220 ± 0.5
Bulk density (g/m^3)	1.27 ± 0.01	1.28 ± 0.01	1.26 ± 0.01	1.25 ± 0.01	1.29 ± 0.01
Porosity (%)	62.11 ± 0.03	59.22 ± 0.02	62.11 ± 0.01	59.22 ± 0.03	60.67 ± 0.028
C-Organic (g/kg)	16.1 ± 0.20	17.6 ± 0.10	14.4 ± 0.11	16.0 ± 0.10	16.0 ± 0.11
Dust-Clay (%)	63 ± 0.35	43 ± 0.30	63 ± 0.4	43 ± 0.4	53 ± 0.3
pH (H_2O)	5.10 ± 0.03	5.40 ± 0.028	5.10 ± 0.03	5.40 ± 0.03	5.25 ± 0.02
P-available (ppm)	1.90 ± 0.01	2.15 ± 0.01	1.90 ± 0.01	2.15 ± 0.01	2.03 ± 0.01
K-exchangeable	0.07 ± 0.01	0.13 ± 0.00	0.07 ± 0.01	0.13 ± 0.00	0.10 ± 0.00
N-Total (%)	0.08 ± 0.00	0.15 ± 0.00	0.08 ± 0.00	0.15 ± 0.01	0.12 ± 0.01

Note: Data are presented as mean ± standard deviations.

Rooting depth

The variation in rooting depth is a critical factor in evaluating soil fertility and structure, as it directly influences plant health and productivity. *Table 4* and *Figure 3* demonstrate that rooting depth varies significantly across the samples, ranging from 175 cm in sample 4 to 220 cm in sample 5. These differences highlight variations in soil characteristics within the study area. The deeper rooting depth observed in sample 5 (220 cm) indicates favorable soil conditions, such as better structure, lower compaction, and improved moisture retention capacity. This is consistent with studies suggesting that deeper rooting allows trees to access a larger volume of soil resources, including water and nutrients, thereby promoting healthier growth and resilience during dry periods (Rafika et al., 2022). In contrast, the relatively shallow rooting depth in sample 4 (175 cm) may indicate more compacted soil or reduced fertility. Soil compaction can limit root penetration, reducing access to vital resources and hindering tree development. Soil compaction is a significant factor that can limit root penetration and affect plant development, as evidenced by various studies. Compacted soil increases bulk density and decreases porosity as shown in *Table 4*, which restricts root growth and access to essential resources like water and nutrients. This can lead to reduced plant productivity and altered root system architecture (Turgut, 2012; Batey and McKenzie, 2006).

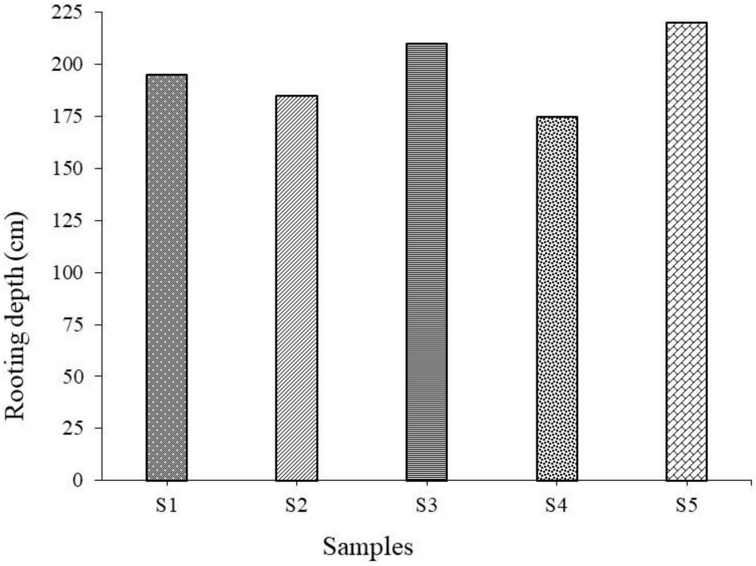

Figure 3. *Rooting depth characteristic.*

These variations in rooting depth have significant implications for teak tree growth. Deeper rooting, as observed in sample 5, facilitates better anchorage, water uptake, and nutrient absorption, which are essential for sustaining growth under variable environmental conditions. On the other hand, the shallow rooting depth in sample 4 could lead to water stress during dry periods, negatively affecting tree health and productivity. The observed differences may also be influenced by underlying soil parent material, management practices, or natural heterogeneity within the site.

Bulk density

Bulk density is a critical measure of soil compaction, directly influencing soil porosity, root growth, and water infiltration. The study (*Figure 4*) highlights that-soils with bulk densities exceeding 1.2 g/cm3, such as sample S5 with a density of 1.29 g/cm3, are approaching the compaction threshold, which can impede root penetration and reduce soil fertility. As compaction increases, soil porosity decreases, leading to higher mechanical impedance, which in turn restricts root growth and water infiltration (Prikner et al., 2004). Compacted soils exhibit a significant reduction in pore space, affecting soil structure and limiting the development of the root system. This can result in reduced plant growth characteristics, such as biomass production and height. Moreover, high levels of compaction, such as those observed at densities of 1.7 g/cm3, are known to severely affect root length, volume, and surface area, ultimately hindering plant productivity (Poukrel et al., 2022; Farrasati et al., 2019). These negative effects on root system development limit the plants’ ability to absorb essential water and nutrients, further exacerbating growth limitations.

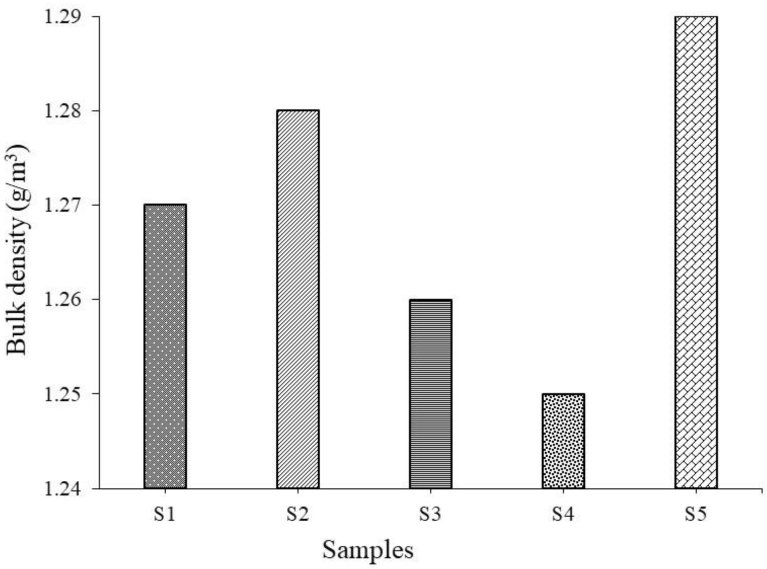

Figure 4. *Bulk density characteristic of soils samples.*

Soil compaction also impedes the absorption of key nutrients, particularly phosphorus (P), potassium (K), and magnesium (Mg), which are vital for healthy plant growth. In compacted soils, these nutrients are less available to plants, leading to deficiencies that restrict plant development (Wang et al., 2024). Interestingly, moderate compaction levels have been shown to enhance certain enzyme activities in the soil, which can facilitate nutrient accumulation. However, despite these increased enzyme activities, the overall plant growth is still limited due to the reduced root length and efficiency in nutrient uptake (Wang et al., 2024). In light of these findings, soil management practices that mitigate compaction, such as the addition of organic matter to improve soil structure, are essential to ensure healthy plant growth and optimal root development. Organic amendments can help increase soil porosity, reduce bulk density, and restore root access to water and nutrients. Further research into the long-term effects of organic matter on compaction and root growth would be beneficial for understanding the full scope of management strategies that could improve soil fertility and plant productivity under compacted conditions.

Porosity

Soil porosity is a critical parameter that influences air and water movement in the soil, directly affecting root development and overall plant health. The observed porosity as shown in *Figure 5* ranged from 59.22% to 62.11%. Soils with higher porosity, such as S1 and S3, exhibited better aeration and water retention, fostering robust root systems. In contrast, the lower porosity observed in S4 indicates soil compaction, which can hinder root expansion and water absorption (Akbar et al., 2022; Sahbudin et al., 2020). Higher soil porosity enhances the soil's water-holding capacity and facilitates improved air exchange, both of which are essential for root respiration (Luong et al., 2015). Soil pores function as pathways for root growth and nutrient uptake, with larger pores enabling more rapid water movement (Tonkha and Dzyazko, 2014). The incorporation of municipal compost, particularly when smaller particle sizes are used, has been shown to significantly increase soil porosity, thereby improving water retention. Enhanced porosity also contributes to higher hydraulic conductivity, which allows plants to efficiently uptake water (Tonkha and Dzyazko, 2014). While higher porosity generally benefits plant health, it is important to note that excessive porosity may result in rapid water drainage, potentially leading to nutrient leaching and reduced water availability during dry periods. Therefore, balancing soil porosity with structural stability is crucial for sustainable agricultural practices (Dippenaar, 2014).

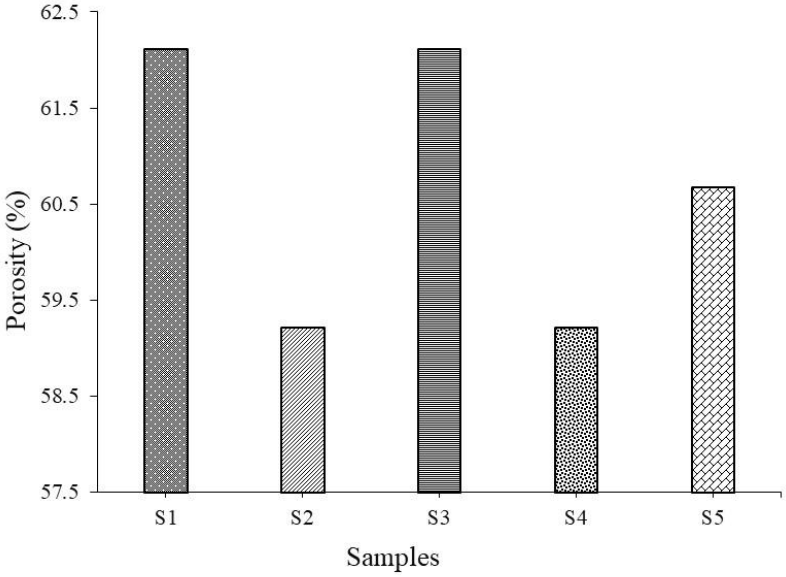

Figure 5. *Porosity characteristics.*

Dust-clay content

The dust-clay content in soil plays a significant role in determining soil texture and water retention capacity, both of which are critical for tree growth, particularly in dryland conditions. *Figure 6* presented the higher dust-clay content, as observed in samples S1 and S3 (63%), was associated with enhanced moisture retention. In contrast, the lower dust-clay content in samples S2 and S4 (43%) indicated quicker drainage and a higher potential for nutrient loss (Manullang et al., 2022). These findings align with existing studies emphasizing the role of clay content in soil moisture retention. A strong positive correlation between clay content and soil moisture retention has been reported, with correlation coefficients reaching up to 0.775 at 1.5 MPa (Husnjak and Bosak, 2014). Clay particles significantly enhance the water-holding capacity of soil, as demonstrated by the logarithmic relationship between clay content and moisture levels in semi-arid regions. The soil composition, particularly the balance between clay and sand, also directly impacts water retention, with increased sand content leading to reduced water-holding capacity (Li et al., 2009). Moreover, clay and cation exchange capacity (CEC) collectively account for over 93% of the variability in soil water content, highlighting the critical role of clay in moisture retention (Botha and Eisenberg, 1993). While higher dust-clay content generally improves moisture retention, excessive clay can result in poor drainage and reduced aeration, potentially restricting root development and adversely affecting overall plant health. Achieving an optimal balance of soil components is thus essential for promoting sustainable plant growth in dryland conditions.

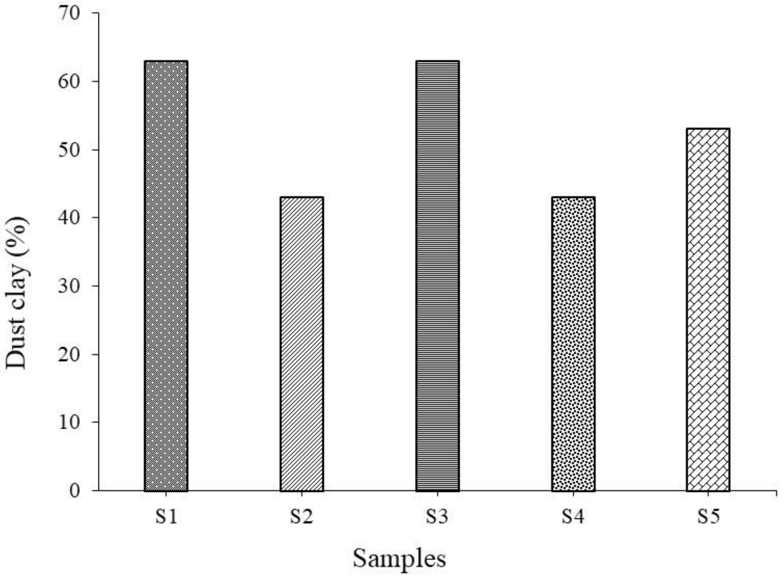

Figure 6. *Dust clay ratio characteristic.*

Chemical properties of the soil

The chemical properties of the soil, such as pH, available phosphorus (P-available), exchangeable potassium (K-exchangeable), C-organic content, and total nitrogen (N-total), are critical indicators of soil fertility. These properties are summarized in Table 4. The analysis of soil pH and nutrient content reveals significant implications for soil fertility and overall health. The moderately acidic pH range (5.09 to 5.40) may hinder the availability of essential nutrients, particularly phosphorus and nitrogen, which are critical for plant growth. Acidic conditions can also lead to toxicities (e.g., aluminum toxicity) and nutrient deficiencies, thereby reducing crop productivity (Osman, 2018). These conditions underscore the importance of maintaining a balanced soil pH to support optimal nutrient availability and microbial activity. The organic carbon content in the soil, measured at 1.44% to 1.76%, is relatively low, limiting the soil's capacity to retain moisture and nutrients, which further compromises soil fertility (Bangroo et al., 2018). Organic carbon, as a component of soil organic matter (SOM), plays a crucial role in nutrient cycling and retention. The interaction between SOM and phosphorus is particularly vital, as it influences phosphorus availability and release dynamics (Jindo et al., 2023).

Nitrogen levels in the soil, ranging from 0.08% to 0.15%, indicate limited nutrient retention capacity, though some potential exists for supporting plant growth (Raiesi and Salek-Gilani, 2020; Rahal et al., 2019; Bordoloi et al., 2018). Similarly, exchangeable potassium levels are notably low, with values around 0.07 ppm, particularly in samples S1 and S3, further highlighting limitations in soil fertility (Bangroo et al., 2018). Low potassium levels can impair essential physiological processes in plants, such as photosynthesis and water regulation, making potassium supplementation a critical aspect of soil management. The low organic matter content suggests insufficient organic inputs, such as crop residues or compost, which are essential for improving soil structure, enhancing water infiltration, and increasing nutrient availability (Boafo et al., 2018). The deficiency in organic inputs may also limit microbial activity, which is essential for nutrient mineralization and cycling. Despite these limitations, the soil's fertility and health can be improved through targeted management practices. Organic amendments, such as compost, manure, or biochar, can enhance soil structure, increase SOM, and improve nutrient dynamics. Additionally, liming acidic soils could help neutralize pH levels, mitigating toxicities and improving nutrient availability. Cover cropping and crop rotation are also effective strategies for building soil organic matter and improving nitrogen levels through biological fixation.

Soil Quality Index (SQI)

The soil quality index (SQI) provides a comprehensive measure of soil health by integrating both physical and chemical properties. As shown in *Table 5*, the SQI values for the teak forest land use type ranged from 0.4603 to 0.5464, placing the soil in the medium fertility category. This moderate fertility classification indicates that while the soil is capable of supporting teak growth, there is room for improvement in soil management practices to enhance fertility and productivity. The predominance of Inceptisol soil, known for its low natural fertility, is one reason for the moderate SQI. Inceptisols typically have low nutrient levels, including nitrogen, phosphorus, and potassium. Intensive soil management practices such as frequent use of synthetic fertilizers can worsen soil acidity, compaction, and the degradation of both physical and biological soil properties. To address these issues, organic matter and lime should be added to neutralize soil acidity and increase nutrient availability (Rafika et al., 2022; Wasis and Fikri, 2021). The findings highlight the need for better soil management in the teak forest areas of Aceh Besar Regency. The relatively low C-organic content and high bulk density suggest that the addition of organic materials, such as compost or manure, would improve soil structure and fertility. Furthermore, efforts to reduce soil compaction, such as reduced machinery use or minimal tillage, could increase porosity and rooting depth, thereby enhancing tree growth (Hakim et al., 2023; Lestari, 2023).

***Table 5**. Average soil quality index (SQI) for various types of dry land use in Aceh Besar Regency.*

Land type	SQI					Average	Criteria
	S1	S2	S3	S4	S5		
Teak forests	0.5464	0.4673	0.5390	0.4603	0.5032	0.5033 ± 0.035	Medium

Note: SQI means soil quality index. S means sample. Data presented as means ± standard deviation.

Conclusion

The soil quality index for teak forests in Aceh Besar Regency is classified as medium, with indicators such as low C-organic content, high bulk density, and low pH, K-dd, P-availability, and N-total. These results suggest that the soil quality is suboptimal for teak growth and requires targeted management. The studied areas include both young plantations (10-20 years old) from government reforestation projects in the 2000s, and older plantations (20-40 years old) from reforestation in the 1980s and 1990s. Management practices should be tailored to the specific needs of each stand. Recommended actions include fertilization, replanting in areas with poor regeneration, and implementing drainage to minimize nutrient leaching. These measures are necessary to improve soil fertility and ensure the long-term sustainability of teak forests. Further studies are needed to assess the long-term impact of these interventions.

Acknowledgement

This research is self-funded.

Conflict of interest

The authors declare there’s are no conflicts of interest associated with the study.

REFERENCES

[1] Akbar, Y., Endiyani, E., Agustina, S., Irhami, I., Rezvani, I., Irmayanti, I. (2022): Analysis of Soil Quality Index of mixed garden land use type on dry land in Blang Bintang sub-district, Aceh Besar district. – JURNAL AGRONOMI TANAMAN TROPIKA (JUATIKA) 4(1): 155-165.

[2] Almulqu, A.A., Renoat, E. (2021): Karakteristik Tegakan Hutan Tanaman Jati di Wilayah Kesatuan Pengelolaan Hutan Kabupaten Kupang. – Bio-Edu 6(3): 311-319.

[3] Arifin, Z. (2011): Analisis nilai indeks kualitas tanah entisol pada penggunaan lahan yang berbeda. – J. Agroteksos 21(1): 47-54.

[4] Bangroo, S.A., Dar, S.B., Itoo, H., Mubarak, T., Malik, A.R. (2018): Effect of physico-chemical properties of soil on available soil nutrients in apple orchards of district Kulgam. – Current World Environment 13(2): 270-276.

[5] Batey, T., McKenzie, D.C. (2006): Soil compaction: identification directly in the field. – Soil Use and Management 22(2): 123-131.

[6] Boafo, D.K., Kraisornpornson, B., Panphon, S., Owusu, B.E. (2018): Effect of organic and reduced mineral fertilisation on pH, nutrient content and microbial properties of acid soil. – Ann. Res. Rev. Biol. 24(1): 1-11.

[7] Bordoloi, L.J., Singh, A.K., Manoj-Kumar, P., Hazarika, S. (2013): Evaluation of nitrogen availability indices and their relationship with plant response on acidic soils of India. – Plant, Soil and Environment 59(6): 235-240.

[8] Botha, A.D.P., Eisenberg, B.E. (1993): Estimation of soil water retention from clay content and cation exchange capacity values of soils. – South African Journal of Plant and Soil 10(3): 141-143.

[9] Bünemann, E.K., Bongiorno, G., Bai, Z., Creamer, R.E., De Deyn, G., De Goede, R., Fleskens, L., Geissen, V., Kuyper, T.W., Mäder, P., Pulleman, M. (2018): Soil quality–A critical review. – Soil Biology and Biochemistry 120: 105-125.

[10] Cherubin, M.R., Carvalho, J.L.N., Cerri, C.E.P., Nogueira, L.A.H., Souza, G.M., Cantarella, H. (2021): Land use and management effects on sustainable sugarcane-derived bioenergy. – Land 10(1): 24p.

[11] Dippenaar, M.A. (2014): Porosity reviewed: quantitative multi-disciplinary understanding, recent advances and applications in vadose zone hydrology. – Geotechnical and Geological Engineering 32(1): 1-19.

[12] Farrasati, R., Pradiko, I., Rahutomo, S., Sutarta, E.S., Santoso, H., Hidayat, F. (2019): C-organik tanah di perkebunan kelapa sawit Sumatera Utara: status dan hubungan dengan beberapa sifat kimia tanah. – Jurnal Tanah Dan Iklim 43(2): 157-165.

[13] Gerke, J. (2022): The central role of soil organic matter in soil fertility and carbon storage. – Soil Systems 6(2): 14p.

[14] Hakim, L., Iemaaniah, Z.M., Rachmadi, A. (2023): Sosialisasi Rehabilitasi Hutan Dan Lahan Dengan Menggunakan Metode Konservasi Sipil Teknis Dalam Pengendalian Tanah Di Desa Rembitan Kecamatan Pujut Lombok Tengah. – Jurnal Siar Ilmuwan Tani 4(1): 112-117.

[15] Huang, J., Li, Y., Fu, C., Chen, F., Fu, Q., Dai, A., Shinoda, M., Ma, Z., Guo, W., Li, Z., Zhang, L. (2017): Dryland climate change: Recent progress and challenges. – Reviews of Geophysics 55(3): 719-778.

[16] Husnjak, S., Bosak, M. (2014): INFLUENCE OF THE SOIL PROPERTIES ON RETENTION OF THE SOIL MOISTURE. – Agronomski Glasnik: Glasilo Hrvatskog Agronomskog Društva 76(1-2): 3-14.

[17] Jindo, K., Audette, Y., Olivares, F.L., Canellas, L.P., Smith, D.S., Paul Voroney, R. (2023): Biotic and abiotic effects of soil organic matter on the phytoavailable phosphorus in soils: A review. – Chemical and Biological Technologies in Agriculture 10(1): 12p.

[18] Lal, R., Bouma, J., Brevik, E., Dawson, L., Field, D.J., Glaser, B., Hatano, R., Hartemink, A.E., Kosaki, T., Lascelles, B., Monger, C. (2021): Soils and sustainable development goals of the United Nations: An International Union of Soil Sciences perspective. – Geoderma Regional 25: 15p.

[19] Lestari, A. (2023): Sifat Fisik dan Kimia Tanah pada Berbagai Tipe Penggunaan Lahan di Desa Lembanna, Kecamatan Tinggimoncong, Kabupaten Gowa. – Universitas Hasanuddin 58p.

[20] Li, Z., Feng, H., Wu, P., Zhao, X., Guo, Z. (2009): Simulated experiment on effects of soil clay particle content on soil water holding capacity. – J. Soil Water Conserv. 23: 204-208.

[21] Luong, J., Mercatoris, B., Destain, M.F. (2015): Measurement of the open porosity of agricultural soils with acoustic waves. – In EGU General Assembly Conference Abstracts 2p.

[22] Manullang, J.F., Pakasi, S.E., Supit, J.M., Porong, J.V. (2020): Analisis sifat fisik dan kimia tanah pada lahan sawah di Kecamatan Kotamobagu Utara. – In Cocos 12(2): 9p.

[23] Lal, R. (2020): Soil quality and sustainability. – In Methods for Assessment of Soil Degradation, CRC Press 13p.

[24] Nisa, K., Sufardi, S., Rusdi, M., Indra, I. (2024): Soil quality index and patchouli yields on various cropping systems in Aceh province, Indonesia: Case study in Aceh Barat Regency. – Case Studies in Chemical and Environmental Engineering 10: 8p.

[25] Nurmaya, E., Fianti, F., Yulianti, I. (2022): Soil Quality Analysis for Dryland Agriculture with Variation of Fertilization and Plant Rotation in Argomulyo District, Salatiga City. – Physics Communication 6(1): 18-24.

[26] Osman, K.T. (2018): Acid soils and acid sulfate soils. – Management of Soil Problems 33p.

[27] Panten, K., Schnug, E., Wulfsohn, D. (2010): Advanced engineering systems for specialty crops: a review of precision agriculture for water, chemical, and nutrient application, and yield monitoring. – Johann Heinrich Von Thunen-Institut 88p.

[28] Partoyo, P. (2005): Analisis Indeks Kualitas Tanah Pertanian Di Lahan Pasir Pantai Samas Yogyakarta (Analysis Of Soil Quality Index For Sand Dune Agriculture Land At Samas Yogyakarta). – Ilmu Pertanian 12(2): 140-151.

[29] Poukrel, S., Maguire, R.O., Thomason, W.E., Stewart, R.D. (2022): Building Healthy Soil with Best Management Practices. – Virginia Cooperative Extension 3p.

[30] Prikner, P., Lachnit, F., Dvorak, F. (2004): A new soil core sampler for determination bulk density in soil profile. – PLANT SOIL AND ENVIRONMENT 50(6): 250-256.

[31] Rafika, A., Zuraida, Z., Muyassir, M. (2022): Aplikasi Kompos Terhadap Sifat Kimia Tanah dan Kandugan Hara Tanaman Jagung pada Lahan Kering Inceptisol Krueng Raya, Aceh Besar. – Jurnal Ilmiah Mahasiswa Pertanian 7(2): 665-671.

[32] Rahal, N.S., Alhumairi, B.A.J. (2019): Modelling of soil cation exchange capacity for some soils of east gharaf lands from mid-Mesopotamian plain (Wasit province/Iraq). – International Journal of Environmental Science and Technology 16(7): 3183-3192.

[33] Raiesi, F., Salek-Gilani, S. (2020): Development of a soil quality index for characterizing effects of land-use changes on degradation and ecological restoration of rangeland soils in a semi-arid ecosystem. – Land Degradation & Development 31(12): 1533-1544.

[34] Sahbudin, S., Khairullah, K., Sufardi, S. (2020): Kemasaman Tanah dan Sifat-sifat Pertukaran Kation pada Mollisols dan Ultisols di Lahan Kering Kabupaten Aceh Besar. – Jurnal Ilmiah Mahasiswa Pertanian 5(3): 25-34.
[35] Saputra, D.D., Putrantyo, A.R., Kusuma, Z. (2018): Hubungan kandungan bahan organik tanah dengan berat isi, porositas dan laju infiltrasi pada perkebunan salak di Kecamatan Purwosari, Kabupaten Pasuruan. – Jurnal Tanah dan Sumberdaya Lahan 5(1): 647-654.
[36] Tonkha, O.L., Dzyazko, Y.S. (2014): Soils and Plant Roots. In: Structural Properties of Porous Materials and Powders Used in Different Fields of Science and Technology. – Engineering Materials and Processes, Springer, London 28p.
[37] Turgut, B. (2012): Soil compaction in forest soils. – Turkish Journal of Forestry 13(1): 66-73.
[38] Umar, H.A., Endiyani, E., Agustina, S., Irhami, I., Anwar, C., Irmayanti, I. (2022): Analysis of Soil Quality Index type of land use on dry land in Blang Bintang sub-district, Aceh Besar Regency. – JURNAL AGRONOMI TANAMAN TROPIKA (JUATIKA) 4(2): 194-206.
[39] United Nations Conference on Desertification (UNCOD) (1977): Round-up, plan of action and resolutions. – UNCOD Web Portal 43p.
[40] Wang, L., Wang, T., Yao, S., Sun, H., Zhang, B. (2024): Soil compaction development facilitated the decadal improvement of the root system architecture and rhizosheath soil traits of soybean in the North China Plain. – Soil and Tillage Research 237: 13p.
[41] Wasis, B., Fikri, M. (2021): Pertumbuhan Semai Mahoni (Swietenia macrophylla) pada Media Tailing dengan Penambahan Arang Tempurung Kelapa dan Pupuk Kompos. – Journal of Tropical Silviculture 12(3): 109-117.
[42] Zhou, L., Chen, H., Hua, W., Dai, Y., Wei, N. (2016): Mechanisms for stronger warming over drier ecoregions observed since 1979. – Climate Dynamics 47: 2955-2974.