SAINS TANAH – Journal of Soil Science and Agroclimatology

Journal homepage: http://jurnal.uns.ac.id/tanah

Soil quality index in some cropping systems in plot 17 of Wanagama forest, Gunungkidul, Yogyakarta, Indonesia

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ARTICLE INFO

Keywords:
Soil quality index
cropping system
Wanagama
Forest
Plantations

Article history
Submitted: 2022-09-19
Accepted: 2024-01-20
Available online: 2024-05-30
Published regularly: June 2024

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ABSTRACT

The Wanagama 1 Forest, owned by Universitas Gadjah Mada in Playen, is an educational and research forest that is home to different species of trees that are managed and treated differently. Finding the quality index values for different cropping strategies in plot 17 of Wanagama Educational Forest 1 was the aim of this study. The soil quality index was determined using three methods: simple addition, scoring and weighting, and summation. The results show that in plot 17 of the Wanagama forest, the highest soil quality index values were found for ebony species and the lowest soil quality index values were found for mahogany and *Eucalyptus* species. The results showed that all land uses with different types of forest plants had lower soil quality indices. The stepwise analysis results showed that porosity, organic C, cation exchange capacity (CEC), P availability, K availability, and C biomass influenced the soil quality index. Measuring soil quality can help you learn more about soil properties and how to improve it through effective management.

How to Cite: Mustofa, A., Utami, S. N. H., Purwanto, B. H. (2024). Soil quality index in some cropping systems in plot 17 of Wanagama forest, Gunungkidul, Yogyakarta, Indonesia. Sains Tanah Journal of Soil Science and Agroclimatology, 21(1): 1-14. https://doi.org/10.20961/stjssa.v21i1.65454

1. INTRODUCTION

Forests are important ecosystems for survival on the Earth's surface. The global forest cover reaches 4 billion hectares, which covers 30% of the total available land. Forests have a dual function, namely, the production of various resources and the maintenance of livelihood security. Globally, a quarter of the human population depends on forests for livelihoods (Jhariya et al., 2020). Forests play an important role in human life and the environment. They positively impact humans as a source of livelihood, providing clean water and air, safeguarding biodiversity, and combating climate change (FAO, 2018). Destruction of forest areas stems from the consumerist lifestyle of society, which puts great pressure on the resources contained in forest ecosystem areas. Forest ecosystems are increasingly under pressure due to changes in environmental factors and increasing disturbances, especially those related to climate change and land use. This is the problem (McDowell et al., 2020).

Over time, forest areas have undergone many changes. Some of the factors that cause changes in forest areas include effective policies aimed at expanding forest areas, community economic growth, and decreasing rural populations or increasing agricultural productivity (FAO, 2016). An effort to increase agricultural productivity is to open agricultural practices in forest areas. Agricultural practices that are very close to forest areas are agroforestry practices. One of the forest areas that apply this system is Wanagama 1. It is an educational forest in Gunungkidul Regency, Yogyakarta. Wanagama was previously a key land with shallow and infertile soil depth, particularly in terms of Nitrogen (N), Phosphorus (P), and Potassium (K) nutrient content and poor organic matter. During the process of reforesting the Wanagama forest, the community and forest managers planted several types of plants such as teak, ebony, and *Gliricidia*. With the increasingly fertile Wanagama forest area, the community applied an agroforestry system to plant agricultural crops between forest crops. The community often planted several types of agricultural crops, such as cassava, peanuts, and kolonjono grasslands (*Brachiaria mutica*) (Kusumandari et al., 2021).

Over time, forest areas have undergone many changes. Factors contributing to changes in forest area include forest area expansion, economic growth of local communities, and effective measures aimed at reducing rural populations and increasing agricultural productivity (FAO, 2016). An effort to increase agricultural productivity is to open farms in forest areas. Agricultural practices that are very close to forest areas are agroforestry practices. One of the forest areas where this system is applied is the Wanagama 1 Forest Area. Wanagama 1 Forest is an educational forest located in Gunungkidul Regency, Yogyakarta Province. Wanagama was once a dangerous land with shallow, barren soils and low levels of nutrients, especially N, P, K, and organic matter. As part of the reforestation of Wanagama forest, communities and forest managers planted various plant species, including teak, ebony, and *Glyricaceae*. As Wanagama forest areas become more fertile, communities adopt agroforestry systems that plant agricultural crops in addition to forest crops. Different types of crops such as cassava, groundnut, and kolonjono grasslands (*Brachiaria mutica*) are commonly planted in this community (Kusumandari et al., 2021).

Agroforestry is the practice of sustainable land management that combines forestry crops with subfloor agricultural production (Santiago-Freijanes et al., 2021). The agroforestry system is aimed at the following approaches: (1) incorporation of annual crops into forestry crops with the goal of improving general land use and preventing erosion, particularly raising livestock and enhancing community revenue; and (2) incorporation of forest land conservation operations into an agroforestry system with the goal of increasing commercial commodities. Other goals of agroforestry include (a) ensuring and increasing food demand; (b) increasing local energy supply, particularly firewood production; (c) improving the quality and diversification of forestry and agricultural raw material output; (d) improving the quality of life in rural areas; and (e) maintaining and, if possible, increasing local production capabilities and environmental services (Chofyan & Andriani, 2020). However, it should be noted in agroforestry practices that there is competition for soil and water nutrients between trees and plants in the field (Pavlidis & Tsihrintzis, 2018). High nutrient competition can reduce the availability of nutrients in the soil. Depletion of nutrient content in the soil can decrease soil fertility in cultivated land. To ensure the long-term viability of soil fertility, it is vital to assess soil quality. Soil quality is highly related to two primary activities in forest ecosystems: biomass production and carbon (C) sequestration (Zhijun et al., 2018). Agroforestry also aims to (a) guarantee and increase food needs; (b) increase local energy supplies, especially firewood production; (c) improve the quality and diversification of forestry and agricultural raw material production; (d) improve the quality of life in rural areas; and (e) maintain and, if possible, increase local production capabilities and environmental services (Chofyan & Andriani, 2020). However, in agroforestry practices, there is competition for soil and water nutrients between trees and plants in the field (Pavlidis & Tsihrintzis, 2018). High competition for nutrients can reduce the availability of nutrients in the soil. Depletion of nutrient content in the soil decreases soil fertility on cultivated land. Therefore, it is necessary to assess the soil quality to maintain soil fertility. Soil quality is closely related to two main functions of forest ecosystems: supporting biomass production and C absorption (Zhijun et al., 2018).

Soil quality is described as the soil's capacity to perform various key activities. The Soil Quality Index (SQI) is a value that identifies the chemical, physical, and biological characteristics of the soil and determines its “fitness” to perform one or more activities (Armenise et al., 2013). SQI measurement increases productivity and environmental sustainability. Thus, an appropriate SQI may have three objective components: environmental quality, agronomic sustainability, and socioeconomic viability (Mukherjee & Lal, 2014).

At present, most studies on the soil conditions of Wanagama forest focus on measuring soil erosion, plant development, and soil physical and chemical properties of the Wanagama soil (Kusumandari et al., 2021; Udayana et al., 2019) and crop development (Winarni et al., 2021). In some previous studies, only the physical and chemical properties of the soil were used as a functional indicator to measure soil quality because of the simplicity of the analytical methods and the low cost of measurement. Therefore, it is important to monitor biological indicators because they are sensitive to environmental changes and play an important role in soil processes that determine the nutrient availability and productivity of forest ecosystems. Therefore, observations of soil properties should cover all physical, chemical, and biological properties that not only influence the functioning of soil nutrient cycling but also change the soil quality. The main aim of this study was to apply the SQI method to the soil quality of different plantation types in Wanagama forest to help forest managers and the surrounding communities assess the soil quality in a sustainable way (Guo et al., 2017). The main objective of this study was to use the SQI method to determine the SQI for Wanagama forest of different plantation types to help forest managers and surrounding communities assess soil quality and apply it in a sustainable manner. This study provides a theoretical and practical basis for Wanagama forest management. Soil quality assessment is a tool for improving soil management and land use systems. Different soil physical, chemical, and biological properties have been used as soil quality indicators for soil quality assessment (Rahmanipour et al., 2014).

Beneficial effects of vegetation cover and litter input influence soil resistance to rainfall and its physical, chemical, and biological qualities. More open land cover will exacerbate soil degradation. Soils that have degraded tend to be of poor quality. Soil degradation is described as a reduction in the soil's ability to perform both productive and protective tasks. This study proposed the hypothesis that differences in land use systems can influence SQI in different cropping systems inside the Wanagama forest.

2. MATERIALS AND METHODS

2.1. Research Location and Time

This study was conducted in plot 17 of Wanagama 1 Forest, Playen, Gunungkidul Regency, Yogyakarta (7°54′17.94″S 110°32′41.29″E), and in the laboratory. Laboratory analysis activities were conducted at the General Soil Laboratory, Department of Soil, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta. The research was conducted from September 2021 to February 2022.

Figure 1 presents location of plot 17 of Wanagama Forest, Gunungkidul, Yogyakarta, while Figure 2 presents Wanagama land cover map.

2.2. Materials and Tools

In the field, GPS, cameras, plastic bags, ropes, label papers, pedology hammers, soil drills, hoes, and stationery were used. In the laboratory, we used digital scales, pH meters, oven, threads, spiritual lamps, tripods, thermometers, pycnometers, erlenmeyer flasks, burettes, measuring pipettes, volume pipettes, cups, test tubes, measuring cups, measuring flasks, a flame photometer, and a spectrophotometer.

The materials used in this study were chemicals for soil analysis in the laboratory and soil samples from various forest areas, namely, teak, *Gmelina*, ebony, bamboo, mahogany, *Indigofera*, panggal buaya, jabon, *Acacia*, and *Eucalyptus*.

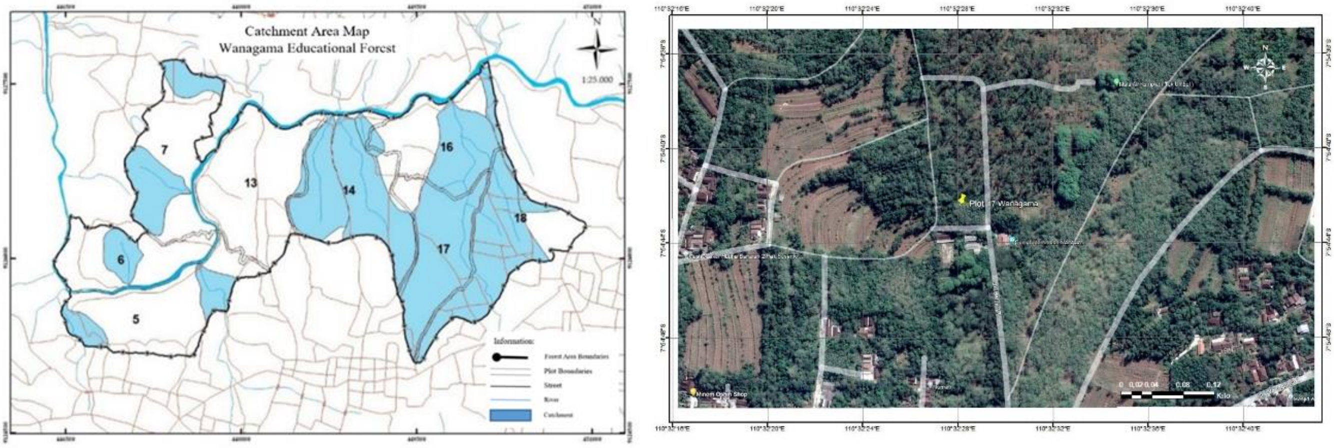

Figure 1. Location of plot 17 of Wanagama Forest, Gunungkidul, Yogyakarta (https://wanagama.fkt.ugm.ac.id/gallery/maps/)

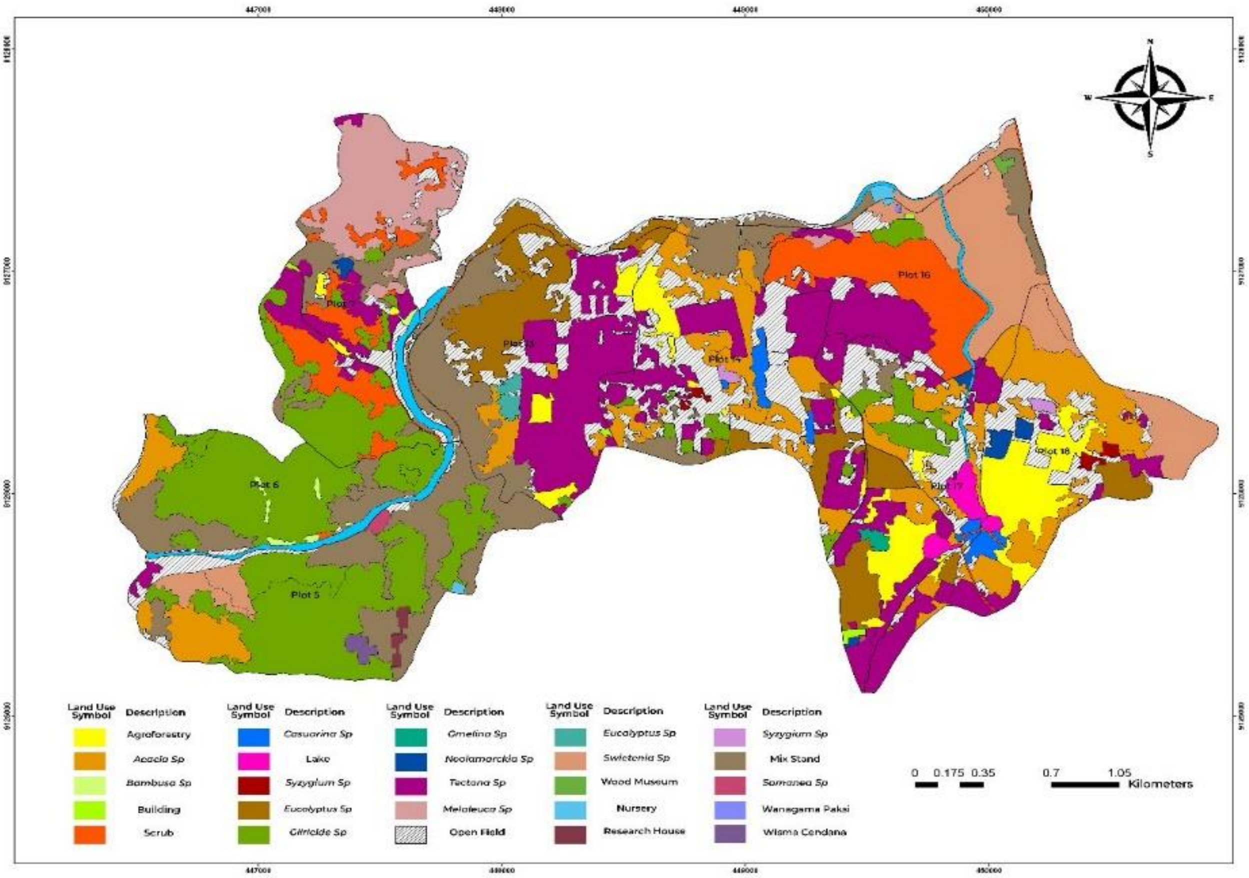

Figure 2. Wanagama land cover map (plot 17 of Wanagama: 7°54′17.94″S 110°32′41.29″E)

2.3. Research Methods

This study used a treatment factor in the form of vegetation types. Sampling was conducted in various planting areas such as teak (*Tectona grandis*), *Gmelina* (*Gmelina arborea*), ebony (*Diospyros celebica*), bamboo (*Bambusa arundinaceae*), mahogany (*Swietenia macrophylla*), *Indigofera* (*Indigofera tinctoria*), crocodile panggal (*Zanthoxylum rhetsa*), jabon (*Neolamarckia cadamba*), *Acacia* (*Acacia crasicarpa*), and *Eucalyptus* (*Eucalyptus urophylla*) (Figure 3).

This study was conducted in plot 17 of Wanagama 1 Forest, Playen, Gunungkidul Regency, Yogyakarta, and in the laboratory. The General Soil Laboratory, Soil Physics Laboratory, Chemistry, and Soil Fertility Laboratory, Department of Soil, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, conducted laboratory analyses. The study lasted from September 2021 to February 2022. This study used purposive sampling. Sample locations were determined on the basis of close planting locations, where one measuring plot measuring 15 m × 15 m contains at least ≥3 plants. Sample points were determined intentionally on the basis of the area of land overgrown with forestry plants; therefore, the data obtained are representative or truly representative of the population. In the measuring plot, soil samples were collected. Soil sampling was performed on 2 kg of soil samples from several plants in the plot. As a representative, soil was collected from the top soil layer (depth of 0–30 cm). At this depth in the upper soil layer, maximum biological activity occurs within the soil, which contains most of the soil's organic matter, in addition to leaching processes of metal ions and clay soil particles (Manahan, 2000). Next, the soil samples were thoroughly mixed, pooled into a single sampling location, air-dried, labeled, and packaged for laboratory analysis. Then, measurement plots were created in three replicates to obtain 3 × 8 soil samples, i.e., 24 samples (Dagnachew et al., 2019).

Laboratory analysis was conducted to observe soil properties such as soil texture 3 fractions using USDA texture triangle, bulk density with ring sample method, porosity by calculating the density value then divided by volume weight, pH H_2O using the glass electrode method, total N using the Kjeldahl method, available K using the extraction method NH_4OAc pH 7, cation exchange capacity (CEC) by extracting NH_4OAc pH 7, organic C soil using the Walkey–Black method, and C mineralization using the titration method (Balittanah, 2009).

2.4. Data Analysis

The research data were processed using Excel 365 and then statistically analyzed in the form of correlation test analysis between parameters using SPSS and stepwise regression statistical analysis using MINITAB 19.

2.4.1 SQI Calculation

SQI was measured using three methods: (1) simple addition, (2) evaluation, and (3) weighted addition.

All SQI measurement methods use soil samples with soil quality indicators as parameters (Table 1). Eight parameters were used: soil density, soil porosity, pH, available K, CEC, total N, organic C, and C mineralization. C mineralization is the conversion of organic C to inorganic C, which occurs mostly during organic material breakdown (Molles & Tibbets, 2002; Purnobasuki & Suzuki, 2005). C mineralization is the primary process of C cycling in ecosystems, in which large organic polymers are broken down into monomers and transformed into inorganic C.

Therefore, mineralized C is a biological property of soil. The results of the soil indicators were used as raw data to measure the soil quality indicators using the three methods mentioned in the Materials and Methods: (1) simple addition, (2) evaluation, and (3) weighting and summation.

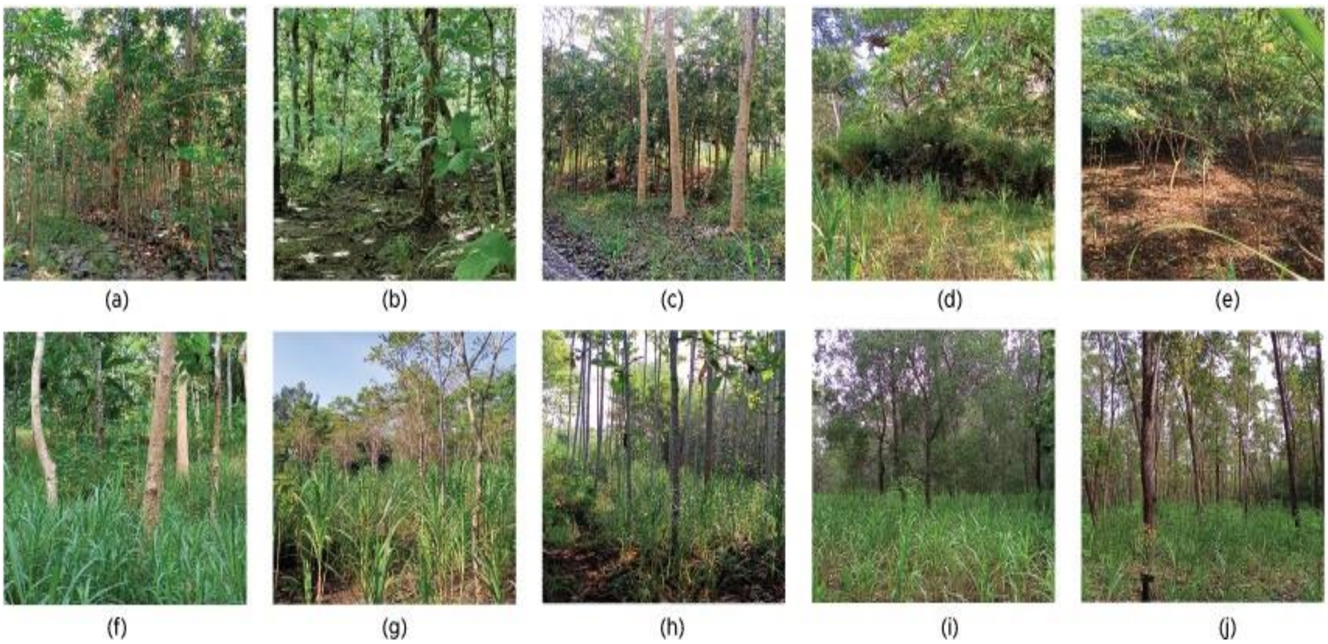

Figure 3. Garden plot: (a) mahogany, (b) teak, (c) ebony, (d) bamboo, (e) *Indigofera*, (f) *Gmelina*, (g) panggal buaya, (h) jabon, (i) *Acacia*, and (j) *Eucalyptus*

Table 1. Selection of Indicators for the Soil Quality Index based on the Physical, Chemical, and Biological Properties of the Soil

Soil fungtion	Indicator	Reference
Nutrient cycle	Soil pH (Erkossa et al., 2007)[1]	Doran and Parkin (1994), Smith and Doran (1997), and Karen et al. (1996)
	C microbe biomass (Seybold et al., 1997)[3]	Gregorich et al. (1997) and Sparling (1997)
	Available P (Bünemann et al., 2018)[1]	Doran and Parkin (1994), Harris et al. (1997), and Chen et al. (1996)
	Soil respiration (Seybold et al., 1997)[3]	Doran and Parkin (1994), Harris et al. (1997), and Karlen et al. (1998)
	Total N (Seybold et al., 1997)[1]	Arshad and Coen (1992), Doran and Parkin (1994), and Harris et al. (1997)
	Cation exchange capacity (Seybold et al., 1997)[1]	Doran and Parkin (1994) and Harris et al. (1997)
	Available K (Bünemann et al., 2018)[1]	Doran and Parkin (1994), Harris et al. (1997), and Karlen et al. (1997)
Physical stability	Bulk density (Seybold et al., 1997)[2]	Doran and Parkin (1994) and Arsyad et al. (1996)
	Texture (Seybold et al., 1997)[2]	Dumanski et al. (2006), Shepherd et al. (2008), and Mueller et al. (2014)
Functional stability	Soil depth (Erkossa et al., 2007)[2]	Arsyad et al. (1996) and USDA (2001)
	Organic C (Erkossa et al., 2007)[3]	Arsyad et al. (1996)), USDA (2001), and Grossman et al. (1999)
Flow of water and solutes	Porosity (Seybold et al., 1997)[2]	Schipper and Sparling (2000), Southorn and Cattle (2000), and Karlen et al. (1998)

Notes: Soil [1]chemical, [2]physical, and [3]biological properties

2.4.2. Indicator Selection

The indications for the SQI were selected on the basis of the soil's physical, chemical, and biological qualities. Soil quality indicators use the minimum dataset from Andrews et al. (2004), which is adapted to the needs and objectives of users. In this study, soil quality assessment is oriented toward land productivity. Soil functions that support productivity include nutrient cycles, water and solute flow, physical stability, and functional stability (resilience). On the basis of this function, the selection of indicators to be observed is shown in Table 1.

2.4.3. Indicator Interpretation

This study uses scores of 1–5 as indicators of soil quality sensitivity ranging from very high to very low. Evaluation of soil quality indicators directly or indirectly affects crops. Soils with a score of 1 to 2 on BV are likely to have a negative impact on plants by inhibiting root development. In terms of pH indicator, soils with scores of 1, 2–4, and 5 have high levels of Al, Mn, and other metals and can only support the growth of tolerant plants ; have P deficiency; and have the optimal conditions for various types of plants and contain P and possible some metals such as Zn, respectively. In the organic C indicator, scores of 1, 2–4, and 5 indicate the possible loss of organic C due to erosion or other processes; a fairly good condition for plant growth; and a excellent condition for plant growth, respectively. In the total N indicator, scores of 1, 2 to 3, and 4 to 5 indicate loss of organic N due to various processes that occur in the soil; sufficient conditions for plant growth; and a superb N reserve, respectively.

Soils with available K index values of 1 to 2, 3 to 4, and 5 indicate K deficiency, sufficient conditions for plant growth, and very low K reserves, respectively (Amacher et al., 2007).

2.4.4. Simple Additive SQI Measurement

The measurement of the SQI is performed by scoring the soil parameter values and then summing up all these soil parameters (Equation 1).

$$\text{SQI} = \Sigma \text{ soil parameter indicator score} \quad [1]$$

2.4.5. Measurement of SQI with Scoring

Each metric is combined into a single metric value using Equation 2.

$$\text{SQI} = \left(\frac{\sum_{i=0}^{n} \text{Si}}{n}\right) \times 10 \quad [2]$$

Information: Si = score on the selected indicator; n = number of soil quality indicators

The final SQI value obtained and the sum result are then entered into the SQI value. The interval calculation formula for determining the value of SQI (1) is Equation 3 (Sukarjo et al., 2018).

$$\text{SQI interval} = \frac{(\text{ST} \times \text{Si}) - (\text{SR} \times \text{Si})}{\text{sum of classes}} \quad [3]$$

Information: ST = highest score; SR = lowest score; Si = number of parameters used

The parameters used in this study amounted to 12 with the highest score of 10 and the lowest score of 0. There were five ratings: very low, low, medium, good, and very good. Therefore, the interval of the SQI (2) values obtained is as Equation 4.

$$\text{SQI interval} = \frac{(5 \times 12) - (1 \times 12)}{5} = 9.6 \quad [4]$$

Class lowest = number of parameters + SQI interval; Class lowest = 12 + 9.6 = 21.6

Furthermore, the SQI values at very low, low, medium, good, and very good are obtained as shown in Table 2.

Table 2. Soil Quality Index Values

Soil quality index value	Dignity
<21.6	Very low
21.6–31.2	Low
31.2–44.8	Currently
44.8–58.4	Good
>58.4	Very good
<21.6	Very low

2.4.6 Measurement of SQI with Weighting and Summation

In this method, the SQI was counted on the basis of modified indicators, weights, and rating function limits, Equation 5 and 6 (Table 1).

SQI weighting and summation = index weight × score from indication .... [5]

RE index weight = weight 1 × weight 2 × weight 3.............[6]

3. RESULTS

3.1. Land Description on Plot 17 of Wanagama Forest

Wanagama 1 Forest is an educational forest that is frequently used in research. It has various tree species with different management and treatment methods. At the beginning of its development, community and forest managers were already involved. Until now, the community has been allowed to manage and empower forest areas by planting agricultural crops/animal fodder plants on the sidelines of forestry plants. The success of reforesting the barren Wanagama area makes many visitors come with the intention of nature tourism or camping. This causes many variations in cropping systems, land use, and human activities (Nugraha & Kusumandari, 2021).

Table 3. Physical, Chemical, and Biological Soil Properties of Various Plants in Plot 17 of Wanagama Forest

Location	SD	SC	T	VW	PO	pH	Org-C	CEC	N	K	C-MIN
Teak	>80	7.5 YR 3/2	Clay	1.01	51.48	7.12	1.25	26.67	0.18	0.245	0.027
Ebony	>80	7.5 YR 3/3	Clay	0.88	57.49	7.04	1.42	23.47	0.21	0.439	0.028
Gmelina	>80	7.5 YR 3/2	Clay	0.85	58.45	6.86	0.98	27.07	0.15	0.175	0.038
Bamboo	>80	7.5 YR 3/2	Clay	0.76	61.30	6.52	0.83	22.40	0.18	0.245	0.025
Indigofera	>80	7.5 YR 3/4	Clay	0.86	58.33	6.61	0.75	19.40	0.14	0.422	0.026
Mahogany	>80	5 YR 3/2	Clay	0.96	54.69	6.84	0.77	19.93	0.11	0.051	0.026
Panggal Crocodile	>80	5 YR 3/3	Clay	0.95	54.47	6.39	1.02	17.93	0.14	0.589	0.029
Jabon	>80	7.5 YR 3/2	Clay	0.92	55.58	6.56	1.33	20.60	0.20	0.378	0.031
Acacia	>80	10 YR 3/2	Clay	0.86	57.05	7.25	1.25	33.93	0.25	0.305	0.024
Eucalyptus	>80	5 YR 3/4	Clay	0.89	55.46	6.18	1.31	21.47	0.14	0.217	0.029

Notes: SD, soil depth; SC, soil color; VW, volume weight; PO, porosity; T, texture; Org-C, organic C; CEC, cation exchange capacity; N, total N; K, available K; C-MIN, mineralized C (soil respiration)

Table 4. Soil Indicators and Quality Assessment Limits (adapted from Andrews et al. (2004))

Soil indicator	Unit	Scoring				
		Very low	Low	Medium	High	Very high
Soil physical properties						
Bulk density (Wander et al., 2002)	g cm^{-3}	>1.66	1.51–1.66	1.37–1.5	1.2–1.36	0.86–1.2
Porosity (Wander et al., 2002)	%	<15	15–20	21–30	31–40	41–61
		>90	81–90	71–80	60–70	
Soil texture (Sys et al. (1993), modified)*	-	C and SiC	f.S.Sf.SS	LS	Si, SiL, SiCL, and CL	L, SC, SCL, SL
Soil chemical properties						
Soil pH (Sys et al. (1993), modified)	-	<5.4	5.4–5.6	5.6–5.8	5.8–6.0	6.0–7.8
		>8.4	8.2–8.4	8.0–8.2	7.8–8.0	
Available N (Okalebo et al., 1993)	mg kg^{-1}	<1	1–3	3.1–9	9.1–15	>15
Organic C (Balittanah, 2009)	%	<1	1–2	2–3	3–5	>5
CEC (Balittanah, 2009)	cmol kg^{-1}	>5	5–16	17–24	25–40	>40
Total N (Balittanah, 2009)	%	<0.1	0.1–0.2	0.21–0.5	0.51–0.75	>0.75
Available P (Balittanah, 2009)	mg kg^{-1}	<5	5.1–7	7.1–9	9.1–11	11.1–15
		>20	18.4–20	16.8–18.3	15.1–16.3	
Available K (Balittanah, 2009)	cmol kg^{-1}	<0.1	0.1–0.3	0.4–0.5	0.6–1	>1
Soil biological properties						
Soil respiration (Supriyadi, 2014)	mgCO_2 g^{-1} $days^{-1}$	<0.0190	0.020–0.0566	0.0567–0.0942	0.0943–0.132	>0.132
C biomass (Supriyadi, 2014)	mg g^{-1}	<0.0190	0.020–0.0566	0.0567–0.0942	0.0943–0.132	>0.132

Notes: * C, clay/loam; SiC, silty clay; SiCL, silty clay loam; SC, sandy clay; SCL, sandy clay loam; CL, clay loam; Si, silt/dust; SiL, silty loam; L, loam; S, sand/sand; LS, loamy sand; SL, sandy loam/loam sand.

Texture; bulk density; soil porosity, depth, and color; pH; organic C; CEC; total N; accessible K; and other soil physical, chemical, and biological parameters were investigated. Observations of soil properties are shown in Table 3.

Table 4 presents the results of soil indicators, which include soil physical, chemical, and biological properties and quality assessment limits (very low to very high). The overall soil properties observed were scored to measure the SQI using three methods: simple addition, scoring and weighting, and summation.

3.2. SQI with Simple Addition

The simple addition SQI is a method that provides threshold values for soil parameters based on literature reviews and expert opinions. Table 5 shows the SQI measurement results. On the basis of the average SQI values for different crops, ebony with a value of 36 and mahogany with a value of 32 had the highest and lowest SQI respectively.

3.3. Soil Quality Index with Scoring

Measurement Index Soil Quality done with collect data about indicators that have chosen For every function ground. Evaluation of quality land use method by scoring data on each indicator. Indicator quality land is the properties; characteristics; or physical, chemical, or biological processes of land that can describe the condition of land (Partoyo, 2005).

Indicator quality land determined by method collect indicator data that has been selected or minimum data sets. Calculation done with give score index to selected indicator. Every mark index For all characteristic measured land, totaled is the total SQI (Andrews et al., 2004). Table 6 shows the parameter scores of the SQI of the study.

On the basis of average SQI values for different crops, ebony with a value of 30.00 and mahogany with a value of 26.67 had the highest and lowest SQIs, respectively. Of all the planting types in plot 17, Wanagama had a low rating.

Different from the evaluation index quality land through scoring. SQI with weighting and summation counted by multiply index weights and scores from indicator. From the results measurement index quality land with method weighting and summation obtained results like Table 7.

On the basis of the SQI values by weighting and summing different forest plant species studied, ebony with a value of 0.87 had the highest SQI value, whereas *Eucalyptus* with a value of 0.82 had the lowest SQI value. Of all the planting types in plot 17, Wanagama receives a low rating.

Table 5. Measurement Results of Soil Quality Index by Simple Addition

Location	SD	T	BD	PO	pH	Org-C	CEC	N	P	K	C-BMT	C-MIN	∑ SQI
Teak	5	1	5	5	5	2	4	2	1	2	1	1	34
Ebony	5	1	5	5	5	2	3	3	1	3	2	1	36
Gmelina	5	1	5	5	5	1	4	2	1	2	1	1	33
Bamboo	5	1	5	5	5	1	3	2	2	2	1	1	33
Indigofera	5	1	5	5	5	1	3	2	2	3	1	1	34
Mahogany	5	1	5	5	5	1	3	2	2	1	1	1	32
Call crocodile	5	1	5	5	5	2	3	2	2	3	1	1	35
Jabon	5	1	5	5	5	2	3	2	1	2	1	1	33
Acacia	5	1	5	5	5	2	4	3	1	2	1	1	35
Eucalyptus	5	1	5	5	5	2	3	2	1	2	1	1	33

Notes: BD, bulk density; PO, porosity ; T, texture; SD, soil depth; Org-C, organic C; N, total N; P, available P; K, available K; C-BMT, C biomass; C-MIN, C mineralization (soil respiration); SQI, soil quality index

Table 1. Parameter Scores and Calculations of Soil Quality Index for Various Planting Types in Plot 17 of Wanagama Forest

Location	SD	T	BD	PO	pH		CEC	N	P	K	C-BMT	C-MIN	∑	SQI	Dignity
Teak	5	1	5	5	5	2	4	2	1	2	1	1	34	28,33	Low
Ebony	5	1	5	5	5	2	3	3	1	3	2	1	36	30.00	Low
Gmelina	5	1	5	5	5	1	4	2	1	2	1	1	33	27.50	Low
Bamboo	5	1	5	5	5	1	3	2	2	2	1	1	33	27.50	Low
Indigofera	5	1	5	5	5	1	3	2	2	3	1	1	34	28.33	Low
Mahogany	5	1	5	5	5	1	3	2	2	1	1	1	32	26.67	Low
Call crocodile	5	1	5	5	5	2	3	2	2	3	1	1	35	29.17	Low
Jabon	5	1	5	5	5	2	3	2	1	2	1	1	33	27.50	Low
Acacia	5	1	5	5	5	2	4	3	1	2	1	1	35	29.17	Low
Eucalyptus	5	1	5	5	5	2	3	2	1	2	1	1	33	27.50	Low

Notes: Score 1 = very low; 2 = low; 3 = moderate; 4 = high; 5 = very high; BD, bulk density; PO, porosity; T, texture; SD, soil depth; organic C; N, total N; P, available P; K, available K; C-BMT, C biomass; C-MIN, C mineralized (soil respiration); SQI, soil quality index.

Table 7. Measurement of Soil Quality Index by Weighting and Summing Various Planting Types in Plot 17 of Wanagama Forest

Soil function	Ground indicator	Soil quality index									
		J	Eb	GM	B	I	M	Pb	Jb	Ac	E
Sustaining biological activity	**Rooting medium**										
	soil depth	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	Bulk density (g.cm^{-3})	0.04	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05
	Humidity										
	Porosity (%)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Organic C (%)	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Silt + clay (%)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	Disgust										
	pH	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
	Available P (g.kg^{-1})	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00
	Available K (cmol (+) kg^{-1})	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00
	Organic C (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total N (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
	CEC (cmol.kg^{-1})	0.02	0.02	0.03	0.02	0.02	0.02	0.01	0.02	0.03	0.02
	C biomass	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
	C mineralization (%)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Regulating and partitioning water	Silt + clay (%)	0.20	0.20	0.21	0.20	0.21	0.21	0.21	0.21	0.19	0.19
	Porosity (%)	0.08	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07
	Bulk density (g.cm^{-3})	0.05	0.06	0.06	0.07	0.06	0.05	0.05	0.06	0.06	0.06
Filtering and buffering	Silt + clay (%)	0.20	0.20	0.21	0.20	0.21	0.21	0.21	0.21	0.19	0.19
	Porosity (%)	0.04	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.03	0.03
	Microbiological process										
	Organic C (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total N (%)	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00
	AMOUNT	0.86	0.87	0.86	0.84	0.85	0.84	0.86	0.86	0.85	0.82

Notes: J, teak; Eb, ebony; Gm, *Gmelina*; B, bamboo; I, *Indigofera*; M, mahogany; Pb, panggal buaya; Jb, jabon; Ac, *Acacia*; E, *Eucalyptus*

Table 8. Measurement of Soil Quality Index by Weighting and Summing

Soil functions	Soil indicators	Score									
		J	Eb	Gm	B	I	M	Pb	Jb	Ac	E
Sustaining biological activity	Bulk density	1.01	0.88	0.85	0.76	0.86	0.96	0.95	0.92	0.86	0.89
	Porosity	51.48	57.49	58.45	61.30	58.33	54.69	54.47	55.58	57.05	55.46
Regulating and partitioning water	pH	7.12	7.04	6.86	6.52	6.61	6.84	6.39	6.56	7.25	6.18
	Total N	0.18	0.21	0.15	0.18	0.14	0.11	0.14	0.20	0.25	0.14
	Available K	0.25	0.44	0.17	0.25	0.42	0.05	0.59	0.38	0.30	0.22
	Organic C	1.25	1.42	1.03	1.25	1.03	1.02	1.04	1.33	1.25	1.31
	CEC	26.67	23.47	27.07	22.40	19.40	19.93	17.93	20.60	33.93	21.47
Filtering and buffering	Mineralized C	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.03
Soil quality index		0.32 L	0.37 L	0.33 L	0.36 L	0.32 L	0.28 L	0.31 L	0.34 L	0.37 L	0.34 L

Notes: J, teak; Eb, ebony; Gm, *Gmelina*; B, bamboo; I, *Indigofera*; M, mahogany; Pb, panggal crocodile; Jb, jabon; Ac, *Acacia*; E, *Eucalyptus*

3.4. Stepwise Regression Analysis

Stepwise regression is a combination of method analysis allowance backward and selection forward (*forward*) (Andayani et al., 2016). The *stepwise* method is done with infiltrate variable one by one until equality satisfactory regression. Enter predictor done gradually based on significant F value (sig F below 0.05), then after that issued back. Entering process combined with elimination of predictor that is not significant (sig F > 0.01) (Rahayu et al., 2014).

When determining the SQI of Wanagama 17 plots, the regression equation between the SQI and each indicator that affects it is obtained (Table 9).

From Table 9, the best regression model is through six stages with each output separately. The last model at this stage produces quite good output with an R^2 value of 90.71%, which means that porosity, organic C, CEC, available P and K, and C biomass affect the SQI, and the remaining 29% is influenced by other indicators. From this analysis, the best regression model obtained is as Equation 7.

Table 9. Stepwise Regression Analysis on Indicators of Soil Quality

	-----Step 1-----		-----Step 2-----		-----Step 3-----	
	Coef	**P**	**Coef**	**P**	**Coef**	**P**
Constant	27.496		25.672		23.058	
Available K	4.544	0	4.84	0	5.296	0
CEC			0.0744	0.009	0.1181	0
Available P					0.2978	0.001
Organic C						
Porosity						
C biomass						
R^2		58.35%		67.82%		78.54%

	-----Step 4-----		------Step 5-----		------Step 6-----	
	Coef	**P**	**Coef**	**P**	**Coef**	**P**
Constant	21.395		23.7		23.49	
Available K	5.278	0	5.306	0	5.02	0
CEC	0.1102	0	0.1112	0	0.1179	0
Available P	0.3828	0	0.3936	0	0.3931	0
Organic C	1.318	0	1.295	0	1.134	0.001
Porosity			−0.0419	0.076	−0.0425	0.061
C biomass					26.4	0.082
R^2		87.85%		89.37%		90.71%

α to enter = 0.15

SQI = 23.49 − 0.0425 porosity + 1.134 organic C + 0.1179 CEC + 0.3931 available P + 5.020 available K + 26.4 C biomass .... [7]

On the basis of results equality regression *stepwise* that has been performed obtained conclude that very influencing parameter index quality land in plot 17 of Wanagama Foret that is porosity, organic C, CEC, available P and K, and C biomass. those parameters are said to be very influential because mark his dignity can be very high nor in contrast in determine SQI value , while other parameters are not enter the model is a parameter that is lacking correlated with IKT. Missing parameters correlated This is considered missing correlations, such as texture , BD, depth soil , pH, total N, and C mineralization.

4. DISCUSSION

The Wanagama 1 Teaching Forest is located in the plain area of Gunungkidul Regency, Yogyakarta. Geologically, the forest area is part of the Phraen Syncline (West Wonosari) geology, which has an approximate west-to-east axis. The straight morphology of the karst morphology of the Wonosari topography can be seen. The source rock type in the area of Wanagama is karst. On the basis of the soil structure, the soil is dominated by a clay fraction with latosol; thus, it belongs to the clay texture class. Conversely, the structure of the soil is lumpy, with moderate to heavy aggregate resistance (Putra et al., 2021).

From the results of observations of soil types on several types of crops in plot 17 of Wanagama forest, it was found that the soil types were Rendzina and Mediterranean. This can be seen from the observations of different soil colors. The soil in the *Acacia*, bamboo, ebony, *Indigofera*, jabon, and jati plantation areas is a very dark grayish brown, and dark brown, which is Rendzina soil, whereas that in Panggal, *Eucalyptus*, and mahogany plantation areas is dark reddish-brown, which is Mediterranean soil (Figure 4). All plots in plot 17 of Wanagama 1 have a clay texture. Rendzina soil is typically heavy silt with a composition different from that of limestone particles (Hristov, 2020), and a high clay content affects the soil's ability to store and exchange nutrients and organic matter. The surface area of clay is large because of the small and layered size of the particles. The majority of the clay surface is negatively charged, which means that positive ions can be attracted to the surface. Figure 5 presents the soil map of the studied are (Wanagama).

In this study, it was found that the available K value was low in the entire cropping plot because the parent material in the study area is lime. Therefore, $CaCO_3$ is a factor that affects the availability of K. A decrease in $CaCO_3$ can increase the content of clay and clay minerals. The high clay content, smectite with different layer loads, and the presence of illite and vermiculite as large K reserves are the reasons for the large amount of nonexchangeable K in this soil (Shakeri & Abtahi, 2018).

From the observations of the SQI by weighting, ebony and *Acacia* with a value of 0.37 have the highest SQI. The high SQI value in these two types of stands was due to the soil in the planted area having a high CEC. CEC plays a crucial role in soil quality and can be influenced by soil physical (e.g., soil texture), chemical (e.g., pH and mineralogy), and biological (e.g., soil organic matter) (Khaledian et al., 2017) characteristics. Another influential factor is the high total N content of these two types of crops. The high N content in the *Acacia* planting area compared with that in other crops was due to the application of rice husk fertilizer by farmers. Conversely, the N content in the ebony planting area is higher than that in other plantations because of the presence of abundant litter.

The outcomes of each land use research are then readily and visibly visible once the three function SQI scores have been rated and assigned a status. The criteria developed by Partoyo (2005), which are displayed in Table 8, were used to determine the ranking and status of soil quality. Maintaining biological activity.

The soil of Wanagama forest can be classified as very good in this assessment because, according to the research results shown in Table 8, it has roots that go deep enough. This study's findings about the depth of roots attained by forest land usage agree with those of studies by Sitanggang et al. (2015) and Palupi et al. (2022), which report that certain forest plants can reach root depths of 100–140 cm. Rooting depth is also influenced by soil qualities, such as unit weight and plant shape. In the end, these factors result in very low pH indicator scores for soil with low C, N, P, and K contents. Organic C and total N are indicators of the composition of soil organic matter. The cycle's organic matter composition is crucial; without it, it cannot function correctly or preserve health. Both land uses have excellent markers for organic C. Because forests receive input only from closed nutrient cycles, their total N use is modest. Water Regulation and Partition.

Several soil physical qualities, such as texture (silt + clay), porosity, and unit weight, play a crucial role in the soil's function as a regulator and distributor of water to be used by plants in meeting their demands. The silty + clay soil content of Wanagama is having a low indication value for water management and insulating activities. The physical characteristics of the soil play a significant role in the ability of the soil to regulate and distribute water to plants to meet their needs, such as texture, porosity, and weight. The soil content of the Wanagama forest has a low indicator value in terms of water management and insulation. Conversely, the porosity of the forest soil is considered good for fulfilling its role as a regulator and a water divider. The porosity of the soil is close to the optimum porosity of 50% because it is balanced between the matrix of the soils and the interstitial space of the soil, resulting in an ideal porosity of 50%. The bulk density of forest soil has a high indicator value and is determined not only by the degree of tillage but also by the distribution of particles in the soil. Bulk density is regulated by particle distribution in the soil in addition to the level of tillage (Palupi et al., 2022).

The ability of soil to filter and buffer contaminants is related to its tolerance and flexibility properties. Silt and clay composition and soil porosity determine the soil's capacity to filter and buffer pollutants. The indicator values of mud and soil with a high clay concentration in the Wanagama forest area are low. In this case, organic C and total N were used as indicators of microbial soil processes and activities.

The organic C content of the Wanagama forest soil is low, indicating that screening and buffering of soils is not possible because the biological activity of terrestrial soils does not sufficiently support soil microbial activity. Adequately available organic C and total N in the soil aid in soil breakdown and play a role in soil buffering processes.

Figure 4. Soil profiles for various types of planting in Plot 17 Wanagama
Description: (a) Jabon, (b) *Eucalyptus*, (c) Teak, (d) *Gmelina*, (e) Bamboo, (f) Acacia, (g) Ebony, (h) Indigofera, (i) Panggal Buaya, (j) Mahogany.

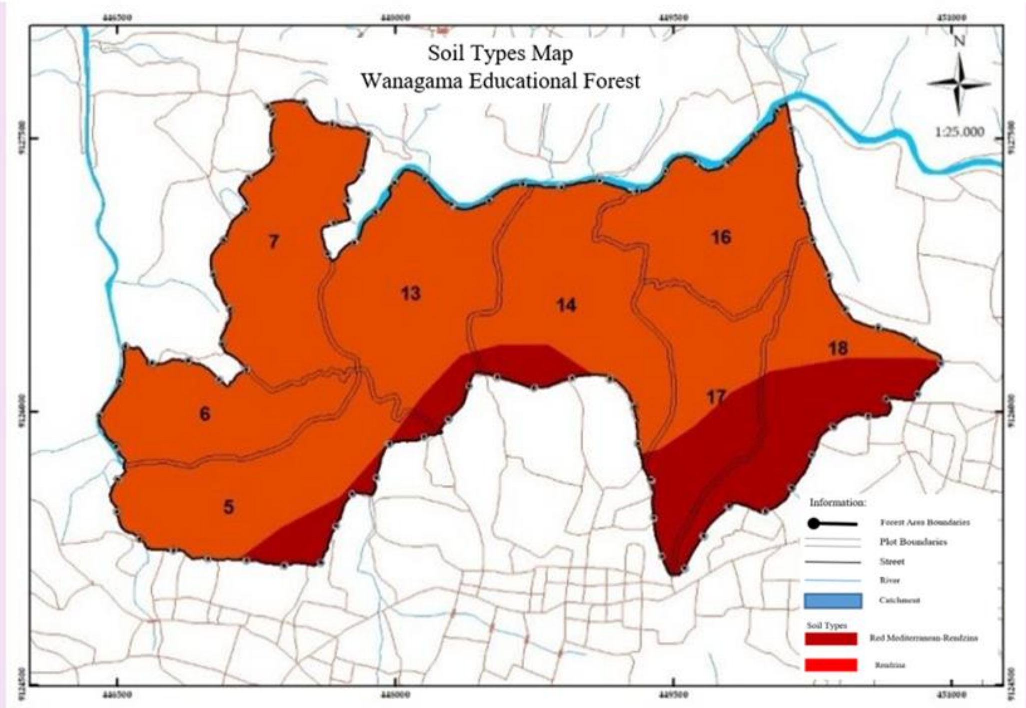

Figure 5. Soil Map of the studied area (https://wanagama.fkt.ugm.ac.id/gallery/maps/)

On the basis of the values of SQI using the weighting and summation method for different types of plantations, The highest SQI value was 0.87 for the ebony type, and the lowest value was for the ebony type. The SQI for the *Eucalyptus* type was 0.82. Of all the planting types in plot 17, Wanagama received a low rating.

From the stepwise regression analysis, the best regression model goes through six stages with each output separately. The last model at this stage produces quite good output with an R^2 value of 90.71%, which means that porosity, organic C, CEC, available P and K, and C biomass affect the SQI total N, bulk density, and organic C affect the SQI, and the remaining 2.55% is influenced by other indicators. On the basis of the findings of the stepwise regression equations, it is possible to conclude that the parameters that have the greatest influence on the SQI in plot 17 of Wanagama forest are porosity, organic C, CEC, available P and K, and C biomass. Soil organic matter is essential for soil productivity because of its role in nutrient availability, gas exchange, and water supply (Powers et al., 1999), as well as for microfauna and macrofauna that are involved in nutrients, soil aggregation, and disease occurrence or prevention (Harvey et al., 1987). Soil organic matter concentration is directly related to soil C, soil nutrients, and physical qualities such as water-holding capacity and unit weight (Vance et al., 2018). To improve soil quality, organic fertilizers, organic mulch, and retaining plant leftovers on the soil surface must be used to maintain and increase soil organic matter content. A high soil organic matter concentration reduces both the soil unit weight and soil total N. Shao et al. (2020) discovered that water-holding capacity, soil organic matter, and total N affect the SQI in a comparable study.

5. CONCLUSIONS

Measurement of the SQI at plot 17 of the Wanagama forest was conducted using three methods: (1) simple addition, (2) scoring, and (3) weighting and summation. The ebony type has the highest SQI value among the three methods in plot 17 of Wanagama forest, whereas the mahogany and *Eucalyptus* types have the lowest. The stepwise analysis results determined that the indicators that affected the SQI values in various types of plantations in plot 17 of Wanagama forest were porosity, organic C, CEC, available P and K, and C biomass. Of all types of planting in plot 17, Wanagama has a low rating on the SQI.

ACKNOWLEDGMENTS

The authors would like to thank Universitas Gadjah Mada for funding this study and publishing it in the form of Recognition Grants Final Project (2022) with assignment letter 1525/UN1/ditlit/dit-lit/PT.01.05/2022.

Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

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