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The Assessment of Soil Quality and Earthworms as Bioindicators in the Alas Bromo Education Forest, Central Java, Indonesia

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Abstract*— Understanding the environmental services provided by healthy forest ecosystems needs accurate soil quality (SQ) assessments. Selecting appropriate SQ indicators is one of the keys to the effectiveness of SQ assessment. Earthworms have the potential to be bioindicators of soil quality because they are sensitive to environmental changes. This study aims to assess the soil quality level and evaluate the potential of earthworms as bioindicators in six land covers at the Alas Bromo Education Forest of Universitas Sebelas Maret, namely: pine, pine-mahogany, mahogany, mixed, annual crops, and pine replanting. SQ assessment is measured by calculating the Soil Quality Index (SQI) using Principal Component Analysis (PCA) with 10 Minimum Data Sets (MDS), namely: bulk density, earthworm abundance, C-organic, N-total, pH, porosity, exchangeable Al, cation exchange capacity (CEC), base saturation (BS), and available K. Statistical analysis using ANOVA, Duncan's Multiple Range Test, correlation, and regression. The results showed that land cover significantly (p-value < 0.01) affected SQI. The SQI for all land cover categories is poor, with the highest value on mixed land cover (0.36) and the lowest on pine-mahogany (0.31). The land cover also significantly (p-value < 0.01) affected earthworm abundance, with the highest on mixed land cover (365 individuals/m^2) and the lowest on pine replanting (25 individuals/m^2). Earthworm density as a determining indicator significantly correlated with SQI (r = 0.495) and contributed 24.5% to the SQI. Future research needs to test the effectiveness of earthworms as a bioindicator of soil quality in other land uses in different areas.

***Keywords*— Land cover; limiting factor; PCA; soil function; SQI.**

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I. INTRODUCTION

Located in Karanganyar Regency, Central Java Province, Indonesia, the Alas Bromo educational forest is strategically important to Universitas Sebelas Maret (UNS) for education, research, and the advancement of science and technology [1]. Like other tropical forests, the Alas Bromo Forest provides numerous environmental benefits and indirectly contributes to biodiversity conservation and climate regulation [2]. In addition to being essential as carbon sinks that support stable carbon storage [3], regulating the water system, and providing livelihoods and various forest products [4]. The primary objective of Universitas Sebelas Maret is to protect and preserve the Alas Bromo forest's health.

Forest management can affect soil quality and the sustainability of the ecosystem [5]. The soil quality also reflects the interaction between the environment below ground and the vegetation above ground [6]. The Alas Bromo Forest has numerous land cover types, including pine, mahogany, pine-mahogany, a mixture of trees, open land, and seasonal plants [7]. The tree canopy densities of these land covers vary, influencing the soil's physical, chemical, and biological characteristics [4]. The diversity of vegetation within a land cover can influence soil structure and nutrient leaching [8], [9]. Land cover can reduce the kinetic energy of falling rainwater, soil temperature, soil evaporation, and plant transpiration, as well as affect soil water content and increase soil moisture [10], [11], [77]. Compared to shrubland, cultivated land, and grazing land, forest soils in the Gumara watershed in Ethiopia had superior soil quality [12]. Compared to shrubs and savannas, forests have the highest soil quality and C storage, storing approximately 150 tons/ha of total C and 115 tons/ha of above-ground C [13]. Soil quality analysis, which has never been done before, is necessary to comprehend the condition of the Alas Bromo Forest.

Soil is a dynamic system influenced by its physical, chemical, and biological properties [14]. Foresters usually evaluate a site's potential to support productive forests based on their understanding of the chemical and physical properties of the soil without considering the soil's biological properties [15], [16]. Recent public interest in understanding how management practices affect soil quality, plant productivity, and the sustainability of forest ecosystem functions has increased the need for comprehensive soil quality assessments based on soil properties [17], [76].

Soil quality is the capacity of soil to sustain plant and animal life in natural and managed ecosystems [18]. It is impossible to measure soil quality directly; physical, chemical, and biological indicators must be measured to infer soil quality [19], [20]. The soil quality index quantifies the level of soil quality. Soil quality evaluation can be a valuable tool for detecting early adverse effects of management practices [21]. It is crucial to assess the impact of forest management practices on the sustainability of forest ecosystem functions [17]. No indicator of forest soil properties is sufficient to describe soil quality because changes in one characteristic will likely affect other properties. Combining chemical, physical, and biological properties is necessarily better for understanding the impact of forest management on soil quality [14].

Identifying and selecting meaningful indicators related to soil threats, ecosystem functions, or services is a significant challenge in soil quality studies [22]. Numerous indicators can be used to assess soil quality. However, the most desirable indicators are simple, easy to measure, relatively quick to quantify, representative of a broad range of soil types, sensitive to environmental change and land management, inexpensive, and simple [22], [76].

Soil organisms have an essential role in sustainable management and maintaining soil quality. They are sensitive to the various soils' chemical, physical, and biological conditions, easy to observe, inexpensive to assess, and widely recognized by field operators, particularly farmers. Communities of soil macroinvertebrates could be used as easy field tools for assessing ecosystem services and soil quality [23], [33].

Earthworms are one of the soil fauna groups that play a crucial role in enhancing the soil's physical, chemical, and biological properties. Their activity of creating holes and distributing organic matter in the soil improves aggregate stability [24]–[26], soil structure, and carbon mineralization [27], [28]. It promotes microbial activity to decompose organic matter and helps spread soil microorganisms [29]. The activity of earthworms is dependent on vegetation and soil conditions [30]. Due to their sensitivity to changes in temperature, earthworms can be used as bioindicators of soil quality [29].

Several studies have described the application of earthworms as soil bioindicators [24], [31], [32]. In the American tropical environment, however, Lavelle et al. [23] found that earthworms' contribution as an indicator of ecosystem services is less significant than that of ants, termites, Coleoptera, Chilipoda, and Isopoda. The objectives of this study are as follows:

- Evaluate the soil quality of different land uses in the Alas Bromo Education Forest of UNS.
- Assess the potential of earthworms as useful bioindicators of the soil quality index.

II. Materials and Method

A. Site Research

This research was conducted in Alas Bromo education forest of UNS, Karanganyar Regency, located at 7°34'21.93"-7°35'38.90" S and 110°59'40.39"-111°0' 49.36" E. It has six types of land cover: Pine, Pine-Mahogany, Mahogany, Mixed land, Annual crops, and Pine replanting land cover (Figure 1). Laboratory analysis was carried out at the Soil Biology and Health Laboratory, the Physics and Soil Conservation Laboratory, and the Chemistry and Soil Fertility Laboratory in the Faculty of Agriculture, Universitas Sebelas Maret, Surakarta.

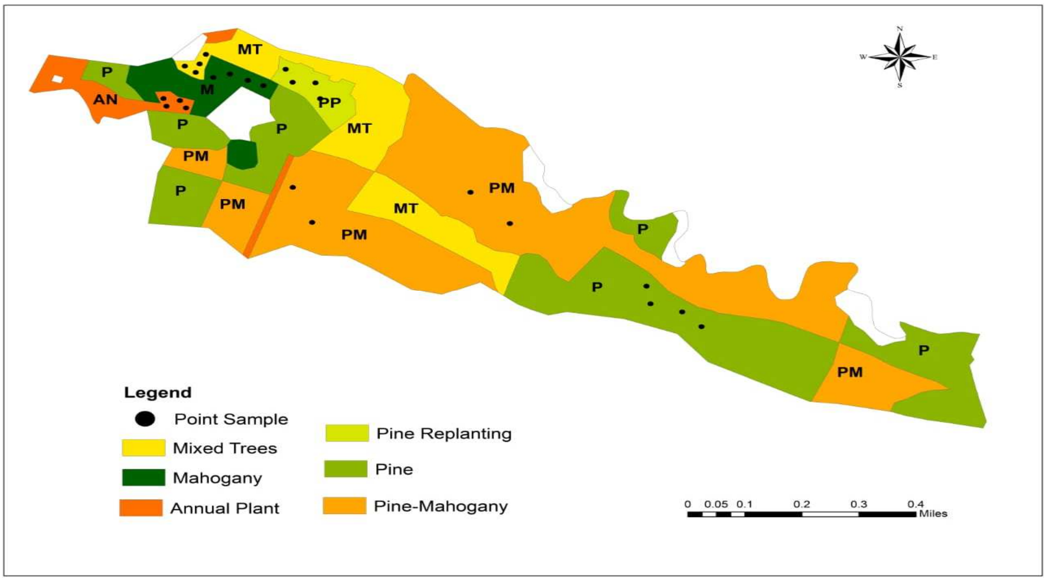

Fig. 1 Map of land covers in Alas Bromo education forest of UNS

B. Soil Sampling

Specific considerations are used for the determination of the soil sampling site. Each land cover had four replicate plots with 3 sample points in each plot. A sampling of soil and earthworms was carried out by making a monolith measuring 25 cm x 25 cm x 30 cm, and then the soil layer was taken at each depth of 0-10 cm, 10-20 cm, and 20-30 cm. Soil samples were homogenized based on the depth in each plot. Soil samples obtained at each depth were air-dried and filtered with sizes of 2 mm and 0.5 mm.

Soil physical analysis included soil texture (pipette method), volume weight, and porosity (pycnometer). Soil chemical analysis included organic carbon (Walkey & Black method), pH (H_2O suspension method (ratio 1:2.5), Cation Exchange Capacity (CEC), base saturation, K-available, and Fe (1N ammonium acetate saturation method (pH 7), P-available (Bray method), total-N (Kjeldahl method), and Al-exchangeable (1M KCL extraction). Soil biological analysis included microbial carbon biomass (fumigation method) and the earthworm density (calculated by converting it into units of individuals/m^2). Each land cover was analyzed for litter quality and quantity, including the assessment of lignin by Georing & Vans Soest and polyphenols measured using the Follin – Denis reagent method [34].

C. Data Analysis

The soil indicator used to calculate the SQI is the Minimum Data Set (MDS) obtained from Principal Component Analysis (PCA) and Pearson correlation analysis. The soil quality index is obtained by multiplying the weight index (Wi) and score index (Si) based on Nusantara et al. [35], which is shown in Equation (1). Weight index (Wi) is the result of dividing the proportion with the cumulative on the PCA analysis. Then the score index (Si) is determined based on Chandel et al. [36], which is shown in Table 1.

Analysis of Variance (ANOVA) was conducted to determine the effect of land cover on SQI and indicators. The effectiveness of earthworms as a biological indicator of soil quality was tested by looking at the contribution of earthworms to SQI on the regression test results. If it has a significant effect ($p<0.05$) on the observed parameters, then proceed with Duncan's Multiple Range Test (DMRT) with a significance level of 95%.

$$SQI = \sum_{i=1}^{n} Wi \, x \, S \, i \quad (1)$$

Remarks:
SQI = Soil Quality Index
Si = Score index
Wi = Weight index
n = number of soil indicators

TABLE I
CLASS OF SOIL QUALITY INDEX

Soil Quality	Range	Class
Very good	0.8-1	1
Good	0.6-0.79	2
Average	0.4-0.59	3
Bad	0.2-0.39	4
Very bad	0-0.29	5

III. Results and Discussion

A. Land Cover Characteristics in Alas Bromo education forest of UNS

Most of the return of nutrients comes from litter. Each land cover has a different litter production influenced by the vegetation on each land cover (Table 2). The highest litter production was on Mahogany land cover (13.6 tons/ha/year), while the lowest was on Pine replanting land cover (0.68 tons/ha/year). Litter production can affect microbial processes of the carbon and nitrogen cycle [37].

Different types of litter affect the polyphenol and lignin content, determining the decomposition rate [38]. The C/N ratio represents the quality of the litter. The highest C/N was in Pine replanting land cover, with a value of 79.15. A high-quality litter can accelerate the decomposition rate, while a low-quality litter with a high lignin concentration can inhibit the decomposition rate [39]. The rate of decomposition and release of nutrients from plant litter is related to litter quality because decomposition is inhibited by compounds such as lignin and stimulated by N concentrations [40]. Each land cover has different nutrient content, and the chemical properties of litter, especially lignin, and N, are necessary controllers in the litter decomposition rate [41].

Forests are often called an abiotic environment with a specific microclimate [42]. Different vegetation creates diversity in the quantity of input litter, such as branches, twigs, leaves, flowers, and fruit. Tree size and density play an active role in reducing the intensity of incoming light, and a dense canopy will shade and affect the microclimate. Differences in microclimate conditions make the litter decomposition rate vary in conditions. Thus, it will affect decomposer fauna to increase the decomposition rate [43]. Differences in microclimate in each land cover are influenced by growing vegetation. The difference in light intensity in each land cover is due to each land cover having different abilities to intercept solar radiation.

The high air temperature can be caused by the land cover's low percentage of canopy density. It is shown in Table 3 that Pine replanting land cover has a high air temperature, but it has a low canopy density (Table 2). The existing vegetation influences the microclimate, such as lowering soil temperature and increasing humidity [44]. Thus, it directly correlates to the soil temperature. The difference in air humidity for each land use is due to a dense canopy that blocks incoming sunlight, causing a decrease in air temperature and increasing air humidity. Vegetation on land cover reduces the amount of solar radiation, air temperature, and relative humidity driven by the existing canopy cover [45].

B. Soil Properties in Alas Bromo education forest of UNS

The soil quality index was obtained using indicators used to describe soil quality. The selected indicators must be easy to measure, based on the soil's physical, biological and chemical functions, and can detect changes in the soil [46]. The properties of each soil are presented in Table 4 with physical properties, Table 5 with chemical properties, and Table 6 with soil biology properties.

Alas Bromo education forest generally has a slightly acidic pH and bulk density between 1-1.3 g/cm^3. Mahogany land cover has the highest clay among other land covers, which is 63.2%. Soil with clay texture has a smooth distribution of soil pores and has an effect that makes Available Moisture Increase. Zaffar and Lu [47] also mentioned that the soil's clay content strongly influences the shape and number of pores.

Soil organic matter derived from litter produced by growing vegetation will reduce soil density, followed by an increase in the value of soil porosity. Minasny and McBratney [48] mentioned that organic matter's content is related to soil porosity. The results showed the highest porosity value in the Mixed land cover and the highest organic carbon in the Mixed land cover of 2.07%. This result is in line with the statement of Fukumasu et al. [49] that the high organic matter content will result in high porosity.

Meanwhile, the highest total N was in Mahogany land cover, and the lowest was in Pine-Mahogany land cover, including in the medium to low category. The difference in vegetation on various land covers in the form of diversity and population number significantly affects the availability of N. It is another factor in the difference in the total N value obtained. Additional accumulation of soil organic matter and soil nutrient reserves can increase N availability and can also increase N mineralization [50].

The highest BS value was also shown in Mahogany land cover, while the lowest BS value was shown in Mixed land cover. Base saturation is calculated from the sum of base cations: Ca, Mg, Na, and K. Base saturation is an essential variable in determining soil fertility, lack of nutrients, acidic soil, and degradation. Soil health results from low base saturation [51].

The value of CEC in the soil can be influenced by factors such as soil pH, texture, and organic matter content [52]. Differences in CEC values are also influenced by clay content. High clay content can usually make high CEC content in the soil, depending on the clay type. The highest CEC value was on Mixed land cover, while the lowest CEC value was on Pine replanting land cover, which was included in the high category.

One of the problems with acid soil is the low supply of phosphorus (P). The available-P value is included in the very low to the low category, with the lowest value in the Mixed land cover, at 0.33 ppm. The higher the available P in the soil will decompose the soil minerals, which release cations that can be exchanged so that the al and Fe in the soil are low [53]. Meanwhile, the highest available K is in Pine land cover (0.894 cmol/kg).

Al and Fe are the main minerals that affect dissolved P in the soil [54]. The highest Al content was in Pine land cover, while the highest Fe content was in Pine replanting land cover. The increase in Al content in the soil could be caused by low pH [56]. Adding organic matter input into the soil can increase soil pH and, at the same time, reduce the availability of Al and Fe nutrients [55].

Land cover affects soil fertility and living microbes, affecting microbial biomass and microbial efficiency in carbon utilization [28]. Biological properties (Table 6) show the highest microbial biomass C value for Pine-Mahogany land cover and annual crops, with the lowest microbial biomass C value on Pine land cover and Pine replanting.

TABLE II
CHARACTERISTICS OF LAND COVERS IN ALAS BROMO EDUCATION FOREST

Land cover	Litter thickness (cm)	Litter production (ton/ha/year)	Canopy density	Litter C-organic	Litter N-total	C/N ratio
			%			
Pine	0.21	9.33	41.57	45.86	0.67	71.27
Pine-Mahogany	0.33	6.32	47.04	40.17	0.87	46.47
Mahogany	0.32	13.67	67.00	43.33	0.79	54.96
Mixed	0.38	11.78	29.97	39.14	1.25	31.48
Annual Crops	0.23	3.00	6.37	43.71	0.84	52.11
Pine Replanting	0.15	0.68	2.58	40.63	0.51	79.15

TABLE III
CHARACTERISTICS OF MICROCLIMATE IN ALAS BROMO EDUCATION FOREST

Land cover	Soil Temperature	Air Temperature	Air Humidity	Soil Humidity	Solar Intensity (Candela)
	(°C)		(%)		
Pine	27.19	29.25	78.23	33.22	13860.75
Pine-Mahogany	27.19	29.11	78.83	34.69	6141.50
Mahogany	27.27	28.87	78.13	33.84	6887.25
Mixed	27.43	28.97	76.92	35.53	5142.63
Annual Crops	27.38	29.83	77.53	42.74	16637.25
Pine Replanting	27.89	30.78	73.52	32.96	17708.13

TABLE IV
SOIL PHYSICAL PROPERTIES IN ALAS BROMO EDUCATION FOREST

Land cover	Bulk density (g/cm^3)	Silt	Clay	Sand	Porosity
			(%)		
Pine	1.3	37.88	59.23	2.9	35.56
Pine-Mahogany	1.3	38.89	56.19	4.92	35.24
Mahogany	1.1	30.5	63.2	4.29	44.45
Mixed	1	38.79	57.7	3.51	48.09
Annual Crops	1.2	61.42	31.41	7.18	38.64
Pine Replanting	1.2	38.84	56.62	4.54	38.68

TABLE V

SOIL CHEMICAL PROPERTIES IN ALAS BROMO EDUCATION FOREST

Land cover	**pH**	**Organic Carbon**	**Total N**	**Available P (ppm)**	**Base Saturation (%)**	**CEC**	**Available K**	**Fe**	**Exchangeable Al (me/100g)**
		(%)				**(cmol)(+) kg^{-1})**			
Pine	5.43	1.36	0.24	0.52	30.24	26.74	0.89	0.18	1.40
Pine-Mahogany	5.46	1.43	0.15	0.38	30.97	23.46	0.798	0.23	0.63
Mahogany	5.71	2.05	0.48	0.47	40.89	24.51	0.894	0.17	0.54
Mixed	5.56	2.07	0.44	0.33	35.12	26.75	0.78	0.37	0.55
Annual Crops	5.58	1.31	0.19	0.54	37.39	22.06	0.764	0.21	0.32
Pine Replanting	5.76	1.49	0.45	0.51	37.72	21.64	0.683	0.39	0.31

TABLE VI

SOIL BIOLOGY PROPERTIES IN ALAS BROMO EDUCATION FOREST

Land cover	**Microbial biomass C ($\mu g\ g^{-1}$)**	**Earthworm density** (individuals/m^2)
Pine	0.66	149
Pine-Mahogany	0.68	135
Mahogany	0.67	99
Mixed	0.67	365
Annual Crops	0.68	78
Pine Replanting	0.66	25

TABLE VII

CORRELATION ANALYSIS OF SOIL INDICATORS

Variable	**pH**	**BD**	**C-org**	**C-mic**	**Total N**	**BS**	**CEC**	**Av.P**	**Av.K**	**Porosity**	**ED**	**Exch.Al**
BD	-0.187											
C-org	0.333	**-0.598***										
C-mic	0.157	0.099	-0.061									
Total N	**0.533***	**-0.691***	**0.654***	-0.089								
BS	0.171	0.095	0.179	0.049	-0.003							
CEC	-0.077	-0.024	0.022	0.028	0.064	**-0.63***						
Av.P	0.037	0.286	-0.304	0.14	-0.137	0.033	-0.022					
Av.K	-0.079	**-0.715***	**0.599***	-0.047	**0.499***	-0.199	0.215	-0.187				
Porosity	0.172	**-0.857***	**0.716***	-0.189	**0.678***	-0.12	0.099	-0.205	**0.703***			
ED	-0.072	**-0.482***	**0.528***	-0.014	0.159	-0.238	0.131	-0.395	**0.613***	**0.606***		
Exch. Al	**-0.447***	0.264	-0.101	-0.088	-0.182	-0.178	0.154	0.057	0.021	-0.185	0.238	
Fe	0.231	-0.286	0.163	-0.322	0.336	-0.274	-0.126	-0.311	0.125	0.332	0.277	-0.231

Remarks: BD= bulk density; C-org= organic Carbon, MBC= microbial biomass Carbon; BS= base saturation; CEC= cation exchange capacity; Av.P= available P; Av.K= available K; ED= earthworm density; Exch.Al= exchangeable Al; *)= significant; **) very significant.

TABLE VIII

PRINCIPAL COMPONENT ANALYSIS

Eigenvalue	**4.3903**	**2.1563**	**1.2479**
Proportion	**0.439**	**0.216**	**0.125**
Cumulative	**0.439**	**0.655**	**0.779**
Variable	**PC1**	**PC2**	**PC3**
pH	0.18	**-0.421**	-0.362
Bulk Density	**-0.422**	-0.033	0.02
C-organic	**0.407**	0.001	0.073
Total N	**0.378**	-0.101	-0.309
Base saturation	0.209	**-0.484**	0.395
CEC	0.01	0.44	**-0.62**
Available K	**0.395**	0.248	0.089
Porosity	**0.436**	0.113	-0.008
Earthworm density	0.282	**0.342**	0.32
Al-dd	-0.108	**0.438**	0.343

C. Soil Quality Index

Soil Quality Index (SQI) is obtained by using the Principal Component Analysis (PCA) method, which produces data in the form of a PC (Principal Component). The Pearson correlation analysis in Table 7 is generated from 13 soil quality indicators with correlated indicators, including pH, bulk density, C-organic, N-total, CEC, available-K, porosity, earthworm density, and Exchangeable Al. The Principal Component Analysis (PCA), which produces the Principal Component, is shown in Table 8. PCs are selected with eigenvalues >1, for values below 1 are not used in calculating the number of factors formed [57]. Thus, there is only 3 PCs are selected in PCA analysis.

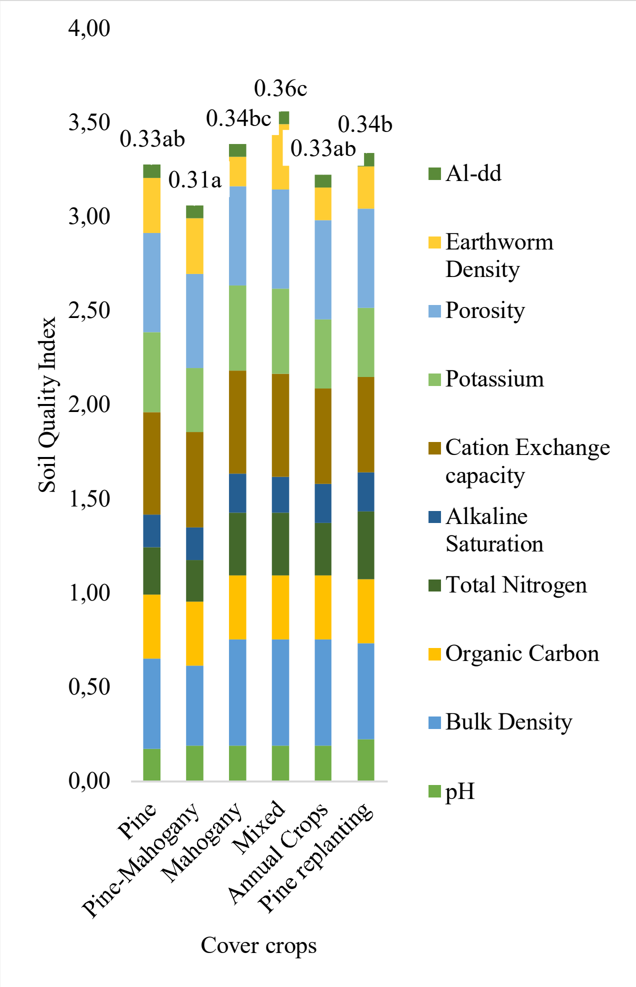

Fig. 2 Soil Quality Index and contribution each indicators

The PCs selected to determine the MDS are PC1 to PC3, which have eigenvalue >1 with a cumulative 78% (Table 8). The result shows that PCs 1 to 3 can explain up to 78% of the data. The selected MDS are ten indicators with a high sensitivity level from the 13 indicators. PC1 represents 43.9% of the data to determine soil quality in various land cover Alas Bromo education forest, namely volume weight (g/cm^3), C-organic, N-total, K available, and porosity. PC2 represents 21.6% of the data to determine soil quality in various land cover Alas Bromo education forest with the selected indicators are pH, KB, Earthworm Density, and Exchangeable Al. PC3 represents 12.5% of the data to determine soil quality in various land covers, which is CEC. The indicator selected as MDS is then scored (Si), and the weighted index value (Wi) is calculated. The index weight for the selected indicator is determined by looking at the proportion of the three selected PCs. For PCs with more than one selected indicator, the weighting is divided according to the number of selected indicators. For example, the indicators on PC1 each have one-fifth of the weight because they are correlated.

The results of the SQI assessment are presented in Figure. 2. In general, based on modified [58], Alas Bromo education forest has a poor class of SQI with the range of SQI values in the research area in the range of 0.31 – 0.36. The highest SQI was in Mixed land cover, while the lowest was in Pine-Mahogany land cover. Land cover significantly affects SQI on each land cover (p-value= 0.001). It is known that the soil quality index on Mixed land cover is significantly different when compared to Pine-Mahogany land cover. This could be due to the higher average nutrient content in the Mixed land cover than the other land covers. These nutrients include high values of volume weight (1 g/cm^3), porosity (48.09%), C-organic (2.07%), CEC (26.75 cmol(+) kg^{-1}), Available-K (2.33 cmol(+) kg^{-1}) and earthworms density (1,461 individuals/m^2). The low value of the soil quality index on the pine-mahogany land cover was caused by the pH value (5.46), low N-total (0.15%), porosity (35.24%) and high Al-dd content (0.63 ppm). Litter production in each land cover is essential in returning nutrients to the soil. The mixed land cover has a litter production of 11.37 tons/ha/year, which is thought to increase the C-organic content in the soil.

Based on the research Umasugi et al. [59], litter has an essential role on the forest floor because it can provide nutrients to the soil by producing litter from any vegetation that falls to the ground. The quality of litter on the Mixed land cover was higher than other land covers, indicated by the C/N ratio value of 31.50%. The high quality of litter can affect the decomposition process so that the contribution of organic matter into the soil is going faster, and earthworms prefer high-quality organic matter or have a low C/N ratio [60]. The diversity of vegetation in mixed land covers causes different types of litter, affecting organisms in the soil. The contribution of organic matter into the soil, such as leaf litter and other dead plant matter, can affect the earthworm population because soil organic matter is a nutrient for earthworms [61]. With the highest density of earthworms in Mixed land cover, the influence of earthworms on the soil is very significant in the soil's physical, chemical, and biological properties.

D. The potential of Earthworms as Biological Indicators

Conditions of supportive soil physicochemical properties, the presence of cover crops, and the addition of litter and organic matter continuously contributed positively to the presence of earthworms [62]. The difference in earthworm density values is influenced by earthworm tolerance to soil physical and chemical properties [29], [63], [64].

The difference in land cover significantly affected the density of earthworms (p-value= 0.000). It is shown in Figure 3 that earthworm density in the Mixed land cover is significantly different from the other land covers. The highest earthworm density was on the Mixed land cover of 365 individuals/m2, and the lowest was on the Pine replanting land cover of 25 individuals/m^2 (Fig. 3). Table 9 shows that earthworm density and litter production correlate significantly (r= 0.508*). The Mixed land cover has a high density of earthworms due to the high litter thickness and production. The life of earthworms depends on the soil with a high organic matter content mostly has a high quantity of earthworms [65], [66].

Earthworms have a close relationship with several characteristics of land cover. Land use patterns, biotic and abiotic factors in the soil, vegetation types, litter input, and microclimate will affect the density of earthworms [67]. Earthworms encourage microbial activity in the decomposition process of organic matter and also spread microorganisms in the soil by leaving the casts, which contain high microbial biomass [29]. Earthworm density affects the presence of beneficial bacteria so that it can increase microbial biomass and is related to the availability of K, P, and N in the soil [68]. Earthworm activity can affect organic matter, transfer organic matter and accelerate N mineralization from organic matter [66]. Thereby, earthworms can be used to indicate soil characteristics and have a role in increasing soil fertility and quality.

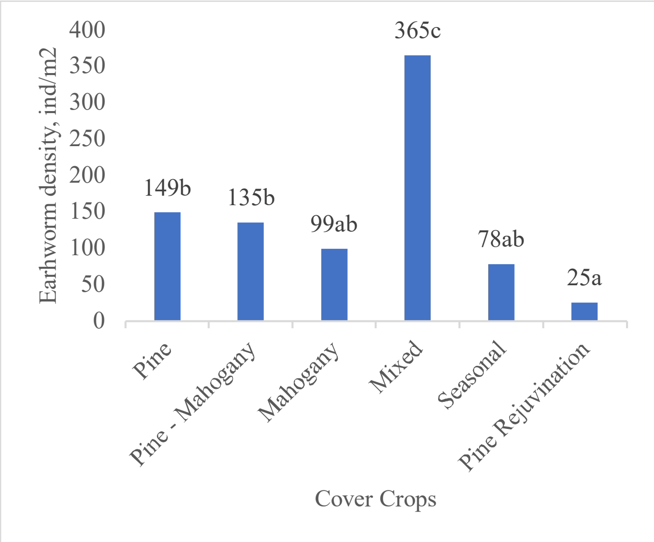

Fig. 3 Earthworm density in Alas Bromo education forest

TABLE IX
EARTHWORM DENSITY CORRELATION WITH LAND COVER CHARACTERISTIC IN ALAS BROMO EDUCATION FOREST

Characteristic	Pearson correlation (r)	Sig.
Litter N-total	0.736*	0.000
C/N Ratio	-0.622*	0.001
C-organic	0.528*	0.008
Litter Production	0.508*	0.011
Bulk density	-0.482*	0.017
Atmospheric temperature	-0.469*	0.021
Solar intensity	-0.448*	0.028

The role of earthworms in mineralization is to accelerate the process of producing nutrients available to plants [69]. Earthworm activity in the decomposition process of organic matter can affect chemical properties due to the mineralization process of organic matter carried out by microorganisms and assisted by earthworms. The earthworm density variable has an adjusted $R^2 = 0.245$ (Fig. 4), which means that the earthworm density affects 24.5% of the soil quality index in various land covers in the study area. The pattern relationship between soil quality index and earthworm density is linear; SQI = 0.32458 + 0.000080 earthworm density (Fig. 4).

The regression analysis revealed that earthworms contributed 24.5 % in influencing the soil quality index, so the density of earthworms had the potential as a bioindicator of soil quality. Observing earthworms is more accessible than calculating the N-total variable because it does not need laboratory analysis and does not require expensive costs. The earthworm is one of the soil biotas that has an essential role as an indicator of soil quality. Earthworms can improve soil properties by destroying organic matter and mixing it with soil to form soil aggregates and improve soil structure [70]. Earthworms play a role in the decomposition of organic matter so that they can be used as indicators in assessing soil quality, acting as agents of organic matter decomposition and contributing to the nutrient cycle that occurs in the soil.

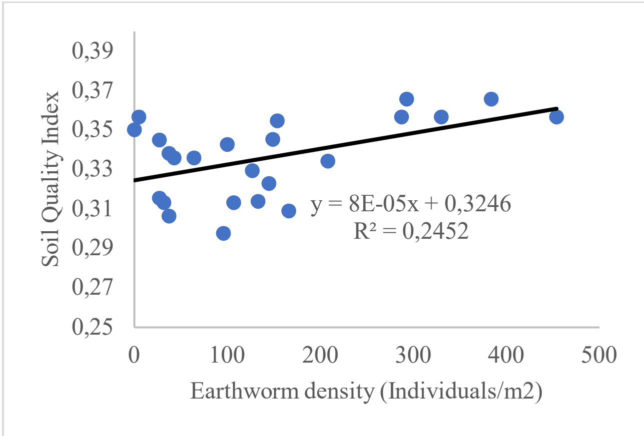

Fig. 4 Relation of soil quality index with earthworm density

E. *Recommendations*

Stepwise regression determines the direction and significance representing the relationship between MDS indicators and soil quality index in the study area. Based on the regression SQI= 0.29922 + 0.0846 N-total + 0.000066 earthworm density. It means that N-Total and earthworm density are two indicators that significantly affect the soil quality index. The pattern relationship between soil quality and N-total indicator is linear: SQI = 0.306 + 0.0925 N-Total, R-adjusted = 0.47 (Fig. 5), meaning N-Total affects 47% of the soil quality index in various land cover in the study area.

The N cycle in the forest has uninterrupted properties. This cycle is an internal cycle between the soil, plant, and microorganisms, which is an ideal condition for the availability of N in the soil [71]. High N-Total is caused by organic matter that contributes to the soil, and it shows that the release of nutrients from the decomposition of organic matter into the soil stimulates N in the soil. The release of nitrogen from organic matter is influenced by soil pH. If the pH increases, it will increase the release of N so that there is an increase in total N soil. Rahmah et al. [72] said that the soil becomes fertile if nitrogen is high enough and is a provider for plants.

In Annual crops land cover and Pine replanting, legume planting can be done to increase the N nutrient in the soil. In addition, planting peanuts combined with elephant grass can be done because elephant grass is suitable for use as a plant for conservation. Planting elephant grass is suitable for degraded land because its roots are associated with nitrogen-fixing bacteria [73].

In the land cover of Pine, Pine-Mahogany, Mahogany, and Mixed using a spacing arrangement system, Sengon plants can be inserted at each spacing. The Sengon plant, as a legume family, is suitable for land rehabilitation because it can grow on marginal land and has fast growth to increase soil fertility from leaf litter produced and root systems containing root nodules. Sengon planting can improve microclimate conditions to affect plant growth under trees and soil conditions [74]. The increase in vegetation types impacts the input of litter production, increasing the input of organic matter. Combining the types of trees planted can increase the number of macrofaunae that live in the soil [75].

TABLE X
CORRELATION SQI WITH MINIMUM DATA SET

Characteristic	Pearson correlation (r)	Sig.
Total N	0.686*	0.000
Available K	0.705*	0.000
Porosity	0.715*	0.000
Bulk Density	-0.639*	0.001
Carbon Organic	0.576	0.003
Earthworm Density	0.495*	0.014
Total N	0.686*	0.000

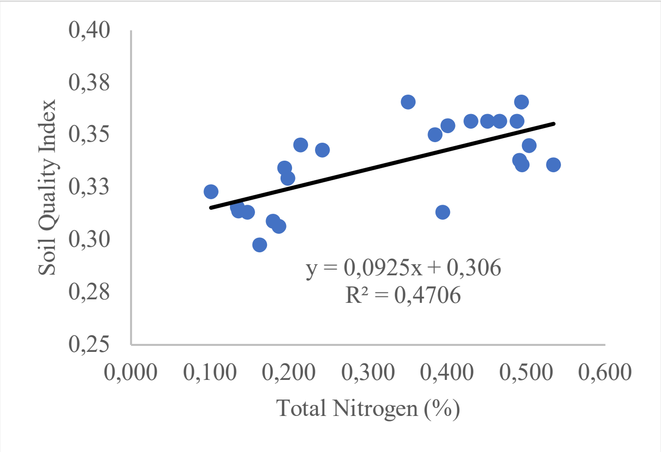

Fig. 5 Relation of soil quality index with total nitrogen

IV. CONCLUSION

The land cover management of the Alas Bromo educational forest of the UNS, which encompasses six different land covers, reveals poor soil quality. Mixed tree land cover had the highest SQI (0.36) among these low categories, while pine-mahogany land cover had the lowest (0.31). The land cover also significantly affects the density of earthworms, with the highest density of 365 individuals/m^2 on mixed-tree land cover and the lowest density of 25 individuals/m^2 on pine replanting land cover. In the future, the earthworm population can be used as a bioindicator to monitor soil quality in the Alas Bromo education forest because its existence influences the health of the soil. The effectiveness of using earthworms as bioindicators in various land uses and locations must first be evaluated.

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REFERENCES

[1] A. A. Darmawan, D. P. Ariyanto, T. M. Basuki, J. Syamsiyah, and W. S. Dewi, "Biomass accumulation and carbon sequestration potential in varying tree species, ages and densities in Gunung Bromo Education Forest, Central Java, Indonesia," Biodiversitas vol. 23, no. 10, pp. 5093-5100, October 2022. DOI: 10.13057/biodiv/d231016.

[2] R. Pillay, M. Venter, J. Aragon-Osejo, P. González- del-Pliego, A. J. Hansen, J. E. M. Watson, and O. Venter, "Tropical forests are home to over half of the world's vertebrate species", Front. Ecol. Environ. vol. 20, no. 1, pp. 10–15, 2022. doi:10.1002/fee.2420.

[3] B. Mackey, C. F. Kormos, H. Keith, W. R. Moomaw, R. A. Houghton , R. A. Mittermeier, D. Hole, and S. Hugh, "Understanding the importance of primary tropical forest protection as a mitigation strategy," Mitigation and Adaptation Strategies for Global Change vol. 25, pp. 763–787, 2020. https://doi.org/10.1007/s11027-019-09891-4.

[4] W. S. Dewi, S. D. C. Prasidina, D. D. Amalina, and S. Wongsoatmojo, "The density and diversity of Arbuscular mycorrhizal spores on land covers with different tree canopy densities at the UNS educational forests," in Proc. IOP Conf. Series: Earth and Environmental Science, Surakarta, Indonesia, 824, 012021, 2021. doi:10.1088/1755-1315/824/1/012021.

[5] D. S. Page-Dumroese, M. D. Busse, M. F. Jurgensen, and E. J. Jokela, "Sustaining forest soil quality and productivity," in Soils and Landscape Restoration, J. A. Stanturf and M. A. Challaham, Jr., eds., United Kingdom: Academic Press, 2021, pp. 63-94. [Online]. Available: https://doi.org/10.1016/B978-0-12-813193-0.00003-5.

[6] Q. Wu, W. Zheng, C. Rao, E. Wang, and W. Yan, "Soil Quality Assessment and Management in Karst Rocky Desertification Ecosystem of Southwest China," Forests vol. 13, no. 1513, 2022. https://doi.org/10.3390/f13091513.

[7] D. P. Ariyanto, Qudsi, Z. A., Sumani, W. S. Dewi, Rahayu, and Komariah, "The dynamic effect of air temperature and air humidity toward soil temperature in various lands cover at KHDTK Gunung Bromo, Karanganyar – Indonesia," in Proc. IOP Conf. Series: Earth and Environmental Science, Surakarta, Indonesia, 724, 012003, 2021. doi:10.1088/1755-1315/724/1/012003.

[8] A. T. Adetunji, B. Ncube, R. Mulidzi, and Lewu, F. B., "Management impact and benefit of cover crops on soil quality: A review," Soil and Tillage Research vol. 204, no. 104717, May 2019. https://doi.org/10.1016/j.still.2020.104717.

[9] S. Daryanto, B. Fua, L. Wang, P-A. Jacinthe, W. Zhao, "Quantitative synthesis on the ecosystem services of cover crops," Earth-Science Reviews vol. 185, pp. 357-373, 2018. https://doi.org/10.1016/j.earscirev.2018.06.013.

[10] N. Meyer, J-E. Bergez, J. Constantin, and E. Justes, "Cover crops reduce water drainage in temperate climates: A meta-analysis," Agron. Sustain. Dev. vol. 39, no. 3, 2019. https://doi.org/10.1007/s13593-018-0546-y.

[11] P. Sharma, A. Singh, C. S. Kahlon, A. S. Brar, K. K. Grover, M. Dia, and R. L. Steiner, "The Role of Cover Crops towards Sustainable Soil Health and Agriculture—A Review Paper". American Journal of Plant Sciences vol. 09, no. 09, pp. 1935–1951, 2018. https://doi.org/10.4236/ajps.2018.99140.

[12] M. A. Wubie and M. Assen, "Effects of land cover changes and slope gradient on soil quality in the Gumara watershed, Lake Tana basin of North–West Ethiopia," Modeling Earth Systems and Environment vol. 6, pp. 85–97, 2020. https://doi.org/10.1007/s40808-019-00660-5.

[13] S. Alam, S. Ginting, M. T. Hemon, S. Leomo, L. M. H. Kilowasid, J. Karim, Y. Nugroho, J. Matatula, and P. Y. A. P. Wirabuana, "Influence of land cover types on soil quality and carbon storage in Moramo Education Estate, Southeast Sulawesi, Indonesia," Biodiversitas vol. 23, no. 9, pp. 4371-4376, September 2022. DOI: 10.13057/biodiv/d230901.

[14] D. S. Page-Dumroese, F. G. Sanchez, R. P. Udawatta, C. H. Perry, and G. González, "Soil Health Assessent of Forest Soils" in Soil Health Series, vol. 1, Approaches to Soil Health Analysis, 1st Ed., D. L. Karlen, D. E. Stott, and M. M. Mikha, eds., Soil Science Society of America: John Wiley & Sons, 2021, pp. 100-138.

[15] M. C. Amacher, K. P. O'Neill, and C. H. Perry, "Soil Vital Signs: A New Soil Quality Index (SQI) for Assessing Forest Soil Health," Res. Pap. RMRS-RP-65WWW. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, pp. 12, May 2007.

[16] S. Mammo, Z. Kebin, A. Chimidi, and H. Ibrahim, "Soil Quality Analysis for Sustainability of Forest Ecosystem: The Case of Chilimo-Gaji Forest, West Shewa Zone, Ethiopia," Journal of Environment and Earth Science vol. 9, no. 3, 2019. DOI: 10.7176/JEES.

[17] M. E. Ngaiwi, E. and Molua, A. E. Egbe, "Forest Soil Quality and Potentials for Food Systems Health in the Takamanda National Park in South Western Cameroon," Natural Resources, vol. 10, pp. 218-229, 2019. https://doi.org/10.4236/nr.2019.106015.

[18] I. Chahal and L. L.Van Eerd, "Quantifying soil quality in a horticultural-cover cropping system," Geoderma, vol. 352, pp. 38–48, May 2019. https://doi.org/10.1016/j.geoderma.2019.05.039.

[19] K. Juhos, S. Czigány, B. Madarász, and M. Ladányi, “Interpretation of soil quality indicators for land suitability assessment – A multivariate approach for Central European arable soils,” Ecological Indicators, vol. 99, pp. 261–272, 2019. https://doi.org/10.1016/j.ecolind.2018.11.063.

[20] C.A. Seybold, M.J. Mausbach, D.L. Karlen, and H.H. Rogers, “Quantification of soil quality” in Soil Processes and the Carbon Cycle, R. Lal, J. M. Kimble, R. F. Follett, and B. A. Stewart, eds., London: CRC Press, pp. 387–404, 1997.

[21] M. S. Askari and N. M. Holden, “Quantitative soil quality indexing of temperate arable management systems,” Soil & Tillage Research, vol. 150, pp. 57–67, 2015. http://dx.doi.org/10.1016/j.still.2015.01.010.

[22] E. K. Bünemann, G. Bongiorno, Z. Bai, R. E. Creamer, G. D. Deyn, R. de Goede, L. Fleskens, V. Geissen, T. W. Kuyper, P. Mäder, M. Pulleman, W. Sukkel, J. W. van Groenigen, and L. Brussaard, “Soil quality – A critical review,” Soil Biology and Biochemistry, vol. 120, pp. 105–125, 2018. https://doi.org/10.1016/j.soilbio.2018.01.030.

[23] P. Lavelle, E. Duran, L. Rousseau, C. Sanabria, and J. Vasquez, “Soil Macroinvertebrate Communities as Indicators of Ecosystem Services in American Tropical Environments,” Biodiversity Online J., vol. 1, no. 4, BOJ.000516, 2021.

[24] H. Sohrabi, M, Jourgholami, M. Jafari, F. Tavankar, R. Venanzi, and R. Picchio, “Earthworms as an ecological indicator of soil recovery after mechanized logging operations in mixed beech forests”, Forests, vol. 12, no. 1, pp. 1–18, 2021. https://doi.org/10.3390/f12010018.

[25] E. Velasquez and P. Lavelle, “Soil macrofauna as an indicator for evaluating soil based ecosystem services in agricultural landscapes,” Acta Oecologica, vol. 100, no. 103446, July 2019. https://doi.org/10.1016/j.actao.2019.103446.

[26] J. Barthod, M. F. Digna,G. Le Mer, N. Bottinelli, F. Watteau, I. Kögel-Knabner, and C. Rumpel, “How do earthworms affect organic matter decomposition in the presence of clay-sized minerals?,” Soil Biology and Biochemistry, vol, 143, no. 107730, April 2020. https://doi.org/10.1016/j.soilbio.2020.107730.

[27] Y. Guo, R. Fan, N. McLaughlin, Y. Zhang, X. Chen, D. Wu, X. Zhang, and A. Liang, “Impacts induced by the combination of earthworms, residue and tillage on soil organic carbon dynamics using 13C labelling technique and X-ray computed tomography,” Soil and Tillage Research, vol. 205, no. 104737, January 2021. https://doi.org/10.1016/j.still.2020.104737.

[28] Z. Guo, J. Han, and J. Li, J., “Response of organic carbon mineralization and bacterial communities to soft rock additions in sandy soils,” PeerJ, vol. 8, no. e8948, 2020. https://doi.org/10.7717/peerj.8948.

[29] S. Al-Maliki, D. K. A. Al-Taey, and H. Z. Al-Mammori, H. Z., “Earthworms and eco-consequences: Considerations to soil biological indicators and plant function: A review,” Acta Ecologica Sinica, vol. 41, no. 6, pp. 512–523, December 2021. https://doi.org/10.1016/j.chnaes.2021.02.003.

[30] A. K Singh, X. J. Jiang, B. Yang, J. Wu, A. Rai, C. Chen, J. Ahirwal, P. Wang, W. Liu, and N. Singh, “Biological indicators affected by land use change, soil resource availability and seasonality in dry tropics,” Ecological Indicators, vol. 115, no. 106369, August 2020. https://doi.org/10.1016/j.ecolind.2020.106369.

[31] G. Pérès, F. Vandenbulcke, M. Guernion, M. Hedde, T. Beguiristain, F. Douay, S. Houot, D. Piron, A. Richard, A. Bispo, C. Grand, L. Galsomies, and D. Cluzeau, “ Earthworm indicators as tools for soil monitoring, characterization and risk assessment. An example from the national Bioindicator programme (France),” Pedobiologia, vol. 54 (SUPPL.), pp. S77–S87, December 2011. https://doi.org/10.1016/j.pedobi.2011.09.015.

[32] S. Fusaro, F. Gavinelli, F, Lazzarini, F., and M. G. Paoletti, “Soil Biological Quality Index based on earthworms (QBS-e). A new way to use earthworms as bioindicators in agroecosystems,” Ecological Indicators, vol. 93, pp. 1276–1292, October 2018. https://doi.org/10.1016/j.ecolind.2018.06.007.

[33] E. Velasquez, and L. Lavelle, P., “Soil macrofauna as an indicator for evaluating soil based ecosystem services in agricultural landscapes,” Acta Oecologica, vol. 100, no. 103446, October 2019. https://doi.org/10.1016/j.actao.2019.103446.

[34] "Sifat Fisik Tanah dan Metode Analisisnya," [Soil Physical Properties and Analysis Methods] U. Kurnia, F. Agus, A. Adimihardja, and A. Dariah, A., eds., Bogor, Indonesia: Balai Besar Litbang Sumber Daya Pertanian, 2006.

[35] R. W. Nusantara, A. Aspan, A. M. Alhaddad, U. E. Suryadi, M. Makhrawie, I. Fitria, J. Fakhrudin, and R. Rezekikasari, "Peat soil quality index and its determinants as influenced by land use changes in Kubu Raya district, West Kalimantan, Indonesia," Biodiversitas, vol. 19, no. 2, pp. 540–545, 2018. https://doi.org/10.13057/biodiv/d190229.

[36] S. Chandel, M. S. Hadda, and A. K. Mahal, "Soil Quality Assessment Through Minimum Data Set Under Different Land Uses of Submontane Punjab," Communications in Soil Science and Plant Analysis, vol. 49, no. 6, pp. 658–674, 2018. https://doi.org/10.1080/00103624.2018.1425424.

[37] K. Bargali, V. Manral, K. Padalia, S. S. Bargali, and V. P. Upadhyay, "Effect of vegetation type and season on microbial biomass carbon in Central Himalayan forest soils, India," Catena, vol. 171, pp. 125–135. December 2018. https://doi.org/10.1016/j.catena.2018.07.001.

[38] Q. W. Wang, M. Pieristè, C. Liu, T. Kenta, T. M. Robson, and H. Kurokawa, "The contribution of photodegradation to litter decomposition in a temperate forest gap and understorey," New Phytologist, vol. 229, no.5, March 2021. https://doi.org/10.1111/nph.17022.

[39] S. Hoeber, P. Fransson, M. Weih, and S. Manzoni, "Leaf litter quality coupled to Salix variety drives litter decomposition more than stand diversity or climate," Plant and Soil, vol. 453, pp. 313–328, June 2020. https://doi.org/10.1007/s11104-020-04606-0.

[40] J. M. Barel, T. W. Kuyper, J. Paul, W. de Boer, J. H. C. Cornelissen, and G. B. De Deyn, "Winter cover crop legacy effects on litter decomposition act through litter quality and microbial community changes," Journal of Applied Ecology, vol. 56, pp. 132–143, June 2018. https://doi.org/10.1111/1365-2664.13261.

[41] Y Li, T. M. Bezemer, J. Yang, X. Lü, X. Li, W. Liang, X. Han, and Q. Li, "Changes in litter quality induced by N deposition alter soil microbial communities," Soil Biology and Biochemistry, vol. 130, pp. 33–42, March 2019, https://doi.org/10.1016/j.soilbio.2018.11.025.

[42] M. Macek, M. Kopecký, M., and J Wild, "Maximum air temperature controlled by landscape topography affects plant species composition in temperate forests," Landscape Ecology, vol. 34, pp. 2541–2556, September 2019. https://doi.org/10.1007/s10980-019-00903-x.

[43] J. F. Penner and D. A. Frank, "Litter Decomposition in Yellowstone Grasslands: The Roles of Large Herbivores, Litter Quality, and Climate," Ecosystems, vol. 22, no. 4, pp. 929–937, 2019. https://doi.org/10.1007/s10021-018-0310-9.

[44] G. Lawson, C. Dupraz, and J. Watté, "Can silvoarable systems maintain yield, resilience, and diversity in the face of changing environments?" in Agroecosystem Diversity, Reconciling Contemporary Agriculture and Environmental Quality, G. Lemaire, P. C. D. F. Carvalho, S. Kronberg, S. Recous, eds., France: Academic Press, pp. 145–168. https://doi.org/10.1016/B978-0-12-811050-8.00009-1.

[45] J. Kermavnar, M. Ferlan, A. Marinšek, K. Eler, A. Kobler, and L. Kutnar, "Effects of various cutting treatments and topographic factors on microclimatic conditions in Dinaric fir-beech forests," Agricultural and Forest Meteorology, vol. 295, no. 108186, December 2020. https://doi.org/10.1016/j.agrformet.2020.108186.

[46] H. R. El-Ramedy, T. A. Alshaal, M. Amer, E. Domokos-Szabolcsy, N. Elhawat, J. Prokisch, and M. Fari, "Soil Quality and Plant Nutrition," in Sustainable Agriculture Reviews 14, Agroecology and Global Change, H. Ozier-Lafontaine and M. Lesueur-Jannoyer, eds., Springer, Cham., pp. 345-447, 2014. https://doi.org/10.1007/978-3-319-06016-3_11.

[47] M. Zaffar and S. G. Lu, "Pore size distribution of clayey soils and its correlation with soil organic matter," Pedosphere, vol. 25, no. 2, pp. 240–249, April 2015. https://doi.org/10.1016/S1002-0160(15)60009-1.

[48] B. Minasny and A. B. McBratney, "Rejoinder to the comment on: B. Minasny & A.B. McBratney. 2018. Limited effect of organic matter on soil available water capacity," European Journal of Soil Science, vol. 69, no. 1, pp. 155–157, January 2018. https://doi.org/10.1111/ejss.12526.

[49] J. Fukumasu, N. Jarvis, J. Koestel, T. Kätterer, and M. Larsbo, "Relations between soil organic carbon content and the pore size distribution for an arable topsoil with large variations in soil properties," European Journal of Soil Science, vol. 73, no. 1, pp. 1–15, January 2022. https://doi.org/10.1111/ejss.13212.

[50] W. Kong, Y. Yao, Z. Zhao, X. Qin, H. Zhu, X. Wei, M. Shao, Z. Wang, K. Bao, and M. Su, "Effects of vegetation and slope aspect on soil nitrogen mineralization during the growing season in sloping lands of the Loess Plateau," Catena, vol. 172, pp. 753–763, January 2019. https://doi.org/10.1016/j.catena.2018.09.037.

[51] A. Rawal, S. Chakraborty, B. Li, K. Lewis, M. Godoy, L. Paulette, and D. C. Weindorf, "Determination of base saturation percentage in agricultural soils via portable X-ray fluorescence spectrometer,"

Geoderma, vol. 338, pp. 375–382, March 2019. https://doi.org/10.1016/j.geoderma.2018.12.032.

[52] Z. Zgorelec, B. Grahovac, A. Percin, V. Jurkovic, L. Gandjaeva, and N. Maurović, "Comparison of two different CEC determination methods regarding the soil properties," Agric. conspec. sci., vol. 84, no. 2, 151–158, 2019.

[53] C. J. Penn and J. J. Camberato, "A critical review on soil chemical processes that control how soil ph affects phosphorus availability to plants," Agriculture, vol. 9, no. 120, pp. 1–18, 2019. https://doi.org/10.3390/agriculture9060120.

[54] Y. Fan, X. Zhong, F. Lin, C. Liu, L. Yang, M. Wang, G. Chen, Y. Chen, and Y. Yang, "Responses of soil phosphorus fractions after nitrogen addition in a subtropical forest ecosystem: Insights from decreased Fe and Al oxides and increased plant roots," Geoderma, vol. 337, pp. 246–255, March 2019. https://doi.org/10.1016/j.geoderma.2018.09.028.

[55] X. Q. Zhao and R. F. Shen, "Aluminum–nitrogen interactions in the soil–plant system," Frontiers in Plant Science, vol. 9, article 807, pp. 1–15, June 2018. https://doi.org/10.3389/fpls.2018.00807.

[56] H. Y. Ch'Ng, H. O. Ahmed, and N. M. A. Majid, "Improving phosphorus availability in an acid soil using organic amendments produced from agroindustrial wastes," The Scientific World Journal, Article ID 506356, pp. 6, 2014. https://doi.org/10.1155/2014/506356.

[57] K. S. Niranjana, K. Yogendra, and K. M. Mahadevan, "Soil Quality Assessment Through Minimum Data Set Under Arecanut Land Use System Hilly Zone of Karnataka, India," International Journal of Environment, Ecology, Family and Urban Studies, vol. 9, no. 1, pp. 27–34, February 2019. https://doi.org/10.24247/ijeefusfeb20194.

[58] M. P. Cantú, ,A. R. Becker, J. C. Bedano, H. F. Schiavo, and B. J. Parra, "Evaluación del impacto del cambio de uso y manejo de la tierra mediante indicadores de calidad de suelo, Córdoba, Argentina," Cadernos Do Laboratorio Xeoloxico de Laxe, vol. 34, pp. 203–214, 2009.

[59] F. Umasugi, W. Nurmawan, dan F. Saroisong, "Produksi Serasah Pohon Spathodea campanulata," Cocos. vol. 8, no. 8. 2021. https://doi.org/10.35791/cocos.v8i8.38281.

[60] G. Tian, B. Kang, and L. Brussaard, "Biological effects of plant residues with contrasting chemical compositions on Plant and Soil under humid tropical conditions," Soil Biology & Biochemistry, vol. 24, no. 10, pp. 1051-1060, October 1992. https://doi.org/10.1016/0038-0717(92)90035-V.

[61] B. P. Simatupang, A. Niswati, and S. Yusnaini, "Populasi Dan Keanekaragaman Cacing Tanah Pada Berbagai Lokasi Di Hutan Taman Nasional Bukit Barisan Selatan (TNBBS)," [Population and Diversity of Earthworms at Various Locations in the Bukit Barisan Selatan National Park Forest] Jurnal Agrotek Tropika, vol. 3, no. 3, pp. 402–408, September 2015. https://doi.org/10.23960/jat.v3i3.1971.

[62] J. Hallam, J. Holden, D. A. Robinson, and M. E. Hodson, "Effects of winter wheat and endogeic earthworms on soil physical and hydraulic properties," Geoderma, vol. 400, no. 115126, October 2021. https://doi.org/10.1016/j.geoderma.2021.115126.

[63] N. Ahmed, and K. A. Al-Mutairi, "Earthworms Effect on Microbial Population and Soil Fertility as Well as Their Interaction with Agriculture Practices," Sustainability, vol. 14, no. 7803, pp. 1–17, 2022. https://doi.org/10.3390/su14137803.

[64] J. V. C. de L. da Silva, M. N. C. Hirschfeld, J. E. Cares, and A. M. Esteves, "Land use, soil properties and climate variables influence the nematode communities in the Caatinga dry forest," Applied Soil Ecology, vol. 150, no. 103474, June 2020. https://doi.org/10.1016/j.apsoil.2019.103474.

[65] M. T. Prendergast-Miller, D. T. Jones, D. T., D. Berdeni, S. Bird, P. J. Chapman, L. Firbank, R. Grayson, T. Helgason, J. Holden, M. Lappage, J. Leake, and M, E. Hodson, "Arable fields as potential reservoirs of biodiversity: Earthworm populations increase in new leys," Science of the Total Environment, vol. 789, no. 147880, October 2021. https://doi.org/10.1016/j.scitotenv.2021.147880.

[66] A. S. Sankar, and A. Patnaik, "Impact of soil physico-chemical properties on distribution of earthworm populations across different land use patterns in southern India," The Journal of Basic and Applied Zoology, vol. 79, no. 1, November 2018. https://doi.org/10.1186/s41936-018-0066-y.

[67] C. Walsh, J. L. Johnson-Maynard, and I. N. Leslie, "Seasonal variations in exotic earthworm populations in wheat fields of the Inland Pacific Northwest, U.S.A," Pedobiologia, vol. 76, no. 150569, September 2019. https://doi.org/10.1016/j.pedobi.2019.150569.

[68] S. Cai, J. Wang, W. Lv, S. Xu, and H. Zhu, "Nitrogen fertilization alters the effects of earthworms on soil physicochemical properties and bacterial community structure," Applied Soil Ecology, vol. 150, no. 103478, 2020. https://doi.org/10.1016/j.apsoil.2019.103478.

[69] N. L. Kartini,"Pengaruh Cacing Tanah Dan Jenis Media Terhadap Kualitas Pupuk Organik,"[The Effect of Earthworms and Media Types on the Quality of Organic Fertilizers] Pastura, vol. 8, no. 1, 2018. https://doi.org/10.24843/pastura.2018.v08.i01.p11.

[70] F. A. Sembiring, S. Yusnaini, H. Buchari, and A. Niswati, "Pengaruh Sistem Olah Tanah Terhadap Populasi Dan Biomassa Cacing Tanah Pada Lahan Bekas Alang-Alang (Imperata cylindrica L.) Yang Ditanami Kedelai (Glycine max L.) Musim Kedua,"[Effect of Tillage System on Earthworm Population and Biomass in Former Imperata (Imperata cylindrica L.) Planted with Soybean (Glycine max L.) Second Season] Jurnal Agrotek Tropika, vol. 2, no. 3, pp. 475–481, September 2014. https://doi.org/10.23960/jat.v2i3.2082.

[71] N. H. Ayuningtias, M. Arifin, and M. Damayani, "Analisa Kualitas Tanah Pada Berbagai Penggunaan Lahan di Sub Sub DAS Cimanuk Hulu," SoilREns, vol. 14, no. 2, pp. 25–32, 2016. https://doi.org/10.24198/soilrens.v14i2.11035.

[72] S. Rahmah, Yusran, and H. Umar, "Sifat Kimia Tanah Pada Berbagai Tipe Penggunaan Lahan Di Desa Bobo Kecamatan Palolo Kabupaten Sigi,"[Soil Chemical Properties in Various Types of Land Use in Bobo Village, Palolo District, Sigi Regency] Warta Rimba, vol. 2, no. 1, pp. 88-95, Juni 2014.

[73] S. S.Videira, M de C. P. e Silva, P. de S. Galisa, A. C. F. Dias, R. Nissinen, L. C. B. Divan, J. D. van Elsas, J. I. Baldani, and J. F. Salles, "Culture-independent molecular approaches reveal a mostly unknown high diversity of active nitrogen-fixing bacteria associated with Pennisetum purpureum - a bioenergy crop," Plant and Soil, vol. 373, pp. 737–754, July 2013. https://doi.org/10.1007/s11104-013-1828-4.

[74] M. Ehret, R. Graß, and M. Wachendorf, "Productivity at the tree-crop interface of a young willow-grassland alley cropping system," Agroforestry Systems, vol. 92, no. 1, pp. 71–83, 2018. https://doi.org/10.1007/s10457-016-0015-z.

[75] L. F. Rivera, I. Armbrecht, and Z. Calle, "Silvopastoral systems and ant diversity conservation in a cattle-dominated landscape of the Colombian Andes," Agriculture, Ecosystems and Environment, vol. 181, pp. 188–194, December 2013. https://doi.org/10.1016/j.agee.2013.09.011.

[76] F. Raiesi and A. Beheshti, "Evaluating forest soil quality after deforestation and loss of ecosystem services using network analysis and factor analysis techniques," Catena, vol. 208, no. 105778, 2022. https://doi.org/10.1016/j.catena.2021.105778.

[77] G. A. Ghani , M. Dimyati , A. Damayanti, "Prediction of Land Cover and Land Surface Temperature in Kuta Selatan Sub-district, Bali Province," IJASEIT, vol. 11 no. 1, 2021