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# Assessing soil properties in various agroforestry lands in Kuningan District, West Java, Indonesia using Visual Evaluation of Soil Structure (VESS)

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**Abstract.** *Purnama TJ, Wijayanto N, Wasis B. 2022. Assessing soil properties in various agroforestry lands in Kuningan District, West Java, Indonesia using Visual Evaluation of Soil Structure (VESS). Biodiversitas 23: 3012-3021.* Land conversion from the forest into intensive agriculture and plantation causes soil degradation. Agroforestry is promoted as a win-win solution to land management that conserves and improves soil quality using a tree-based farming system. This study aimed to evaluate the physical soil quality of various land-use patterns, including agroforestry in Kuningan District, West Java. In doing so, we employed the Visual Evaluation of Soil Structure (VESS) method to be compared with laboratory analysis. Soil physical quality of seven land-use types was evaluated, namely natural forest, complex agroforestry of coffee, complex agroforestry of galangal, simple agroforestry of coffee, simple agroforestry of sweet potato, coffee monoculture and maize monoculture. The VESS technique was used to assess the quality of soil structure, whereas the conventional soil analysis method was used to determine soil bulk density and porosity. Other soil properties including soil organic carbon, cation-exchange capacity (CEC), pH, and soil macrofauna and mesofauna as well as dry litter weight, vegetation composition and individuals' density were also obtained. The results of the VESS method (reflected as Sq value) revealed that the soil physical quality varied, ranging from Sq value of 1.16-3.1. Complex agroforestry of galangal had Sq value of 1.56 which was not significantly different from that of natural forest land (Sq 1.16), implying that both land uses had a similar physical soil quality. The VESS score and the soil property parameters have a reasonable correlation (r) (BD = 0.80, soil porosity =-0.80, SOC =-0.88, CEC = 0.89, diversity of fauna soil index = 0.82). This study shows that a multi-strata agroforestry system can be a strategy for recovering soil quality on degraded lands, and the VESS method can be used to analyze soil quality in these areas.

**Keywords:** Land management, macro-mesofauna of soil, soil organic carbon, soil physical quality, VESS method

## INTRODUCTION

Indonesia's tropical primary forest plays an essential role in biodiversity conservation, carbon sequestration and water regulation. However, despite its importance, land-use changes in this region have resulted in high rates of deforestation. Data by WRI (2021) showed that Indonesia was the fourth-largest country to lose the tropical primary forest in 2021 with 202,905 ha. Deforestation and land-use conversion affect land quality, especially if the forest is converted into intensive agriculture and plantation areas (Li et al. 2020; Naharuddin et al. 2019; Sena et al. 2021; Song 2017). Such conversion involves complex cultivation activities, including land clearing and preparation, intensive planting and maintenance, and harvesting which usually use heavy mechanical tools (Veldkamp et al. 2020; Assefa et al. 2017). Intensive agricultural practices have negative impacts on soil physical properties, such as the increase in soil bulk density and resistance to penetration, and decrease in soil aeration, aggregation stability and water infiltration, and therefore increase in the risk of soil erosion (Cherubin et al. 2016b, 2017; Hasannudin et al. 2022). It takes a long time to improve soil quality following soil degradation due to intensive agriculture (Veldkamp et al. 2020; Sena et al. 2021). In this regard, agroforestry is an alternative land use option to recover soil conditions.

Agroforestry is a land management that combines the practice of agriculture and forestry. Agroforestry refers to the integration of trees into farming systems to enhance productivity, profitability, diversity and ecosystem sustainability (Xu et al. 2013). Agroforestry provides several environmental benefits in conserving and improving soil quality (Guimarães et al. 2014; De Stefano and Jacobson 2017; Siarudin et al. 2021). Agroforestry is able to maintain soil physical properties through the accumulation of soil organic matter from litterfall, increase soil nutrients, biological elements and root activities, as well as maintain and increase the availability of water in the root layer (Siaruddin et al. 2021; Franco et al. 2016). Agroforestry system has certain patterns in the combination of plants in one space and time. There are two general agroforestry systems practiced, i.e., complex agroforestry which uses many species of trees and simple agroforestry, which only uses single tree species. A complex agroforestry system with a high number of tree species and individuals can improve soil's physical properties (Bahuguna et al. 2018; Bahnemiri et al. 2019). Complex agroforestry performs better in improving root density, soil organic carbon and soil macroporosity compared to simple agroforestry and monoculture (Saputra et al. 2020).

Analysis of soil's physical and chemical properties can indicate the level of soil quality in supporting plant growth (Arévalo-Gardini et al. 2015). Soil with good physical properties has many advantages in terms of the ability to drain and store water, facilitate roots to penetrate into the soil, increase aeration, and the ability to withstand retention as well as plant nutrients (Wasis 2012; Wasis et al. 2019). Conversely, degraded soil will reduce plants' ability to absorb soil nutrients (Wasis 2012). In addition, soil biological properties are beneficial for macrofauna, mesofauna and microbes living underground, which play an important role in the decomposition process which can increase soil fertility (Suin 2012). Soil physical, chemical, and biological properties are interrelated and affect soil fertility which is essential for plant growth and survival. Thus, an assessment of soil properties is necessary to determine soil quality.

Visual Evaluation of Soil Structure (VESS) is a method of analyzing soil physical properties developed through soil structure assessment (Ball et al. 2017a; Cherubin et al. 2018; Aji et al. 2021; Briliawan et al. 2022). This method is thought to be simple enough to define soil quality based on its structural elements. The main methods of visual evaluation of soil structure focus on describing soil aggregates, porosity and rooting that relate to water storage and transport, root development and nutrient uptake (Ball et al. 2017a). Visual soil structure quality may be measured in several methods. These methods include VESS (Ball et al. 2017a; Cherubin et al. 2018; Aji et al. 2021; Briliawan et al. 2022), SOILpak (McKenzie 2013), Profil Cultural (Peigné et al. 2013), and GrassVESS (Emmet-Booth et al. 2018; Briliawan et al. 2022). According to Ball et al. (2017a), compared to other methods, VESS is the simplest and most useful initial test for scientific purposes to provide information on the general quality of the soil and can then be used as a guide to the required scales for soil sampling and the types of samples required. Cherubin et al. (2019) stated that the VESS method has the advantage of easy understanding, little requirements of equipment, and can be applied in places that are difficult for humans to reach. The disadvantage of VESS evaluation, like other visual approaches, relies exclusively on categorization scores, thus to inform soil management, the validity of such scores is ideally supported by other soil quality data such as bulk density, resistance to penetration, macroporosity or infiltration rates, and by soil biological and yield data (Ball et al. 2017a). This method has been widely applied to assess the changes in soil properties caused by land use (Cherubin et al. 2017; Guimarães et al. 2017a); tillage and crop management (Guimarães et al. 2013; Tormena et al. 2016) and pasture management systems (Cui et al. 2014). This method has been applied to various types of land use in various countries, such as in sugarcane cultivation (Cherubin et al. 2017) and maize cultivation (Tormena et al. 2016) in Brazil. Recently, Cherubin et al. (2018), Aji et al. (2021) and Briliawan et al. (2022) verified that VESS can efficiently detect the changes in soil quality in tropical agroforestry lands.

Despite the potential use of VESS in determining soil quality, this method is still very rarely applied in Indonesia. Therefore, it is interesting to conduct an analysis of soil properties using this VESS method on various lands, including agroforestry lands in Indonesia. In this regard, the purpose of this study was to evaluate the physical soil quality of various agroforestry land patterns in Kuningan District, West Java using the VESS method. We hypothesized that: (1) agroforestry systems are able to recover the physical soil properties of degraded soil caused by the land-use change from forest to agricultural land; (2) the VESS method is able to evaluate soil properties and becomes a useful method for monitoring the changes in soil quality.

## MATERIALS AND METHODS

### Study area and period

This research was conducted in the working area of the Regional VIII Forestry Service Branch of West Java, Kuningan District, located in Cilimus Sub-district and Jalaksana Sub-district, Kuningan District (543 m asl), from August to October 2021. The average daily temperature is around 20-28°C, and the annual rainfall is 2000 mm. The study location has a flat slope and the soil is categorized as Andosol. Soil analysis was carried out at the laboratory of Vocational High School 1 Kuningan, Laboratory of the Faculty of Forestry at IPB University, and the Indonesian Center for Biodiversity and Biotechnology (ICBB) Laboratory in Bogor, West Java, Indonesia.

### Site description

The research was carried out on 7 various land covers including agroforestry system in the study area as shown in (Figure 1): (i) Complex agroforestry (CAGF) of coffee, consisted of cloves stands (*Syzygium aromaticum*), mahogany (*Swietenia mahagoni*), stink bean or 'petai' (*Parkia speciosa*), melinjo (*Gnetum gnemon*), durian (*Durio zibethinus*), and coffee (*Coffea arabica*); (ii) Simple agroforestry (SAGF) of coffee, consisted of clove stands (*S. aromaticum*), and coffee (*Coffea canephora*); (iii) Complex agroforestry (CAGF) of galangal, consisted of cloves (*S. aromaticum*), mahogany (*S. mahagoni*), melinjo (*G. gnemon*), durian (*D. zibethinus*), sungkai (*Peronema canescens*), galangal (*Alpinia galanga*) and turmeric (*Curcuma longa Linn*.); (iv) Simple agroforestry (SAGF) of sweet potato, consisted of clove (*S. aromaticum*) and sweet potato (*Ipomoea batatas*); (v) Coffee monoculture; (vi) Maize monoculture; and (vii) Natural forest with stands of pine (*Pinus merkusii*), saninten (*Castanopsis* sp), pasang (*Quersus sundaica*), and ferns. Most of these lands were cultivated in a mixed manner (organic and chemical cultivation) except for simple agroforestry of sweet potato and maize monoculture, which were only cultivated organically.


**Figure 1.** The research sites: A. CAGF coffee; B. SAGF coffee; C. CAGF galangal; D. SAGF sweet potato; E. M coffee; F. M maize; and G. natural forest

**Data collection procedures**

*VESS method*

Measurement and assessment using the VESS method have been fully described by Ball et al. (2017a), Cherubin et al. (2018) and Aji et al. (2021). At three sampling points, a hole with a size of 30×30×30 cm was dug to extract the undisturbed sample of soil block of 20×10×25 cm using a shovel, then collected and transferred to the sacks/plastics. Soil evaluation included observing and measuring the number of layers contained in the soil block sample, observing the soil aggregate on the sample by crushing the soil block, as well as fragmenting the largest soil aggregate into smaller sizes (~1,5-2 cm). Visual observation of the soil structure included aggregate size, soil sample, visible soil pores, roots, and fragmented soil aggregate. Soil sampling by using the VESS method was carried out on seven types of land cover, including agroforestry in the area. Soil sampling by using the VESS method took about 15-30 minutes as reported in several literatures (e.g., Cherubin et al. 2017; Cherubin et al. 2018; Aji et al. 2021). The soil depth taken in this study consisted of 2 to 3 layers. According to Aji et al. (2021) and Cherubin et al. (2018), no more than three layers are possible to identify a shovel in the depth of 25 cm by using the VESS method. It is irrelevant to assess at depths of greater than 25 cm. Soil samples were taken with the soil conditions not too wet and not too dry. This condition will support the VESS-based soil sampling process (Ball et al. 2017a; Cherubin et al. 2017; Guimarães et al. 2017a; Aji et al. 2021). The soil quality is reflected in soil structure with the formula as shown in the equation below:

$$VESS\ Sqscore = \sum_{i=1}^{n} \frac{SqiTi}{TT}$$

Where: Sqscore: VESS score; Sqi: VESS score a thickness to i; Ti: soil sample thickness to i; TT: total thickness of the whole soil

VESS scores were classified from Sq 1 (good soil quality) to Sq 5 (poor soil quality) (Table 1). Soil quality assessment on the VESS method has been described in detail and thoroughly by Cherubin et al. (2018) and Aji et al. (2021). Soil sampling cannot be carried out on soils that are too dry or too wet. If there is heavy rain during or before the observation process, soil sampling just can be done 24-48 hours after the rain (Ball et al. 2017a; Aji et al. 2021).

**Tabel 1.** Soil quality score classification (Ball et al. 2017a; Cherubin et al. 2018; Aji et al. 2021)

| Sq score | Soil structural quality | Management need |
|---|---|---|
| 1-2 | Good | No changes needed |
| 2-3 | Fair | Needs to be improved to prevent further degradation |
| 3-5 | Poor | Urgently needs to improve soil condition to plant growth |

*Soil sample*

Soil sampling was carried out on the disturbed soil using the purposive sampling method. The disturbed soil sample was taken at a depth of 0-20 cm, at three sampling points in one plot, then it was composited until evenly distributed. It was then put in a plastic bag and labeled (Aji et al. 2021). After that, soil analysis was carried out at the ICBB Laboratory to measure several variables, including C-organic, pH and cation exchange capacity (CEC). Whole undisturbed soil samples were taken using a sample ring. Samples for bulk density and porosity analysis purposes were taken at three points in one plot (Al-Shammary et al. 2018). Further testing was carried out at the Laboratory of Vocational High School 1 Kuningan.

The observed soil biological characteristics were macrofauna and mesofauna. Observations were conducted on each observation plot. Three sub-plots with a size of 25×25 cm and a depth of 0-5 cm were observed. The technique of collecting and separating samples of macrofauna and mesofauna in the litter was conducted by hand sorting (Suin 2012). Animal samples were put into collection bottles containing 70% alcohol using tweezers for identification purposes. Identification of soil fauna was carried out by morphological identification at the Forest Entomology Laboratory of IPB using a stereomicroscope and optilab. Identification refers to the websites of Bugguide.net and Antkey.org.

*Measurement of canopy density and litter weight*

The measurements of canopy density and litter weight help us to describe the vegetation condition of the whole components for each type of land use. Data were collected from points of light which were reflected by a densitometer covering four points of each small square. This procedure was repeated for each of the four cardinal points (north, south, east, and west). The illuminated points were added up and multiplied by the point average by 1.04. Header coverage was the opposite of this result (1/Openness) (Freitas et al. 2017). The measurement of litter weight was carried out by taking litter at three points of observation plots with a subplot of 1×1 m. Then, the litter was put in a plastic or envelope. Litter weight was generally expressed in dry weight. The wet weight (WW) of each sample was measured, then the sample was put in an oven at 60°C for 48 hours to get dry weight (DW). This analysis process was carried out in the laboratory of Ecology, Faculty of Forestry, Kuningan University. Litter weight (LW) was obtained from the difference between wet weight (WW) and dry weight (DW) (Aji et al. 2021) which is shown in the equation below:

LW (g m-2) = WW-DW

## Data analysis

The data were processed by using analysis of variance (ANOVA) in a completely randomized design to examine the effect of land-use systems on the VESS score. When the ANOVA F test was significant ($p < 0.05$), the mean values in each land use were compared with Duncan's test ($p < 0.05$). Furthermore, person linear correlation analysis was carried out between the VESS score and other soil properties parameters. Data analysis was performed using Microsoft Excel and SPSS 26.

# RESULTS AND DISCUSSION

## VESS scores

The VESS value for each land-use type ranged from Sq 1.16-3.1 (Figure 2). These values reflect the varying soil qualities across land-use types, ranging from very good to poor. The smaller the VESS value, the better the soil quality (Ball et al. 2017a). When the seven sites were analyzed together, land cover had a significant effect on the VESS value at the confidence level of 5% (Figure 2). The VESS values of natural forests and the two complex agroforestry systems were not statistically different. The VESS value of complex agroforestry of galangal had a statistically significant difference with two simple agroforestry and two monoculture lands. The complex agroforestry of galangal had the best VESS value (Sq 1.56) after natural forest (Sq 1.16) compared to other agricultural lands. A high VESS score in the complex agroforestry of galangal is related to the number of forest tree species in this area since they can improve soil quality (Jahed et al. 2014; Khaleel et al. 2020). In particular, the permanent soil cover by litter from forest trees enhanced the physical quality of the soil (Cherubin et al. 2017; Guimarães et al. 2017b).

Our finding is in accordance with a previous study that found the VESS scores on natural forest cover ranged between Sq 1 dan 2 (Guimarães et al. 2013, 2017a; Auler et al. 2017; Cherubin et al. 2017, 2018; Aji et al. 2021; Briliawan et al. 2022). The soil structure at the natural forest and complex agroforestry of galangal is classified as crumbly, making the soil beam samples taken from these two locations easily crushed when held by hand. Soil fragments (~1.5 cm diameter) were very easily obtained when the soil block was crushed and almost filled with roots (Figure 3). Soils that tend to be easily destroyed are commonly found in forest land in which plant's roots still remain in the soil sample (Cherubin et al. 2018). Roots are able to adapt optimally to good soil conditions so that they can support the formation of macroaggregates in the soil (Wiley and John 2016). Good soil structure is also thought to be influenced by vegetation and litter in those areas. The vegetation component in the natural forest and complex agroforestry of galangal was dominated by trees. They produce a large quantity of litter as organic matter, providing continuous inputs of organic C in the soil (Table 2). Under natural vegetation, constant litter cover, continual organic C inputs into the soil, and the lack of disturbance are essential drivers of soil aggregation and improved physical quality (Auler et al. 2017; Cherubin et al. 2017; Guimarães et al. 2017b). Litter coverage protects the soil from direct raindrop contact, minimizing soil disaggregation and surface sealing, and thereby lowering soil erosion losses (Cherubin et al. 2018). In addition, natural forest areas are associated with higher diversity and activity of soil fauna compared to agricultural land uses

(Table 2). The presence and activity of soil fauna impact one of the characteristics of good soil structure (Llado et al. 2018; Franco et al. 2017; Sun et al. 2020). Franco et al. (2017) recently confirmed that lower VESS scores (i.e., better soil physical quality) were associated with a higher abundance of isopteran and coleopteran, groups known as soil engineers. Furthermore, big-size trees in tropical rainforest ecosystems generate a better microclimate and loose soil owing to the abundance of soil organic matter, resulting in a large diversity of forest microorganisms (Flores-Rentera et al. 2020).

Medium VESS values (Sq 2-2.93) were found in complex agroforestry of coffee, simple agroforestry of coffee, and coffee monocultures. Medium-large soil aggregate fragments dominated the soil samples in coffee monoculture, but they were present in small amounts in complex and simple agroforestry of coffee (Figure 3). In some areas, the fragments (~1.5 cm) had few pores and roots, as in coffee monocultures. The vegetation component and land management were likely to have an impact on this. The soil structure at these three locations had a rounded lump structure. Complex and simple agroforestry of coffee had slightly better soil quality because soil fragments (~1.5) had roots (Figure 3). According to Barlagne et al. (2021), forestry plants have a role in producing organic matter through litterfall and the importance of shade plants' roots in loosening the soil. In the context of land management, soils with moderate quality require only long-term soil improvement (Aji et al. 2020).

Simple agroforestry of sweet potato and maize monoculture had poor soil quality with VESS value of Sq 3.05-3.1. Soil aggregate fragments were mostly large in size. The soil structure at these two locations was lumpy at an angle. Fragments (~1.5 cm) in maize monoculture were characterized by forming sharp angles at several corners of the soil aggregate (Figure 3). According to Moncada et al. (2014), soil aggregates with an angular shape at the ends are soils with poor structural quality. Simple agroforestry of sweet potato and maize monoculture had no forest vegetation component, making the soils to be compacted. Soil compaction and loss of biological-chemical processes can lead to soil degradation (Guimaraes et al. 2017a; Guimaraes et al. 2017b). The main strategy for improving soil structure with poor quality is to plant trees as a source of organic matter to lower soil bulk density (Siqueira et al. 2020). Another way is to increase the soil's carrying capacity to the roots of agricultural crops by using large amounts of organic fertilizers (Pleguezuelo et al. 2018). Agricultural land under intensive management has favorable short-term results, but also has detrimental long-term consequences, such as soil structure damage (Cherubin et al. 2016b).

**The role of agroforestry on soil properties**

This study reveals that the application of agroforestry systems can improve soil quality. Agroforestry provides several environmental benefits in conserving or improving soil quality (Guimarães et al. 2014; De Stefano and Jacobson 2017). Based on the result of VESS values other parameters, the agroforestry system maintained soil physical properties at the same level as those under natural forests, implying that agroforestry systems had a positive effect on soil physical quality. Complex agroforestry of galangal had a relatively good VESS value of Sq 1.56, which was close to the VESS value of natural forests (Sq 1.16). Except for simple agroforestry of sweet potato, the VESS value of agroforestry systems was lower when compared to other types of land use such as coffee monoculture and maize monoculture. This is in accordance with research conducted by Aji et al. (2021) that agroforestry can improve soil structure quality. Meanwhile, the simple agroforestry of sweet potato had a slightly high VESS value because the tree stands on the land were still relatively young.

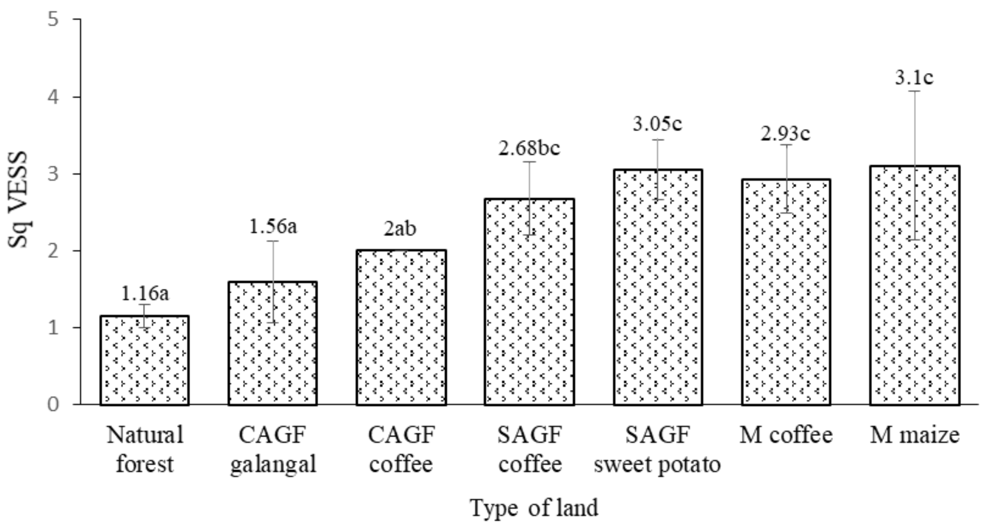


**Figure 2.** VESS average score of each land-use type. Note: The treatment had a significant effect on the 95% confidence interval with a significant value (p-value) of < 0.05 (α). The numbers followed by the same letter indicate that the treatments were not significantly different at the 95% confidence interval


**Figure 3**. Cross section and aggregate form (~1.5 cm): A. natural forest; B. CAGF galangal; C. CAGF coffee; D. SAGF coffee; E. SAGF sweet potato; F. M coffee; and G. M maize

In complex agroforestry systems, soil structure quality was better than in monoculture (Figure 2, Table 2). This condition is due to the role of forest plants in giving organic matter through litterfall and the root activity of shade plants in loosening the soil (Barlagne et al. 2021). The multi-strata canopy enhances litterfall intensity (Afentina et al. 2020). The litter protects the soil from raindrops not directly falling to the soil surface, minimizing soil disaggregation and surface sealing and thereby lowering soil erosion. However, soil compaction in the subsurface layer was not reduced by the planting system with saplings and diverse soil covering (Cherubin et al. 2018). Despite that, long-term sustainable agroforestry planting can improve the quality of the soil's physical properties (Aji et al. 2021).

Agroforestry land had better soil properties than other types of land use such as coffee monoculture and maize monoculture. The soil properties included bulk density, soil porosity, soil permeability, C-organic content, CEC, soil pH, and soil faunal diversity index (Table 2). Agroforestry lands had a low soil density of 0.97-1.19 g $cc^{-1}$ and a high soil porosity of 54.99-63.26%. The lowest bulk density value was in complex agroforestry of galangal (0.97 g $cc^{-1}$) which was almost the same as natural forest (0.98 g $cc^{-1}$). The presence of fresh material from agroforestry vegetation litter for soil fauna will act as an agent to increase aggregate stability (Guimarães et al. 2014) and promote better pore distribution, thereby improving soil physical quality (Stocker et al. 2019). Soil bulk density is closely related to permeability and porosity. If the density is high, the permeability and porosity are low, and vice versa (Pivic et al. 2020). Woody vegetation and trees assist in minimizing run-off in addition to their role as litter producers that help preserve soil porosity (Johannes et al. 2021). Tree litter also serves as a natural mulch, preventing soil compaction (Beuschel et al. 2020). The research by Cherubin et al. (2018) also showed the same result that there is an increase in soil physical quality through applying agroforestry systems.

C-organic soil in the agroforestry area was 1.29-2.36%, which was less than 5%. Generally, tropical natural vegetation sites have C-organic values that exceed 5% due to the high litter produced by their constituent vegetation (Wiryono et al. 2021). The low value of organic C on land is related to vegetation species that have not reached balance. However, according to Siregar (2017), C-organic soil of more than 1.2% is categorized as high in the context of agricultural land. C-organic soil in complex agroforestry of galangal (2.36%) was higher compared to other types of agricultural cover (simple agroforestry and monoculture). It is necessary to add compost or manure to agricultural plants to increase C-organic soil. In sustainable agroforestry systems, high carbon inputs at the soil surface by litterfall of various species can maintain soil biodiversity, and C-organic soil accumulation (De Stefano and Jacobson 2017; Bahuguna et al. 2018; Bahnemiri et al. 2019; Siaruddin et al. 2021) and indirectly influence soil physical quality (Arévalo-Gardini et al. 2015) as well as other associated ecosystem services (Bucheli dan Bokelmann 2017). More existing trees will increase the C-organic value as well (Bahnemiri et al. 2019). The cation exchange capacity (CEC) on agroforestry lands had a value of 15.42-19.54 $cmol^{(+)}$ $kg^{-1}$. CEC is the ability of soil colloids to absorb and exchange cations. Soil CEC can be influenced by soil texture and soil organic matter content (Tomašić et al. 2016; Yunanto et al. 2022). The pH value on agroforestry lands was between 5.8 and 6.5. The pH value can be a factor that influences crop yields, soil nutrient release, and soil microbial activity to a large extent (Heggelund et al. 2014). This condition shows that agroforestry practices can improve several aspects of soil's physical properties. Factors that likely affect soil quality in agroforestry land in this study among others are the amount of vegetation, canopy density, and availability of litter that can trigger microorganism activity. The other study reveals that long-term agroforestry systems of cocoa can support improvements in soil physical and chemical quality (Arévalo-Gardini et al. 2015).

The component of agroforestry consisting of trees and coffee affected soil nutrients which were almost similar to those in natural forests. The number of trees and coffee was directly proportional to the amount of litter produced (Table 2). Each type of land cover has an influence on the value of the soil structure quality (Briliawan et al. 2022). Planting trees in agroforestry systems has a positive effect on physical soil conditions through root activity and diverse root types. Agroforestry practices are able to improve the quality of the soil physical properties along with the age of the tree and the increase in the number of vegetation on the land (Cherubin et al. 2019). In this study, the canopy density on agroforestry lands ranged from 29.22-77.01%. High canopy density can constrain raindrops that fall down on the soil surface so that it reduces the leaching of nutrients on the soil surface. The soil flocculation rate was higher, amounting to 24%, and the soil moisture was higher, amounted 80%. In addition, the soil resistance to penetration was lower than in conventionally managed soils (Guimarães et al. 2014).

Land managed using agroforestry systems generated a litter weight of 30.47-166.3 g $m^{-3}$ (Table 2). Litterfall helps the natural return of soil nutrients into the soil in addition to other inputs such as fertilization activity. The soil covered by litter, continuous input of C-organic into the soil and the absence of disturbance is the main drivers of soil aggregation and improvement of soil physical quality under natural vegetation (Auler et al. 2017; Cherubin et al. 2017; Guimarães et al. 2017b, Wiryono et al. 2021). The natural forest has a higher diversity and activity of soil biota than agricultural land (Franco et al. 2016). The abundance and diversity of soil fauna could be increased through the establishment of additional nutrition and microhabitats, such as agroforestry practice (Kinasih et al. 2016). The value of species diversity will change and differ over time and there is a transfer of function from that place. The index value of fauna species diversity on agroforestry lands was between 0.69 and 1.38. The different index values of fauna species diversity in the research location indicated that litter quality values for different stands are very varied (Singh et al. 2012; Kinasih et al. 2016). Changes in canopy composition from pure to mixed stands, as well as other broadleaved species, appeared to increase the intensity of C and N cycling. As a result, it has the potential to alter the rate of soil acidification, nutrients, and biological activity in the topsoil (Bahuguna et al. 2018; Bahnemiri et al. 2019). Soil organic matter has an important role in improving soil properties. Litter availability will affect the amount and species diversity of soil fauna. Soil biota plays a positive role in soil aggregation through the exudation of biopolymers, particle entanglement, and incorporation of fresh organic matter into the soil by digging channels (Lehmann et al. 2017).

**Relationship between VESS score and soil properties**

The VESS value which has a good correlation with soil properties is a key in determining the soil's physical quality (Ball et al. 2017b). In this study, the VESS value and the soil physical properties had a very strong correlation (Figure 4A, 4B). The correlation value (r) between the VESS value and the soil bulk density was 0.80, while the VESS value with soil porosity had a negative correlation with an r-value of-0.80. A very strong positive correlation was also shown in the soil C-organic value with an r-value of 0.88 (Figure 4C). The good correlation between VESS values and soil bulk density, porosity and soil organic carbon is also revealed by previous studies (Gumaraes et al. 2013; Cherubin et al. 2018; Bűnemann et al. 2018; Aji et al. 2021). Soil organic carbon plays many roles in maintaining chemical, physical and biological properties and the important processes in the soil. Therefore, soil organic carbon is considered the main indicator for soil quality assessment (Cherubin et al. 2016; Bűnemann et al. 2018).

**Table 2.** Number of vegetation species, litter weight, canopy density, soil bulk density, soil porosity, soil organic carbon, cation exchange capacity, soil pH and soil fauna diversity in each research site

| Type of land use | Vegetation species (number) | Litter weight (g $m^{-2}$) | Canopy density (%) | BD (g $cc^{-1}$) | Po (%) | SOC (%) | CEC (cmol(+) $kg^{-1}$) | pH $H_2O$ | H' |
|---|---|---|---|---|---|---|---|---|---|
| Natural forest (20x20)$m^2$ | *P. merkusii* (19), *Q. sundaica* (16), *Castanopsis* sp. (2), *S. zalacca* (5), ferns (30) | 1529.92 | 90.22 | 0.88 | 66.62 | 3.97 | 12.26 | 6.6 | 1.79 |
| CAGF galangal (20x20)$m^2$ | *A. galanga* (29), *S. mahagony* (9), *S. aromaticum* (5), *G. gnemon* (2), *P. canescens* (1), *D. zibetinus* (1), *C. arabica* (14), *P. speciosa* (7), *P. americana* (3), *C. longa* (5), *Musa* sp (6) | 166.3 | 77.01 | 0.97 | 63.26 | 2.36 | 15.42 | 6.5 | 1.36 |
| CAGF coffee (20x20)$m^2$ | *C. arabica* (82), *P. speciosa* (3), *S. aromaticum* (14), *A. pauciflorum* (1), *T. sureni* (1), *P. americana* (5), *C. pentandra* (3), *D. zibetinus* (2), *Citrus* sp (1), *A. heterophyllus* (1), *Musa* sp (16), | 100.16 | 66.72 | 1.19 | 54.99 | 1.93 | 15.89 | 6.3 | 0.86 |
| SAGF coffee (20x20)$m^2$ | *C. canephora* (53), *S. aromaticum* (22) | 155.34 | 64.17 | 1.14 | 57.13 | 1.29 | 16.32 | 5.8 | 1.38 |
| SAGF sweetpotato (20x20)$m^2$ | *I. batatas* (320), *S. aromaticum* (11) | 30.47 | 29.22 | 1.18 | 55.33 | 1.74 | 19.54 | 6.3 | 0.69 |
| M coffee (10x40)$m^2$ | *C. canephora* (80) | 185.36 | 51.01 | 1.18 | 55.51 | 1.36 | 16.77 | 5.7 | 0.69 |
| M maize (20x20)$m^2$ | *Z. mays* (400), *C. citratus* (380) | 43.57 | 15.96 | 1.11 | 57.96 | 1.25 | 19.92 | 6.2 | 0.45 |

Note: BD: bulk density; Po: Porosity; SOC: soil organic carbon; CEC: cation exchange capacity; H': diversity index of soil fauna

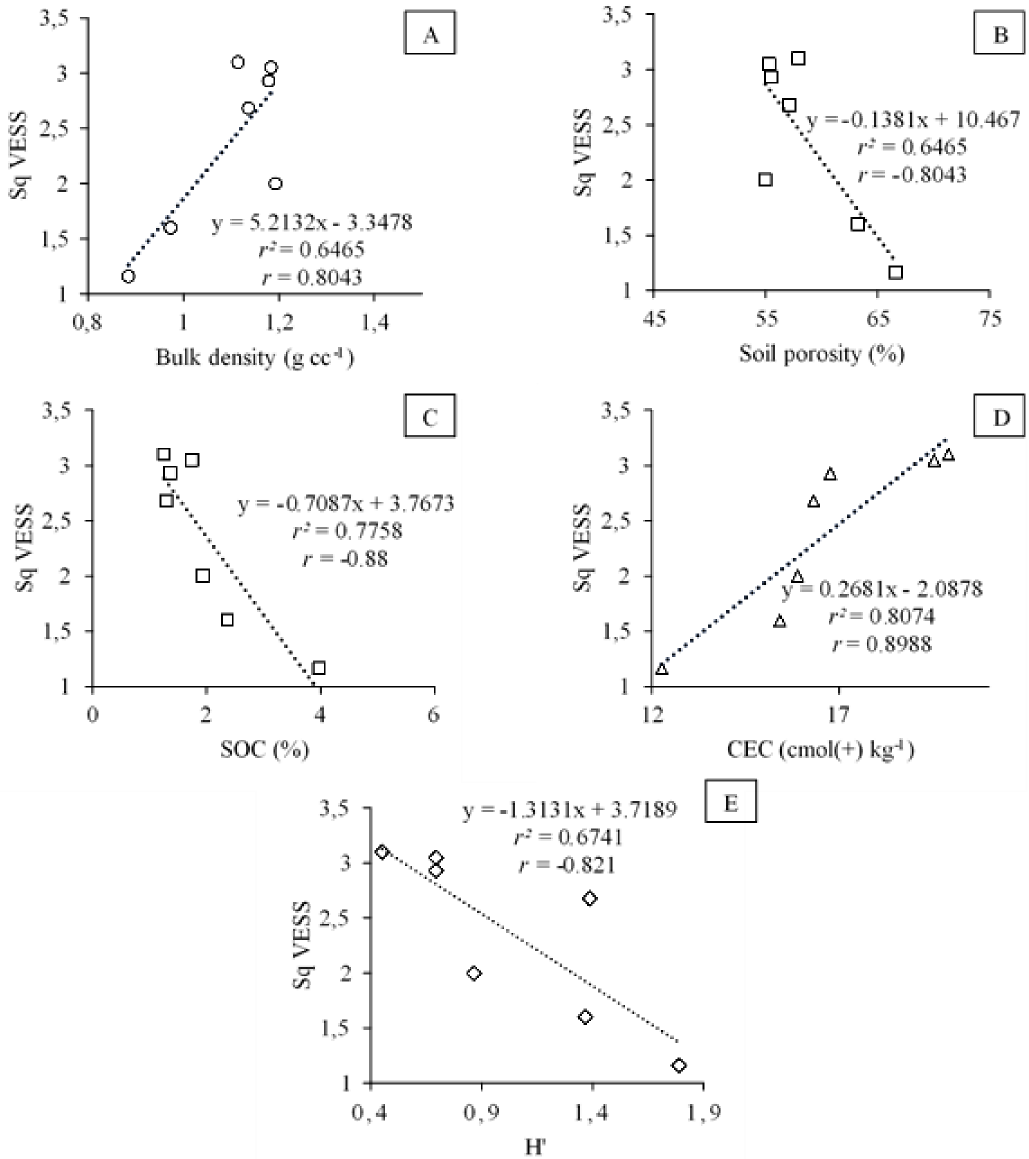


**Figure 4.** Correlation between VESS scores and soil properties: A. soil bulk density, B. soil porosity, C. Soil Organic Carbon (SOC), D. cation exchange capacity (CEC ), and E. diversity of fauna soil index

Another degree of relationship showed that the VESS value was also very strongly correlated with the soil CEC value. The correlation between VESS and soil CEC reached 0.89 (Figure 4D). VESS correlation with soil fauna diversity index also had a very strong negative relationship with the r-value of-0.82 (Gambar 4E). Soil that has a high clay content also has a higher CEC than soil that has a sandy content (Wasis 2012). Recently, Franco et al. (2017) explained that the lower VESS scores significantly correlated with the higher abundance of isopteran and coleopteran faunal groups. Soil fauna is essential for soil formation, litter decomposition, nutrient cycling, biotic regulation, and better plant growth (Briones 2018). All correlation values between VESS and other soil properties were significant and had a very strong correlation. Based on this research, the application of the VESS method was effective in analyzing soil properties. VESS is one of the simplest methods that provides the first indication of overall soil quality (Ball et al. 2017a; Moncada et al. 2014; Cherubin et al. 2017; Briliawan et al. 2022).

The application of the VESS method in this study effectively reduces time and the need for complicated tools in observing soil properties. The use of the VESS method for determining soil structure quality can be directly applied in the field by using simple equipment such as shovels, hoes, sack mats, and machetes. The time for determining the soil quality score using the VESS method for one soil sample takes around 15 to 30 minutes, as it had been applied in the field. This method is easier and faster than the conventional soil analysis method in the laboratory which takes approximately 2 to 14 days. Cherubin et al. (2019) stated that the VESS method has the advantage of being easy to implement in hard-to-reach places. Furthermore, it can be applied by various groups such as students, researchers, farmers, and other land managers to evaluate soil quality. The VESS method is the most widely known and used method for evaluating soil quality among communities and universities (Paiva et al. 2020). Based on the VESS value, the soil properties on the land of complex agroforestry of galangal were generally close to those of natural forest soils. Multi-strata agroforestry system can be a strategy for recovering soil quality on degraded lands. The VESS value had a very strong correlation to several soil properties parameters. The VESS method is effective for evaluating the physical quality of the soil in this study.

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