

# Visual soil structure quality and its correlation to quantitative soil physical properties of upland rice site in *Falcataria moluccana* agroforestry system

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**Abstract.** Briliawan BD, Wijayanto N, Wasis B. 2022. Visual soil structure quality and its correlation to quantitative soil physical properties of upland rice site in *Falcataria moluccana* agroforestry system. *Biodiversitas* 23: 1894-1903. Sengon and upland rice are plants that have the potential to be combined in the agroforestry system. However, its development often results in poor quantitative soil physical properties. Measuring the soil's physical properties is expensive and complicated to do by some people. This study aims to measure the visual soil structure quality from different land covers and calculate its correlation to the parameters of the soil's physical properties. The research was conducted in the Cikabayan forest and used the purposive sampling method to take soil samples. The research was conducted by comparing nine land covers in the form of agroforestry and monoculture developed in organic and conventional agriculture with tropical rainforests as natural vegetation. Three samples were taken for each land cover type and analyzed with a completely randomized design. The research showed that the vegetation of tropical rainforest generated the best score on all visual soil structure quality measurement methods (VESS, GrassVESS Sq and GrassVESS Rm). The measurement of soil physical properties at natural vegetation of tropical rainforests generated the highest score on the porosity (57.303%). Meanwhile, monoculture-conventional land generated the highest bulk density (1.373 g.cm<sup>-3</sup>). The VESS method had the highest correlation with soil physical properties compared to other visual soil structure quality measurement methods. Thus, natural vegetation is the best type of land cover compared to all cultivated land and the VESS method is the most appropriate method for estimating soil physical properties.

**Keywords:** Bulk density, GrassVESS Rm, GrassVESS Sq, porosity, VESS

## INTRODUCTION

Agroforestry is an integrated planting system between forestry trees and various cover crops such as agricultural crops, bamboo and grasses to produce high biodiversity and yields (Bishaw et al. 2022; Duffy et al. 2021). Agroforestry is an environmentally friendly planting solution (Pantera et al. 2021; Rizvi et al. 2020). Agroforestry can also improve degraded land and enhance the quality of soil (Baig et al. 2021; Damianidis et al. 2021). Agroforestry is also dubbed as the sustainable agriculture of the future (Hussain et al. 2020). Natural tropical ecosystems such as tropical monsoon forests and tropical rainforests have similarities with agroforestry systems because of their high biodiversity and stratified canopy (Ballesteros-Correa & Pérez-Torres 2022; Flores-Rentería et al. 2020). Agroforestry is also often referred to as secondary forest with accelerated succession and is expected to produce environmental quality equivalent to natural tropical forests (Bateni et al. 2021; Damasco et al. 2022).

There are two significant agroforestry systems classifications: complex agroforestry (*wono*, *kebon*, *pekarangan*, *talun*, *parak*, etc.) and simple agroforestry

(*tumpangsari*) (Jensen 1993). However, the application of *tumpangsari*, which resembles an intercrop system, is increasing in Indonesia because of the loose crown cover and the potential for the cultivation of shade-intolerant agricultural crops (Figyantika et al. 2020). The combination of the sengon (*Falcataria moluccana* (Miq.) Barneby & J.W.Grimes) and upland rice (*Oryza sativa* L.) is one of the options for intercropping development. Sengon is one of the forest plant species cultivated in Indonesia (Tsaniya et al. 2022). Sengon is a Leguminosae species belonging to the Fabaceae family that can live in arid areas and improve poor soil quality (Ghaida et al. 2020; Husna et al. 2021; Ramos-Font et al. 2021). Sengon is also often grown in Javanese bamboo Talun-Kebon systems and small-scale privately-owned forests, including complex agroforestry with various shade-tolerant plants (Christanty et al. 1996; Siarudin et al. 2022). Rice is one of Indonesia's most important agricultural crops (Kurniati et al. 2017). Upland rice is one of the alternative rice-producing plants in the era of urbanization. In addition, upland rice can also grow on rain-fed dry land because of its low water requirement (Champrasert et al. 2020). However, conventional agriculture often causes soil pollution, reducing soil microbiological processes and

lowering soil quality, as well as soil degradation and soil compaction (Flores-Rentería et al. 2020; Škrbić et al. 2021). Alternative options for organic farming types are considered environmentally friendly and do not cause deteriorating soil quality (Ordóñez-Fernández et al. 2018; Rosati et al. 2021).

Soil quality is one of the parameters of sustainable agriculture (Hermans et al. 2021). Measurement of post-harvest soil quality is fundamental to knowing the potential for the cultivation of arable land (Beuschel et al. 2020). Soil quality is closely related to quantitative soil physical properties (Cavalcanti et al. 2020). Bulk density is a quantitative soil physical property associated with the ability of the soil to support plant bodies. Meanwhile, porosity indicates the level of availability of soil pores that impact root growth (Al-Shammari et al. 2018). However, the method of measuring soil physical properties is often neglected because the method is difficult, high cost and cannot be carried out by everyone (Ball et al. 2016). Thus, it is necessary to evaluate soil physical characteristics that are relatively easy and have a significant correlation to the value of quantitative soil physical properties (Guimarães et al. 2011).

Soil structure is a relatively easy and straightforward qualitative soil physical characteristic parameter (Johannes et al. 2021). Thus, many methods have been developed that describe soil structure in a semi-quantitative form called soil structure evaluation (Giarola et al. 2013). There are several methods of measuring soil quality using visual soil structure quality. These methods include VESS and GrassVESS. Research on the VESS method on tropical soils has been carried out inland covers such as tropical monsoon forest, tropical rainforest, tropical montane forest, tropical savanna, pasture and sugarcane fields (Cherubin et al. 2017; Paiva et al. 2020). In contrast, the GrassVESS method is a modification of the VESS method used in Grassland (Emmet-Booth et al. 2018a). Visual soil structural quality is one of the parameters often used to measure soil quality because it is easy, cheap and fast (Cornelis et al. 2019). The application of evaluation of soil structure in the tropics is very important because of the characteristics of soils that have apparent fertility and are prone to damage (Giarola et al. 2013). This is related to the tropical climate which has high rainfall during the rainy season in seasonal areas (monsoonal) and rains that occur throughout the year around the equator (equatorial) (Körner 2013). Therefore, research on visual soil structure quality and its correlation with soil physical properties is vital because of its vast potential for utilization. This study aims to measure the visual soil structure quality among different land covers and calculate its correlation to the parameters of the soil's physical properties.

## MATERIALS AND METHODS

### Experiment area

The study was conducted at the Cikabayan, IPB University, Darmaga in the Bogor Regency, West Java Province, Indonesia (Figure 1). The research location lies at

latitude 06°32'48.1"S and longitude 106°43'00.1"E divided into two categories. The first location has environmental conditions resembling lowland tropical rainforest with a humid forest site, evergreen trees and high plant diversity. The second location has environmental conditions in the form of rain-fed dry land (non-irrigation ricefield), which is an agroforestry system and a monoculture system. This area is also an organic rice farming system and a conventional rice farming system. The type of soil at the research site is Inceptisol. The climate in the study area is characterized by rainfall throughout the year (*non-seasonal forecast area*). According to the Köppen-Geiger climate classification, the region is classified as Af (tropical rainforest or equatorial climate) with precipitation is more than 60 mm every month (Beck et al. 2018). All research sites are located at an altitude of 165 meters above sea level (masl) with an average annual temperature of 30°C, an average annual humidity of 70%. The average of rainfall in this study was 242.52 mm per month (BMKG 2021).

### Procedures

#### *Experimental design*

All experiments in this study were arranged in a Randomized Completely Design (RCD) with 3 replications for every level. The factor was "land cover" with 9 levels. Each level in the study has characteristics based on different vegetation types, fertilizers and pesticides. The levels of land cover factor can be seen in (Table 1).

#### *Visual soil structural quality measurement*

The soil sampling for the visual soil structural quality measurement amounted to three samples at each location (a total of 27 soil samples). The soil sampling was carried out by purposive sampling, by selecting an area overgrown with rice crops (rice plant rhizosphere area) and avoiding several areas such as snake nests, ant nests, termite nests, and the primary roots of large trees (Cherubin et al. 2017). The soil sampling in tropical rainforests was carried out in areas overgrown with weeds (*Imperata cylindrica*) as a reference for grass plants and shaded by at least three layers of the canopy as a characteristic of tropical moist forests.

The visual methods of the soil structure quality used in this study include: VESS (*Visual Evaluation of Soil Structure*), GrassVESS Sq (*Visual Evaluation of Soil Structure for Grassland Structure Quality*), and GrassVESS Rm (*Visual Evaluation of Soil Structure for Grassland Root Mat*). The soil sampling to measure VESS and GrassVESS Sq was carried out by digging a hole 20 cm × 20 cm × 20 cm deep under rice plants and wild grasses (mainly native vegetation). In the GrassVESS Rm method, measurements were made on the rhizosphere layer of rice and grass plants. The soil evaluation includes a manual breakdown of soil aggregates, measurement of layer thickness, and scoring by comparing the visual soil structure quality of the sample with reference sources. Soil structure is a basic, quick, and inexpensive approach for estimating soil quality, and it is linked to soil function (Rabot et al. 2018). Furthermore, soil structure, which comprises the type of structure (crumb, granular, platy,

angular blocky, sub-angular blocky, prismatic, and columnar), and its size, is a parameter that responds the quickest if the management system on native vegetation or cultivated land is changed (Saputra et al. 2020; Sasal et al. 2017).

All visual soil structure quality approaches have the same score criteria: the lower the score produced from parameter calculations, the better the soil quality (Johannes et al. 2021). The literature on the VESS method's parameters, indicators and assessment is described as follows (Guimarães et al. 2011). Meanwhile, the literature on parameters, indicators and assessments of the GrassVESS Sq and GrassVESS Rm methods is described as follows (Emmet-Booth et al. 2018a). According (Emmet-Booth et al. 2018a; Guimarães et al. 2011), the parameters used in measuring the soil structure evaluation include structure quality, size, and appearance of aggregates, visible porosity, and root, distinguishing feature, etc. The main difference between the VESS and GrassVESS Sq methods lies in how conclusions are drawn. VESS methods tend to find the average between parameters, while the GrassVESS Sq methods tend to take the form of an identification key. In comparison, the GrassVESS Rm methods emphasize the root form of grass plants against soil aggregate (Emmet-Booth et al. 2018b).

#### Quantitative soil physical properties measurement

The soil sampling was carried out once in each replication (27 soil samples). The soil samples taken were the soil samples around the root layer of rice plants. Meanwhile, the soil sampling on natural vegetation (tropical rainforest) was carried out on wild grass species (Family: Graminae) site. To measure bulk density and porosity, the undisturbed soil samples (intact soil samples) were collected using the core method (volumetric cylindrical method) (Cherubin et al. 2016a). The undisturbed soil samples were taken with a soil sample tube or soil sample ring hammered and pressed into the soil to collect intact soil samples. The bulk density and porosity in dry land can be calculated using the formula (Al-Shammary et al. 2018):

$$\text{Bulk Density} = \frac{Ms}{Vs}$$

$$\text{Porosity} = \left(1 - \frac{Bd}{Bp}\right) \times 100\%$$

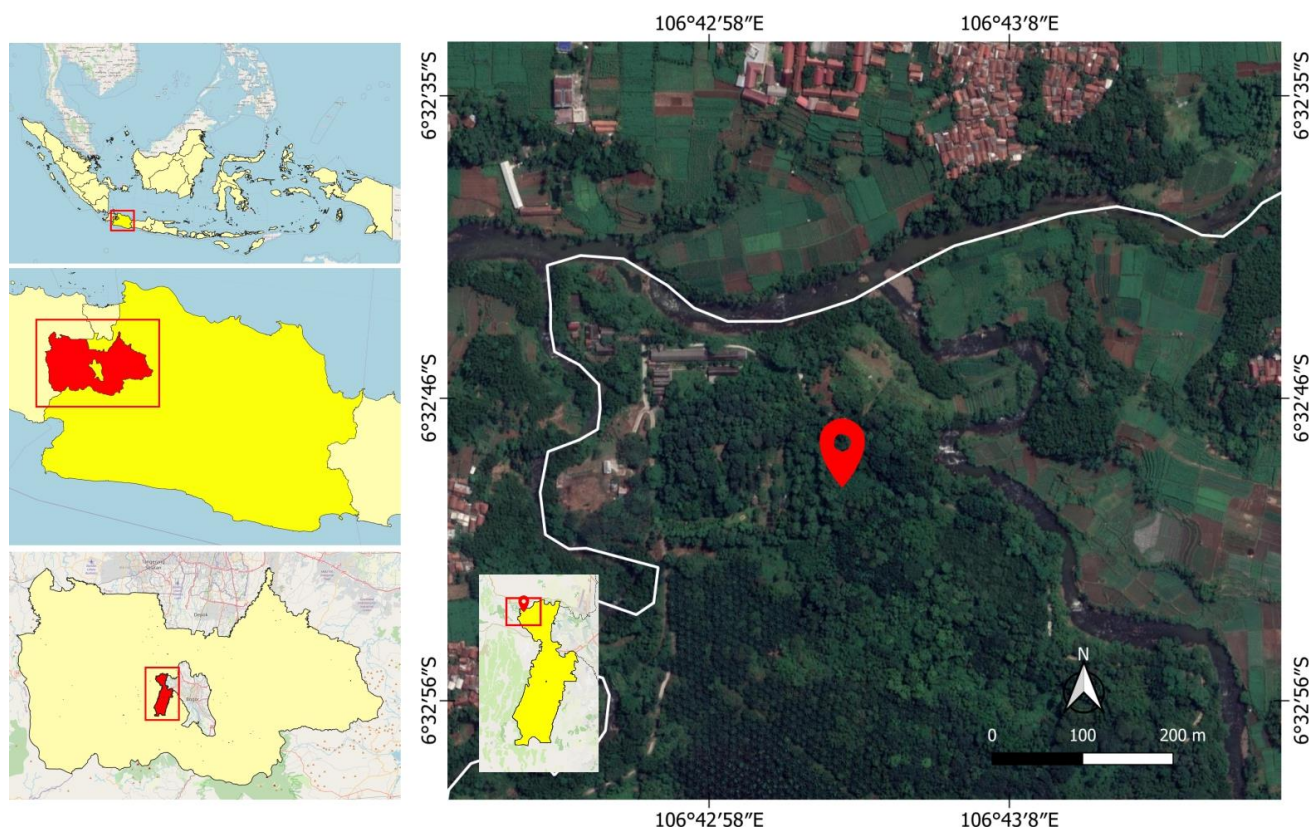
Remarks :

*Ms* : Mass of dry soil sample without ring sample after being oven-dried at 105°C for 48 hours (g)

*Vs* : Volume of undisturbed soil in ring sample (cm<sup>3</sup>)

*Bd* : Bulk density (g.cm<sup>-3</sup>)

*Bp* : Particle density (2.65 g.cm<sup>-3</sup>)



**Figure 1.** Location of Cikabayan, IPB Darmaga, Bogor, Indonesia

**Table 1.** The type of land cover observed in the study

Land cover	Vegetation		Fertilizer	Pesticide
	Common or local name	Scientific name		
Tropical rainforest (20 m × 20 m)	<i>Bendho</i>	<i>Artocarpus elasticus</i>	Natural vegetation without fertilizer treatment from humans	Natural vegetation without pest control
	<i>Petong</i>	<i>Dendrocalamus asper</i>		
	<i>Rasamala</i>	<i>Altingia excelsa</i>		
	<i>Engkabang</i>	<i>Shorea macrophylla</i>		
	Light red meranti	<i>Shorea leprosula</i>		
	<i>Awar-awar</i>	<i>Ficus septica</i>		
	<i>Trembelu</i>	<i>Maesopsis eminii</i>		
	<i>Kleresede</i>	<i>Gliricidia sepium</i>		
	Big-leaf mahogany	<i>Sweitenia macrophylla</i>		
	<i>Sesuruhan</i>	<i>Piper</i> spp.		
	<i>Aglaonema</i>	<i>Aglaonema</i> spp.		
	<i>Senggani</i>	<i>Melastoma malabathricum</i>		
	<i>Apos</i>	<i>Gigantochloa apus</i>		
	Wild tea	<i>Acalypha siamensis</i>		
	Cogon grass	<i>Imperata cylindrica</i>		
Agroforestry 1 organic (0.15 ha)	Sengon local kendal	<i>Falcataria moluccana</i>	Green manure, compost and biofertilizer	Azadirachtin biopesticide
	Upland rice Rindang 1	<i>Oryza sativa</i>		
	Agritan			
Agroforestry 2 organic (0.15 ha)	Sengon solomon F2	<i>Falcataria moluccana</i>	Green manure, compost and biofertilizer	Azadirachtin biopesticide
	Upland rice Rindang 1	<i>Oryza sativa</i>		
	Agritan			
Agroforestry 3 organic (0.15 ha)	Sengon solomon F1	<i>Falcataria moluccana</i>	Green manure, compost and biofertilizer	Azadirachtin biopesticide
	Upland rice Rindang 1	<i>Oryza sativa</i>		
	Agritan			
Monoculture organic (0.15 ha)	Upland rice Rindang 1	<i>Oryza sativa</i>	Green manure, compost and biofertilizer	Azadirachtin biopesticide
Agroforestry 1 conventional (0.15 ha)	Sengon local kendal	<i>Falcataria moluccana</i>	Synthetic fertilizer (Urea, SP36 and KCl)	Firponil pesticide
	Upland rice Rindang 1	<i>Oryza sativa</i>		
	Agritan			
Agroforestry 2 conventional (0.15 ha)	Sengon solomon F2	<i>Falcataria moluccana</i>	Synthetic fertilizer (Urea, SP36 and KCl)	Firponil pesticide
	Upland rice Rindang 1	<i>Oryza sativa</i>		
	Agritan			
Agroforestry 3 conventional (0.15 ha)	Sengon solomon F1	<i>Falcataria moluccana</i>	Synthetic fertilizer (Urea, SP36 and KCl)	Firponil pesticide
	Upland rice Rindang 1	<i>Oryza sativa</i>		
	Agritan			
Monoculture conventional (0.15 ha)	Upland rice Rindang 1	<i>Oryza sativa</i>	Synthetic fertilizer (Urea, SP36 and KCl)	Firponil pesticide

## Data analysis

### Statistical analysis

The statistical analysis aims to determine the significance value of factor and Pearson's correlation between visual soil structural quality and soil physical properties. The data were analyzed using analysis of variance (ANOVA) to determine the effect of land cover in this study. In this regard, if the ANOVA at the 95% confidence interval generated a significant impact on the observed variables, then proceed with the DMRT (*Duncan's Multiple Range Test*) at the 5% level to determine the difference of the effect between the various factor (Azizah et al. 2019). Pearson correlation analysis was also carried out to determine the relationship between parameters (Cooray et al. 2021). The results of the Pearson correlation are used to assess the effectiveness of the use of various visual soil structure quality methods whose use is simpler to estimate quantitative soil physical properties (Cherubin et al. 2019).

## RESULTS AND DISCUSSION

### Visual soil structure quality

The visual assessment of soil structure quality is a straightforward approach for determining soil quality using soil structure characteristics (Cherubin et al. 2019). Visual soil structure quality can be employed as a low-cost, simple, and accessible method of estimating soil properties (Guimarães et al. 2017). Visual Evaluation of Soil Structure (VESS) was given to this method when it was first created. However, this method has evolved into various variations, one of which is the Visual Evaluation of Soil Structure for Grassland (GrassVESS), which is used to assess the quality of soil that has been overgrown with grasses (Emmet-Booth et al. 2018b). The influence of various land cover on soil quality as measured by the VESS, GrassVESS Sq and GrassVESS Rm methods can be seen in (Table 2).

According to (Table 2), land cover generated a significant effect on all visual soil structure quality values

determined by various visual soil structure quality methods at a level of 5%. The DMRT results may be seen in Table 3.

According to (Table 3), the natural vegetation of lowland tropical rainforests generated the best visual soil structure quality score, with a VESS score of 1.664. This is supported by a number of earlier investigations as well. This is also supported by the research of (Guimarães et al. 2017) in the Amazon lowland tropical rainforest resulting in a VESS value of 1.2 in primary forest and 1.3 in secondary forest. According to research (Cherubin et al. 2017), the VESS value in natural ecosystems in Cerrado tropical semi-deciduous forests is 1.80, and the VESS value in Cerrado tropical savannah ecosystems is 1.81. According to research (Aji et al. 2021), the VESS value in Pangalengan tropical montane forest ecosystems is 1.3. Tropical rainforests have a GrassVESS score of 1 for visual soil structure quality measurement using the GrassVESS Rm and Sq method. A perfect score on all visual soil structure quality methods implies the best soil quality and excellent plant growth conditions (Emmet-Booth et al. 2018a).

In agroforestry, visual soil structure quality is better than monoculture ricefield (Table 3). This condition is due to the role of forestry plants in supplying organic matter through litterfall and the roots activity of shade plants in loosening the soil (Barlagne et al. 2021; Celentano et al. 2020). Planting forestry trees can improve soil quality (Celentano et al. 2017; Jahed et al. 2014; Khaleel et al. 2020; Yotapakdee et al. 2019). Some studies even claim that agroforestry has better soil quality than secondary forest (Chaves et al. 2020). This is because nutrient inputs from fertilizers contribute to better soil quality in agroforestry (Rosati et al. 2021).

Land cover in organic agroforestry has a superior soil structure evaluation value than other types of land cover resembling a tropical rainforest (Table 3). The presence of

trees in tropical rainforests and agroforestry plays a role in soil improvement through litter production (Cavalcanti et al. 2020). Litterfall intensity increases due to the multi-strata crown (Afentina et al. 2020). Litterfall from emergent plants accounts for the higher score in tropical rainforests. Furthermore, due to the quantity of soil organic matter, dense trees in tropical rainforest ecosystems create a better microclimate and loose soil, resulting in a large diversity of forest microorganisms (Flores-Rentería et al. 2020). Furthermore, multi-strata stand with limited soil erosion and a healthy topsoil layer that supports root development (Bateni et al. 2021; Susilowati et al. 2020).

All types of agroforestry tested in the study without being distinguished by types of organic and conventional agriculture had values that were not statistically significant differences from one another (Table 3). The agroforestry planting system 1 has the best visual soil structure quality score compared to other agroforestry systems. A high score in agroforestry 1 is related to a large canopy area and good growth. Tree's roots develop well due to this, which loosens the soil around the roots (Hojjati et al. 2021). Nonetheless, according to (Azizah et al. 2019), the root growth of Solomon Sengon was superior to that of local Kendal Sengon which has been shown since initial planting. However, Solomon Sengon will be more susceptible to pest attack after 6 months than other Sengon provenances (Sopacua et al. 2021). The research was conducted on the 36 months old sengon, which resulted in a higher visual soil structure quality score under the shade of Kendal local Sengon. The trees that grow well will produce a lot of litter (Tuchtenhagen et al. 2018). Tree litter encourages the growth of soil microbial activity and can reduce the size of the soil aggregate (Cherubin et al. 2019). Furthermore, litter acts as a natural crop mulch, protecting a loose topsoil layer from erosion caused by run-off (Adeniyi et al. 2019).

**Table 3.** DMRT result on visual soil structure quality measurement method for the effect of various land cover

Land cover	Visual soil structure quality measurement methods		
	VESS	GrassVESS Sq	GrassVESS Rm
Tropical rainforest	1.664 a	1.000 a	1.000 a
Agroforestry 1 organic	1.816 b	1.500 b	1.667 bc
Agroforestry 2 organic	1.837 b	1.667 b	1.667 bc
Agroforestry 3 organic	1.848 b	1.667 b	1.333 ab
Monoculture organic	1.992 c	2.500 c	3.000 d
Agroforestry 1 conventional	1.967 c	2.167 c	2.000 c
Agroforestry 2 conventional	1.982 c	2.167 c	2.000 c
Agroforestry 3 conventional	1.973 c	2.167 c	2.000 c
Monoculture conventional	2.119 d	3.167 d	3.000 d

Note: Numbers followed by different letters in the same column are significantly different at a confidence interval of 95% (P-Value) < 0.05

**Table 2.** ANOVA effect of various land cover on the visual soil structure quality measurement methods

Observation Factor	Visual soil structure quality measurement methods		
	VESS	GrassVESS Sq	GrassVESS Rm
Land cover	*	*	*

Note: \*= Various land cover has a significant impact at the 5% level respectively (P-value)<0.05 ( $\alpha$ )

The hard and dense soil causes the low visual soil structure quality score on conventional monoculture areas (Stöcker et al. 2020). Land plowing is one of the measures to maintain good visual soil structure quality on arable land (Kurniati et al. 2017). Furthermore, rigorous land management must continue to be practiced to keep the visual soil structure quality score from deteriorating (Rathore et al. 2020; Tormena et al. 2016). Land degradation will occur if the monoculture system with conventional agriculture continues (Seruni et al. 2021). Planting trees as a source of organic matter to reduce soil density is the major technique to enhance soil structure quality (Siqueira et al. 2020). Another alternative is to boost the carrying capacity of the soil to the roots of agricultural crops by applying organic fertilizers on a big scale (Pleguezuelo et al. 2018). The importance of the organic matter in achieving a higher score on visual soil structure quality showed in (Table 3), which indicates how monoculture organic is superior to monoculture conventional land cover. So there are numerous viewpoints that conventional agriculture would degrade soil quality over time (Baimuratov et al. 2021).

### Quantitative soil physical properties

Bulk density and soil porosity are two quantitative soil physical parameters investigated in this study. The carrying capacity of the soil to stabilize plant development is related to bulk density (Cavalcanti et al. 2020). Meanwhile, soil porosity is associated with the soil's carrying capacity for plant root growth (Paltineanu et al. 2020). The type of land cover is one of the factors that changes the physical properties of the soil (Celentano et al. 2017). A further test of the effect of land cover on soil physical properties at the research site is shown in (Table 4).

The variance analysis (Table 4) reveals that land cover substantially impacts the quantitative soil physical parameters. (Table 5) present the results of the DMRT, which illustrates the impact of various land cover on quantitative soil physical properties.

The porosity value in the tropical rainforest is 57.303 percent is the greatest among other land types (Table 5). Tropical rainforests have an extremely high porosity value due to the accumulation of organic debris on the forest floor (Gerzabek et al. 2019). In addition to their role as litter producers that help to maintain soil porosity, Woody trees also help reduce run-off (Johannes et al. 2021). This has to do with reducing soil density and erosion caused by heavy rainfalls in the climate of the tropics (Cornelis et al. 2019). Tree litter also forms a natural mulch that protects the soil from compaction (Beuschel et al. 2020). In

addition, abundant undergrowth and natural regeneration in tropical rainforests can reduce the velocity of surface run-off which causes the preservation of loose and quality topsoil (Körner 2013).

Monoculture systems generated the highest bulk density value and are notably different from tropical rainforest and agroforestry (Table 5). The higher bulk density in the monoculture system is due to soil compaction caused by the high kinetic energy of rainwater (Bondi et al. 2021). Monoculture cultivation methods also result in reducing soil porosity (Shanmuganathan & Rajendran 2020). Low soil organic matter is also linked to dense soil in monoculture systems (Vashisht et al. 2020). Furthermore, low porosity is linked to the lack of daily litter sources in monoculture planting systems (Beuschel et al. 2020).

Compared to tropical rainforest and monoculture systems, the value of bulk density in agroforestry is dramatically different (Table 5). One of the advantages of agroforestry as a sustainable cultivation system is that the bulk density and porosity values are more moderate (Afentina et al. 2020; Pantera et al. 2021). Medium bulk density and porosity values indicate that soil is favorable for root growth and able to support plant bodies (Santiago-Freijanes et al. 2021). Organic farming types generated medium bulk density and porosity values compared to tropical rainforests and conventional agriculture. Organic farming is a sustainable style of agriculture that can also help prevent soil and water pollution (Aleksandrova et al. 2016). As a result, multiple studies have concluded that organic upland rice farming promotes environmental sustainability (Panjaitan et al. 2020).

**Table 5.** DMRT results on quantitative soil physical properties for the effect of various land cover

Land cover	Quantitative soil physical properties	
	Bulk density	Porosity
Tropical rainforest	1.133 a	57.303 a
Agroforestry 1 organic	1.237 b	53.407 b
Agroforestry 2 organic	1.243 b	53.087 b
Agroforestry 3 organic	1.237 b	53.327 b
Monoculture organic	1.333 d	49.646 d
Agroforestry 1 conventional	1.270 c	52.103 c
Agroforestry 2 conventional	1.273 c	51.867 c
Agroforestry 3 conventional	1.273 c	51.940 c
Monoculture conventional	1.373 e	48.253 e

Note: Numbers followed by different letters in the same column are significantly different at a confidence interval of 95% (P-Value) < 0.05

**Table 4.** ANOVA mean square (MS) effect of research factors on the quantitative soil physical properties values

Factor	Quantitative soil physical properties	
	Bulk density	Porosity
Land cover	*	*

Note: \*: Various land cover has a markedly different effect at the 5% level respectively (P-value)<0.05 ( $\alpha$ )



A higher bulk density value distinguishes the monoculture conventional than that of monoculture organic (Table 5). The high bulk density in conventional monocultures is related to the low organic matter found in the plant site (Celentano et al. 2017). The application of traditional-conventional rice cultivation in the form of open land with continuous application of inorganic fertilizers causes high soil bulk density (Kurniati et al. 2017). The bulk density of  $1.373 \text{ g.cm}^{-3}$  in conventional monoculture land is still at a low value. This is very different from the research of (Guimarães et al. 2017) which states that the bulk density in conventional monoculture lands is  $1.6 \text{ g.cm}^{-3}$ . The research location adjacent to the forest is suspected of causing the bulk density value not too high in conventional monoculture lands (Cherubin et al. 2016b). Despite the fact that research (Kurniati et al. 2017) claims that conventional rice growing in Dramaga only produces a bulk density of  $0.9 \text{ g.cm}^{-3}$ . However, the study was conducted on irrigated rice fields. In comparison to irrigated land, rain-fed land has lower soil qualities, which soil it harder and more susceptible to harm (Rathore et al. 2020). As a result, adding organic fertilizers or planting trees as a source of soil organic matter from liters fall is the long-term approach to increasing the porosity of the rain-fed ricefield area (Johannes et al. 2021).

A decrease in bulk density and an increase in soil porosity are strongly linked to the availability of soil organic matter (Cavalcanti et al. 2020). This is connected to the issue of cultivated land having a high bulk density due to intensive human activities. Mineral soil with the highest soil organic matter and nutrients content is optimal for plant growth (Handayani et al. 2021). This is demonstrated in (Table 5) that organic agriculture has a higher porosity value than conventional agriculture. This is linked to the advantages of organic fertilizers, which improve the soil's physical qualities different from inorganic fertilizers, which just increase plant nutrition (Shooshtari et al. 2020).

### Pearson correlation

Visual soil structure quality is a parameter that can be used to estimate the quantitative soil physical properties. The correlation test is one way to determine the relationship between research parameters (Tuchenhagen et al. 2018). The relationship between soil structure quality and soil physical parameters showed in (Table 6).

All soil structure evaluation methods have a correlation of more than 0.8 on bulk density and soil porosity (Table 6). Various parameters for evaluating soil structure such as the size of the soil structure are closely related to bulk density and soil porosity. The larger the size of the soil structure, the greater the bulk density. The small size of the soil structure will provide space for the formation of soil pores. Thus, the smaller the soil structure, the greater the porosity value (Celentano et al. 2017; Sasal et al. 2017).

A very high value was found in a Pearson correlation test of various visual soil structure quality and quantitative soil physical characteristics. As seen in (Table 6), The VESS technique has a strong correlation value with bulk density and soil porosity. The correlation test between VESS and bulk density showed the r-value of 0.94, while the relationship between VESS and soil porosity yielded the r-value of -0.944. According to the research (Aji et al. 2021) in the Pangalengan Highlands, the VESS correlation to bulk density and porosity values reached 0.97 and -0.972, respectively. Furthermore, various studies in the lowlands of Southern Brazil (Tuchenhagen et al. 2018) found a correlation coefficient between VESS and bulk density showed the r-value of 0.91, and the correlation coefficient between VESS and porosity showed the r-value of -0.8. The wide scope and usage of the VESS approach, which is not limited to one ecosystem, has a big impact on the high correlation between it and soil attributes (Emmet-Booth 2018a). According to (Cherubin et al. 2019), The VESS approach can be applied to any land cover type. The VESS approach will be more effective if performed on soils with a clay + silt composition of greater than 66%. (Cherubin et al. 2016b; Guimarães et al. 2011).

The correlation between GrassVESS Sq with bulk density and soil porosity shows a lesser correlation than VESS. However, a 0.913 correlation between GrassVESS Sq and bulk density and a -0.916 correlation between GrassVESS Sq and porosity (Table 6). The lower Pearson correlation coefficient of GrassVESS and soil characterization is related to the method's smaller scope of application, which is solely meant for land with the kind of cover of Grassland. The GrassVESS method is a new method that is a variation of VESS that is used to assess grassland soils rather than VESS, which is better suited to analyzing forest and arable land (Emmet-Booth et al. 2018b).

**Table 6.** Pearson correlation among visual soil structure quality and quantitative soil physical properties

Variable		R <sup>2</sup>	r-value (correlation value)	Equation
x-variable	y-variable			
VESS	Bulk density	0.883	0.940 <sup>x</sup>	$y = 1.8497x - 0.4265$
GrassVESS Sq	Bulk density	0.833	0.913	$y = 8.8369x - 9.1673$
GrassVESS Rm	Bulk density	0.809	0.899 <sup>*</sup>	$y = 9.6734x - 10.261$
VESS	Porosity	0.892	-0.944 <sup>x</sup>	$y = -0.0492x + 4.4831$
GrassVESS Sq	Porosity	0.839	-0.916	$y = -0.2345x + 14.268$
GrassVESS Rm	Porosity	0.801	-0.895 <sup>*</sup>	$y = -0.2547x + 15.289$

Note: The symbol (-) indicates an inverse correlation. \*: the weakest correlation. x: strongest correlation

The advantage of the GrassVESS approach for measuring soil quality in grasslands is in the study of the root layer, also known as GrassVESS Rm (Emmet-Booth et al. 2018a). According to (Table 6), the correlation coefficient between GrassVESS Rm and bulk density and porosity is 0.899 and 0.895, respectively. Compared to the VESS and GrassVESS Sq techniques, this result displays the lowest correlation coefficient value. The correlation coefficient should be between 0.8 and 1.0 or between -1 and -0.8, indicating a significant association between parameters (Guimarães et al. 2017).

Based on the findings, it is possible to deduce that different methods of agriculture will result in changes in soil structure qualities and quantitative soil physical properties. Compared to monoculture agricultural land, agroforestry land has a value similar to a natural forest. As a result, agroforestry land development is critical for ecological, economic, and social sustainability. All visual soil structure quality techniques have an excellent correlation to bulk density and soil porosity. However, the VESS method is a visual soil structure qualities evaluation method with the considerable correlation value compared to other methods. Thus, the VESS method is the most effective soil structure evaluation method for predicting quantitative soil physical properties compared to other methods.

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