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Soil Physical Quality Indices Across Various Land-Use Systems in Giripurno Village, Kota Batu

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Abstract

Background: *Continuous land use and soil cultivation without proper management can affect soil productivity and physical properties. The quality of soil physical properties plays a crucial role in agricultural development. Soil physical properties are key factors supporting crop production because they influence the availability of water and plant nutrients; therefore, it is essential to understand their quality. This study aims to determine and evaluate the quality of soil physical properties on mixed-use farmland, dry fields, and paddy fields in Giripurno Village.* **Methodology:** *This study was conducted using a survey method, and soil sampling was performed using purposive sampling, resulting in 12 sample points. Soil samples were collected using a soil sampling ring at soil depths of 0–30 cm and 30–60 cm for each land-use type. The observed soil physical parameters were soil texture, bulk density, permeability, particle density, porosity, and aggregate stability. Data analysis was performed using Excel 2013, and the soil physical property quality index was calculated based on criteria specific to each land-use type.* **Findings:** *The results of the study showed that the best soil physical property quality index value was found in mixed gardens at 0.84 with a "good" rating, while the worst was found in rice fields at 0.36 with a "bad" rating. The higher the soil physical quality index, the better the soil quality of a given plot of land. Land use that involves proper, non-excessive cultivation will help maintain soil quality.* **Contributions:** *The findings provide a practical basis for sustainable soil management by identifying land-use systems with better physical soil conditions and highlighting the need to improve degraded paddy field soils.*

Keywords: *Bulk Density; Land-Use; Soil Physical Properties; Soil Porosity; Soil Quality Index*

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INTRODUCTION

Land use and land management practices have a significant impact on natural resources, including water, soil, minerals, plants, and animals (Prasetya et al., 2023). Continuous land use can lead to changes in the physical properties of the soil on a given plot of land. Different soil management activities can affect the condition of soil properties, including its physical, chemical, and biological characteristics (Delsiyanti et al., 2016). It is common to find land-use patterns that do not align with the land's carrying capacity, leading to various problems such as the emergence of millions of critical land areas, the loss of fertile land, and soil contamination (Permatasari, 2017). These critical lands include sloped areas that have been converted into agricultural cultivation land. Examples of such critical lands include the conversion of forest land (primary, secondary, or plantation forests) into cultivated land (dry fields), settlements, scrubland, or even open land (Kubangun et al., 2016).

Giripurno is a village in the Bumiaji subdistrict of Batu City, situated at an elevation of 600–700 meters above sea level (Fathoni et al., 2023). The village of Giripurno features a hilly topography, making it highly suitable for agriculture. Most of the land use in Giripurno Village is dedicated to agriculture, with apple and avocado orchards, vegetable crops such as shallots and garlic, and food crops including corn and rice. The residents of Giripurno Village primarily utilize their land for agricultural activities. These lands are mostly used as dry-land fields planted with annual crops on slopes of varying gradients (Putra et al., 2021).

Soil possesses complex physical, chemical, and biological properties (Yunus et al., 2024). These physical properties of soil play a crucial role in the movement of water, air, heat, and dissolved substances within the soil. Soil physical properties can change as a result of soil tillage activities (Suprihatin & Amirullah, 2018). Soil physical properties are closely related to soil suitability for various planned land uses (Meli et al., 2018). Soil physical properties are one of the key factors supporting crop production. Even if soil possesses good chemical properties, without being supported by appropriate physical properties, crop yields will not reach the desired levels (Mawaddah et al., 2018). Soil physical properties influence the availability of water, air, and plant nutrients; therefore, the condition of soil physical properties significantly impacts maximum crop productivity. Soil physical properties generally change in response to land management activities (Megayanti et al., 2022).

Soil quality refers to the soil's ability to support ecosystem functions, namely, supporting plant growth and regulating water. Improper and inadequate soil management practices can lead to a decline in soil quality. Excessive soil management practices can damage soil structure and reduce biological activity within the soil. Conversely, appropriate and suitable soil management—such as reducing the use of heavy machinery during plowing and using organic fertilizers—can improve soil quality (Gulo & Waruwu, 2024). The objective of this study is to evaluate the physical properties of soil across various land uses in Giripurno Village.

METHODS

The study was conducted from December 2024 to March 2025 in Giripurno Village, Bumiaji Subdistrict, Batu City, East Java Province. Geographically, Giripurno Village is located at an elevation of 600–700 meters above sea level, covers an area of 1,728.865 hectares, and has an average annual rainfall of 1,813.88 mm. Laboratory analysis was conducted at the Land Resources Laboratory of UPN "Veteran" East Java. The equipment used in this study included a soil sample ring, a hoe, a soil auger, a GPS, a clinometer, label paper, a value cloth, a knife, a crowbar, a hammer, and writing utensils. The materials used in this study included 1:15,000 land use maps, 1:15,000 slope maps, 1:15,000 soil type maps, undisturbed soil samples, aggregate soil samples, and disturbed soil samples.

This study is a descriptive study that uses a survey method with the assistance of ArcGIS software to determine land conditions in the field, which are then used to identify sample points. Sample points were determined using purposive sampling, which involves the deliberate selection of study locations based on specific criteria. Sample points were identified by overlaying a 1:15,000-scale land-use map with a 1:15,000-scale land-slope map. Based on the map overlay results, 12 sample points were identified for this study, covering intercropped gardens, dryland, and paddy fields with slopes of 8–15%, 15–25%, 25–40%, and >40%. The samples studied were collected from depths of 0–30 cm and 30–60 cm, with three replicates representing each land unit determined based on slope class and land use.

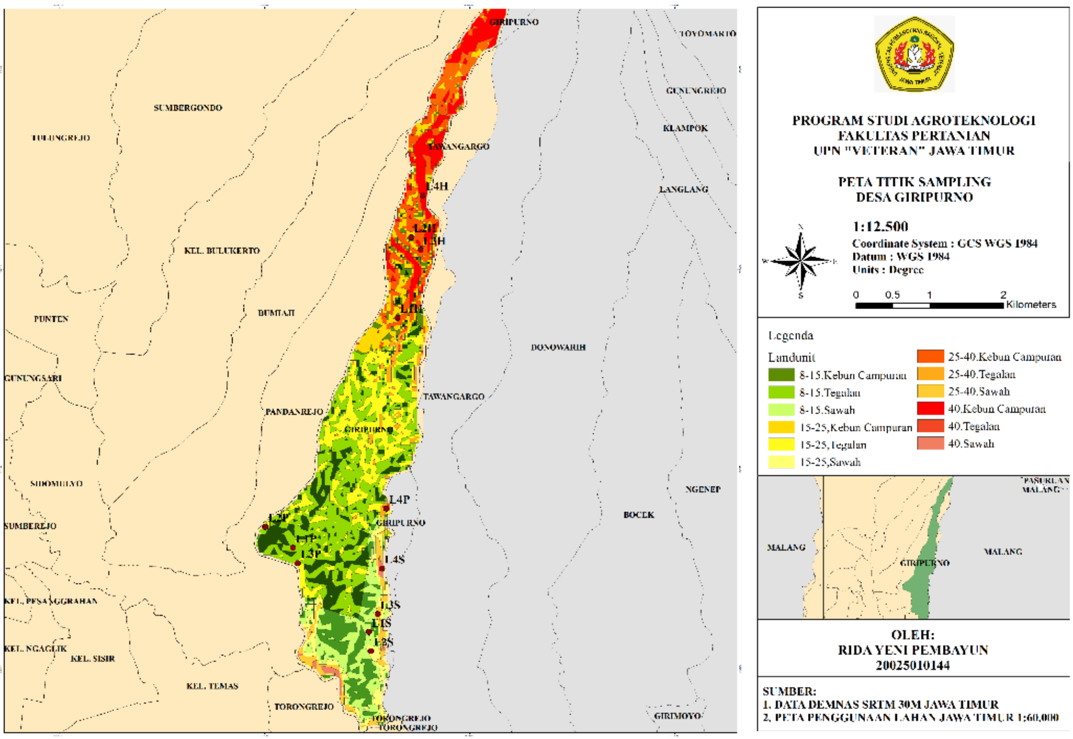

Figure 1. Map of Sampling Points in Giripurno Village

Study Procedure

The observational activities in this study included data collection through direct observation of the environmental geomorphological conditions or direct examination of the objects under study. Soil sampling was conducted in accordance with SNI 03-4148 1:2000, which covers the collection of undisturbed soil samples, soil aggregate samples, and disturbed soil samples. Undisturbed soil samples were collected using the soil ring sampling method, taken from specific soil layers in an undisturbed state. Soil aggregate samples are collected from the same horizon to obtain intact soil aggregates or clumps of soil that do not easily disintegrate, ensuring homogeneous data. For disturbed soil samples, soil is excavated from the same area to a specific depth, yielding 1–2 kg of material. The collected disturbed soil samples and aggregates are then air-dried and stored in containers for subsequent laboratory analysis. Disturbed soil samples are sieved using a 2.00 mm sieve before texture and particle density analysis; undisturbed soil samples are saturated before volume density and permeability analysis; and aggregate soil samples are analyzed for aggregate stability. Soil samples are then analyzed according to the appropriate method for each parameter under study.

Table 1. Observation Parameters and Analysis Methods

No.	Parameters	Analysis Methods
1.	Soil Texture	Pipette
2.	Aggregate Stability	Dry and Wet Sieving
3.	Permeability	Constant Head Method
4.	Bulk Density	*Gravimetri*
5.	Particle Density	*Gravimetri*
6.	Porosity	*Gravimetri*

Data analysis

Data analysis was conducted after the data obtained from all field parameters and laboratory results were mathematically calculated and tabulated using Excel 2013. A T-test was performed to compare each parameter based on land use, and a scoring system was applied to determine the soil physical quality index. The determination of the soil physical quality index for each parameter was carried out by scoring according to the conditions of the laboratory analysis results (Table 2). The indices were then summed to obtain the SPQI value by Putri et al., (2021) using the following equation.

$$SPQI = \sum \frac{S}{n} \times i \quad \text{...} \quad (1)$$

Description,
SPQI = Soil Physics Quality Index
S = Soil parameter score
N = Number of parameters
I = Maximum index

Table 2. Criteria for the Soil Physical Quality Index Score

No.	Parameter	Unit	Score					
			0	1	2	3	4	5
1	Texture	-	Sa	LSa	SiC	SaL, Cl	SCl, Si, SiL, SiCl	L, SiClL, ClL, SaClL
2	Bulk Density	g/cm^3	> 1.6	1.4 – 1.6	1.2 - 1.4	1.0 – 1.2	0.8 – 1.0	≤ 0.8
3	Porosity	%	< 20	20 – 30	30 – 40	66 – 80	50 – 60	> 60
4	Permeability	cm/jam	< 0.025	0.025 – 0.125	0.125 – 0.50	0.5 – 2.0; > 25.0	2.0 – 6.25; 12.5 – 25.0	6.25 – 12.5
5	Agregat Stability	-	< 40	40 - 50	50 - 66	66 - 80	80 – 200	>200

Description: Sa = Sand; LSa = Loamy Sand; SaL = Sandy Loam; L = Loam; SiL = Silty Loam; SiClL = Silty Clay Loam; SaClL = Sandy Clay Loam; ClL = Clay Loam; SaCl = Sandy Clay; Si = Silt; SiCl = Silty Clay; Cl = Clay.

Table 3. Physical Soil Quality Index Criteria

Class	Value	Criteria by Putri et al., (2021)
1	< 0.20	Very bad
2	0.20 – 0.39	Bad
3	0.40 – 0.54	Rather bad
4	0.55 – 0.69	Moderate
5	0.70 – 0.79	Rather good
6	0.80 – 0.89	Good
7	0.90 – 1.00	Very good

RESULT AND DISCUSSION

Physical Characteristics of Soil

Soil Texture

Based on the results of the soil texture analysis in Giripurno Village presented in Table 3, different land uses exhibit varying texture classes. The silty loam texture is found in mixed-crop fields across all slopes, where the silt fraction is higher (53–62%) compared to the sand fraction (21–23%) and the clay fraction (17–25%). A silty loam texture is a soil texture that contains a higher proportion of silt than sand and clay. Soils with this texture have moderate soil porosity, allowing water in the soil to be retained and released in a balanced manner (Pa et al., 2023). Additionally, this silty loam texture can retain and absorb nutrients effectively (Rizal et al., 2022).

Upland fields on slopes of 15–25%, 25–40%, and >40% have loamy soil textures with sand (28–48%), silt (29–42%), and clay (21–33%) fractions. On dryland and paddy fields with a slope of 8–15%, the soil texture is silty clay loam, with a lower sand content (15–17%) compared to the silt content (46–54%) and clay content (31–37%). Rice fields on slopes of 40% have a clay soil texture. This clay texture has a higher clay fraction (49%) compared to the sand and silt fractions. Meanwhile, rice fields on slopes of 8–15% have a clay loam texture. A clay-loam texture is one in which the silt fraction is higher (42%) than the sand fraction (24%) and the clay fraction (34%).

Table 3. Soil Texture Analysis Results for Various Land Uses

Sample	Slope Gradient	Fraction (%)			Texture Class
		Sand	Silt	Clay	
L4K	>40%	21	62	17	Silty Loam
L4T	>40%	48	29	23	Loam
L4S	>40%	24	27	49	Clay
L3K	25-40%	23	57	20	Silty Loam
L3T	25-40%	28	40	33	Loam
L3S	25-40%	24	42	34	Clay Loam
L2K	15-25%	22	53	25	Silty Loam
L2T	15-25%	41	38	21	Loam
L2S	15-25%	37	42	21	Loam
L1K	8-15%	22	57	21	Silty Loam
L1T	8-15%	17	46	37	Clay Loam
L1S	8-15%	15	54	31	Silty Clay Loam

Description: K = Mixed garden; T = Dryland field; S = Paddy field

According to Monde et al., (2025), changes in soil texture can be influenced by erosion, sedimentation, and human activities such as land clearing and the addition of organic matter to the soil. According to Megayanti et al., (2022) that differences in soil texture across various land-use types are also influenced by soil fraction composition, which in turn affects soil physical properties.

Soil Bulk Density and Particle Density

Soil bulk density is the ratio of soil mass to the volume of soil particles, which includes the volume of soil pores. Soil bulk density is a parameter used to determine soil density. The lower the soil bulk density value, the looser the soil is considered to be; conversely, the higher the soil bulk density value, the denser the soil is (Khair et al., 2017). Based on the analysis results in Table 4, it was found that the highest bulk density was observed in rice field land use on slopes of 15 – 25%, at 1.22 $g.cm^{-3}$. Meanwhile, the lowest bulk density was observed in mixed orchard land use on slopes greater than 40%, at 0.90 $g.cm^{-3}$.

The results of the t-test for bulk density on mixed orchard and dry field soils showed a significant difference, where the calculated T_{value} (5.88) > T_{table} (2.44). The results of the t-test for bulk density on mixed orchard and paddy field soils showed a significant difference, with the calculated T_{value} (5.53) > T_{table} (2.44). The results of the t-test for bulk density values on dryland and paddy fields showed no significant difference, where the calculated T_{value} (2.21) > T_{table} (2.44). Soils with a fine texture have a higher bulk density compared to sandy-textured soils (Kalembiro et al., 2018). Factors influencing bulk density include organic matter content, soil porosity, texture, and plant root systems. High organic matter content reduces soil bulk density by increasing soil porosity, thereby lowering soil density (Megayanti et al., 2022). Adding organic matter to the soil can reduce its bulk density (Surya et al., 2017). Mixed-crop gardens have more diverse vegetation, resulting in a greater and more abundant contribution of organic matter (Fadila et al., 2022). Therefore, mixed-crop gardens exhibit lower bulk density, indicating that the soil is looser.

Table 4. Analysis of Bulk Density and Particle Density in Various Land Uses

Sample	Slope Gradient	Bulk Density ($g.cm^{-3}$)	Particle Density ($g.cm^{-3}$)
L4K	>40%	0.90	2.47
L4T	>40%	1.09	2.59
L4S	>40%	1.10	2.55
L3K	25-40%	0.96	2.47
L3T	25-40%	1.09	2.62
L3S	25-40%	1.15	2.54
L2K	15-25%	0.93	2.46
L2T	15-25%	1.07	2.58
L2S	15-25%	1.22	2.56
L1K	8-15%	0.99	2.50
L1T	8-15%	1.06	2.57
L1S	8-15%	1.10	2.54

Description: K = Mixed garden; T = Dryland field; S = Paddy field

Particle density is a value that indicates the overall density of solid particles in the soil. Based on the results of particle density analysis in Table 3, paddy fields with a slope of 25–40% had the highest particle density value of 2.62 g/cm^3, while the lowest value was found in mixed orchard land with a slope of 15–25%, at 2.46 g/cm^3. Land use with higher particle density could be caused by intensive land cultivation, which reduces organic matter content (Siahaan & Kusuma, 2021). Particle density can be influenced by soil texture and organic matter (Fadhilah et al., 2023).

Porosity

The results of the study show that the highest porosity value was found in mixed-crop land use on slopes of <40%, with a value exceeding 63%. Meanwhile, the lowest porosity value was found in rice field land use on slopes of 15–25%, with a value of 52%. The low soil porosity value in rice field land use is attributed to frequent soil tillage on these plots. This aligns with the study by Listyarini et al., (2025), which states that intensive soil tillage can cause the soil structure to become easily eroded by rainwater impact. Direct impact of rainwater on the soil causes the soil to break into smaller particles that can fill soil pores, thereby hindering water infiltration. This can lead to an increase in soil volume and a decrease in soil porosity. The T-test results for soil porosity in mixed orchard and dry field lands showed a significant difference, where the calculated T_{value} (4.54) > T_{table} (2.44). For mixed orchard and paddy fields, there was a significant difference where the T_{value} (4.37) > T_{table} (2.44). Meanwhile, the results of the T-test on soil porosity values for dryland and paddy fields did not show a significant difference, with the T_{value} (2.21) > T_{table} (2.44).

Table 5. Analysis of Porosity in Various Land Uses

Sample	Slope Gradient (%)	Porosity (%)
L4K	> 40	63.68
L4T	> 40	57.91
L4S	> 40	56.86
L3K	25 - 40	60.76
L3T	25 - 40	58.39
L3S	25 - 40	55.07
L2K	15 - 25	62.19
L2T	15 - 25	58.52
L2S	15 - 25	52.34
L1K	8 - 15	60.24
L1T	8 - 15	58.43
L1S	8 - 15	56.69

Description: K = Mixed garden; T = Dryland field; S = Paddy field

This significant difference in porosity suggests that changes in land use affect porosity values. Changes in land use—such as converting land previously covered by dense, complex vegetation into agricultural land (yards or grasslands)—can lead to a decrease in soil porosity (Setyowari, 2020). Listyarini et al., (2025) state that soil cultivation activities can cause a decrease in soil porosity, as well as a reduction in organic matter content. Additionally, soil porosity values on a given plot can be influenced by other factors, namely particle size, bulk density, and soil specific gravity (Utami et al., 2024). Soil with good porosity indicates that it has the ability to absorb water effectively, making it less prone to releasing water (Rizal et al., 2022).

Permeability

Soil permeability is one of the assessment factors for soil management purposes and also serves to enhance water movement and water absorption by the soil (Silalahi et al., 2019). The value of soil permeability is also influenced by soil texture. The higher the clay content in the soil, the slower the water infiltration or permeability (Rizal et al., 2022). Table 4 shows that the permeability analysis results for mixed agricultural land indicate higher permeability values compared to dry land and paddy fields. The highest permeability value was found in mixed orchard land with a slope > 40%, with a value of 7.63 $cm.Hour^{-1}$ (Moderately rapid). Meanwhile, the lowest permeability value was found in paddy fields with a slope of 8–15%, with a value of 0.10 $cm.Hour^{-1}$ (Slow). The results of the t-test on permeability for mixed orchard land and dry land showed a significant difference, with the calculated T_{value} (6.01) > T_{table} (2.44). For mixed orchard land and paddy fields, there was a significant difference, with the calculated T_{value} (6.56) > T_{table} (2.44). Additionally, the results of the t-test for dry field land and paddy fields showed a significant difference, with the calculated T_{value} (4.27) > T_{table} (2.44).

Table 6. Analysis of Permeability in Various Land Uses

Sample	Slope Gradient (%)	Value ($cm.Hour^{-1}$)	Permeability Class
L4K	> 40	7.63	Moderately rapid
L4T	> 40	0.63	Moderately slow
L4S	> 40	0.39	Slow
L3K	25 - 40	4.71	Moderate
L3T	25 - 40	0.58	Moderately slow
L3S	25 - 40	0.38	Slow
L2K	15 - 25	6.17	Moderate
L2T	15 - 25	0.74	Moderately slow
L2S	15 - 25	0.10	Slow
L1K	8 - 15	3.97	Moderate
L1T	8 - 15	0.93	Moderately slow
L1S	8 - 15	0.24	Slow

Description: K = Mixed garden; T = Dryland field; S = Paddy field

Slope gradient can affect permeability; as the slope of the land becomes steeper, surface runoff accelerates, and more soil particles are carried away by water due to erosion on the soil surface (Mansyur et al., 2023). According to Siahan & Kusuma (2021), the magnitude of this permeability value is due to high porosity; therefore, permeability and porosity are directly proportional. Clay-textured soils generally result in soils with low permeability. This is because the pore size in clay-textured soils has small pore spaces (Mulyono et al., 2019).

Aggregate Stability

Table 7 shows the results of the analysis, which indicate that the aggregate stability index for each land use type has different values and classes. The highest aggregate stability index value was found for mixed orchard land use on slopes > 40%, with a value of 358.09 (very stable). Meanwhile, the lowest aggregate stability index value was found in rice field land use on slopes of 8–15%, with a value of 23.37 (unstable). The results of the t-test on aggregate stability in mixed orchards compared to dry fields showed a significant difference, where the calculated t-value (3.48) was greater than the critical t-value (2.44). In mixed orchard and paddy fields, there was a significant difference with a T_{value} (3.48) > T_{table} (2.44). In mixed orchard and paddy fields, there was a significant difference with a T_{value} (3.67) > T_{table} (2.44). Similarly, in dryland and paddy fields, there was a significant difference with a T_{value} (3.25) > T_{table} (2.44).

Table 7. Analysis of Aggregate Stability in Various Land Uses

Sample	Slope Gradient (%)	Index Stability	Class
L4K	> 40	358.09	Very stable
L4T	> 40	42.06	Less stable
L4S	> 40	28.62	Unstable
L3K	25 - 40	270.82	Very stable
L3T	25 - 40	29.01	Unstable
L3S	25 - 40	27.38	Unstable
L2K	15 - 25	327.54	Very stable
L2T	15 - 25	43.50	Less stable
L2S	15 - 25	25.81	Unstable
L1K	8 - 15	76.81	Mantap
L1T	8 - 15	35.98	Unstable
L1S	8 - 15	23.37	Unstable

Description: K = Mixed garden; T = Dryland field; S = Paddy field

These differences in aggregate stability index values may occur due to several factors, one of which is organic matter in the soil. This soil organic matter can originate from plant residues present and growing on the land. The high aggregate stability index value in this mixed garden is due to the presence of organic matter derived from plant residues. According to Al Hady et al. (2023), vegetation on a plot plays a role in the process of soil aggregate formation, as evidenced by root development; the more vegetation present, the larger the roots of that vegetation will grow.

Soil Physical Quality Assessment Index

The results of the physical soil quality index assessment for mixed-crop farmland ranged from 0.72 to 0.84, corresponding to a rating of fairly good to good. For dry field land use, the values range from 0.48 to 0.56, corresponding to the criteria of somewhat poor to moderate. Meanwhile, for paddy field land use, the values range from 0.36 to 0.60, corresponding to the criteria of poor to moderate. The highest quality index value is found in mixed orchard land use on slopes > 40%, at 0.84 (good). Meanwhile, the lowest quality index value is found in rice field land use on slopes of 15–25%, at 0.36 (bad). The type of land use influences soil quality. According to Suleman et al., (2016) that land cultivation activities, such as agricultural practices, can degrade soil quality, as evidenced by the rice field land use.

Table 8. Index Criteria of Soil Physics in Various Land Uses

Sample	Slope Gradient (%)	Value	Criteria by Putri et al., (2021)
L4K	> 40	0.84	Good
L4T	> 40	0.48	Rather bad
L4S	> 40	0.60	Moderate
L3K	25 - 40	0.80	Good
L3T	25 - 40	0.48	Rather bad
L3S	25 - 40	0.52	Rather bad
L2K	15 - 25	0.80	Good
L2T	15 - 25	0.48	Rather bad
L2S	15 - 25	0.36	Bad
L1K	8 - 15	0.72	Rather good
L1T	8 - 15	0.56	Moderate
L1S	8 - 15	0.52	Rather bad

Description: K = Mixed garden; T = Dryland field; S = Paddy field

CONCLUSSION

Based on the study results, it can be concluded that the best soil physical property quality index was found in mixed-crop land use on slopes > 40%, at 0.84, meeting the "good" criteria. Meanwhile, the worst soil physical property quality index was found in paddy field land use on slopes of 15–25%, at 0.36, meeting the "bad" criteria. Rice field land use with poor physical properties primarily faces issues related to aggregate stability and permeability. The difference in soil physical property quality index values is likely due to differences in land use, as each land type involves distinct soil management practices. Additionally, the presence or absence of organic matter addition can influence soil physical properties, particularly soil aggregate stability.

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