JUATIKA
JURNAL AGRONOMI TANAMAN TROPIKA
VOL. 8 No. 2 May 2026

DOI :https://doi.org/10.36378/juatika.v8i2.5011
eissn 2656-1727
pissn 2684-785X
pages : 653 – 658

REVIEW ARTICLE Open Access

Aggregate Stability Study on Various Land Uses and Land Slopes in Tutur District, Pasuruan Regency, East Java Province, Indonesia

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Abstract

Aggregate stability is an important indicator in assessing soil quality and the potential for land damage due to erosion. Land use that is not in accordance with soil capacity and intensive agricultural activities in sloping areas can reduce the stability of aggregates and increase the risk of soil degradation. This study was conducted in Tutur District, Pasuruan Regency, which has a variety of land uses, including dry fields, apple orchards, coffee plantations, mixed plantations, and natural forests, as well as three classes of slope inclination, namely 8-15%, 16-25%, and 26-45%. The objectives of this study were to examine the aggregate stability index values for various land uses and slope inclinations and to analyze the soil factors that influence these values. The purposive random sampling method was used to determine 45 sample points at soil depths of 0–20 cm and 20–40 cm. The samples were analyzed in the laboratory to obtain data on texture, bulk density, permeability, organic matter (organic C), and aggregate stability index. The data were then analyzed using correlation and linear regression tests to determine relationships among soil physical variables. The results showed that the lowest aggregate stability was found in apple orchards with a slope of 16-25%, while the highest value was found in natural forests with a slope of 8-15%. Organic C and soil texture were recorded as having the greatest influence on the variation in aggregate stability values across all land uses. This finding is a strength of the study because it provides a strong scientific basis for practical recommendations, namely the need to increase organic matter and cover vegetation as a conservation strategy to maintain soil aggregate stability.

Keywords: Land Conservation, Organic Matter, Physical Properties of Soil, Soil Stability, Soil Texture

1. Introduction

The increasing needs of humanity are in line with the need for land. This increasing need for land often leads to inappropriate land use. Agricultural activities can damage aggregate stability, particularly on land with low organic matter and during land-use changes. Tutur District, located in Pasuruan Regency, has diverse land uses and slopes. Local communities utilize the land intensively for agricultural activities. Tutur District's mountainous location results in varying degrees of slope. Even in sloping areas, land use continues, often leading to changes in the physical properties of the soil, which affect aggregate stability. Land use does not preclude the possibility of changes in land use, which will impact soil organic matter. These differences in land use will result in different litter, canopies, and root systems in the soil.

Intensive soil cultivation practices can cause the detachment of soil particles from soil aggregates, resulting in a low aggregate stability index. Intensive agricultural practices create an imbalance between the input and output of organic matter. Low organic matter will make soil aggregates more easily destroyed and more susceptible to damage (Pujawan et al., 2016). Monoculture cultivation practices negatively impact soil structure and water retention capacity, which are closely related to low levels of organic carbon in the soil. Damage to soil structure can occur through decreased soil aggregate stability, which makes the agricultural environment more vulnerable to degradation. This can ultimately reduce crop productivity.

Cementation, or binding, is closely related to the level

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of available organic matter, which acts as a natural adhesive. This observation is exacerbated by another factor influencing erosion, namely slope. Research indicates that, according to Hanifah & Listyarini (2020), the higher the soil organic matter content, the higher the soil aggregate stability. According to Sholikah et al (2024), steeper slopes increase the force of surface flow or runoff, which can increase erosion. Previous research (Hikmawati & Prijono, 2022) focused on coffee plantations and only examined land cover correlations. This study, however, explores a more diverse range of land uses.

This study considers the complex relationship between land use, slope gradient, soil aggregate stability, and its implications for ecosystem health and agricultural productivity in Tutur District, Pasuruan Regency. Based on this, the urgency of this study will reveal how much the existing factors influence the context of aggregate stability in several land uses at several slope levels. This study also contributes to the provision of science regarding soil aggregates. This study aims to analyze the factors that influence aggregate stability in several land uses and land slopes in order to provide scientific recommendations or a basis for developing sustainable land management strategies.

2. Material and Methods

Pickup location: The sample is located in Tutur District, Pasuruan Regency, East Java. Tutur District lies between 7.30' - 8.30' South Latitude and 112' 30' - 113' 30' East Longitude. The condition of the Tutur District area is a medium to highland area with an altitude ranging from 600 meters above sea level to more than 1900 meters above sea level (above sea level) with hilly to mountainous land surface conditions. Location Determination: The determination of soil sampling points was carried out using the *purposive random sampling method*, namely a sampling method based on certain considerations, including land complexity, area size in each land unit, time, and ease of reaching the location. The locations observed were dry fields, mixed gardens, apple orchards, coffee plantations, and natural forests.

Each land use will be sampled based on slope levels of 8-15%, 16-25%, and 26-45%. Each land use unit will be sampled at three points to represent the area based on land use (dry fields, mixed gardens, apple orchards, coffee plantations, and natural forests) and three slope levels (8-15%, 16-25%, and 26-45%) in Tutur District, resulting in a total of 45 sampling points. The predetermined sampling points will then be used to take soil samples at depths of 0-20 cm and 20-40 cm.

The equipment used in this study consists of two categories, namely tools for sampling in the field and tools for laboratory analysis. For sampling, the equipment required includes a hoe, crowbar, hammer, ring, GPS, clinometer, cutter, trowel, camera, and stationery. Meanwhile, equipment for laboratory analysis includes a digital balance, test tubes, volumetric pipettes, measuring pipettes, fume hoods, Erlenmeyer flasks, beakers, volumetric flasks, cups, electric stoves, permeameters, desiccators, ovens, electric sieve shakers, sieves of various sizes, stopwatches, and spectrophotometers. The materials used during sampling in the field include rubber, gauze, and plastic. The materials required for laboratory analysis include intact aggregate soil samples, water, distilled water, 10% H_2O_2, 2N HCl, $K_2Cr_2O_7$, and H_2SO_4.

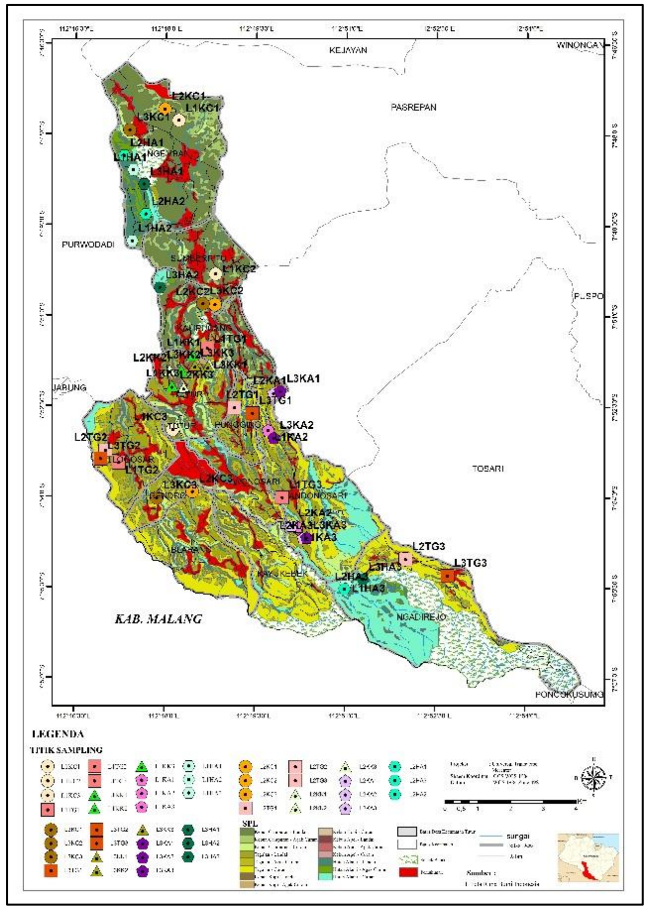

Figure 1. Sampling point location

Soil test analysis was conducted at the Land Resources Laboratory, Faculty of Agriculture, UPN "Veteran" East Java. The parameters analyzed in the study included aggregate stability using the double sieving method, soil texture using the pipette method, saturated hydraulic conductivity (KHJ) using *the constant head method*, organic carbon using the Walkey and Black methods, specific gravity using the gravimetric method, and bulk density using the ring volumetric method. Meanwhile, direct observation data including soil structure, slope gradient, planting pattern, vegetation population, plant types, and undergrowth were measured during the sampling process.

Data analysis from field surveys and laboratory analyses to obtain aggregate stability index values was then carried out to assess soil aggregate stability. Quantitative aggregate stability in the laboratory was carried out using dry and wet sieving methods according to the method proposed by De Leenheer and De Boodt (1959). This method is intended to find the difference in the average diameter of soil aggregates in dry and wet sieving. Next, calculate *the Mean Weight Diameter* (MWD) or average diameter weight, which will later be used to calculate the aggregate stability index. MWD is calculated using the formula:

$$\mathbf{MWD} = \frac{\sum_{i=1}^{N} W_i \overline{X_i}}{\sum_{i=1}^{n} W_i}$$

Where:
X = average diameter weight of aggregate (g, mm)
I = 1, 2, …….
n = number of aggregate classes
$\overline{X\iota}$ = average diameter of an aggregate class (mm)
Wi = aggregate weight with average diameter $\overline{X\iota}$

The aggregate stability index is analyzed using the double sieving method (dry and wet sieving). To calculate the aggregate stability index, the following equation is used:

$$\frac{\mathbf{1}}{\mathbf{MWDk - MWDb}} \times \mathbf{100}$$

Where:
MWDk = average diameter weight of dry sieving
MWDb = average diameter weight of wet sieving

The data obtained from the laboratory analysis was tabulated to facilitate further processing and interpretation. Correlation and regression tests were then conducted to determine the closeness of the relationship between the observation results using Excel version 2510.

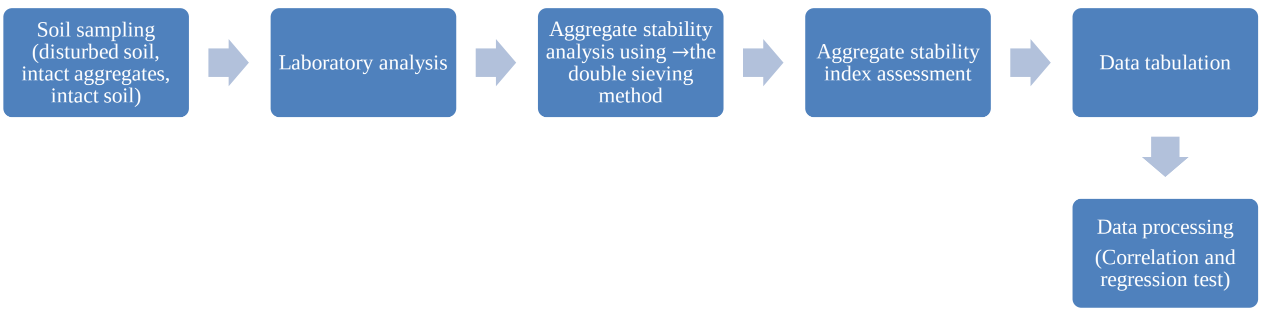

Figure 1 Research flow diagram

3. Results and Discussion

3.1. Aggregate Stability Index Value

The aggregate stability index value of soil can vary depending on the land cover, such as mixed gardens, coffee plantations, apple orchards, dry fields, and natural forests. Aggregate stability is an important indicator of soil quality. Soil with good aggregate stability is generally more fertile and productive. This is because stable aggregates provide sufficient air and water pores, creating an optimal microenvironment for plant root growth.

3.2. Relationship between Factors and the Aggregate Stability Index Value

The regression results show a relationship between the clay fraction (x) and the stability index (y), expressed in the linear regression equation y = 0.9623x + 72.896, indicating a positive relationship between the two variables. This means that every 1% increase in the clay fraction is associated with an increase in the stability index by 0.9623 units. The R^2 value = 0.4032 indicates that the clay fraction influences 40.32% of the stability index. Based on research, Ramadhani et al (2025) stated that clay can bind strongly with other particles such as sand and dust, as well as organic materials, to form soil aggregates.

This is also supported by Afand (2019), who states that clay particles are capable of clumping or flocculation, which can trigger the aggregation process and reduce soil dispersion. Other studies show that the sensitivity of the relationship between aggregate stability and clay depends on the method of measuring aggregate stability. Based on research by Rieke et al. (2022), the relationship between clay and aggregate stability is only weak to moderate, meaning that the clay fraction is an important influence but not a dominant factor.

The results of the regression test show a relationship between the Dust Fraction (x) and the stability index (y) expressed in the linear regression equation y = −0.4708x+129.74, which indicates a negative relationship between the two variables. This means that every 1% increase in the dust fraction is associated with a decrease in the stability index by 0.4708 units. The R^2 value = 0.1128 indicates that the dust fraction explains 11.28% of the variation in the stability index. This result shows that aggregate stability has a negative and weak relationship with the dust fraction. The higher the content of the dust fraction in the soil, the more the stability index tends to decrease. This assertion is in accordance with the nature of the dust fraction, which is easily released when exposed to rainwater, thus weakening the stability of the soil aggregate.

Soil with a dominant dust fraction will be most susceptible to erosion, because the dust fraction has a size of 0.002-0.2 mm, causing it to be easily washed away by water. The stability of the soil aggregate is very weak because the cohesion between the primary particles is very weak (Utomo seperti yang dikutip dalam Tanjung & Wiskandar, 2022).

Table 1 Aggregate stability index values at the research location

Sample Code	Aggregate Stability Index Value at					
	Slope (8 - 15%)	**Criteria**	**Slope (16 - 25%)**	**Criteria**	**Slope (26 - 45%)**	**Criteria**
1	***2***	***3***	***4***	**5**	**6**	**7**
KC1 (0-20 cm)	70.80	Excellent	109.46	Very Steady	109.80	Very Steady
KC1 (20-40 cm)	75.98	Excellent	92.40	Very Steady	90.65	Very Steady
KC2 (0-20 cm)	66.38	Excellent	87.86	Very Steady	82.73	Very Steady
KC2 (20-40 cm)	77.79	Excellent	110.24	Very Steady	68.56	Excellent
KC3 (0-20 cm)	98.25	Very Steady	103.54	Very Steady	84.52	Very Steady
KC3 (20-40 cm)	92.50	Very Steady	104.63	Very Steady	90.12	Very Steady
KK1 (0-20 cm)	110.21	Very Steady	94.03	Very Steady	80.87	Very Steady
KK1 (20-40 cm)	88.55	Very Steady	81.37	Very Steady	68.78	Excellent
KK2 (0-20 cm)	108.65	Very Steady	69.75	Excellent	44.56	Not Steady
KK2 (20-40 cm)	88.03	Very Steady	85.52	Excellent	47.66	Not Steady
KK3 (0-20 cm)	105.96	Very Steady	62.63	Quite Steady	43.17	Not Steady
KK3 (20-40 cm)	110.28	Very Steady	104.30	Very Steady	47.88	Not Steady
KA1 (0-20 cm)	110.26	Very Steady	39.01	Not Steady	68.38	Excellent
KA1 (20-40 cm)	110.24	Very Steady	43.98	Not Steady	45.83	Not Steady
KA2 (0-20 cm)	98.44	Very Steady	44.65	Not Steady	67.88	Excellent
KA2 (20-40 cm)	110.23	Very Steady	48.53	Not Steady	48.55	Not Steady
KA3 (0-20 cm)	98.66	Very Steady	43.22	Not Steady	47.66	Not Steady
KA3 (20-40 cm)	110.23	Very Steady	47.64	Not Steady	49.32	Not Steady
TG1 (0-20 cm)	110.24	Very Steady	63.56	Quite Steady	76.08	Excellent
TG1 (20-40 cm)	84.88	Very Steady	86.73	Very Steady	110.24	Very Steady
TG2 (0-20 cm)	83.27	Very Steady	98.26	Very Steady	64.28	Quite Steady
TG2 (20-40 cm)	88.57	Very Steady	106.88	Very Steady	95.39	Very Steady
TG3 (0-20 cm)	91.33	Very Steady	97.60	Very Steady	93.44	Very Steady
TG3 (20-40 cm)	95.65	Very Steady	84.78	Very Steady	101.51	Very Steady
HA1 (0-20 cm)	110.28	Very Steady	64.55	Quite Steady	52.50	Quite Steady
HA1 (20-40 cm)	66.60	Excellent	99.50	Very Steady	87.83	Very Steady
HA2 (0-20 cm)	67.34	Excellent	71.23	Excellent	59.60	Quite Steady
HA2 (20-40 cm)	76.48	Excellent	89.55	Very Steady	110.24	Very Steady
HA3 (0-20 cm)	69.79	Excellent	73.39	Excellent	53.64	Quite Steady
HA3 (20-40 cm)	68.77	Excellent	95.64	Very Steady	98.56	Very Steady

Source: processed data (2025), classification according to(Kurnia Undang, 2023). Information: Slope (8-15%) = L1; Slope (16-25%) = L2; Slope (26-45%) = L3; Mixed garden = KC; Coffee garden = KK; Apple garden = KA; Dry land = TG; Natural forest = HA.

This finding is consistent with research by Obalum et al. (2019), examining aggregate stability in *silty-loam soils*, which found that soils with high silt fractions are highly susceptible to dispersion when exposed to water, but testing methods and environmental conditions strongly influence their response. Another study by Liu et al, (2024) on fine-fraction soils in karst areas also showed that aggregate stability is more determined by organic matter and slope position than by the silt fraction itself, so that the silt fraction only makes a partial contribution to the level of aggregate stability. Based on comparisons with previous research, the low R^2 in this study indicates that the silt fraction is not a dominant factor in determining aggregate stability. Other factors such as organic matter, biological activity, root structure, and land management are far more determinant, so aggregate stability analysis ideally uses a multivariate approach, not just based on texture.

The regression test results show a relationship between C ORG (x) and the stability index (y) expressed in a linear regression equation y = 22.606x + 58.817, which indicates a positive relationship between the two variables. This means that every 1 unit increase in C ORG content is associated with an increase in the stability index by 22.606 units. The R^2 value = 0.5747 indicates that C ORG influences 57.47% of the aggregate stability index. This result is in accordance with research by Shalsabila et al. (2017), stating that soil with high C-organic content will be able to form stable soil aggregates. This finding is consistent with recent studies that emphasize the central role of organic matter in forming and stabilizing aggregates.

The results show that increasing *soil organic carbon (* SOC) encourages the formation of macro-aggregates, increases *the mean weight diameter* (MWD), and increases the percentage of aggregates that are resistant to rainwater disintegration (Gentsch et al., 2024).

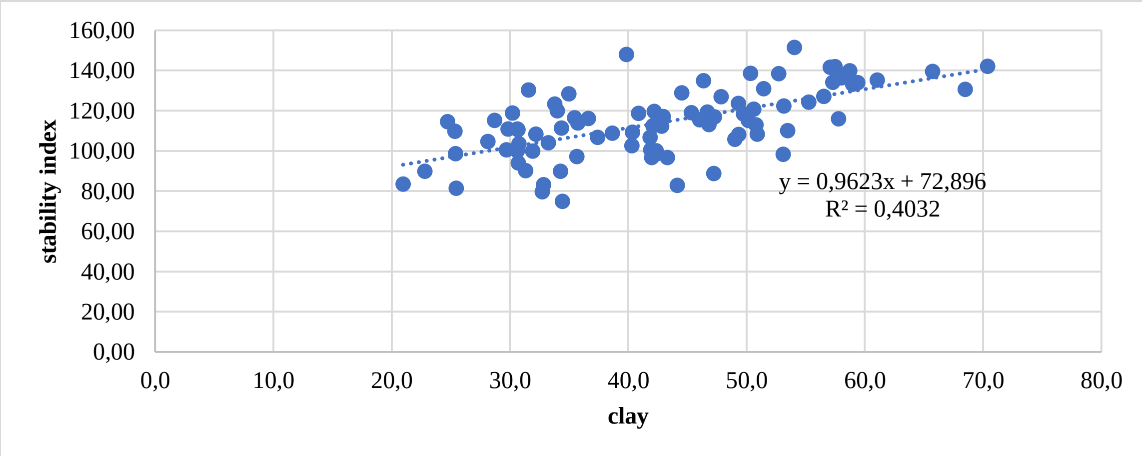

Figure 3. Relationship Curve between Clay Fraction and Soil Aggregate Stability

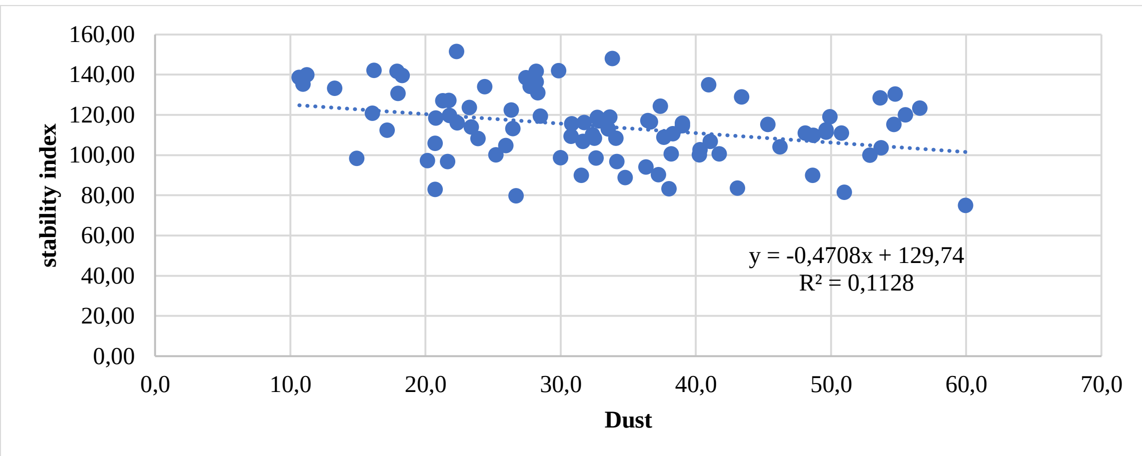

Figure 4. Relationship Curve of Dust Fraction and Aggregate Stability

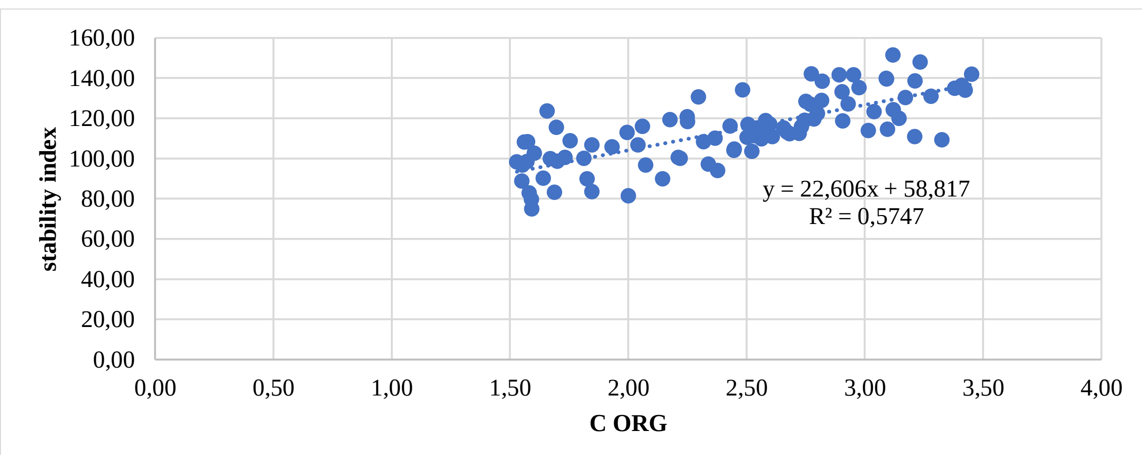

Figure 5. Relationship Curve of C-Organic and Aggregate Stability

Organic carbon content can help maintain aggregate stability and maintain a stable condition. This is because organic matter acts as a natural adhesive that can bind soil fraction particles into aggregates. In accordance with the opinion of Reflianty and Erawati, as quoted in [1], Fadila et al. (2022) state thatthe surface of organic matter contains ions that can bind soil particles to form soil aggregates. Stable soil aggregates will be able to maintain their shape even when exposed to water or other mechanical disturbances; this makes the soil more resistant to erosion. Conversely, soil that is less able to maintain its aggregates will be easily carried away by water flow, so that the nutrient-rich top layer can become thinner and affect soil fertility.

The organic matter content in soil depends on inputs, both naturally occurring and intentionally added. Natural inputs of organic matter are influenced by the quantity and diversity of growing vegetation, resulting in different litter types. The abundance and diversity of vegetation on the land will return more and more organic matter quickly. Growing vegetation contributes organic matter by dropping leaves, twigs, fruit, and so on. These materials are decomposed by microorganisms and eventually mixed with the soil, increasing the soil's organic matter content. Other research shows that the addition of organic matter such as biochar, straw, and compost, as well as the implementation of conservation practices such as *cover crops* and *no-till*, can increase the organic carbon (SOC) content while increasing the size and stability of soil aggregates. This finding is consistent with the positive coefficient in your research's regression equation, which indicates that each unit increase in organic carbon results in a significant increase in the aggregate stability index (Sun et al., 2023).

4. Conclusion

Based on the results of the research that has been conducted, it can be concluded that the stability of soil aggregates is greatly influenced by the organic C content and soil texture, especially the clay fraction. The most dominant factor was organic carbon, contributing 57.47% to aggregate stability. This indicates that the higher the organic matter content, the stronger the bonds between soil particles, resulting in more stable aggregates. These findings are relevant to field conditions and are highly useful as a basis for decision-making in soil conservation. Analysis of aggregate size distribution, both macroaggregates and microaggregates, is recommended. More focused research on estimating erosion, erosion hazard levels, and even landslides is also needed, given the relatively hilly terrain with steep slopes.

Acknowledgment

We would like to thank all authors for their active participation in every stage of the project, from data collection to manuscript preparation. We also extend our gratitude to all parties who provided support and assistance in the implementation of this research testing process.

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