International Journal of Plant & Soil Science

Volume 38, Issue 6, Page 253-266, 2026; Article no.IJPSS.159596
ISSN: 2320-7035

Soil Erodibility Across Land Use and Slope Gradients in Tokat Province, Türkiye

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Authors' contributions

This work was carried out in collaboration among all authors. Author SD designed the study, performed the statistical analyses, and wrote the first draft of the manuscript. Author ŞA contributed to laboratory analyses and data interpretation. Author İB participated in field sampling and data collection processes. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i66115

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/159596

Original Research Article

Received: 12/03/2026
Accepted: 29/05/2026
Published: 03/06/2026

Abstract

Background: Soil erosion is a major form of land degradation in Türkiye, where steep topography, intensive land use, and changing climatic conditions increase soil susceptibility to erosion. Understanding how land use and slope gradients influence soil erodibility is therefore essential for sustainable soil management and conservation planning.

Aims: This study aimed to investigate the relationships between land-use patterns, slope gradients, and soil erodibility in Tokat Province, Türkiye.

Study Design: The study was a comparative, field-based soil erosion assessment across different land-use and slope classes.

Place and Duration of Study: The study was conducted in Tokat Province, Türkiye, and soil samples were collected and analyzed between April and October 2024.

Methodology: A total of 108 soil samples were collected from 0–20 cm soil depth under 0–5%, 6–29%, and >30% slope classes. Aggregate stability (AS), structural stability (SS), dispersion ratio (DR), and erosion ratio (ER) were evaluated under different crop management systems. Statistical analyses were performed to determine the relationships among soil erodibility parameters and topographic conditions.

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Cite as: *Demir, S., Arslan, S., & Bolca, I. (2026). Soil Erodibility Across Land Use and Slope Gradients in Tokat Province, Türkiye. International Journal of Plant & Soil Science, 38(6), 253–266. https://doi.org/10.9734/ijpss/2026/v38i66115*

Results: Cropland soils exhibited the highest dispersion ratio values (78.8 ± 2.1%), whereas forest soils showed lower dispersion ratio values (66.9 ± 2.4%) and greater structural stability. Similarly, erosion ratio values were highest in croplands (84.86 ± 0.82%) and lowest in forest lands (79.06 ± 4.38%). Forest ecosystems maintained higher and more stable aggregate stability values (57.47–60.21%) than cropland (45.83–57.98%) and pasturelands (47.31–57.39%). A significant inverse relationship was observed between dispersion ratio and structural stability, indicating that greater dispersion potential increased susceptibility to aggregate degradation. Regression analysis also demonstrated a strong negative relationship between structural stability and the erosion ratio, confirming that structural stability is an important indicator of soil resistance to erosion. Aggregate stability decreased with increasing slope gradient, particularly in anthropogenically disturbed lands, whereas forest cover effectively reduced the negative effects of topography on soil properties.

Conclusion: The results demonstrated that land use, slope conditions, and soil properties significantly influence soil erodibility. Natural vegetation cover improved soil resistance through higher organic matter accumulation and root development. Structural stability was identified as one of the most important factors controlling soil erodibility in the study area.

Keywords: Soil erodibility; structural stability; land use; Tokat; slope gradient.

1. Introduction

Soil is a fundamental natural resource formed through the interaction of parent material, climate, organisms, topography, and time. As the primary medium for plant production, it sustains terrestrial ecosystems, supports food security, and conserves biodiversity (Lehmann et al., 2020; Reis et al., 2021). Effective land and water management controls soil erosion and maintains soil productivity (Saygın et al., 2019). Soil susceptibility to erosion refers to the tendency of soil to undergo erosion under the influence of external forces (Celilov & Dengiz, 2019). Soil erodibility represents the inherent susceptibility of soil to erosion, determined by its structural properties and resistance to erosive forces (Weng et al., 2023; Tunç, 2020). Therefore, sustaining soil productivity in agricultural, forest, and pasture lands requires accurate characterization of soil properties and comprehensive evaluation of the factors responsible for soil degradation (Okebalama et al., 2024). Erosion is one of the most critical forms of land degradation in Türkiye, where steep topography, variable rainfall regimes, and intensive land-use practices significantly increase soil susceptibility to erosion (Erpul & Deviren Saygın, 2012; Eraslan et al., 2016, Dou et al., 2020). Recent studies integrating the Revised Universal Soil Loss Equation (RUSLE) with GIS and remote sensing techniques have demonstrated that slope length and steepness (LS factor) constitute the dominant driver of erosion risk, followed by rainfall erosivity (R) and soil erodibility (K) (Alebachew et al., 2025; Gezici *et al.,* 2025, Gürtekin & Gökçe, 2021). In addition, land cover plays a crucial role, as well-vegetated areas exhibit greater resistance, whereas bare or degraded lands remain highly vulnerable to erosion processes. Therefore, understanding the combined effects of topography, climate, soil properties, and land use is essential for developing effective soil conservation strategies and mitigating long-term degradation of soil and ecosystem functions.

Erosion results from the combined effects of rainfall erosivity and soil erodibility. Rainfall erosivity indicates the erosive power of precipitation. Soil erodibility reflects a soil's resistance to erosion. During rainfall events, erosion occurs when the erosive force of rainfall exceeds the soil’s resistance to detachment and transport (Jin et al., 2021; Zhang et al., 2025; Wu *et al.,* 2024). In addition to natural factors, human activities accelerate erosion processes. Land use changes, such as urbanization, expansion of agricultural land, and monoculture farming, intensify erosion (Madenoğlu et al., 2024 Nourizadeh et al., 2023). Improper agricultural practices, overgrazing, forest fires, land abandonment, and construction activities further exacerbate soil erosion (Desta et al., 2021).

Turkey is highly vulnerable to soil erosion due to steep topography and diverse climatic conditions. Approximately 46% of the land has slopes greater than 40%, and more than 62.5% have slopes greater than 15%, which increases erosion risk (Alebachew et al., 2025; Özdemir & Tatar, 2016). Land use changes further increase erosion risk; cultivated land, forest areas, and pasture areas are all affected, with active erosion observed in 59% of cultivated land, 54% of forest areas, and 64% of pasture areas (Kılıç, 2021). Human activities such as deforestation, conversion of forests to agricultural land, improper irrigation practices, particularly in the Harran Plain, and urbanization intensify soil loss by reducing vegetation cover and increasing surface runoff. Climate change projections indicate that average erosion rates may remain stable or increase slightly in some regions. Spatial changes in rainfall patterns can shift erosion-prone areas. This indicates that targeted land management strategies, such as afforestation, terracing, and sustainable agricultural practices, can reduce soil degradation.

Despite documented erosion risk in Türkiye, quantitative comparisons of soil erodibility across land-use types remain limited (Erdoğan & Yavuz, 2024, Babur et al., 2021). Forest soils typically demonstrate lower erodibility than agricultural lands, where reduced organic matter and structural degradation increase susceptibility (Liu et al., 2019). Pasture soils exhibit intermediate resistance, attributed to root-mediated aggregation and surface cover (Macit et al., 2021, Karaoğlu, 2023). These land-use-mediated variations in organic carbon, aggregate stability, and hydraulic conductivity directly govern erosion processes. Consequently, quantifying these relationships is essential for targeted soil conservation and sustainable land management.

This study aims to characterize soil erodibility across major land-use types in Tokat Province and to determine how land-use patterns shape key erodibility parameters. For this purpose, soil samples collected from agricultural, pasture, and forest lands were evaluated using a set of erosion-related indicators, including dispersion ratio, erosion ratio, clay ratio, colloid-to-moisture equivalent ratio, aggregate stability, and structural stability index. A comparative assessment of these parameters across land-use classes establishes a strong foundation for regional erosion risk evaluation and facilitates the formulation of targeted, sustainable land management strategies. It was hypothesized that land use type and slope gradient significantly affect soil erodibility indices and structural stability characteristics.

2. Materials and Methods

2.1 Materials

Tokat Province is located in the inland part of Turkey's Black Sea Region, between approximately 39°30′–41°00′ N latitudes and 35°00′–37°30′ E longitudes. The region represents a transitional zone between the humid Black Sea climate and the semi-arid continental climate of Central Anatolia, resulting in pronounced spatial variability in precipitation patterns, temperature regimes, and vegetation cover. Elevations across the province range from approximately 250 m to over 1.900 m in mountainous areas, and this pronounced topographic gradient plays a critical role in shaping hydrological processes and soil erodibility.

The topography of Tokat is characterized by extensive plains, undulating plateau surfaces, and dissected slopes. The primary morphological units include the Kazova Plain and the surrounding plateau and mountainous terrain. Land slope varies considerably, ranging from gentle gradients in the plains to very steep slopes in the highlands. This topographic heterogeneity exerts a decisive control over surface runoff generation, infiltration capacity, and soil erodibility. The climate is classified as semi-arid to semi-humid, with hot, dry summers and cold, relatively wet winters. Average annual precipitation ranges from approximately 400 to 600 mm, with most falling during autumn, winter, and spring. During short periods of high-intensity rainfall particularly under sparse vegetation cover surface runoff increases markedly, thereby accelerating soil erosion processes. The mean annual temperature is approximately 12–13 °C (Turkish State Meteorological Service, 2024).

Soils in the region exhibit considerable variability due to differences in parent material, topography, and land-use history. Alluvial soils are predominantly distributed in valley bottoms, whereas colluvial and residual soils are widespread across sloping terrains. According to the USDA Soil Taxonomy, soils in the study area primarily belong to the Entisol, Inceptisol, and Alfisol orders, with textures ranging from sandy loam to clay. Organic matter content is generally low to moderate. Soil physicochemical properties including aggregate stability, infiltration capacity, and susceptibility to surface crusting constitute key factors controlling soil erodibility, as they directly influence the soil's response to rainfall and the development of surface runoff processes.

Land-use patterns in Tokat Province are dominated by dry farming areas, rangelands, and forested lands, which together occupy extensive portions of the region. Major agricultural products include wheat, sugar beet, sunflower, and other cereal crops. Agricultural practices such as tillage methods, crop rotation, vegetation density, and surface cover conditions strongly influence soil resistance to rainfall impact and susceptibility to particle detachment. In particular, intensive grazing in pasturelands can substantially reduce vegetation cover, exposing the soil surface and thereby increasing the risk of erosion. Owing to its climatic variability, pronounced topographic diversity, heterogeneous soil characteristics, and the coexistence of multiple land-use types, Tokat Province constitutes a highly representative study area for assessing soil erodibility and erosion processes.

2.2 Methods

This study aimed to determine soil erodibility indices, including dispersion ratio (DR), erosion ratio (ER), clay ratio (CR), colloid-moisture equivalent ratio (CMER), aggregate stability (AS), and structural stability (SS), under different land-use types (cropland, forest, and pasture). A total of 108 disturbed soil samples were collected from the 0–20 cm soil depth, with 36 samples obtained from each land-use type. Sampling locations were selected to represent different slope gradients and land-use conditions across Tokat Province, and geographic coordinates were recorded using a handheld GPS device. Soil samples were collected in triplicate and composite samples were prepared for laboratory analyses.

Soil texture was determined using the Bouyoucos hydrometer method (Bouyoucos, 1935). Moisture equivalent was measured using a Soil Moisture Pressure Plate equipped with ceramic plates at 0.33 atm pressure (Gülçur, 1974). Dispersion ratio (DR) was determined according to the method of Middleton by shaking 2-mm sieved soil samples in distilled water without applying mechanical or chemical dispersion. The ratio was calculated by dividing the amount of silt + clay dispersed into suspension by the total silt + clay content obtained through standard mechanical analysis. Water-stable aggregate stability (AS) was determined using the wet-sieving method with a Yoder-type sieving apparatus (Kemper & Rosenau, 1986).

Differences among land-use types and slope classes were evaluated using analysis of variance (ANOVA), and mean comparisons were performed using Tukey's test at $P < 0.05$. Correlation and regression analyses were also performed to evaluate relationships among soil erodibility indicators. Statistical analyses were conducted using SPSS 22.0 software.

The structural stability index (SSI) was calculated according to Atalay (2006), and its interpretation was supported by contemporary approaches linking soil structure with organic matter dynamics and aggregation processes (Six et al., 2000):

$$S = \sum n - \sum b \quad (1)$$

S: Durability criterion, $\sum$n: the total of silt + clay fractions obtained through mechanical analysis, $\sum$b: the total of silt and clay fractions dispersed from aggregates into the suspension.

Fig. 1. Location map of the research site

The erosion resistance threshold for the soil was set at 15%. Soils with a dispersion ratio exceeding this threshold are classified as highly susceptible to erosion. The colloid/moisture equivalent ratio is considered an important index reflecting soil permeability. A higher colloid/moisture equivalent ratio corresponds to lower field capacity, which in turn enhances infiltration capacity.

3. Results and Discussion

Topography and land-use patterns play an important role in soil formation within the study area. Due to relatively slow pedogenic differentiation in arid and semi-arid regions, some soil properties retain characteristics of the parent material. However, slope and land-use type (cropland, pasture, and forest) exert a decisive impact on soil physical properties and erosion susceptibility. As slope gradient increases, surface runoff and transport processes accelerate, altering erodibility parameters such as soil structure, aggregate stability, and dispersion ratio. Similarly, land-use type influences erosion processes by affecting vegetation density, organic matter accumulation, and soil surface protection. Therefore, evaluating the erodibility characteristics of the studied soils across slope classes and land-use types provides insight into their sensitivity to erosion.

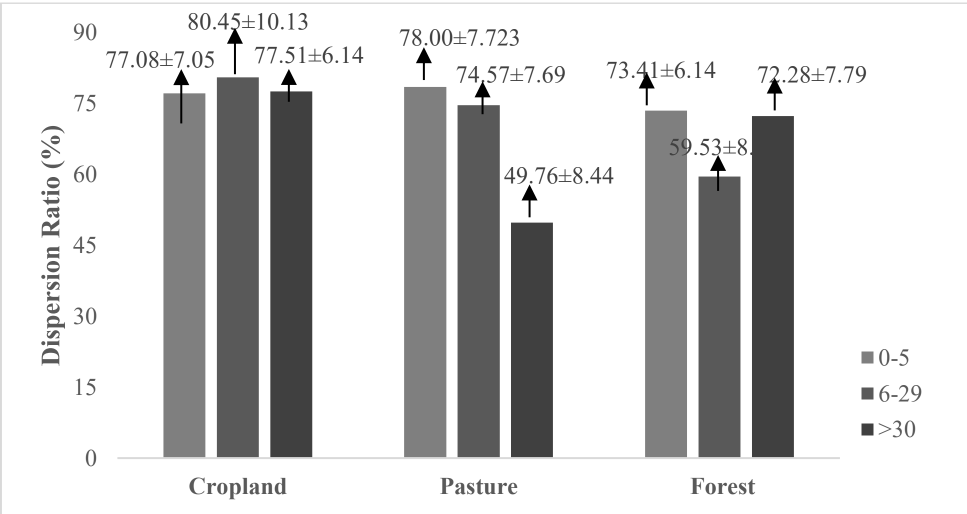

Fig. 2. Variation of DR across land-use types and slope classes

Table 1. Correlation coefficients among erodibility indices

	DR	Slope	Land	CMER	ER	CR	AS	SS
DR	1	-.145	-.147	-.394**	.879**	.339**	.032	-.858**
Slope		1	0.000	.084	-.148	-.142	-.380**	.165
CMER				1	-.655**	-.744**	-.083	.585**
ER					1	.715**	.030	-.786**
CR						1	.059	-.427**
AS							1	-.064
SS								1

**Correlation is significant at the 0.05 level. **Correlation is significant at the 0.01 level.*

DR varied markedly across land-use types and slope classes (Fig. 2). Croplands displayed the highest DR values (range: 77.1–80.5%, mean ± SE: 78.8 ± 2.1%, n=36), followed by pastures (range: 49.8–78.0%, mean ± SE: 68.3 ± 5.1%, n=36) and forest lands (range: 59.5–73.4%, mean ± SE: 66.9 ± 2.4%, n=36). Slope effects were land-use-dependent: croplands maintained high DR values across all slope classes, with greater variability on moderate slopes (6–29%; 80.5 ± 3.4%). In contrast, pastures exhibited a marked decline in DR on steep slopes (>30%: 49.8 ± 2.8% vs. 0–5%: 78.0 ± 2.6%), suggesting erosion-induced particle sorting or colluvial redistribution processes. Furthermore, correlation analysis revealed a significant inverse relationship between the DR and the CMRE (r = −0.394, $P < 0.01$), as well as a strong negative correlation with fine fraction content (SS) (r = −0.858, $P < 0.01$) (Table 1). A strong positive relationship was also observed between DR and erosion rate (ER) (r = 0.879, $P < 0.01$). Regression analysis further supported this association, with a high coefficient of determination (R^2 = 0.773), indicating a strong relationship between dispersion and erosion susceptibility (Fig. 3).

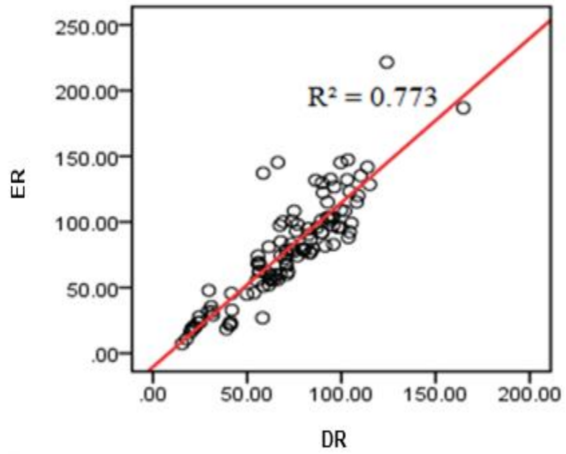

Fig. 3. Relationship between DR and ER of soils under different land use types

The observed patterns in dispersion ratio across land-use types and slope classes indicate that soil structural integrity is strongly influenced by both anthropogenic disturbance and topographic controls. These findings demonstrate that land use and topography jointly regulate soil structural stability. Dispersion rates tended to decline with increasing slope gradient, particularly in pasture areas, likely due to the preferential removal of finer colloidal particles by surface runoff. In forested areas, variability across slope classes reflects the moderating effect of vegetation cover on soil structure. Land-use type remained a dominant factor controlling soil erodibility, with agricultural lands exhibiting higher dispersion and erosion rates, whereas forest systems showed greater aggregate stability due to continuous organic matter input and surface protection. These results are consistent with previous studies reporting improved soil stability under natural vegetation and increased susceptibility under intensive land use (Gan et al., 2023). Furthermore, the combined influence of slope and land use intensified structural degradation in sloping agricultural areas, increasing susceptibility to aggregate breakdown and erosion (Erdoğan & Yavuz, 2024). These results highlight the importance of maintaining vegetation cover and implementing conservation practices to enhance soil stability and reduce erosion risk in sloping landscapes.

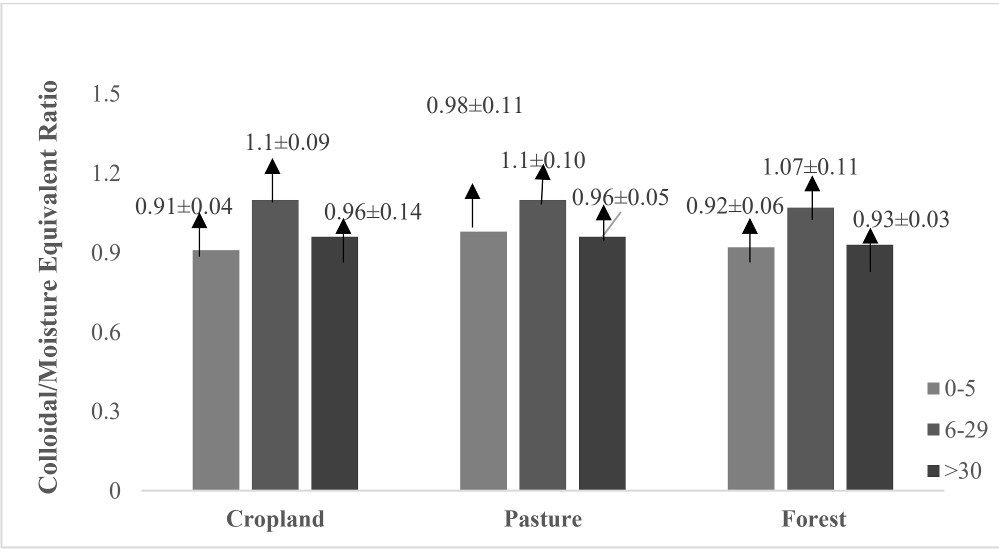

Fig. 4. Variation of CMER across land-use types and slope classes

CMER varied significantly among land-use types ($P < 0.05$) and showed little variation with slope gradient (n=36 per group). In the gentle slope class (0–5%), pastures exhibited the highest CMER (1.10 ± 0.08), exceeding croplands (mean ± SE: 0.91 ± 0.06) and forests (mean ± SE: 0.92 ± 0.07). On moderate slopes (6–29%), CMER values were similar across land uses (cropland:1.10 ± 0.09; pasture:1.10 ± 0.07; forest:1.07 ± 0.05). In contrast, steep slopes (>30%) showed lower CMER values across all land uses (0.93–0.96; n=36) (Fig. 4), indicating that CMER responds more strongly to land use than to slope gradient under the studied conditions. Correlation analysis further supports these findings and shows a negative, statistically significant relationship between CMER and DR (r =-0.394, $P < 0.01$) (Table 1). This indicates that as the water retention capacity of colloidal fractions increases, their tendency to disperse decreases. Moreover, CMER is negatively correlated with both EO and clay rate (r=-0.655 and r =-744, respectively; $P < 0.01$) (Table 1, Fig. 5), suggesting that greater colloidal stability is associated with lower soil erodibility. Regression analysis supports this relationship and reveals a moderate negative association between CMER and EO (R^2 = 0.43) (Fig. 5), indicating that erosion decreases as CMER increases and that colloidal structure contributes to greater soil stability.

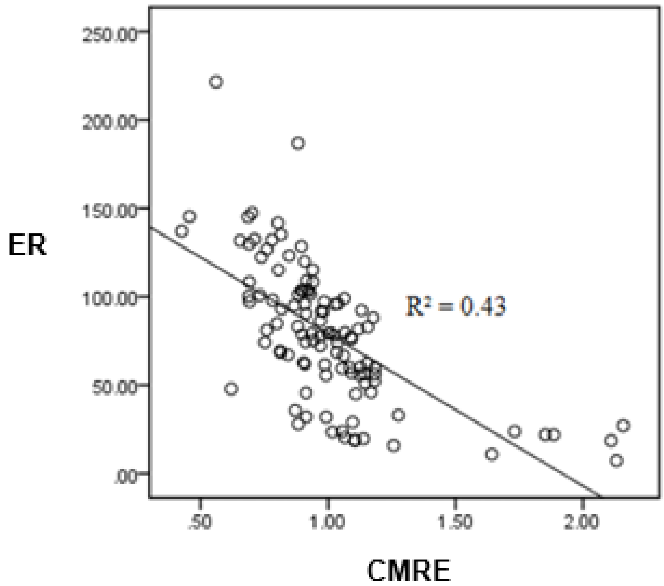

Fig. 5. Relationship between CMRE and erosion ratio ER

The variation in CMER across land-use types and slope classes indicates that soil colloidal behavior is primarily controlled by land use rather than topographic gradient. This relationship aligns with previous studies demonstrating that land-use practices exert a dominant control over soil erodibility through their influence on soil structure and aggregation (Cen et al., 2024). Soils under natural vegetation exhibit greater structural stability and lower erodibility compared to cultivated lands, reflecting the beneficial effects of continuous organic matter input and surface protection. This supports the trends observed in the present study. CMER values are generally higher in the moderate slope class (6–29%) across land-use types, likely due to increased surface runoff and the selective transport of fine fractions as slope gradient increases. In croplands, cultivation practices disrupt aggregates and release colloidal fractions, thereby intensifying colloid–water interactions and contributing to variability in CMER values. In contrast, continuous vegetation cover in forest systems supports organic matter accumulation and enhances structural stability. These results are consistent with previous studies showing that soil erodibility indices are governed by land use and soil physical properties. George Okoro et al. (2024) reported that soil texture, fine fraction distribution, and structural characteristics significantly influence soil erodibility across different land-use conditions. The findings indicate that CMER is jointly controlled by topography and land use, highlighting the role of colloidal structure and fine fractions in soil erodibility.

ER varied across land-use types and slope classes. Croplands exhibited relatively stable ER values (range: 83.82–86.59%; mean ± SE: 84.86 ± 0.82%; n= 36), while forest soils showed moderate variation (range:71.02–86.06%; mean ± SE: 79.06 ± 4.38%; n= 36). In contrast, pasture soils displayed the widest variation in EO values (range: 55.05–89.37%; mean ± SE: 73.08 ± 9.92%; n = 36) (Fig. 6).

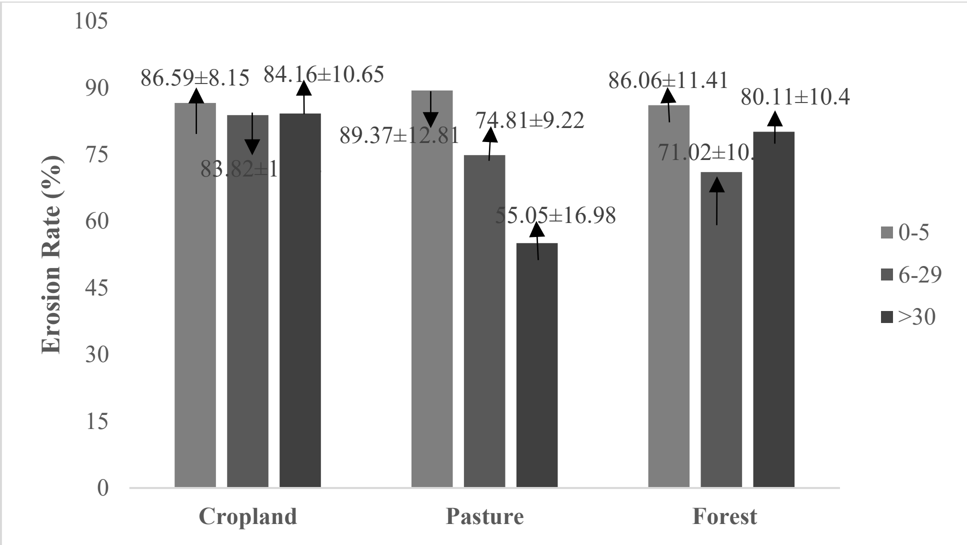

Fig. 6. Variation of ER across land-use types and slope classes

ER showed limited variation across slope classes in cropland and forest soils, whereas in pasture soils ER decreased with increasing slope gradient. This pattern can be attributed to enhanced surface runoff and the selective transport of fine particles on sloping terrain. These results are consistent with previous studies showing that land-use type controls erosion processes. Karaş and Oğuz (2017) reported higher erosion rates in agricultural soils due to reduced vegetation cover and soil disturbance, which increase surface runoff and soil loss. Similarly, Yan et al. (2018) showed that land-use change modifies erosion dynamics, with cultivated soils exhibiting higher erosion rates than natural vegetation covers.

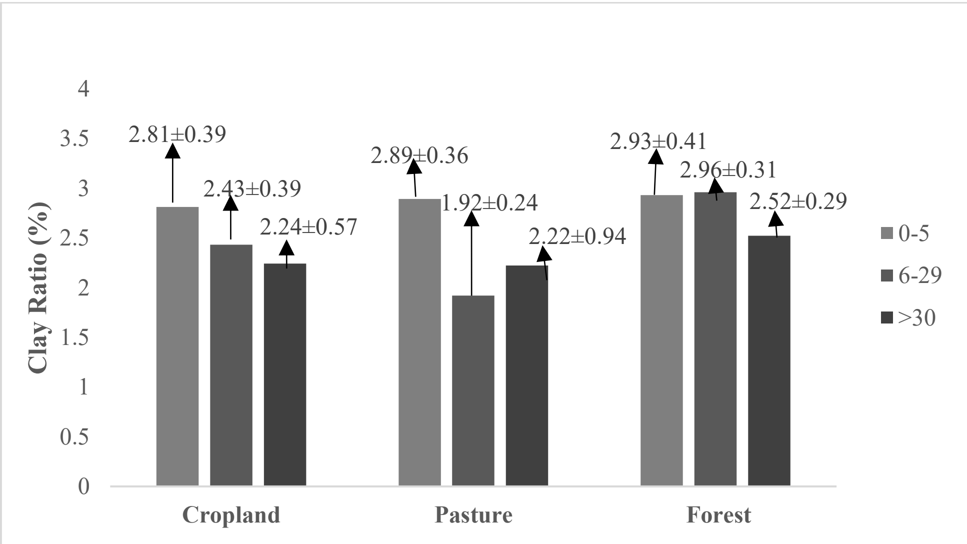

Fig. 7. Variation of CR across land-use types and slope classes

Clay ratio (CR), an indicator of the proportion of fine particles, varied across land-use types and slope classes, reflecting differences in soil erodibility. In this study, croplands showed CR values of 2.24–2.81 (mean ± SE:2.49 ± 0.29, n= 36), pasturelands showed a wider range of 1.92–2.89 (2.34 ± 0.50, n = 36), and forest soils had relatively higher values of 2.52–2.96 (2.80 ± 0.23, n = 36), indicating greater clay content (Table 1, Fig. 7). SE values ranged from 0.36 to 0.41 in croplands, 0.24 to 0.39 in pasturelands, and 0.29 to 0.94 in forest soils (Fig. 7).

The variation in clay ratio across land-use types and slope classes reflects the combined influence of land use and topographic conditions on the distribution of fine soil fractions. CR an indicator of fine-particle proportion, varied across land-use types and slope classes. CR changed little across slope classes in cropland and forest soils, whereas pasture soils showed lower CR values on moderate slopes, likely due to runoff-driven downslope transport of fine particles. This trend is consistent with previous reports that increasing slope gradient accelerates runoff, enhances selective removal of fine fractions, and ultimately increases erosion susceptibility (Ediş et al., 2023; Guo et al., 2021). Overall, the results support the view that land use and slope jointly regulate clay distribution and, consequently, soil structural resistance to erosion, with higher clay-rich forest soils generally exhibiting lower erodibility than more disturbed land-use types (Gantulga et al., 2023; He et al., 2023; Kumar et al., 2023; Pradana et al., 2025). Thus, the preservation of clay-rich horizons under forest cover serves as a critical structural buffer against erosive forces, underscoring the importance of permanent vegetation in transition zones.

The observed variation in SE values across land-use types and slope classes highlights the role of fine fractions and colloidal structure in regulating soil stability. Notably, increased SE values in forest soils on moderate slopes suggest that colloidal fractions and fine particles contribute to better structural stability in these areas. This aligns with Sharma et al. (2024), who noted CR increases with land-use disturbance from forests to degraded systems, and higher CR correlates with increased soil erodibility. Correlation analysis further indicated that clay-related indices are closely linked to erosion dynamics: improved colloidal organization and favorable fine-particle distribution support aggregate stability and reduce erosion susceptibility. These findings indicate that the distribution of fine particles plays a critical role in controlling soil erodibility by influencing soil structure and runoff response.

AS varied across land-use types and slope classes, showing that soil resistance to erosion depends on both topography and land management. Cropland soils had AS values between 45.83% and 57.98%, while pasture soils ranged from 47.31% to 57.39% (Table 1, Fig. 8). Forest soils showed higher and more consistent AS values (57.47–60.21%). SE values derived from AS ranged from 1.13 to 2.30 in cropland, 0.69 to 2.02 in pasture, and 2.35 to 3.10 in forest soils (Fig. 8). Higher AS and SE values in forest soils indicate a more stable, erosion-resistant structure, meaning these soils are less vulnerable to structural degradation. Correlation analysis showed negative associations between AS and both the detachment and erosion rates.

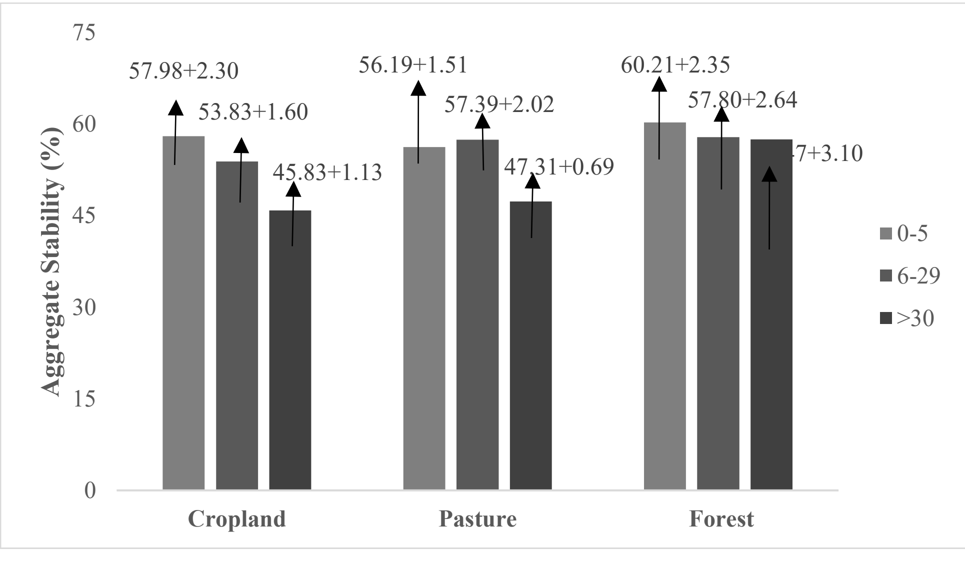

Fig. 8. Variation of AS across land-use types and slope classes

The variation in aggregate stability across land-use types and slope classes reflects the combined influence of topographic conditions and land management on soil resistance to erosion. This relationship is consistent with previous studies demonstrating that natural vegetation enhances aggregate stability and erosion resistance through increased organic matter input and improved structural organization. Higher aggregate stability under natural vegetation has been shown to directly reduce soil detachment and enhance resistance to erosive forces

(Gan et al., 2023). Similarly, Li et al. (2024) identified land-use type as a primary factor controlling aggregate stability, with natural ecosystems consistently exhibiting greater stability than cultivated lands. Aggregate stability decreased with increasing slope gradient, particularly in cropland and pasture soils, reflecting the combined effects of intensified surface runoff and mechanical disturbance on aggregate breakdown and fine particle transport. In contrast, forest soils showed limited variation across slope classes, indicating that continuous vegetation cover buffers rainfall impact and preserves soil structural integrity.

The relationship between aggregate stability and derived structural indices highlights the critical role of soil structure in controlling resistance to erosion. Higher AS and SE values in forest soils indicate a more stable, erosion-resistant structure, meaning these soils are less vulnerable to structural degradation. Correlation analysis showed negative associations between AS and both the detachment and erosion rates. These results demonstrate that higher AS improves soil resistance to erosion by reducing aggregate detachment and limiting fine particle transport.

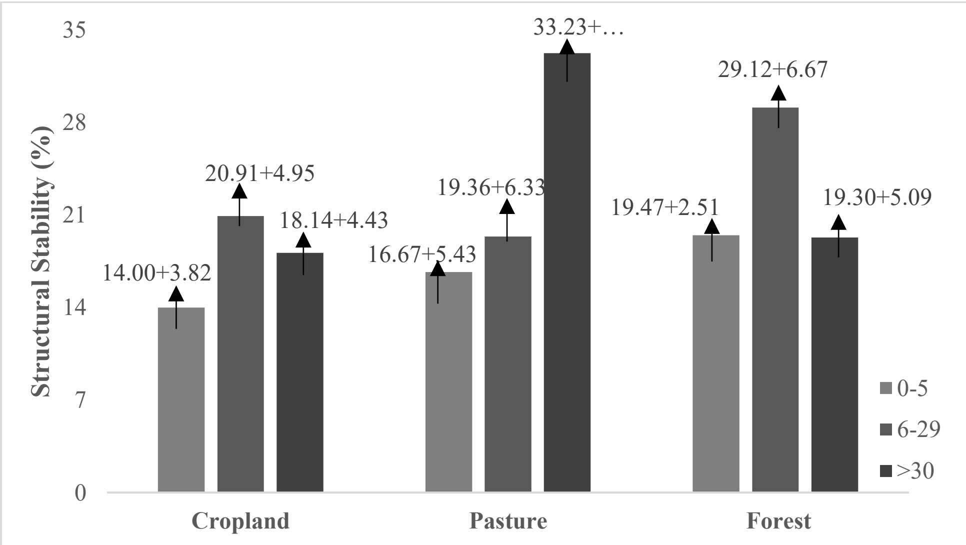

Fig. 9. Variation of SS across land-use types and slope classes

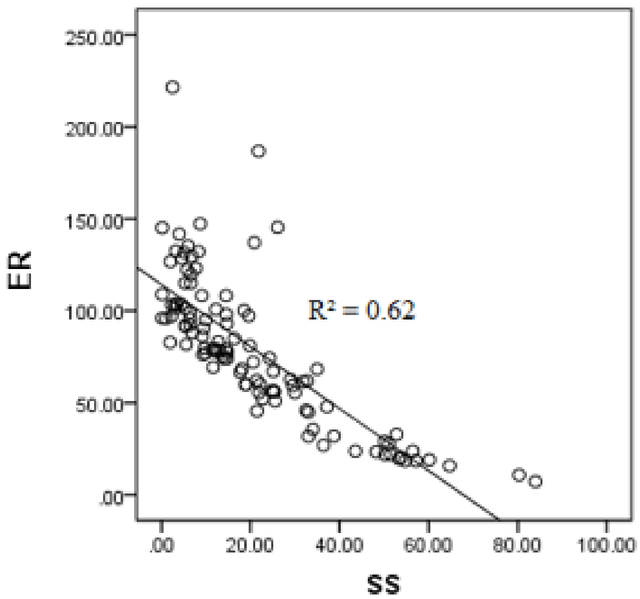

Fig. 10. Relationship SS and ER of soils under different land use types

SS values measured across slope classes and land-use types in the study area indicate that soil structural stability is strongly controlled by both topography and land-use pattern. Values ranged from 14.00 to 20.91 in cropland, 16.67 to 33.23 in pasture, and 19.30 to 29.12 in forest, with high SS values in steep-slope pasture, indicating greater aggregate resistance to disintegration (Table 1, Fig. 9). The SE values, evaluated together with structural stability, ranged from 3.82 to 4.95 in cropland, 5.43 to 6.33 in pasture, and 2.51 to 6.67 in forest. Correlation analysis revealed a negative and statistically significant relationship between the DR and SS (Table 1), indicating that soils with a higher tendency to disperse are more prone to aggregate breakdown and consequently exhibit lower resistance to erosion. This finding highlights the role of soil structural integrity in controlling particle detachment and transport processes. Regression analysis further demonstrated a strong negative association between SS and the ER ($R^2 = 0.62$; Fig. 10), suggesting that increased structural stability enhances aggregate cohesion and reduces susceptibility to erosion. The comparatively higher SE values in pasture suggest that aggregates in these areas form a more stable structure and that overall soil structural stability is greater. The lower SS values in cropland likely result from agricultural practices and tillage weakening aggregate integrity. The interaction between dispersion processes and soil structural properties provides key insights into the mechanisms that control soil erodibility. Correlation analysis revealed that soils with a higher tendency to disperse are more prone to aggregate breakdown and consequently exhibit lower resistance to erosion. This finding highlights the critical role of soil structural integrity in controlling particle detachment and transport processes. The relationship between structural stability and erosion dynamics provides a robust framework for understanding soil resistance to erosive forces. The strength of this relationship indicates that SS is a reliable indicator of soil resistance to erosive forces. SS varied with both land-use type and slope conditions, with more stable structural characteristics observed under natural vegetation. This pattern reflects the combined influence of organic matter accumulation, root development, and reduced mechanical disturbance in these areas. The findings of this study demonstrate that physical soil attributes, particularly aggregate stability and structural stability, serve as robust indicators of soil erodibility. Accordingly, structural stability can be considered a key determinant of soil erodibility in the study area.

4. Conclusion

The investigation of soil erodibility indicators across Tokat Province demonstrated that susceptibility to erosion was strongly influenced by the interaction between land management practices and topographic conditions. Croplands generally exhibited higher dispersion ratios and erosion rates than forest and pasture ecosystems, likely due to intensive tillage practices and seasonal reductions in vegetative cover, which may promote aggregate degradation. In contrast, forest soils exhibited greater aggregate and structural stability, suggesting that natural vegetation enhances resistance to erosion through improved structure and organic matter accumulation. Topographic conditions also influenced erodibility, although the magnitude of this effect varied with land-use type. While increasing slope gradients tended to enhance structural degradation in croplands, pasture areas occasionally exhibited relatively more stable surface conditions, possibly due to the selective removal of finer particles. Overall, the results indicate that erodibility is controlled by the combined effects of physical properties, vegetation cover, and slope conditions. Therefore, conservation practices such as reduced tillage, cover cropping, and protection of vegetative cover on steep slopes may help improve long-term stability and reduce erosion risk in the region. Although the study provides important field-based information, the results are limited to the conditions in Tokat Province and the evaluated land-use systems. Future studies should account for temporal variability, include additional soil quality indicators, and examine different climatic regions.

Acknowledgements

The authors would like to thank the Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Tokat Gaziosmanpaşa University, for its scientific and technical support throughout the study.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology.

Details of the AI usage are given below:

1. AI technologies were used only for language editing and grammatical improvement.

Competing Interests

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/159596