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Original Article

Relationship of Some Soil Physical and Erodibility Factors with Biological Properties

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ABSTRACT

Agriculture is the most necessary sector to meet the food needs of the growing population. Knowing the fertility of soils is a necessary issue for food management. Evaluation of soil physical and biological properties, which are highly effective on productivity, is very important for sustainable management. In this study, the relationships between some soil physical (sand, clay, and silt) and erodibility factors (aggregate stability, structural stability index, clay content, and crust index) and biological properties (organic carbon, microbial biomass carbon, basal respiration, dehydrogenase enzyme activity, urease, and alkaline phosphatase) were investigated. Among the textural fractions, a low but statistically significant negative correlation ($r = 0.22$; $p < .001$) was obtained between sand content and alkaline phosphatase enzyme activity of soils, while positive correlations were found between crust formation index and dehydrogenase ($r = 0.26$; $p < .001$) and urease ($r = 0.33$; $p < .001$) enzyme activities. Significant correlations were also found between biological traits. The highest relationship was found between microbial biomass carbon, basal respiration rate and aggregate stability ($r = -0.36$; $p < .001$). As a result of the study; it was revealed that there were significant relationships between physical parameters of soils and biological properties.

Keywords: Enzyme activity, soil erodibility, textural fraction

Introduction

In a world where the effects of global warming and climate change are increasing day by day, it has been revealed by studies that the productivity level of the soil, where the most important food needs are met, will also be affected (Rosenzweig et al., 2014; Deng et al., 2023). Soil fertility shows the potential for plant growth and agricultural production capacity of land and is determined by the interaction of many indicators. Global warming can affect the water cycle and cause a decrease in water resources. Higher temperatures and increased evaporation lead to reduced soil moisture levels and an increased risk of drought. High levels of drought in soil lead to the deterioration of soil structure and increased soil erosion (Dandapat et al., 2024). In addition, the activities of some microorganisms are negatively affected, leading to a decrease in biological activity in the soil. This negatively affects the balance of soil ecosystems and biodiversity (Brockett et al., 2012; Zheng et al., 2024).

The physical properties of the soil affect processes such as soil fertility, plant growth potential, and water management. Water retention, one of the physical properties of soil, affects plant roots' access to water. While air spaces in the soil provide plant roots with access to oxygen, good drainage, and air circulation support the healthy growth of roots and prevent problems such as rot and degradation in the soil (Gregorich et al., 2015; Hirte et al., 2017). Soil with good structure, aggregate stability, and low erosion sensitivity is an ideal environment for the root development of plants and the uptake of nutrients. Soil compaction, another physical parameter, affects the progression of plant roots through the soil. Its uncompacted structure does not provide optimum conditions for plants to access nutrients and grow, encouraging good soil root development (Frene et al., 2024).

While soil biological properties are effective in the processes of organic matter (OM) decomposition and humus formation, OM decomposition enables the release of nutrients in the soil and facilitates plants' access to these nutrients. It also improves soil structure and increases water retention capacity. The activities of microorganisms increase the formation and stability of soil aggregates, reduce soil erosion, regulate water movement, and ensure aeration (Li et al., 2017; Sun et al., 2024). One of the important factors that enable biochemical reactions

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to occur is enzyme activity in the soil. Enzymes play an active role in regulating a number of biological processes in soil, such as OM decomposition, nutrient cycling, carbon cycling, and plant nutrition. High enzyme activity indicates that biological processes in the soil are active and is an indicator that the soil ecosystem is healthy (Daunoras et al., 2024). High soil respiration, which occurs as a result of the respiration process of microorganisms and other living creatures in the soil, indicates that there is active microbial activity and that OM decomposition is effective (Conant et al., 2011; Ma et al., 2019).

It should be fully revealed how the textural fractions, which are the genetic characteristics of dynamic soil, and the erodibility factors obtained in relation to them are related to biological properties. This study aims to assess the connections between certain soil physical properties, erodibility factors, and biological properties. In this context, the research significantly contributes to the scientific literature on soil studies. In many studies, physical, chemical, and biological properties are evaluated together. In this study, examining the relationship between biological characteristics and erodibility factors is considered the novelty of the study.

Material and Methods

Material

This study was conducted in approximately 13 micro sub-basins located in the Tekkeköy district of Samsun. The Tekkeköy district of Samsun province is located between the coordinates 2760,000–296,000 E and 4548,000–568,000 N (WGS84, Zone 37, UTM m) (Figure 1). It is 1 km south, at 13 km of the Samsun-Ordu highway. It is located inland and the district area covers 225.6 km^2.

The study area is located between 0 and 951 m above sea level. Although the northern and northeastern parts of the study area have slightly sloping lands, the southwest of the area consists of steep and very steep lands with more than 20% slope (Figure 2). The Central Black Sea climate prevails in the district. Summers are hot and humid, winters are mild, and spring and autumn are rainy. The hottest month is August, with an average temperature of 25°C, and the coldest month is January, with an average temperature of 7°C (MGD, 2022). Looking at the geological pattern of the study area, the slightly sloping lands in the north and northeast consist of alluvial deposits, while a large part of it consists of sandstone-mudstone and limestone. Additionally, there are volcanic rocks consisting of basalt and andesite in the southeast of the study area. According to the Old American Soil Classification of the study area (Baldwin et al., 1938), the dominant great soil groups in the area are brown forest soils and gray-brown podzolic soils. Alluvial soils are also found in the northern and northeastern parts of the area (Figure 2).

Method

Soil samples were taken to represent 0–20 cm from the surface. For surface soil sampling, a 0–20 cm soil depth was preferred for representativeness of disturbed samples. Soil samples were taken from 300 different points determined during office work to represent the area. Three hundred disturbed and undisturbed soil samples were taken from different land uses representing 13 micro sub-basins in the study area (Figure 3).

Soil samples taken from the field were made ready for analysis by undergoing preliminary processes such as drying and grinding. The physical and biological analysis methods performed are listed in Table 1.

Boxplot graphics and descriptive statistics of soil properties, correlation matrices (Methane package), and texture fractions (Soil texture package) were determined using the R core program (Anonymous, 2024).

Results and Discussion

In this study, some structural parameters and biological properties were examined. Descriptive statistics of some physical and erodibility properties of soils are given in Table 2.

Sand, silt, and clay contents of the soils varied between 3.17–89.32%, 0.93–89.32%, and 8.57–72.66%, respectively. The clay ratio was determined between 0.376 and 10.65, the crust formation index was determined between 0.73 and 18.37, the structure stability index of the soils was determined as 58.47% on average, and aggregate stability was determined as 62.78%. Boxplot graphs of sand, silt, clay, aggregate stability, and structure stability index are shown in Figure 4. The distribution states of the texture classes are shown in Figure 5. The soils examined in the study are generally classified in medium and heavy texture groups.

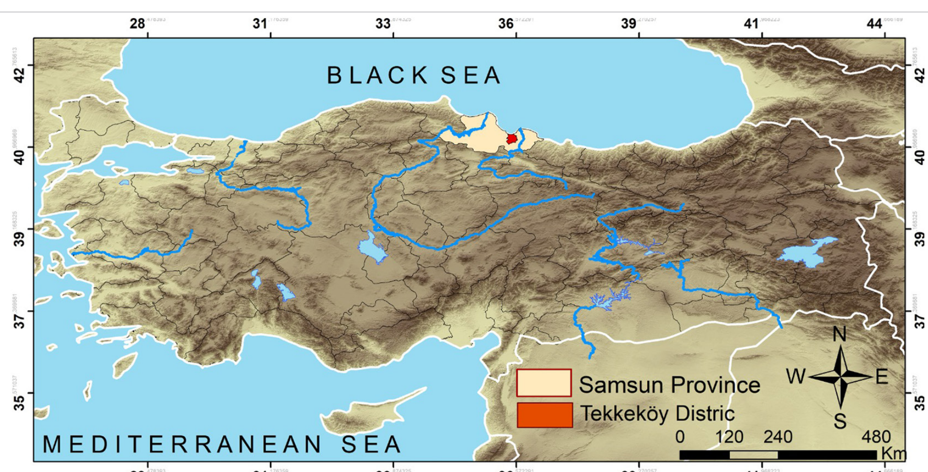

Figure 1.
Study Area Location Map.

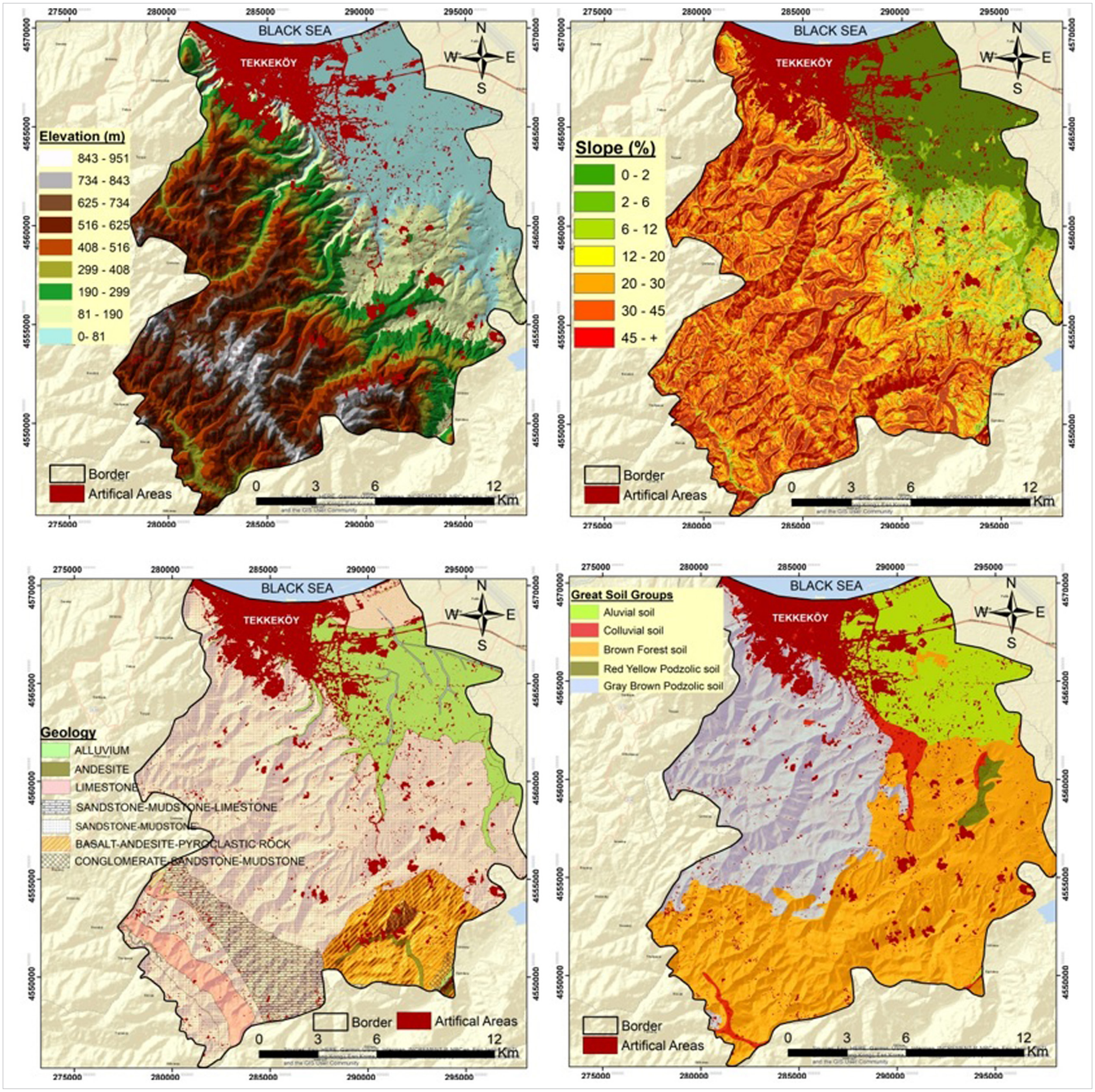

Figure 2.
Elevation, Slope, Geology, and Soil Maps of the Study Area.

Boxplot charts include the first quartile, median–median, and third quartile. While the median is the value in the middle of the data for the variables, the first quartile represents the region between the median and minimum, and the third quartile represents the region between the median and maximum. It is seen that there are both upper and lower outlier values for the upper outlier silt, which deviates from the general distribution in the sand content of the soils. It is observed that there are more outliers in aggregate stability compared to other features, and the general distribution is lower than the median value. This causes the skewness to be negative. A similar situation applies to structural stability. If the structural stability index is greater than 15%, it is resistant to erosion (Alaboz et al., 2021). It can be seen in the boxplot that there is a single outlier value less than 15%. Soils generally have high resilience. Soils with aggregate stability higher than 30% exhibit high durability (Alaboz et al., 2021). Again, the durability of soil samples, except the lower outliers, is high.

Standard deviation is a parameter that shows the spread of the distribution; however, it is not possible to compare different features with each other depending on their magnitude or size. It shows the general

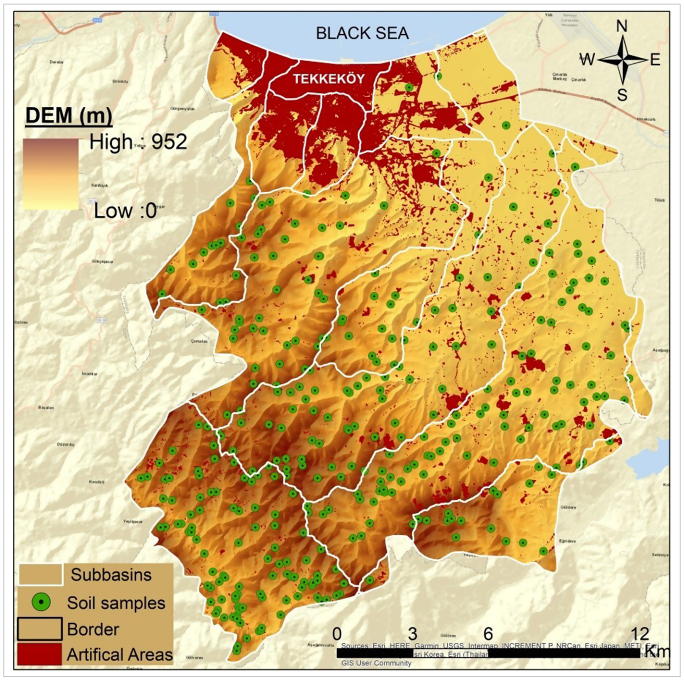

Figure 3.
Soil Sampling Pattern and Sub-basins.

deviation within the data set. For this purpose, the use of the coefficient of variation (CV), which determines the percentage change of the values in the distribution compared to the average, is seen as a more accurate approach.

The CV, used to determine the variability in soil properties, is classified as low (<15%), medium (<35%), and high (>35%) according to Wilding (1985). The highest CV, which varies depending on values deviating from the average, was determined in sand content with 44.51%.

Table 1.
Method of Soil Analysis

Analysis	Unit	Methods
Texture—Bouychous	%	Burt (2014)
Structure stability index—SSİ	%	Leo (1963)
Aggregate stability—AS	%	Kemper and Rosenau (1986)
Clay ratio—CR	%	Bouyoucos (1935)
Crust formation index—CI	%	Pieri (1989)
Organic carbon—OC-Walkey Black	%	Kacar (2009)
Microbial biomass carbon—Cmic	mg C g^{-1} 24 h^{-1}	Anderson and Domsch (1978)
Basal respiration—CO_2	mg C g–^{1} 24 h^{-1}	Anderson, 1982
Dehydrogenase enzyme activity—DHA	µg TPF g^{-1} 24 h^{-1}	Pepper et al. (1995)
Urease—UA	µg N g dry $soil^{-1}$	Hoffmann and Teicher (1961)
Alkaline phosphatase—-AP	µg p-nitrophenol/g soil/hour	Tabatabai and Bremner (1969)

Aggregate stability, SSI, and clay showed "medium" variability, while other properties showed "high" variability.

The crusting index of the soils varies between 0.73 and 18.37, and the clay ratio varies between 0.37 and 10.6. The boxplot graphics are shown in Figure 4. It is seen that there are upper outliers in both parameters and generally higher values than the median value. As a result, the skewness coefficient was positive and had a distribution farther from normal.

Crust formation index and clay ratio were determined among the features with high CV. High deviations from the mean and upper outliers are a result of the high CV. According to Pieri (1989), if the crust index value is less than 5, it is classified as "very severe," between 5 and 7 as "severe," between 7 and 9 as "low," and at values greater than 9, physical degradation is classified as "absent." In the box plot graphics, accumulations at values higher than the median and the third quarter being 6.89 generally indicate that there is severe degradation in the soils. Clay ratio values show a distribution far from normal. Erosion decreased with increased clay content (Ayoubi et al., 2022).

Descriptive statistics of some biological properties of soils are given in Table 3, and boxplot graphs are shown in Figure 6. Organic C content, which plays an important role in the biological activity of soils, varies between 0.35% and 3.81%, and the CV was determined as 43.93%.

Microbial biomass carbon content in soils varied between 5.025 and 74.53 mg C g^{-1} 24 h^{-1}, and basal respiration varied between 0.005 and 0.45 mg C g^{-1} 24 h^{-1}. The presence of upper outliers deviating from the mean values caused the coefficient of variation to be high (Figure 6). Bayraklı et al. (2023) indicated that since most chemical activities in the soil occur through microorganisms, they have an important effect on soil formation and fertility. Therefore, measures of biological activity such as the number of microorganisms in the soil, CO_2 production, and enzyme activity are also accepted as measures of soil fertility. According to their study conducted on hazelnut cultivation areas in the Black Sea region, the average values of urease enzyme and acid phosphatase enzyme activities are 15.35 and 110.17 µg g^{-1}. In the current study, it was found that Dehydrogenase, UA, and AP contents were on average 16.15 µg TPF g^{-1} 24 h^{-1}, 22.59 µg N g dry $soil^{-1}$, 135.04 µg p-nitrophenol/g soil/hour. In addition, statistical distributions of these biological properties exhibited a positive skewness coefficient. The distribution shows positive asymmetry; the mean is larger than the median, it is concentrated on the left side, it is skewed to the right, and the values are generally lower than the mean. It was determined that the upper outliers and deviations from the average were high in the box plot graphics. Microbial biomass carbon/basal respiration represents the ratio of the amount of carbon stored in the cells of microorganisms and the release of carbon dioxide as a result of the metabolic activities of microorganisms. Basal respiration refers to the amount of CO_2 released by microorganisms by breaking down OM to produce energy and sustain life activities. A high ratio may be an indication that microorganisms store more carbon in their cells and require less OM for energy production. The Cmic : CO_2 (metabolic quotient—qCO_2) ratio of the soils varied between 0.08 and 15.53. The metabolic quotient reflects the energy efficiency of the microbial community (Wang & Kuzyakov, 2023). It has been emphasized that parameters such as microbial biomass carbon and soil aggregation, carbon–nitrogen transformations, and the continuity of the nutrient cycle are related (Feng & Balkcom, 2017). Cmic : CO_2 ratio (qCO_2) varies between 0.5 and 2 in healthy agricultural soils. Higher values indicate higher C consumption by microorganisms, whose potential to sequestration C to the soil decreases (Ashraf et al., 2022).

Table 2.
Descriptive Statistics of Some Physical Soil Properties

Proporties	Mean	St. Dev.	CV	Min.	Q1	Med.	Q3	Max.	Skew.	Kurt.
Sand %	35.22	15.67	44.51	3.17	23.58	34.18	47.34	89.32	0.26	−0.5
Silt %	27.49	5.57	20.27	0.93	23.95	27.20	30.91	42.28	−0.22	1.66
Clay %	37.28	14.67	39.37	8.57	24.87	36.56	48.37	72.66	0.28	−0.75
AS %	62.78	13.16	20.96	17.45	55.00	64.92	71.01	93.19	−0.56	0.5
SSI %	58.47	14.50	24.8	10.29	47.21	59.65	69.08	89.49	−0.22	−0.48
CI %	5.38	2.86	53.27	0.73	3.35	4.71	6.89	18.37	1.3	2.55
CR %	2.22	1.56	70.47	0.37	1.06	1.735	3.02	10.65	1.63	3.78

Note: AS = aggregate stability; CR = Clay ratio; CI = Crust formation index; CV = Coefficient of variation; Kurt = Kurtosis; Min = Minimum; Med = Median–median; Max = Highest; Skew = Skewness; SSI = Structure stability index; St. Dev = Standard deviation; Q1 = First quartile.

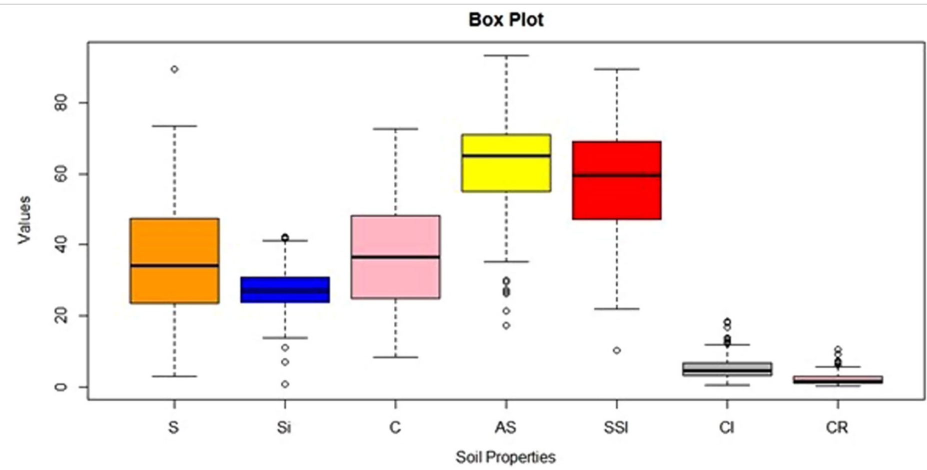

Figure 4.
Boxplot Graphs of Soil Physical and Erodibility Properties. AS = Aggregate stability; SSI = Structure stability index; CR = Clay ratio; CI = Crust formation index; S = Sand; Si = Silt; C = Clay.

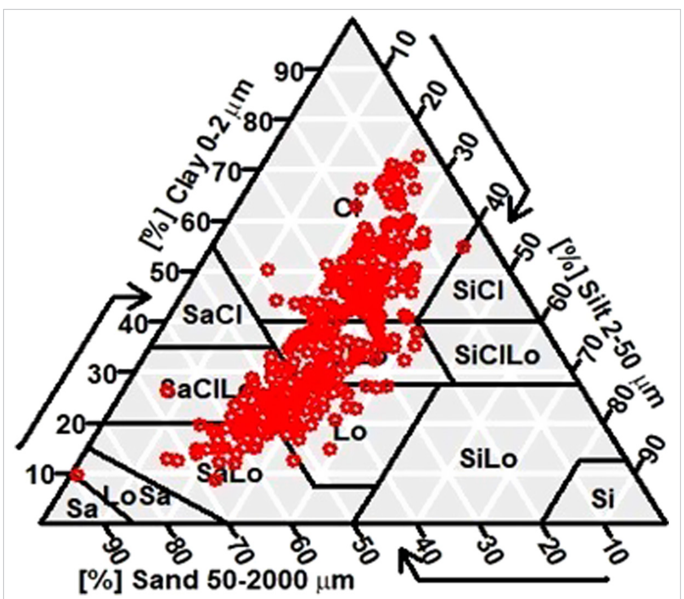

Figure 5.
Distributions of Soil Textural Fractions. Sa = Sand; Lo = Loam, Si = Silt, C = Clay.

Saygın et al. (2023), in a study by which the soil quality of tea cultivation areas was evaluated, the microbial biomass carbon content of the soils was determined as 1.11–32.5 mg C g^{-1} 24 h^{-1}, and the basal respiration to be 0.02–1.84 mg C g^{-1} 24 h^{-1}. Kızılkaya (1998) reported that the urease enzyme activity of soils where rice cultivation was conducted ranged between 24.12 and 39.03 mg N per 100 g dry $soil^{-1}$. Abdo et al. (2022) stated that the urease enzyme is produced by the hydrolysis of urea molecules by microorganisms in the soil and plays an important role in the soil nitrogen cycle.

The correlation matrix between biological and physical properties of soils is shown in Figure 7. Positive relationships were detected between dehydrogenase enzyme activity, crusting index (r = .26; p < .001), and basal respiration (r = .32; p < .001). Singh et al. (2018) examined the relationship between dehydrogenase enzyme activity and soil properties in agricultural soils under different management; they stated that dehydrogenase enzyme activity exhibited a positive relationship with factors such as soil pH, soil moisture content, OM, and soil texture. Meena and Rao (2021) found that there is a positive relationship between dehydrogenase enzyme activity and basal respiration. As a result, high basal respiration was generally observed in soils with high dehydrogenase enzyme activity.

When the correlation matrix of soil properties is examined, urease enzyme activity and crusting index (r = .33; p < .001), basal respiration

Table 3.
Descriptive Statistics of Some Biological Soil Properties

Proporties	Mean	St. Dev.	CV	Min.	Q1	Med.	Q3	Max.	Skew.	Kurt.
Corg %	1.89	0.83	43.93	0.35	1.27	1.73	2.48	3.81	0.51	−0.58
Cmic mg C 24 h^{-1}	25.67	12.04	46.88	5.025	16.66	22.99	33.55	74.53	0.68	0.23
BR mg CO_2 24 h^{-1}	0.13	0.07	54.68	0.005	0.08	0.12	0.16	0.45	1.1	1.65
Cmic : CO_2	0.43	0.23	53.93	0.08	0.27	0.37	0.49	15.53	1.79	4.36
DHA µg TPF g^{-1} 24 h^{-1}	16.15	8.03	49.76	0.07	11.07	15.88	20.90	40.50	0.42	0.29
UA µg Ng dry $soil^{-1}$	22.59	14.65	64.86	2.56	12.30	19.42	27.94	94.75	1.85	4.7
AP µg p-nitrophenol/ g soil/hour	135.04	47.33	35.05	4.21	103.10	138.43	174.64	446.69	0.37	4.78

AP = Alkaline phosphatase; BR = Basal respiration; CV = Coefficient of variation; Cmic = Microbial biomass carbon; Corg = Organic carbon; DHA = Dehydrogenase enzyme activity; Kurt. = Kurtosis; Med = Median; Max = Highest; Min = Lowest; Q1 = First quartile; St. Dev. = Standard deviation; Skew = Skewness; TPF = Triphenyl-formazan; UA = Urease.

($r = .37$; $p < .001$), alkaline phosphatase enzyme ($r = .34$; $p < .001$), organic carbon ($r = .47$; $p > .001$), and microbial biomass carbon ($r = .43$; $p < .001$). Cmic : CO_2 ratio and crusting index ($r = -.48$; $p < .001$), aggregate stability (r = statistically significant negative relationships were determined between 0.36; $p < .001$) and silt ($r = -.27$; $p < .001$), and positive ($r = .24$; $p < .001$) relationships between structural stability and alkaline phosphatase. Wei et al. (2014) evaluated AP activity as more sensitive to processing in aggregates between 0.25 and 1 mm. In the study, positive significant relationships were found between basal respiration and microbial biomass carbon. Similar results were also revealed by Rahman et al. (2024).

In addition, a low positive relationship between aggregate stability and urease enzyme activity was detected. Urease is the enzyme responsible for the separation of urea, which is the final process of the organic phase. While Chakrabarti et al. (2004) stated that urease activity in soils depends on the OM–enzyme complex, humus C in organic material was evaluated as effective in urease activity. In the same study, it was stated that urease activity exhibited a positive correlation with clay and OM content. The detection of a significant negative high correlation ($r = -.64$; $p < .001$) between organic carbon and Cmic : CO_2 ratio is noteworthy. As mentioned before, a negative relationship is expected as a high ratio may indicate that microorganisms store more carbon in their cells and need less OM for energy production. A low Cmic : CO_2 ratio (qCO_2) means better growth and less C released into the atmosphere. Dengiz et al. (2013) studied variables of microbial response in soil aggregates for soil characterization formed on Bafra Delta Plain. It was determined that the Corg content varies between 0.41% and 0.91% in soil samples. Cmic content was also found at a higher level in aggregates involved <250 and 250–425 µm diameters compared to other aggregate size classes. Moreover, we detected that the Corg:Cmic ratio was much higher in macroaggregates than in microaggregate fractions. BR levels were also greater in macroaggregates of >6300, 4750–6300, and 2000–4750 µm than in the other macroaggregate sizes and microaggregates. According to their conclusion, it showed that microbial habitats and their response to different soil aggregate sizes formed in various developed soils.

Liu et al. (2020) reported that urease enzyme activity showed positive correlations with factors such as soil pH, moisture, OM, and total nitrogen, while Xu et al. (2021) stated that there was a positive correlation between urease enzyme activity and alkaline phosphatase. Similar results were reported by Wang et al. (2018). In the study, significant negative and positive relationships were detected between alkaline phosphatase and sand. In the literature, the existence of a negative correlation between alkaline phosphatase and sand content

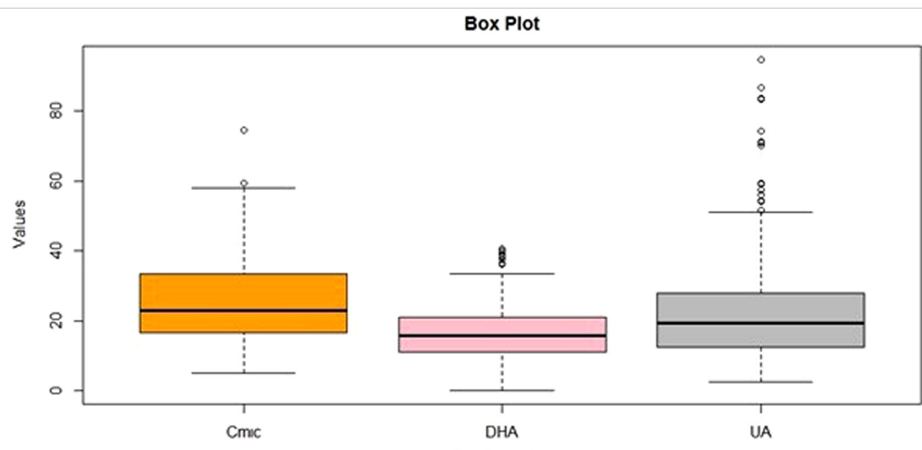

Figure 6.
Boxplot Graphs of Some Soil Biological Parameters. Cmic = Microbial biomass carbon; DHA = Dehydrogenase enzyme activity; UA = Urease.

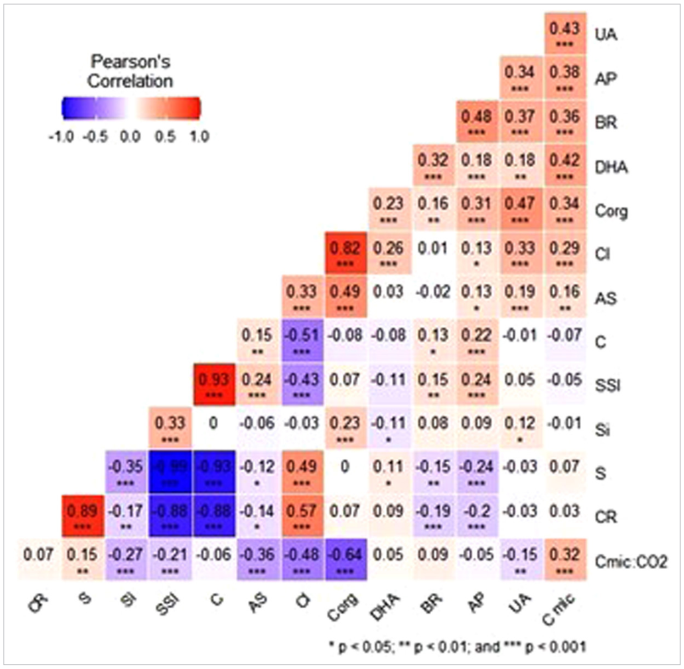

Figure 7.
Correlation Matrix between Biological and Physical Properties of Soils. AS = Aggregate stability; SSI = Structure stability index; CR = Clay ratio; CI = Crust formation index; OC = Organic carbon; Cmic = Microbial biomass carbon; CO_2 = Basal respiration; DHA = Dehydrogenase enzyme activity; UA = Urease; AP = Alkaline phosphatase; C = Clay; Si = Silt; S = Sand.

has been revealed (Tunç et al., 2022). It was reported by Erdel (2022) that the highest urease and catalase activity was determined in macro aggregates (0.850–0.425 mm aggregate size), and this is because macro aggregates contain more organic matter and organic carbon than micro aggregates.

Conclusion and Recommendations

In this study, the relationship between some soil physical properties and erodibility factors and soil biological properties was examined. It has been determined that biological properties exhibit significant correlations within the study soils, where the medium texture group dominates. Significant relationships were determined between textural fractions and alkaline phosphatase enzyme activity, dehydrogenase and Cmic/CO_2 ratio, and erosion sensitivity parameters.

The study reveals that soil physical properties have an impact on biological properties as well. It has been evaluated that while improving physical conditions, biological properties will be positively affected. Additionally, soil structure has been considered an important property for ecological balance. Carrying out this study on soils with a temperate climate is considered the limit of the study. Differences in climate, which is one of the soil-forming processes, affect many soil properties. In future studies, it is planned to reveal the effect of climate in arid regions where fragmentation and weathering are active.

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References

- Abdo, A. I., Xu, Y., Shi, D., Li, J., Li, H., El-Sappah, A. H., Elrys, A. S., Alharbi, S. A., Zhou, C., Wang, L., & Kuzyakov, Y., Alharbi, S. A., Zhou, C., Wang, L., & Kuzyakov, Y. (2022). Nitrogen transformation genes and ammonia emission from soil under biochar and urease inhibitor application. *Soil and Tillage Research*, *223*, 105491. [CrossRef]
- Alaboz, P., Dengiz, O., Demir, S., & Şenol, H. (2021). Digital mapping of soil erodibility factors based on decision tree using geostatistical approaches in terrestrial ecosystem. *CATENA*, *207*, 105634. [CrossRef]
- Anderson, J. P. E. (1982). Soil respiration. In A. L. Page, R. H. Miller & D. R. Keeney (Eds.). *Methods of soil analysis: Part 2 - Chemical and microbiological properties. second ed. Agronomy Monographs*, *9* (pp. 831–871). ASA and Madison, WI: SSSA. [CrossRef]
- Anderson, T. H., & Domsch, K. H. A. (1978). A Physiological method for the quantitative measurement of microbial biomass in soils. *Soil Biology and Biochemistry*, *10*(3), 215–221, [CrossRef]
- Anonymous (2024). *The R project for statistical computing*. https://www.r-project.org/.
- Ashraf, M. N., Waqas, M. A., & Rahman, S. (2022). Microbial metabolic quotient is a dynamic indicator of soil health: Trends, implications and perspectives (Review). *Eurasian Soil Science*, *55*(12), 1794–1803. [CrossRef]
- Ayoubi, S., Milikian, A., Mosaddeghi, M. R., Zeraatpisheh, M., & Zhao, S. (2022). Impacts of clay content and type on shear strength and splash erosion of clay–sand mixtures. *Minerals*, *12*(11), 1339. [CrossRef]
- Baldwin, M., Kellog, E. C., & Throp, J. (1938). *Soil classification. Yearbook of agriculture, USDA* (pp. 979–1001). Indianapolis: Bobbs-Merrill.
- Bayraklı, B., Dengiz, O., & Kars, N. (2023). Soil quality assessment based on MCDA–GIS hybrid approach for sustainable hazelnut farming under humid ecosystem environment. *Rendiconti Lincei. Scienze Fisiche e Naturali*, *34*(3), 921–940. [CrossRef]
- Bouyoucos, G. J. (1935). The clay ratio as a criterion of soils to erosion. *Agronomy Journal*, *27*(9), 738–741. [CrossRef]
- Brockett, B. F. T., Prescott, C. E., & Grayston, S. J. (2012). Soil moisture is the major factor influencing microbial community structure and enzyme activities across seven biogeoclimatic zones in western Canada. *Soil Biology and Biochemistry*, *44*(1), 9–20. [CrossRef]
- Burt, R. (2014). Soil survey field and laboratory methods manual. *United States Department of Agriculture*. Natural Resources Conservation Service. National Soil Survey Center. Kellog Soil Survey Laboratory.
- Chakrabarti, K., Sinha, N., Chakraborty, A., & Bhattacharyya, P. (2004). Influence of soil properties on urease activity under different agro-ecosystems. *Archives of Agronomy and Soil Science*, *50*(4–5), 477–483. [CrossRef]
- Conant, R. T., Ryan, M. G., Ågren, G. I., Birge, H. E., Davidson, E. A., Eliasson, P. E., Evans, S. E., Frey, S. D., Giardina, C. P., Hopkins, F. M., Hyvönen, R., Kirschbaum, M. U. F., Lavallee, J. M., Leifeld, J., Parton, W. J., Megan Steinweg, J., Wallenstein, M. D., Martin Wetterstedt, J. Å., & Bradford, M. A. (2011). Temperature and soil organic matter decomposition rates—Synthesis of current knowledge and a way forward. *Global Change Biology*, *17*(11), 3392–3404. [CrossRef]
- Dandapat, A. K., Panda, P. K., Sankalp, S., & Jothimani, M. (2024). Quantifying soil erosion in drought-impacted central Odisha, India, through geospatial mapping with RUSLE. *Applied and Environmental Soil Science*, *2024*, 1–14. [CrossRef]
- Daunoras, J., Kačergius, A., & Gudiukaitė, R. (2024). Role of soil microbiota enzymes in soil health and activity changes depending on climate change and the type of soil ecosystem. *Biology*, *13*(2), 85. [CrossRef]
- Deng, X., Huang, Y., Yuan, W., Zhang, W., Ciais, P., Dong, W., Smith, P., & Qin, Z. (2023). Building soil to reduce climate change impacts on global crop yield. *Science of the Total Environment*, *903*, 166711. [CrossRef]
- Dengiz, O., Kızılkaya, R., Erkoçak, A., & Durmuş, M. (2013). Variables of microbial response in natural soil aggregates for soil characterization in different fluvial land shapes. *Geomicrobiology Journal*, *30*(2), 100–107. [CrossRef]
- Erdel, E. (2022). Effects of salinity and alkalinity on soil enzyme activities in soil aggregates of different sizes. *Eurasian Soil Science*, *55*(6), 759–765. [CrossRef]

- Feng, Y., & Balkcom, K. S. (2017). Nutrient cycling and soil biology in row crop systems under intensive tillage. In *Soil health and intensification of agroecosytems* (pp. 231–255). Cambridge: Academic Press.
- Frene, J. P., Pandey, B. K., & Castrillo, G. (2024). Under pressure: Elucidating soil compaction and its effect on soil functions. *Plant and Soil*, 1–12. [CrossRef]
- Gregorich, E. G., Beare, M. H., St-Georges, & P. (2015). Compaction effects on soil pore size and soil respiration in a mollisol after two decades. *Soil and Tillage Research*, *146*, 250–259.
- Hirte, J., Leue, M., & Leinweber, P. (2017). Impact of compaction and organic matter addition on pore structure, microbial biomass and enzyme activity of arable soils. *Journal of Plant Nutrition and Soil Science*, *180*(2), 168–176.
- Hoffmann, G. G., & Teicher, K. (1961). Ein kolorimetrisches Verfahren zur Bestimmung der urease Aktivitat in Boden. *Z. Pflanzenernahr. Dung. Bodenk.*, *91*, 55–63.
- Kacar, B. (2009). *Soil analyses* p. 467. Ankara: Nobel Publication Distribution.
- Kemper, W. D., & Rosenau, R. C. (1986). Aggregate stability and size distribution. In A. Klute (Ed.). *Methods of soil analysis, Part I-Physical and Mineralogical Methods* (2nd ed), 425–442. Wisconsin: SSSA Book Series No: 5, SSA and ASA: Madison Book Company. [CrossRef]
- Kızılkaya, R., Arcak, S., Horuz, A., & Karaca, A. (1998). Enzyme activities of paddy soils and relationships with the soil properties. *Pamukkale University Journal of Engineering Sciences*, *4*(3), 797–804
- Leo, W. M. (1963). A rapid method for estimating structural stability of soils. *Soil Science 96*: 342-346.
- Li, S. Y., Wu, J. S., Yang, L. Z., Li, D. C., & Wu, X. P. (2017). Microbial community structure and enzyme activities in response to temperature and moisture gradients in a paddy soil. *Scientific Reports*, *7*(1), 1.
- Liu, Y. M., Cao, W. Q., Chen, X. X., Yu, B. G., Lang, M., Chen, X. P., & Zou, C. Q. (2020). The responses of soil enzyme activities, microbial biomass and microbial community structure to nine years of varied zinc application rates. *Science of The Total Environment*, *737*, 140245.
- Ma, S., Chen, J., Ji, C., Liu, C., & Wang, S. (2019). Temperature sensitivity of soil respiration is affected by prevailing environmental conditions during the six-year warming and nitrogen addition in a meadow steppe. *Soil Biology and Biochemistry*, *130*, 52–60.
- Madison, W. I. *ASA and SSSA* (pp. 837–871)
- Meena, A., & Rao, K. S. (2021). Assessment of soil microbial and enzyme activity in the rhizosphere zone under different land use/cover of a semi-arid region, India. *Ecological Processes*, *10*(1), 1.
- Meteorology General Directorate (MGD) (2020). http://www. mgm.gov.tr / veridegerlendirme/yillik-toplam-yagis verileri .aspx #sfU.
- Pepper, I. L., Gerba, C. P., & Brendecke, J. W. (1995). *Environmental microbiology: A laboratory manual*. Academic Press, Inc.
- Pieri, C. (1989). Fertilité des terres de savanes. *Bilan de trente ans de recherche et de développement agricoles au sud du Sahara*. CIRAD-IRAT.
- Rahman, M. M., Maqbool, N., Ay, A., Gülser, C., & Kizilkaya, R. (2024). Role of hazelnut husk compost and phosphate solubilizing bacteria in improving productivity and quality parameters of wheat (Triticum aestivum L.) and their effects on some soil biological properties. *Communications in Soil Science and Plant Analysis*, *55*(13), 2042–2058. [CrossRef]
- Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., Boote, K. J., Folberth, C., Glotter, M., Khabarov, N., Neumann, K., Piontek, F., Pugh, T. A. M., Schmid, E., Stehfest, E., Yang, H., & Jones, J. W. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(9), 3268–3273. [CrossRef]
- Saygın, F., Şavşatlı, Y., Dengiz, O., Yazıcı, K., Namlı, A., Karataş, A., Şenol, N. D., Akça, M. O., Pacci, S., Karapıçak, B., Ay, A., & Demirkaya, S. (2023). Soil quality assessment based on hybrid computational approach with spatial multi-criteria analysis and geographical information system for sustainable tea cultivation. *Journal of Agricultural Science*, *161*(2), 187–204. [CrossRef]
- Singh, G., Bhattacharyya, R., Das, T. K., Sharma, A. R., Ghosh, A., Das, S., & Jha, P. (2018). Crop rotation and residue management effects on soil enzyme activities, glomalin and aggregate stability under zero tillage in the Indo-Gangetic Plains. *Soil and Tillage Research*, *184*, 291–300. [CrossRef]
- Sun, F., Xiao, B., & Tuller, M. (2024). Multifaceted impacts of moss-dominated biocrusts on dryland soils: From soil pore structure to aeration and water infiltration. *CATENA*, *236*, 107755. [CrossRef]
- Tabatabai, M. A., & Bremner, J. M. (1969). Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biology and Biochemistry*, *1*(4), 301–307. [CrossRef]
- Tunç, E., Könez, Y., Çelik, Ö., & Demir, M. (2022). Investıgatıon of alkali phosphatase enzyme activity of Gaziantep agricultural soils. *International Journal of Energy and Engineering Sciences*, *7*(2), 76–87.
- Wang, C., & Kuzyakov, Y. (2023). Energy use efficiency of soil microorganisms: Driven by carbon recycling and reduction. *Global Change Biology*, *29*(22), 6170–6187. [CrossRef]
- Wang, R., Sun, Q., Wang, Y., Zheng, W., Yao, L., Hu, Y., & Guo, S. (2018). Contrasting responses of soil respiration and temperature sensitivity to land use types: Cropland vs. apple orchard on the Chinese Loess Plateau. *Science of the Total Environment*, *621*, 425–433. [CrossRef]
- Wei, K., Chen, Z. H., Zhang, X. P., Liang, W. J., & Chen, L. J. (2014). Tillage effects on phosphorus composition and phosphatase activities in soil aggregates. *Geoderma*, *217–218*, 37–44. [CrossRef]
- Wilding, L. P. (1985). Spatial variability: Its documentation, accommodation and implication to soil surveys. In D. R. Nielsen & J. Bouma (Eds.). *Soil spatial variability: Pudoc* (pp. 166–194p). Wageningen: Netherlands.
- Xu, H., Qu, Q., Chen, Y., Liu, G., & Xue, S. (2021). Responses of soil enzyme activity and soil organic carbon stability over time after cropland abandonment in different vegetation zones of the Loess Plateau of China. *CATENA*, *196*, 104812. [CrossRef]
- Zheng, X., Wei, L., Lv, W., Zhang, H., Zhang, Y., Zhang, H., Zhang, H., Zhu, Z., Ge, T., & Zhang, W., Zhu, Z., Ge, T., & Zhang, W. (2024). Long-term bioorganic and organic fertilization improved soil quality and multifunctionality under continuous cropping in watermelon. *Agriculture, Ecosystems and Environment*, *359*, 108721. [CrossRef]