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Morphological Characteristics and Changes in Chemical Properties of Sandy Soil Under Chili Plants in Erosion-prone Areas, Ternate, Indonesia

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ABSTRACT

Sandy soils are characterized by their loose texture, low water-holding capacity, and generally low organic matter content, all of which significantly influence soil chemical properties. Soil chemistry serves as a critical indicator of soil fertility and directly affects plant productivity. This study aimed to analyze both the morphological characteristics and the changes in chemical properties of sandy soils cultivated with chili plants in erosion-prone areas. A descriptive quantitative method was employed, with soil samples collected before planting and after harvest. Sampling followed the standards outlined in the USDA Field Book for Describing and Sampling Soils. The chemical parameters analyzed included soil pH (H_2O), soil organic carbon, total nitrogen, available phosphorus (P_2O_5), and potassium (K_2O). The results indicated measurable changes in all tested soil chemical properties. The sandy soils in the study area were classified as Inceptisols, distinguished by horizon differentiation observed in the subsoil layer. Post-harvest analysis revealed increases in organic carbon, total nitrogen, and available phosphorus levels, while pH and potassium concentrations decreased. These findings suggest that agricultural activity in erosion-prone sandy soils can influence nutrient dynamics, potentially supporting sustainable vegetative conservation practices. Appropriate land management strategies—such as the incorporation of organic matter, implementation of terracing, and adoption of agroforestry systems—are strongly recommended to mitigate soil degradation and enhance agricultural productivity. Furthermore, this study supports the objectives of Sustainable Development Goal's (SDGs) 15, which advocates for sustainable land use to combat soil degradation and promote ecosystem resilience.

Keywords: *erosion, land degradation, soil chemical properties, soil conservation, soil fertility*

INTRODUCTION

Soil plays a fundamental role in agricultural productivity, serving as both a growth medium and a primary source of nutrients for plants (Jannah & Pagiu, 2021). Globally, soils vary widely in their physical and chemical characteristics, influencing land use and crop potential. One such type is sandy soil, which is characterized by rapid infiltration, susceptibility to drought and erosion, low water-holding capacity, and generally low fertility (Yost & Hartemink, 2019). According to the World Reference Base (WRB) classification system, sandy soils are dominated by coarse particles (70% in the 0.05–2.0 mm range) and contain only about 15% fine particles (<0.002 mm) (FAO WRB, 2014). These soils occupy approximately 31% of the global land surface, covering nearly 5 billion hectares (Huang & Hartemink, 2020; Franz *et al*., 2025), and are commonly found in volcanic regions due to the deposition of easily weathered pyroclastic materials following eruptions.

A key aspect of soil function is its chemical composition, which is critical in maintaining fertility and supporting plant growth. Soil chemical properties such as pH, organic carbon, nitrogen, phosphorus, and potassium are dynamic and can be influenced by several factors, including land management practices, cropping systems, and environmental stressors like erosion. Erosion, in particular is prevalent in areas with moderate to very steep slopes (15% – >40%), including volcanic landscapes such as Ternate Island. Located at the foot of Mount Gamalama an active volcano Ternate's varied topography makes it highly prone to erosion, especially in agricultural zones (Hidayat *et al*., 2022). The erosional process begins with the impact of raindrops that dislodge and transport topsoil, which is typically rich in organic matter and nutrients. This leads to decreased soil fertility and reduced productivity (Di Stefano & Ferro, 2016; Tian *et al.,* 2020; Zhang *et al*., 2025). Surface runoff, resulting from rainfall exceeding infiltration capacity, further accelerates hillslope erosion (van Dijk & Kwaad, 1996).

Erosion control efforts often involve vegetative measures that protect the soil surface. However, monoculture systems, though commonly used, may exacerbate land degradation over time (Kassa *et al*., 2017). Continuous monoculture practices have been linked to increased erosion, declining soil nutrients (Chatterjee *et al*., 2022), reduced biomass production (Aji *et al*., 2020), and loss of soil fertility (Hartati *et al*., 2023). Recent studies show that erosion rates in monoculture-based industrial timber plantations (HTI) are significantly higher (0.19 tons ha^{-1}) compared to those in agroforestry systems (0.06 tons ha^{-1}) (Lias *et al*., 2024).

This study aims to assess the morphological characteristics and changes in chemical properties of sandy soils cultivated with chili plants in erosion-prone areas. The findings are expected to contribute to sustainable land management strategies and offer practical recommendations to mitigate the adverse impacts of monoculture practices on soil fertility.

MATERIALS AND METHODS

Study area

This study was conducted on Ternate Island, located between 0°25’41.82”–1°21’21.78”N and 126°07’32.14”–127°26’23.12”E. Administratively, the research area is situated in Loto Village, West Ternate Sub-district, Ternate City, North Maluku Province, Indonesia (Figure 1). The topography of the study site is classified as moderately steep, with slopes ranging from 15% to 25%, based on direct field measurements. According to rainfall data from the Meteorology, Climatology, and Geophysics Agency (BMKG), the average annual precipitation in the area ranges from 2.000 to 2.300 mm.

Soil sampling and morphological observation

Soil sampling was conducted in a horticultural monoculture system cultivated with chili plants. Morphological observations were carried out directly in the field using standard soil profile description techniques. Soil samples for chemical analysis were collected at two stages: before planting and after harvest. Samples were taken from the topsoil (0–30 cm), which represents the effective root zone for most horticultural crops. All soil sampling followed the guidelines outlined in the *USDA Field Book for Describing and Sampling Soils* (Soil Survey Staff, 2024). Soil chemical analyses were performed in accordance with the laboratory protocols established by the Agricultural Instrument Standardization Agency, Ministry of Agriculture, Indonesia.

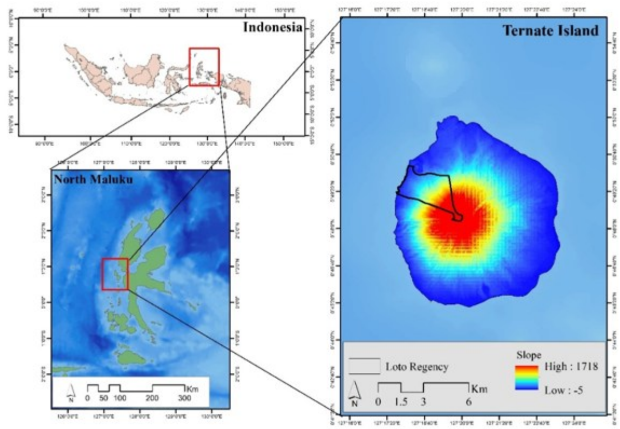

Figure 1. Administrative map of the research area

Soil chemical analysis

The following soil chemical properties were analyzed, soil pH measured in a 1:5 soil-to-water ratio using an electrometric method (pH meter), soil organic carbon (SOC) determined using the Walkley and Black wet oxidation method, total nitrogen (N) measured using the Kjeldahl titrimetric method, available phosphorus (P_2O_5) determined by the Olsen extraction method and quantified using a spectrophotometer available potassium (K_2O) measured using Atomic Absorption Spectrophotometry (AAS).

RESULTS AND DISCUSSION

Characteristics of soil morphology

The morphological characteristics of the soil in the study area have been presented in Table 1. Based on morphological observations in the field, the soil classification at the study site is Inceptisols. Inceptisols are classified as young soils or newly developed soil types. The level of development is still relatively weak (Hartati *et al*., 2020).

The parent material of the Inceptisols in the study area originates from recent volcanic ash deposits produced by the eruption of Mount Gamalama. Volcanic activity plays a significant role in influencing soil development, morphological characteristics, and the dynamic processes of the surrounding pedogenic cycle (Nurcholis *et al*., 2019; Aji *et al*., 2024). The soil at the research site exhibits con-

Table 1. Characteristic of soil morphology

Parent Material	Horizon	Soil Depth (cm)	Texture	Color	Structure	Consistency	Root	Soil Classification (Order)
	Ap	0 – 30	Sandy Loam	10YR2/2	Subangular Blocky	Slightly sticky	Meso	
Weathering of Volcanic Ash	Bw1/C	30 – 50	Sandy Loam	10YR3/6	Angular Blocky	Slightly sticky	Meso	Inceptisols
	Bw2	50 – 75	Loam	10YR3/4	Subangular Blocky	Slightly sticky	Meso	

siderable depth, generally exceeding 60 cm. This substantial soil thickness is indicative of successive pedogenetic processes, primarily the accumulation and sedimentation of volcanic ash material (Noviyanto, 2024). The soil morphology at the site is stratified into three distinct horizons (Figure 2). These horizons have developed through pedogenic processes such as eluviation and illuviation, resulting in the formation of a cambic horizon (Bw). The development of these horizons is attributed to ongoing physical and chemical transformations within the soil profile (Mulyadi & Makhrawie, 2023).

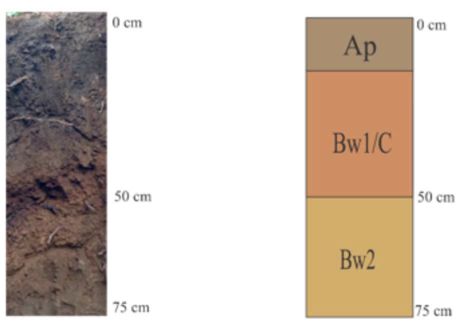

Figure 2. Soil profile and soil horizon

The soil structure has formed clods and it is believed that the soil has sufficient pore space for rooting media. The consistency of the morphology at the research site is also in the somewhat sticky category. The level of soil consistency is influenced by the condition of the soil texture. Furthermore, rooting at the research site is classified as meso. This means that a good pore space already has a good number of voids so that the roots can penetrate into the soil body.

Soil chemistry exchanging

Soil sampling to determine changes in soil chemical properties was carried out twice, before planting and after harvesting, which are presented in Table 2.

Based on the analytical results, the initial soil pH (measured in H_2O) at the research site was neutral, with a value of 7.4. However, following cultivation, the pH declined to a slightly acidic level of 6.22. Typically, the surface or plow layer contains a substantial amount of humus and decomposed organic tion, the pH declined to a slightly acidic level of 6.22. Typically, the surface or plow layer contains a substantial amount of humus and decomposed organic matter, which significantly influences soil pH. As noted by Nangaro et al. (2021), although soils exhibit stratification, the topsoil remains the most critical layer for plant growth due to its higher organic matter content relative to subsoil layers. The slightly acidic pH is attributed to the incomplete decomposition of organic matter. Soils initially classified as alkaline tend to acidify over time as a result of waterlogging and microbial decomposition of organic materials, which generates CO_2 and subsequently forms carbonic acid (Patti *et al*., 2013). Furthermore, acidification processes are reinforced by the formation of iron sulfate ($FeSO_4$) and aluminum sulfate ($Al_2(SO_4)_3$), both of which negatively impact soil fertility (Santri *et al*., 2021).

The soil organic carbon (SOC) content at the study site was recorded at 1.5% during the initial stage and increased to 1.81% after harvest. This enhancement is primarily attributed to anthropogenic intervention, specifically the application of 20 tons/ha of organic fertilizer. SOC is widely recognized as a key indicator of soil fertility and quality. The incorporation of organic amendments can accelerate SOC accumulation (Rofita *et al*., 2022). However, the observed increase in SOC was not significantly affected by planting position. The research site is dominated by sandy-textured soils and is situated within an erosion-prone zone. Consequently, geomorphological processes, particularly severe surface erosion, are prevalent. Erosive forces facilitate the detachment and transportation of soil particles by rainfall, leading to land degradation and, potentially, desertification (Sari *et al*., 2023).

Total nitrogen content was low at both the initial and final measurements, with only a slight increase post-harvest. The marginal rise in nitrogen levels may be linked to fertilization practices; however, the overall low levels are likely due to previous agronomic activities, such as crop harvesting, which depletes soil nitrogen (Aqidah *et al*., 2024). As noted by Patti *et al*. (2013), nitrogen concentrations may be reduced significantly prior to harvest due to increased plant uptake for grain development. Additionally, elevated temperatures in the study area may enhance evaporation, further reducing nitrogen availability (Purwanto & Alam, 2020). Considering its critical role in plant physiological functions, nitrogen content must be carefully managed to sustain productivity (Utami *et al*., 2020).

Phosphorus (P_2O_5) levels showed an increase from pre- to post-cultivation, although they remained within the medium category. The mineralization of organic matter influences phosphorus availability by releasing both inorganic phosphate (PO_4^{3-}) and organic phosphorus compounds such as phytin and nucleic acids, which are accessible to plants (Alori et *al*., 2017). In contrast, potassium (K_2O) levels declined markedly after harvest, primarily due to nutrient leaching and the intrinsic mobility of potassium in the soil matrix. Moreover, the sandy texture dominant in the study area further contributes to low potassium retention, as coarse-textured soils typically possess reduced cation exchange capacity and lower nutrient reserves (Melsasail *et al*., 2019).

Effective land management in erosion-prone sloped areas should prioritize slope stabilization. Erosion can expose subsoil layers with reduced clay content, thereby altering soil physical and chemical properties (Noviyanto *et al*., 2020). Recommended strategies for erosion control and fertility improvement include the incorporation of organic matter, the use of drip irrigation systems, and the application of organic fertilizers (Avianto *et al*., 2024).

Table 2. Changes in soil chemical properties

No	Soil Parameter	Results	
		Pre – Planting	Post – Harvest
1	pH H_2O (1:5)	7.4 (n)	6.22 (sa)
2	Soil Organic Carbon (%)	1.5 (l)	1.81 (l)
3	Total Nitrogen (%)	0.02 (vl)	0.12 (l)
4	P_2O_5 (ppm)	21 (m)	30.97 (m)
5	K_2O (mg 100 g^{-1})	57 (h)	23 (m)

Note: Neutral (n); Very Low (vl); Low (l); Moderate (m); High (h). Slightly acidic (sa)

CONCLUSION

This study concludes that the sandy soils on erosion-prone slopes in Ternate are classified as Inceptisols, characterized by evident horizon differentiation and a relatively thick solum, indicating a more advanced stage of pedogenesis. Cultivation of chili plants in these soils resulted in increased levels of organic carbon, total nitrogen, and available phosphorus (P_2O_5), while soil pH and available potassium (K_2O) declined. These findings suggest that agricultural practices in erosion-prone areas significantly influence soil chemical dynamics. To promote sustainable nutrient management and reduce degradation, conservation-oriented practices, such as incorporating organic matter and transitioning from monoculture to agroforestry systems, are strongly recommended.

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