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Topsoil Thickness and Its Chemical Properties between Tea Plantation and Bare Land on Different Slopes

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Abstract. *Land degradation in Indonesia is often attributed to human activities and high rainfall. The existence of forest land clearing and conversion into non-agricultural land causes topsoil erosion and structural damage, reducing the capacity to hold water and nutrients. The phenomenon contributes to the degradation of tea (Camellia sinensis) plantation, showing the need to improve agricultural land by maintaining soil ecosystems. Therefore, this study aimed to compare soil from tea plantation with bare land on two different slopes based on the chemical quality at Gambung Tea Plantation, Research Institute for Tea and Cinchona. The selected land slope was gentle (0 - 8%) and steep (30 - 40%), producing four environmental combinations. Soil sampling was carried out in two different layers, at 0 - 20 cm and 20 - 40 cm. The experimental parameters observed were topsoil thickness, soil water content, pH, and soil nutrients. The results showed that in steep slope land conditions, tea cover crops maintained topsoil with a thickness of 15.01 cm compared to bare land. This corresponded to topsoil degradation of 19.6% compared to gently slope topographic conditions. In gently slope conditions, both types of land cover did not show significant differences. Tea plant cover maintained better soil water content and reduced soil N loss, although steep slopes showed lower soil nutrient content due to absorption.*
Keywords: *land cover; soil degradation; tea plant; topography; topsoil.*

Type of the Paper: Regular Article.

1. Introduction

Land degradation is a process of decreasing land productivity, temporarily or permanently due to decreased physical, chemical, and biological soil quality. One of the causes of massive land degradation is soil erosion due to inappropriate land management, such as unmeasured land use conversion [1]. Furthermore, the level of soil erosion is determined by several main factors including climate, topography, vegetation, and soil [2].

The event of land degradation is often experienced in Indonesia, due to the location on the equator with a tropical climate. This country is in the ring of fire paths, which contributes to the formation of many volcanoes either still active or not. The climate and topography that vary significantly make ecosystem services complex to support human life. Sukarman and Dariah [3] reported that Indonesia had an Inceptisols land area of 70.5 million ha (37.5%), Entisols 18 million ha (9.6%), Andisols 5.4 million ha (2.9%) and Alfisols 5.1 million ha (2.7%). Suboptimal soil preservation causes severe runoff that occurs above soil, leading to the erosion of soil layer and

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nutrient leaching. Soil cultivation carried out in various human activities, such as mining and agriculture, often impacts land sustainability, including reduced topsoil and other organic matter playing a significant role in buffering the ecosystems.

Among several plantation commodities in Indonesia, tea (*Camellia sinensis*) is an annual plant with abundant benefits and economic value. Although tea plant comes from a subtropical country, it thrives optimally in a tropical climate, particularly in the highlands area. Tea plantation is widespread in the western part of the country, such as in North Sumatra, West Sumatra, Jambi, West Java, Central Java, and East Java comprising 6.1, 3.7, 1.8, 86.8, 9.1, and 2.2 thousand hectares, respectively [4]. This plant is a source of functional food, such as medicinal ingredients, cosmetics, and other refreshments. According to BPS [4] data, tea consumption in Indonesia is still relatively low, at 456 g per capita, compared to other countries, such as Turkey at 3,1 kg per capita, Ireland at 2,2 kg per capita, and Morocco at 1,2 kg per capita. However, Indonesia is a tea-exporting country with an income of 96.323 USD.

As an annual plant derived from dicotyledonous seeds and formed taproot, tea can survive in relatively marginal environmental conditions. It is often planted at various elevations and land topography, although without meeting the growing conditions requirements. Liu et al. [5] stated that tea plantations in rural Meitan, China, had an economic impact and conservation of water, soil, and source of carbon storage sources, with ecological benefits of 469.2 million USD. In tea cultivation, pruning and frame formation are carried out for easy accessibility to the pluckers and have a wide plucking frame. This method helps preserve soil due to the presence of organic waste in the form of branches from pruning and reduces the direct impulse between raindrops as well as soil surface caused by the canopy.

Tea plantation has a significant impact on environmental sustainability, including erosion control. The land area tends to have good soil properties and qualities, protecting against degradation. Geekiyanage et al. [6] reported that land covered with productive tea plantation produced better soil nutrient content of N, P, and organic carbon compared to shrub and annual plant land cover. Nutrients in soil can be influenced by various soil properties, both physical, chemical, and biological including vegetation cover. These nutrients can be maintained when there are several supporting factors such as preserving the structure and layers of soil, including preventing the movement and loss of nutrients in soil [7].

Currently, there are several changes in land use, particularly from converting from agricultural to non-agricultural purposes. Due to the lack of information regarding the role of tea plant as a soil conservation in maintaining topsoil layer, the ecosystem service aspects of tea are often neglected. The rapid population growth and economic needs make land use more focused on the aspect of economic value, while plantation commodities tend to decrease. As shown by BPS

[4], tea plantation area decreased by approximately 25.3% from 2001 to 2020 due to conversion into oil palm and other non-agricultural purposes such as infrastructure development and housing.

Generally, topsoil layer, containing numerous organic matters, plays an essential role in the soil ecosystem and the sustainability of plant growth. Topsoil serves as a good energy source of microorganisms to support nutrients solubilizing soil and other layers. It can also act as a nutrient binder and acidity buffer, affecting the diversity of soil microorganism community [8]. Therefore, this study aimed to determine the difference in the impact of land cover between tea plantation and bare land on topsoil thickness, water holding capacity, and chemical properties. The results were expected to be used as a reference for the role of tea plantation in ecosystems, particularly in Indonesia.

2. Materials and Methods

2.1. Observation Time and Location

Observations were made on two land covers and slopes located at Gambung Tea Plantation, Research Institute for Tea and Cinchona from June 2022 until August 2022. The observed land cover was tea plant cover and bare land with two different slopes, consisting of gentle (0 - 8%) and steep slopes (30 - 40%), totaling four land conditions. The location of the land sampling was taken at a close distance to each other assuming that soil and agro-climatic properties were not significantly different. The coordinates of soil sampling are presented in Table 1, while the sampling point in Gambung tea plantation is shown in Fig. 1.

Fig. 1. Sampling and Observation Locations. A = Tea Plant + Steep Slope; B = Tea Plant + Gently Slope; C = Bare Land + Gently Slope; D = Bare Land + Steep Slope.

Table 1. Description of Sampling Locations

Land Cover	Land Slope	Land Coordinate	Elevation (m)	Soil Order
Tea Plant	Flat (0 - 8%)	7° 8'18.86"S 107°30'12.45"E	1296	Inceptisols
	Steep (30 - 40%)	7° 8'16.93"S 107°30'10.03"E	1274	Inceptisols
Bare Land	Flat (0 - 8%)	7° 8'14.17"S 107°30'23.85"E	1280	Inceptisols
	Steep (30 - 40%)	7° 8'18.34"S 107°30'28.76"E	1256	Inceptisols

2.2. Soil Sampling and Analysis

Soil sampling was carried out on each land cover and slope at two different depths in 3 replications. The samples were taken at a depth of 0 - 20 cm and 20 - 40 cm from using drill. Chemical properties of the samples were determined, including soil electrical conductivity with a 1:5 soil water ratio ($EC_{1:5}$) [9], organic-C based on Walkley and Black method [10], and total-N (t-N) based on Kjeldahl method [11]. Other properties included soil water content (SWC) based on gravimetric measurements, pH H_2O using the electrode method, available-P (av-P) based on Bray I, exchangeable-K (Ex-K), and exchangeable-Mg (Ex-Mg) through Ammonium Acetate Extraction method [12].

Minipits with a size of 50 x 50 x 50 cm were made close to the soil sampling point to measure the thickness of topsoil based on Balai Penelitian Tanah [13]. Topsoil observations were performed by initially cleaning organic litter from the surface and measuring thickness of black soil from the top side (0 - 15 cm) to another layer with a change in color [14]. Meanwhile, topsoil thickness measurement was performed by measuring three points representing the thinnest, moderate, and thickest on topsoil layer.

2.3. Statistical Analysis

The split-plot design was used as a trial layout design where the land cover served as the main plot and the land slope as the subplot. Statistical Analysis of Variance (ANOVA) was performed on soil chemical properties with a Duncan Multiple Range Test with α= 5%. An Independent T-test was performed with a 95% confidence level to observe the difference in the thickness of topsoil. Statistical analysis was carried out with the support of IBM SPSS Statistics version 20 software.

3. Results and Discussion

3.1. Soil Chemical Properties on Different Land Covers and Slopes at 0 - 20 cm Depths

The analysis results showed that SWC, pH, $EC_{1:5}$, and available-P did not show significant differences in each land cover and slope at 0 – 20 cm of soil depth Table 2. Furthermore, in sloping topography, tea plant cover showed lower organic-C and t-N compared to bare land due to the more nutrients absorbed by tea plant.

Table 2. Soil Chemical Properties on Different Land Covers and Slopes at 0 - 20 cm Depths

Land Category	Soil Chemical Properties							
	SWC (%)	**pH H_2O**	**$EC_{1:5}$ (µS.cm^{-1})**	**Org-C (%)**	**t-N (%)**	**av-P (ppm)**	**Ex-K (cmol.kg^{-1})**	**Ex-Mg (cmol.kg^{-1})**
BL + GS	4.03 a	6.16 a	79.30 a	6.04 b	0.64 b	3.22	0.96 b	0.60 b
BL + SS	4.24 a	6.28 a	76.85 a	6.14 b	0.63 b	7.35	0.31 a	0.26 a
TPC + GS	3.92 a	5.97 a	102.00 a	5.89 b	0.81 c	9.24	0.15 a	0.35 a
TPC + SS	4.37 a	6.00 a	95.60 a	4.63 a	0.47 a	7.16	0.25 a	0.24 a

Notes: The mean value followed by a different letter showed a significant difference with a P value ≤ 0.05. BL = Bare Land; TPC = Tea Plant Cover; GS = Gently Slope; SS = Steep Slope.

Tea is among plantation commodities where leaves are the target organ and often prioritized. The formation of leaf organs requires more dominant elements of N and Mg, particularly for tea plants where leaf plucking occurs very intensively [15,16]. According to Hajiboland [17], tea plant clones with high productivity of 5 tons per ha per year require approximately 600 kg N per ha per year. Moreover, there is the possibility that organic matter still be present in bare land due to little grasses and nutrient translocation as reported by Ahmed et al. [18]. This phenomenon allows the mineralization of organic matter for nutrients such as nitrogen to be available on bare land. Previous reports stated that land with high organic matter sowed relatively increased soil nitrogen and other macronutrient content, including microbial activity [19–21].

Land with a gentle topography often shows a higher total N content than bare land. In this topography, the organic - C in soil shows no significant difference, indicating that vegetation cover can affect the rate of N loss. To address this problem, tea plant is capable of reducing the rate of evaporation and leaching of N elements in soil. Similarly, Tripathi and Singh [22] stated that land use affected the transformation of soil N. The results showed that cropping land had relatively higher N content than bare land due to the presence of root plants, the rate of denitrification, faster mineralization, and the development of soil biota to obtain high biomass-N.

The low organic-C in tea plant cover with the steep slope is not in line with the thickness of topsoil, showing a difference of 10.67 cm. This phenomenon needs to be explored further regarding the relationship between topsoil thickness and soil organic carbon content.

In the case of exchangeable K and Mg, interchangeability showed that there was a significant difference only in bare land conditions with gently slope topography. The results showed that the highest exchangeable K and Mg were obtained to be 0.96 cmol.kg^{-1} and 0.60 cmol.kg^{-1}. K and Mg nutrients were known as the second most important nutrient after N nutrient with high mobility. The availability of K and Mg nutrients was relatively high in bare land conditions with a gentle slope topography. This was because the nutrients were not significantly mobilized by runoff and plant uptake. Under steep slope topographic conditions, the nutrients are expected to be easily leached and mobilized by runoff [23]. Meanwhile, under tea land cover conditions, K and Mg elements will be easily absorbed by plants, where these nutrients are one of the main elements needed by tea plants for the formation of chlorophyll leaves [24].

3.2. Soil Chemical Properties on Different Land Covers and Slopes at 20 - 40 cm Depths

The analysis showed no significant difference in soil $EC_{1:5}$, total - N, available - P, exchangeable - K, and exchangeable - Mg in each land cover and slope at 20 - 40 cm of soil depth. Furthermore, tea land cover affects soil water content at a depth of 20 - 40 cm Table 3.

Table 3. Soil Chemical Properties on Different Land Covers and Slopes at 20 - 40 cm Depths

Land Category	Soil Chemical Properties							
	SWC (%)	pH H_2O	$EC_{1:5}$ (µS.cm^{-1})	Org-C (%)	t-N (%)	av-P (ppm)	Ex-K (cmol.kg^{-1})	Ex-Mg (cmol.kg^{-1})
BL + GS	4.84 c	6.03 a	74.07 a	5.08 b	0.49 a	4.12 a	0.14 a	0.19 a
BL + SS	3.28 a	6.35 b	55.03 a	2.15 a	0.28 a	3.57 a	0.13 a	0.37 a
TPC + GS	4.35 bc	6.03 a	75.33 a	5.56 b	0.58 a	1.81 a	0.13 a	0.24 a
TPC + SS	3.99 b	6.20 ab	65.00 a	3.19 a	0.36 a	3.66 a	0.15 a	0.42 a

Notes: The mean value followed by a different letter showed a significant difference with a P value $\leq$ 0.05. BL = Bare Land; TPC = Tea Plant Cover; GS = Gently Slope; SS = Steep Slope.

On the gently slope topography, there was no significant difference between tea land cover and the bare land on SWC as well as other soil chemical properties at 20 – 40 cm depth. However, there was a significant difference in soil organic-C, where the gently slope topography in both tea and bare land cover showed a better value. SWC in the bare land with gentle slope showed higher results when compared to the steep slope conditions.

The existence of a significant difference in soil pH between the gently and steep slope topography could be expected due to the higher organic matter content in the steep slope. This organic matter contributed to the addition of organic and humic acids which could affect soil pH [25]. Generally, organic matter acts as pH buffer to minimize significant changes in soil reactions. The presence of organic acids from the metabolic results of soil microorganisms have better microbial activity under conditions of high availability of organic matter [26].

Tea plant cover with a steep slope can maintain SWC due to the shade of the canopy and plant roots that can still withstand evaporation and maintain percolation water better. Furthermore, there is a possibility that the absorption of nutrients by tea plant is less optimal due to health or low absorption of nutrients by roots. According to a previous study, roots of tea plant could grow to a depth of approximately 60 cm. However, this growth could be inhibited by several factors, including harvesting and pruning, light shade, and soil compactness [27].

Another possibility is that soil nutrient eluviation occurs, where there is a decrease in nutrient quantity from the 0 - 20 cm layer Table 2. The presence of eluviation in this layer causes a nutrient transfer from the layer above and accumulates in the horizon below, leading to the absorption of small nutrients at a depth of 20 - 40 cm. Eluviation often occurs in the soil horizon A - E at a depth of about 10 – 40 cm, particularly on Inceptisols [28–30].

3.3. Topsoil Thickness on Different Land Covers and Slopes

The analysis results presented in Table 4 show that land cover has a significant influence on topsoil thickness. In steep slope land topography conditions, tea plant cover has a better topsoil thickness compared to bare land but does not show a significant difference when compared to gentle slope topography conditions. Furthermore, tea plant cover showed no significant differences in topsoil thickness in either gentle slope or steep slope topography. In comparison, bare land in steep slope topography conditions showed a significant decrease in topsoil thickness Fig. 2.

Table 4. Mean difference of topsoil thickness between tea plant cover and bare land at different slopes

Land Cover	Topsoil Thickness (cm)	
	Gently Slope	Steep Slope
Tea Plant Cover	18.67a A	15.01b A
Bareland	13.34a B	4.34a A

Notes: The values followed by the same notation do not show significant differences according to the Independent T-test with P value ≤ 0.05. Notations in lowercase letters are read vertically (columns) and capital letters are read horizontally (Rows)

The difference in topsoil on sloping land conditions was caused by variations in impacts that occurred due to rainwater and surface runoff. The formation of a plucking frame in the practice of tea cultivation to form a wide plant canopy caused a reduction in topsoil from rainwater. Tea taproot is also capable of holding and maintaining soil aggregate, thereby preventing easy separation from other soil particles at a fairly extreme slope. The pruning of tea plants every four years contributes to the addition of soil organic matter, which can form a horizon of rough and fine organic matter.

As shown in Fig. 2, the bare land at the experimental location was still found with grasses, showing potential to withstand the impact of rainwater. This condition is still effective for maintaining soil fertility in land with relatively flat slopes. However, in sloping land with a slope of > 30%, the bare land has a poor ability to maintain topsoil layer and soil nutrients. The presence of grasses can be used for vegetation conservation to prevent erosion and leaching of soil nutrients [31,32]. This is because grasses will be effective in maintaining soil fertility, particularly from soil erosion, with a dense population and deep grassroots [33].

Based on Tables 1 and 2, tea land cover has the potential to maintain plant nutrients without a significant difference between sloping and flat land in terms of soil nutrients. However, bare land with sparse grass density showed a significant difference between sloping and flat land. It is suspected that there is an influence on the thickness of topsoil between the two land covers, where a good layer can withstand the rate of leaching of nutrients in the soil. Topsoil contains organic matter in the form of humus which has a high negative charge, allowing the adsorption of soil nutrients and increasing cation exchange capacity (CEC) [34]. Furthermore, organic-C content in topsoil layer can support the development of functional soil microbes, playing an important role in mineralization and the provision of nutrients [35]. This suggests that soil with a thick topsoil layer has good health to support plant growth [36].

Fig. 2. Differences in topsoil thickness on different land cover and slope. A = Bare Land + Gently Slope, B = Bare Land + Steep Slope, C = Tea Plant Cover + Gently Slope, D = Tea Plant Cover + Steep Slope.

Vegetation conservation generally uses the canopy and root to protect soil from degradation and erosion. According to Barchia et al. [37], soil conservation with vegetation use has several advantages including high economic value, along with the ability to maintain or preserve soil. Annual plants have the benefit of reducing soil degradation with a minimal deterioration index value (< -5%), which can be caused by erosion, leaching, and damage to soil structure [38].

Volungevičius et al. [39] reported that changes in topsoil could be influenced by several factors, including land use, tillage, climate, and vegetation. Topsoil can generally describe the level of soil health, affecting soil biological, physical, and chemical properties.

4. Conclusions

In conclusion, this study showed that land cover and slopes had different effects on soil chemical properties. At a soil depth of 0 - 20 cm, soil nutrient content in tea land cover was less than in the bare land due to absorption by tea plant. The results showed that tea plantation cover could maintain better SWC, with a value of 3.99% at 20 – 40 cm. Tea plantation cover also maintained topsoil better (19.6% decrement) compared to bare land (67.4% decrement) from soil erosion on steep slope conditions. A significant decrease in the availability of nutrients was observed in tea plantation, although N loss was prevented from evaporation or leaching. Moreover, further experiments were recommended on different soil layers and other commodities to measure the effectiveness of tea plantation for vegetation conservation and determine the rate of nutrient leaching.

Abbreviations

SWC	Soil Water Content
Av-P	Available P
Ex-K	Exchangeable K
Ex-Mg	Exchangeable Mg
BL	Bare Land
TPC	Tea Plant Cover
GS	Gently slope

Data availability statement

All data underlying this article would be shared on reasonable request to the corresponding author in the following link: (https://bit.ly/DataTopsoil).

CRediT authorship contribution statement

Faris Nur Fauzi Athallah: Conceptualization, Methodology, Resources, Formal analysis, Writing – original draft. **Restu Wulansari**: Project administration, Resources, Writing – review & editing.

Declaration of Competing Interest

The authors of this manuscript declare no conflict of interest or competing interest.

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