Journal of Technology and Value Addition, Volume 6 (2), July 2024: (19-35)

Research Article

Assessment of the Variability of Soil Properties at Different Slope Positions of Immature Rubber Plantation in *Boralu* Soil Series

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Abstract

Rubber (Hevea brasiliensis) is a plantation crop in Sri Lanka, yet faces a critical issue of topsoil erosion, which leads to fertility issues and a decline in production. The study aimed to evaluate soil properties across different slopes in immature rubber growing lands. Soil samples were collected from immature rubber growing lands in the Boralu soil series at Dartonfield estate under three slope positions: upper (US), middle (MS), and lower (LS) categorized based on their slope lengths. The sampling was done for each of the three Lands (L1, L2, and L3), all under similar conditions. Soils were analyzed for certain physical (bulk density) and chemical (soil pH, soil organic carbon (SOC), exchangeable potassium (Ex. K), exchangeable magnesium (Ex. Mg), total nitrogen (TN), and available phosphorus (Av. P)) parameters. Randomized Completely Block Design (RCBD) was practiced, and data were analyzed using analysis of variance (ANOVA) followed by mean separation using the LSD test. The kriging method was utilized to prepare spatial variability maps for all measured soil parameters. Results indicated a significantly higher SOC in MS of L1, Av. P in the US of L1 and L3 and TN in LS in L2. No significance was observed for pH, Ex. K, Ex. Mg and, bulk density across the three lands within the gradients. Results revealed that while the slope influenced certain soil properties specifically SOC, Av. P, and TN, overall soil fertility appears to be relatively stable with the gradient. Therefore, further research is needed to understand better how the gradient affects soil fertility in immature rubber plantations.

Keywords: *Boralu series, Immature rubber, Slope positions, Soil erosion*

1. Introduction

Hevea brasiliensis belongs to the Euphorbiaceae family and is the primary commercial source of natural rubber (Kudaligama, 2021). Rubber has three growth phases including the nursery phase, immature phase, and mature phase. Among these phases, the immature phase is significant. During the immature phase, tapping is not commenced and this phase ends when 70% of plants reach a girth of nearly 50 cm and 120 cm from the highest point of the stock scion union (Nayanakantha, 2021).

Traditional rubber growing areas in Sri Lanka are *Kegalle*, *Kalutara*, *Ratnapura*, *Colombo*, *Galle*, and *Matara* (Seneviratne, 2021). Most of these rubber plantations are located on steep terrains, that receive the highest annual cumulative rainfall throughout the year more than 2500 mm/year (Wimalasiri and Ampitiyawatta, 2022). Though rubber can grow in different soil types, its performance and economic viability mainly depend on the soil type. *Ratnapura, Homagama, Agalawatta, Boralu, Matale, Parambe,* and *Deniya* are the different rubber growing soil series in Sri Lanka, and among these, *Boralu* is the most widely distributed rubber growing soil in Sri Lanka which belongs to the great soil group of Red Yellow Podzolic (Hettiarachchi, 2021b).

According to the data of the Ministry of Plantation Industries (2021), between 2016 to 2021, the total area of rubber lands in Sri Lanka increased from 136,100 ha to 138,600 ha. However, the average rubber yield declined from 817 $kgha^{-1}$ to 679 $kgha^{-1}$ during the same period (Ministry of Plantation Industries, 2021). Several factors contributed to this decline, including adverse weather conditions, and disease, but the most prominent reason is the fertilizer shortage on immature rubber plantations that caused stunted tree growth and ultimately delayed the tapping stage of plantations (Central Bank of Sri Lanka, 2022).

Expansion of the uneconomical immature phase beyond the recommended age remains a major issue in rubber cultivation in Sri Lanka. The majority of rubber plantations are located in areas with steep and adverse terrain, leading to soil loss from erosion. These sloppy lands exhibit various morphological features, such as different lengths, widths, and positions of the slopes (Zhang et al., 2021). The spatial variability of soil nutrients and physical properties concerning the slope position in immature rubber growing lands is unclear and there are limited studies available on it. Therefore, it is crucial to investigate the variability of soil nutrients under these conditions to understand the prevailing nutrient status in the field which will help to maintain the necessary nutrient conditions in the field, that need to reduce the expansion of the immature phase of rubber trees beyond the recommended age. The use of a Geographic Information System (GIS) is effective for spatial prediction of the existence of nutrient conditions in the field for a better understanding of soil fertility.

2. Material and Methods

2.1 Study area

The study area (Figure 1) was located at the premises of the Rubber Research Institute of Sri Lanka, *Dartonfield*, *Agalawatta* (80^0 9’59.63” E, $6^0$30’46.05” N) and it was characterized by a slope gradient of approximately 45% which belongs to the *Boralu* soil series. It is situated in the WL$_{1a}$ agroecological region and receives an annual cumulative rainfall of over 3200 mm (Wijesuriya and Rathnayaka, 2021). *Pueraria phaseoloides* was the most commonly identified cover crop in the field. To define the boundaries of the study area, geographic coordinates were recorded at each turning point using a Trimble Juno SB, a high precision handheld GPS device renowned for its robust performance in outdoor environments.

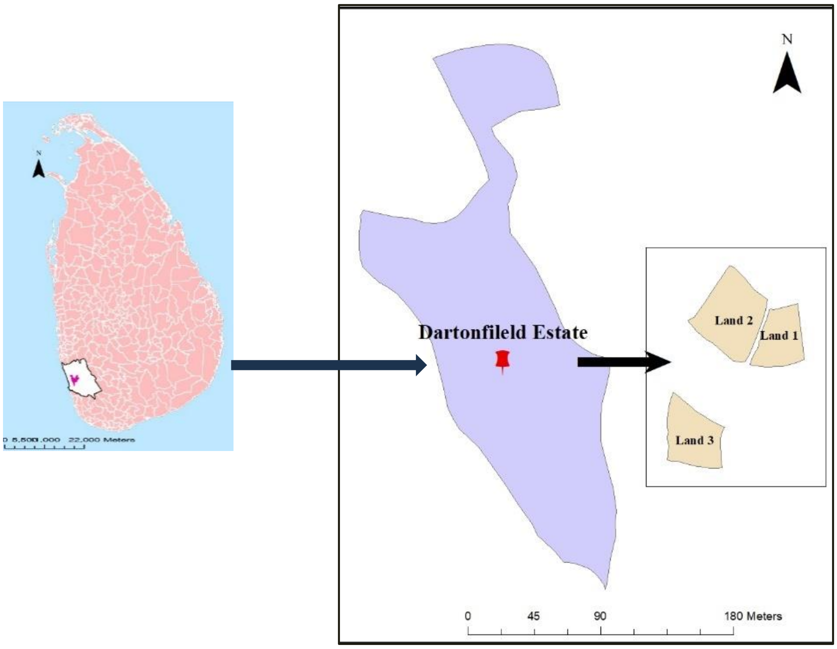

Figure 1: Study area: Ridirekhagama GN Division

Subsequently, GPS points were collected within each designated study area to identify specific soil sampling sites, ensuring a comprehensive representation of the area's soil characteristics.

2.2. Experimental design

The experiment was conducted using a Randomized Completely Block Design (RCBD). Soil physical and chemical variations were compared across slope positions, namely, upper (US), middle (MS), and lower (LS) which served as treatments.

2.3. Samples collection and preparation

Soil samples were collected from three distinct slope positions on a single piece of land, categorized into US, MS, and LS based on slope length. Six soil samples were collected randomly within each category from manure circles from topsoil (0-0.15 m). This process was replicated for each slope position on the three lands: L1, L2, and L3, resulting in 18 soil samples from one land.

Minimum disturbed fresh soil samples were taken using the cylindrical core, then weighed and dried at 105 °C for 24 h to measure bulk density (BD) (Bhattacharya et al., 2020). For other soil analysis soil was sampled using the Edelman augur and soil samples were air dried and sieved.

SOC was determined by Walkely and Black (1934). The soil pH was measured in a soil suspension (soil: water = 1:2.5) (Rowell, 1994). Bray method was used to determine the Available P (Bray and Kurtz, 1945). The Total Nitrogen concentration was measured using the Kjeldahl digestion method (Bremner, 1965). Exchangeable K and Exchangeable Mg were determined by ammonium acetate extraction method (pH = 7) (David, 1960). Soil bulk density (BD) was determined by using the core sampling method (Blake, 1965).

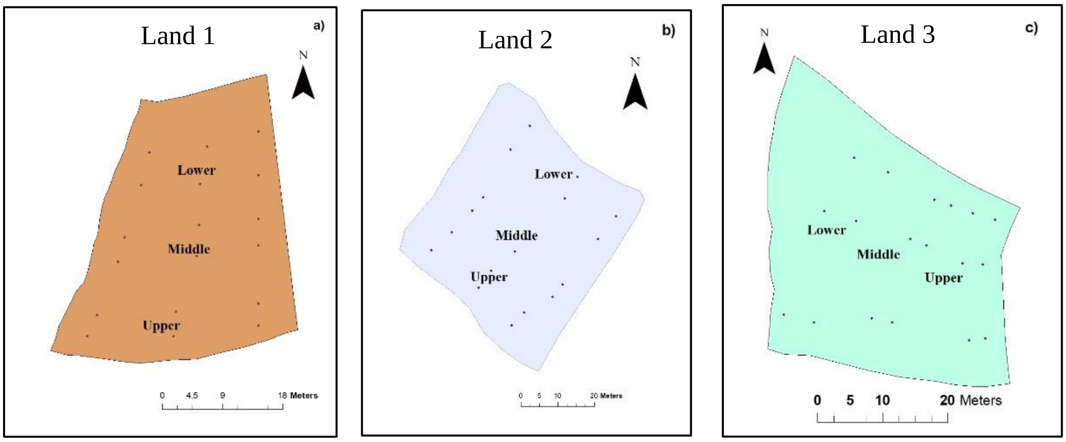

Figure 2: Distribution of soil sample points among rubber lands (a. Land 1, b. Land 2 and c. land 3).

2.4. Data analysis

Data was statistically analyzed by using the ANOVA procedure in R version 4.1.2. The data analyzed were graphically represented using Microsoft Excel.

3. Results and Discussion

3.1. Effects of slope positions on soil nutrients in the manure circle of the surface soil

The effect of slope positions on the soil nutrients in the 0- 0.15 m soil layer is summarized in Figure 3 to Figure 15. Soil nutrient parameters, including Av. P, SOC, and TN, exhibited significantly with slope positions ($p<0.05$). However, pH, exchangeable K, exchangeable Mg, and bulk density showed no significance. Specifically, SOC content was notably higher on the MS of the L1, while Av. P content was significantly elevated in the US of the L1 and L3. TN content exhibited a significant increase in the LS of the L2.

3.2. Soil pH

Soil pH is a critical soil chemical property that governs soil fertility and has a significant influence on plant growth, yield, and biomass production (Hong et al., 2019). It also plays a pivotal role in determining the soil's cation exchange capacity (Gondal et al., 2021). As illustrated in Figures 3 and, 4, the soil pH in the studied fields fluctuates between 5.0 and 6.0, a range that is conducive to rubber cultivation in Sri Lanka. This falls within the optimum pH range of 4.0 to 6.0 for rubber cultivation in Sri Lanka. (Hettiarachchi, 2021b). The slightly acidic nature of the soils observed can be attributed to several factors, primarily the leaching of basic cations, which is intensified by heavy rainfall in the wet zone (Orimoloye et al., 2010). Additionally, variations in soil pH across different fields may be influenced by fertilizer applications and inherent soil characteristics.

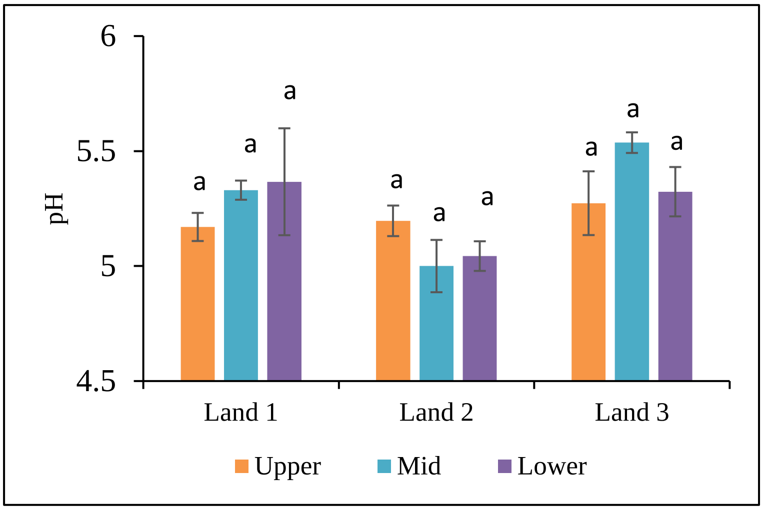

Figure 3: Distribution of soil pH with slope positions of the three lands

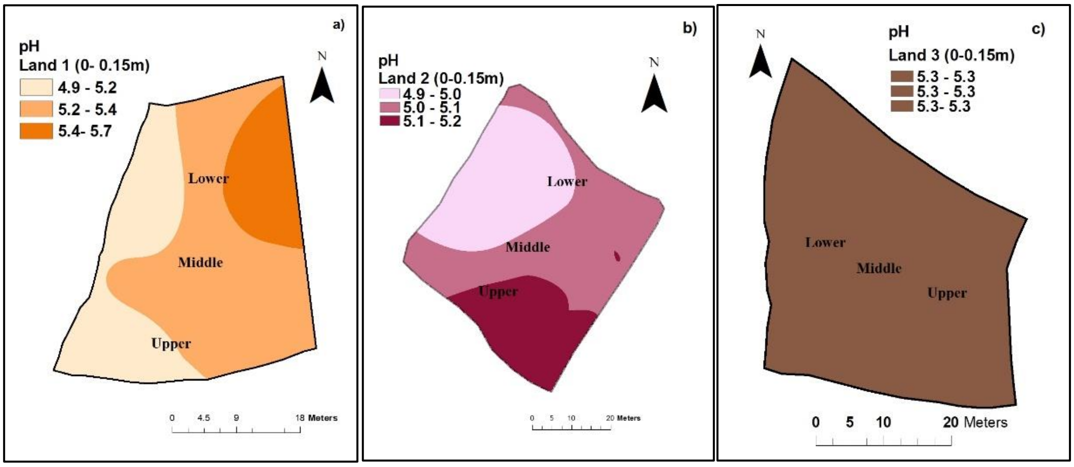

Figure 4: Spatial distribution of soil pH with slope positions (a. Land 1, b. Land 2, and c. land 3) among three lands.

3.3. Exchangeable potassium

According to Hettiarachchi (2021c), the *Boralu* soils are typically estimated to contain exchangeable potassium (Ex. K) in the range of 40 – 60 mgkg^{-1}. However, as illustrated in Figure 5 and Figure 6, the observed Ex. K content in the studied fields exceeds this range. This increase in soil potassium levels may be attributed to several factors, including the over-application of potassium rich fertilizers, weathering of potassium bearing minerals, and the decomposition of organic matter, which can release potassium into the soil. As noted by Wang et al. (2013) elevated Ex. K availability enhances the soil's capacity to support plants in coping with biotic and abiotic stresses, such as disease, salinity, pest infestations, drought, and waterlogging. This enhanced potassium content can therefore play a crucial role in enhancing crop resilience and overall agricultural productivity under varying environmental conditions.

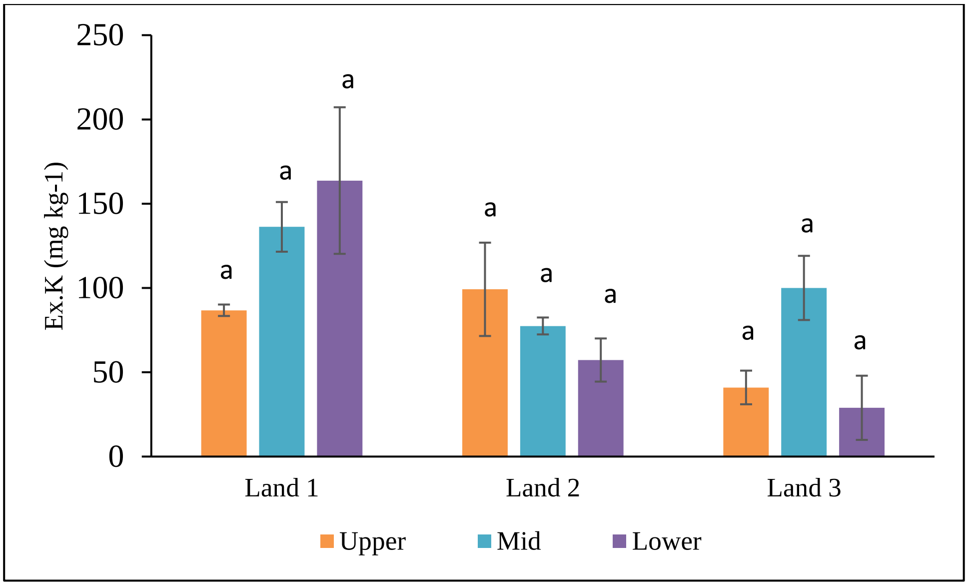

Figure 5: Distribution of Ex. K with slope positions of the three lands.

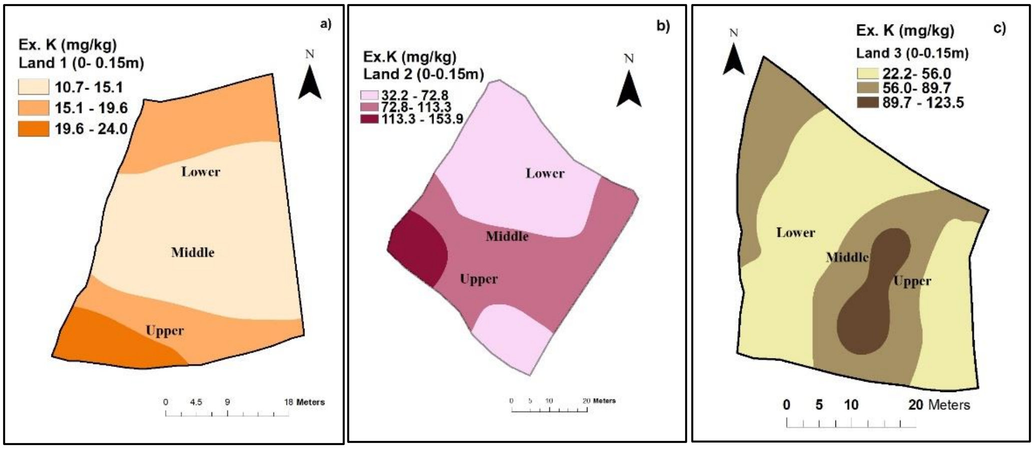

Figure 6: Spatial distribution of Ex. K with slope positions (a. Land 1, b. Land 2, and c. land 3) among three lands

3.4. Soil organic carbon

The significantly highest SOC content was observed in MS of L1 (Figure 7 & Figure 8). This elevated SOC can be attributed to the annual deposition of leaf litter and the accumulation of leguminous cover crops, which are known to enhance SOC levels in rubber-growing soils (Hettiarachchi, 2021b). SOC is crucial in improving the soil's physical properties, such as reducing bulk density, increasing porosity, and enhancing water-holding capacity (Yang et al., 2011). Consequently, the higher SOC content observed in immature rubber-growing lands may contribute significantly to increased soil fertility. Field observations further revealed that the MS of L1 had a higher density of the leguminous cover crop *Mucuna bracteata*, which is known for its ability to enhance SOC. In contrast, the other slope positions across the three fields were predominantly covered with *Pueraria phaseoloides*, a different legume species, potentially contributing to the variations in SOC content observed among the fields.

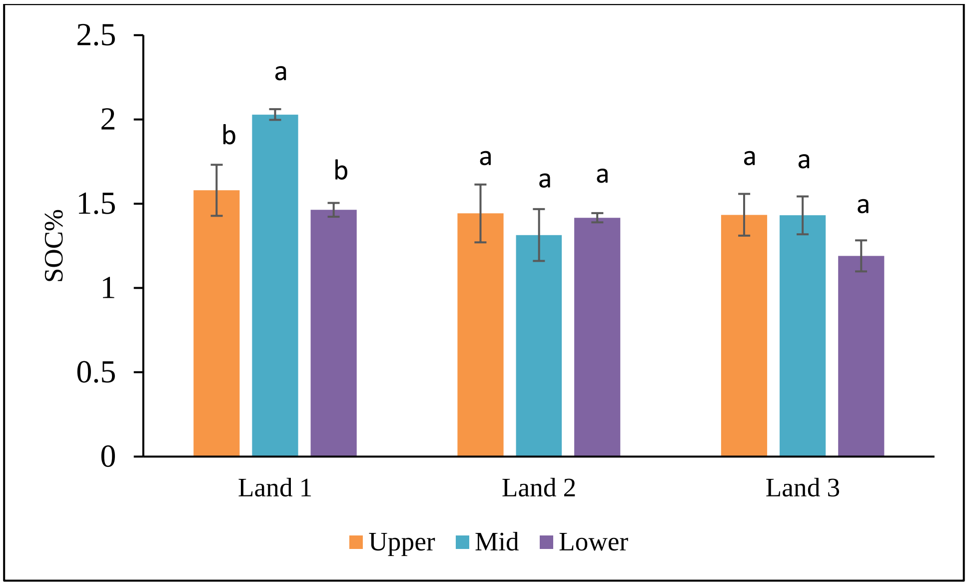

Figure 7: Distribution of SOC with slope positions of the three lands.

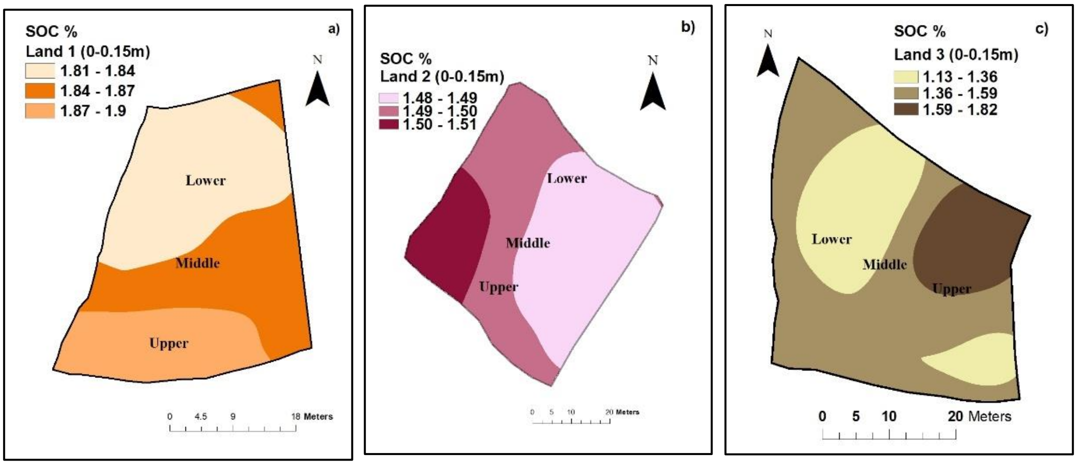

Figure 8: Spatial distribution of SOC with slope positions (a. Land 1, b. Land 2, and c. land 3) among three lands.

3.5. Exchangeable magnesium

Figure 9 and Figure 10, reveal that the majority of the field areas exhibit exchangeable magnesium (Ex. Mg) levels below the typical range of 20 - 30 mgkg^{-1} for rubber growing soils in the *Boralu* soil series (Hettiarachchi, 2021b). In agricultural systems, the availability of magnesium to crops is influenced by several factors, including soil texture, cation exchange capacity, climatic conditions, anthropogenic activities, and agronomic management practices (Wang et al., 2020). Soil acidity is a key factor contributing to the low levels of Ex. Mg observed. Under acidic conditions, the increased mobility of Mg^{2+} ions lead to enhanced leaching, resulting in magnesium deficiency within the root zone. This depletion of Mg availability may adversely affect crop nutrition and soil fertility, particularly in rubber cultivation.

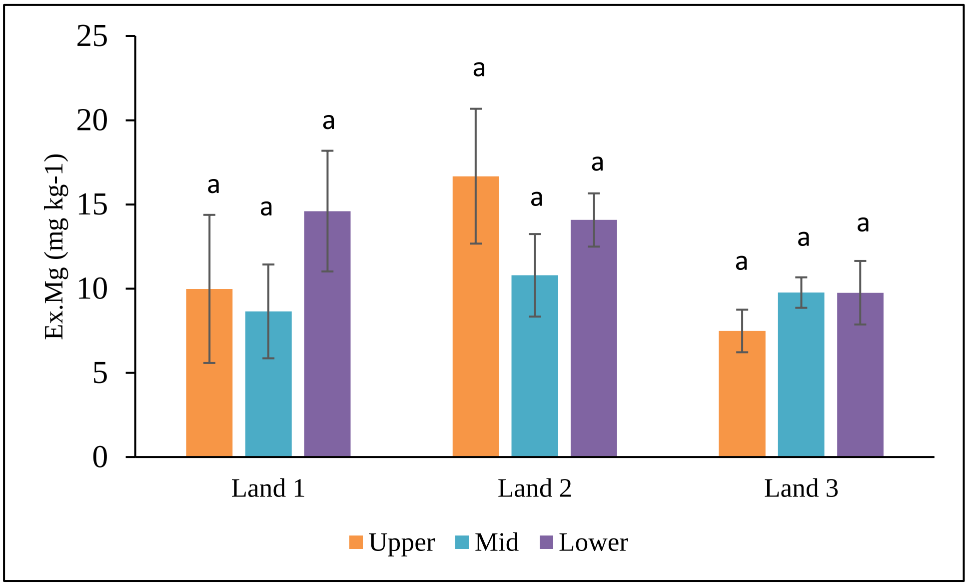

Figure 9: Distribution of Ex. Mg with slope positions of the three lands.

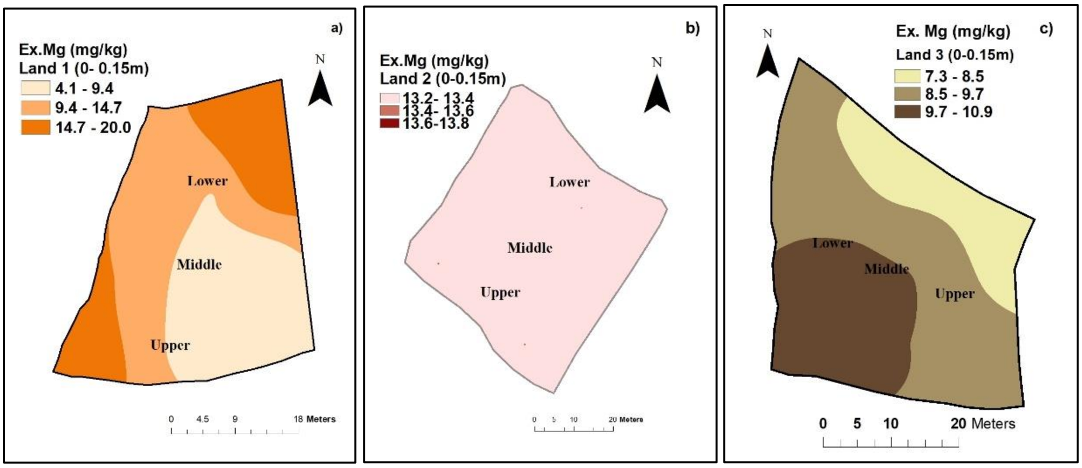

Figure 10: Spatial distribution of Ex. Mg with slope positions (a. Land 1, b. Land 2, and c. land 3) among three lands.

3.6. Available phosphorus

The upper slopes (US) of both L1 and L3 recorded the significantly highest levels of available phosphorus (Av. P) at 19.73 ± 2.35 $mgkg^{-1}$ and 10.4 ± 0.9 $mgkg^{-1}$, respectively ($p < 0.05$) (Figures 11 & 12). The elevated Av. P levels in the upper slopes due to fertilizer application and reduced runoff at these positions, limiting nutrient loss. However, soil erosion, particularly in sloped areas, can result in the movement of phosphorus-rich topsoil to lower slope positions (Liu et al., 2020). This process leads to phosphorus accumulation in the lower slopes (LS), where runoff water deposits eroded soil, potentially explaining the increased Av. P content was observed in the lower areas. These dynamics underscore the influence of slope position and erosion on nutrient distribution in rubber-growing soils.

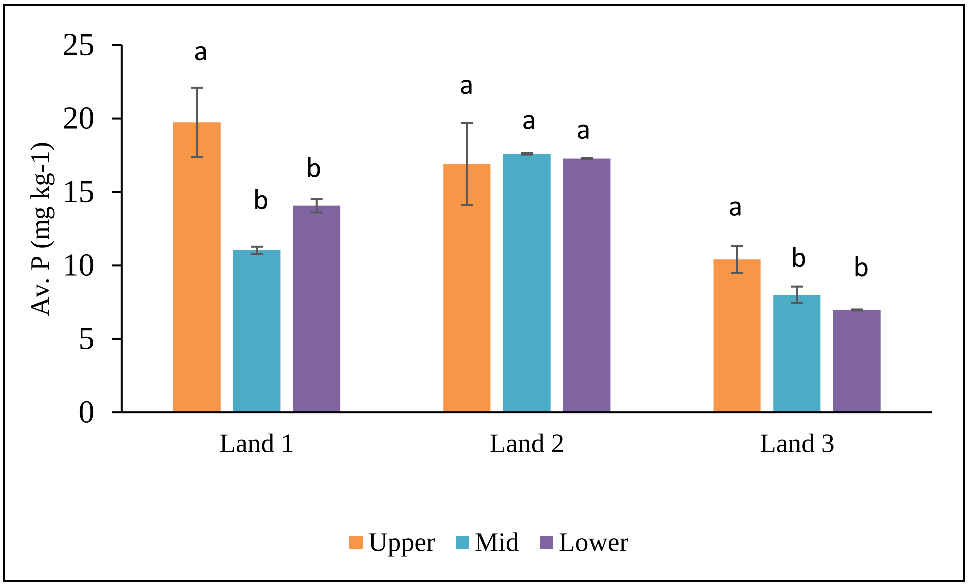

Figure 11: Distribution of Av. P with slope positions of the three lands

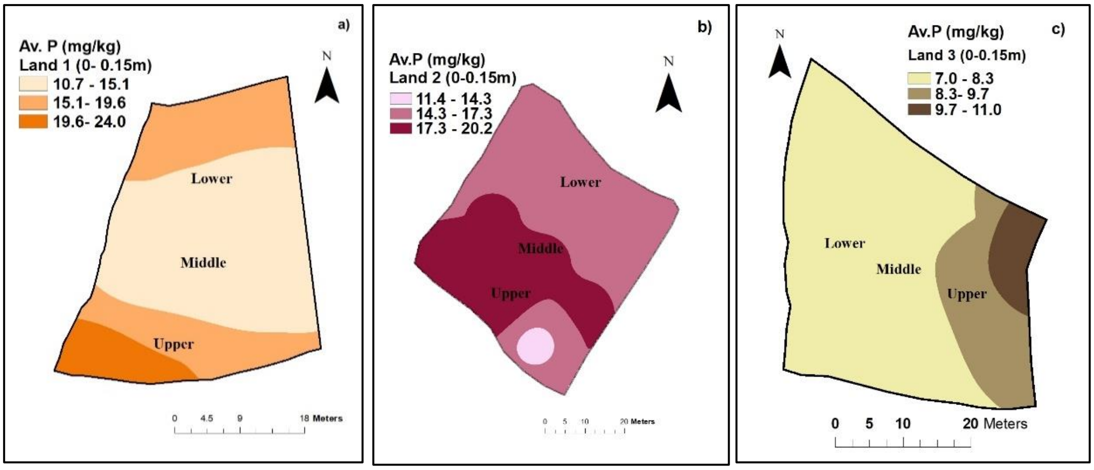

Figure 12: Spatial distribution of Av. P with slope positions (a. Land 1, b. Land 2, and c. land 3) among three lands.

3.7. Total nitrogen

The statistical analysis revealed that total nitrogen (TN) levels were significantly higher on the LS of L2, at 0.14 ± 0.003 $mgkg^{-1}$ ($p < 0.05$), as shown in Figures 13 and 14. Despite this increase, the data do not suggest that soil erosion is the primary cause, as other soil nutrients do not exhibit similar elevated concentrations at the lower slope. The increase in TN could be attributed to factors unrelated to slope gradient, such as localized nutrient deposition through organic matter accumulation, microbial activity, or site-specific fertilization practices. These factors may contribute to the higher nitrogen availability observed in the lower slope. Further research is necessary to explore the complex interactions governing soil nutrient dynamics and to elucidate the underlying mechanisms responsible for this TN variation.

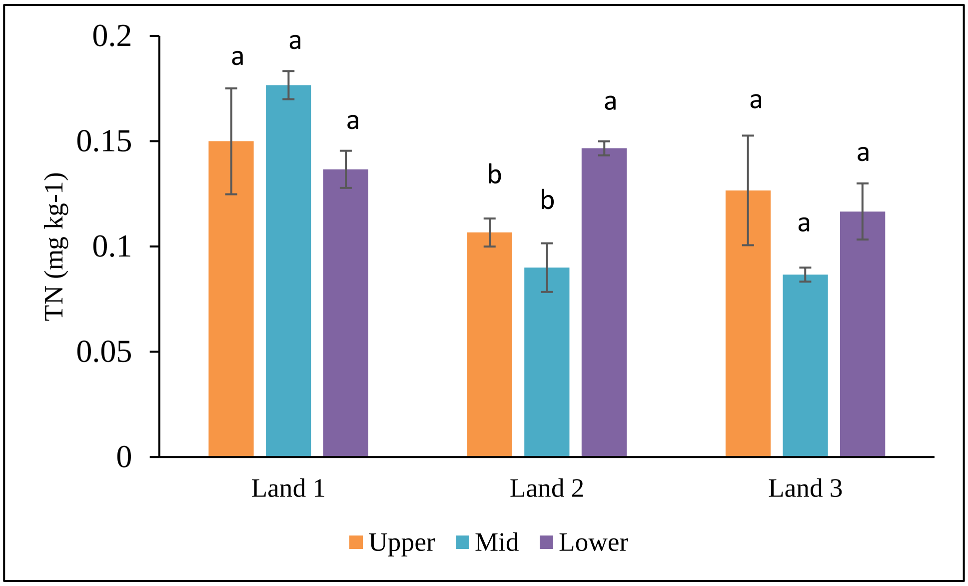

Figure 13: Distribution of TN with slope positions of the three lands.

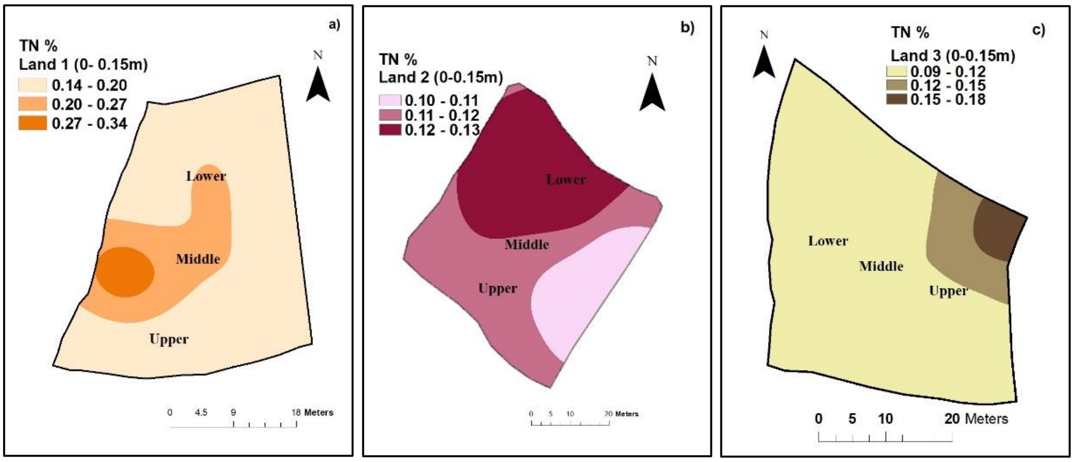

Figure 14: Spatial distribution of TN with slope positions (a. Land 1, b. Land 2, and c. land 3) among three lands.

3.8. Bulk density

In this study, no statistically significant deviation ($p < 0.05$) in bulk density was observed across the examined gradient (Figure 15). This consistency in bulk density values indicates that the soil structure remains stable throughout the gradient, likely due to several contributing factors. Notably, the use of cover crops plays a significant role in minimizing soil compaction and preserving structural integrity. Additionally, the presence of organic matter enhances soil structure by improving aggregate stability and increasing porosity, which collectively help to mitigate compaction.

These factors highlight the importance of effective soil management practices in maintaining soil health and promoting optimal conditions for rubber cultivation.

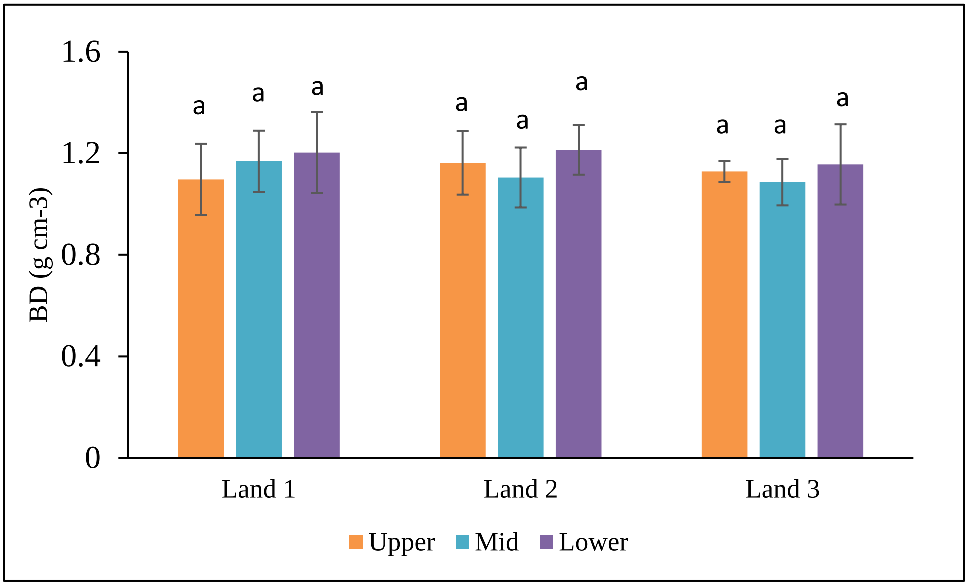

Figure 15: Distribution of BD with slope positions of the three lands.

4. Conclusion

The study aimed to assess the influence of slope position on key soil properties and evaluate the potential impact of slope gradient on soil fertility in immature rubber plantations.

The research found that soil pH, Ex. K, Ex. Mg and bulk density were not significantly different across the slope positions of the three lands. However, some soil parameters, such as SOC were significantly higher in the MS of L1, TN was significantly higher in the LS of L2, and Av. P was significantly higher in the US of both L1 and L3. These results indicate that the slope had a localized effect on certain soil properties but did not substantially impact overall soil fertility across the lands. Notably, the lack of increased nutrient concentrations in the lower slope positions suggests minimal soil erosion across the study areas, further indicating the effectiveness of current land management practices in conserving soil quality.

In summary, the slope had a localized influence on specific soil properties. However, its impact on overall soil fertility was not substantial. The results suggest that soil erosion is minimal in all the lands, indicating that the current management practices are effective for soil conservation. Further research is required to better understand how the gradient effect impacts soil fertility in immature rubber plantations.

5. Acknowledgments

The authors gratefully acknowledge the staff of the Soils and Plant Nutrition Department at the Rubber Research Institute of Sri Lanka, *Dartonfield, Agalawatta*, for their invaluable support in conducting this research.

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