

Do Canopy Gaps Impact Soil Properties in a Monoculture Tree Plantation? A Case Study of Tropical *Hevea brasiliensis*

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ABSTRACT

The study examined the impact of canopy gaps on soil properties in a tropical rubber (*Hevea brasiliensis*) plantation. The benchmarks for selecting canopy gaps and a systematic random sampling approach were adopted for the study. Fifteen (15) canopy gaps were selected, and soil samples were collected at a depth of 0-15 cm at 15 m intervals from both the center of the canopy gaps and the under-canopy of the adjoining trees. Thus, a total of 30 soil samples were collected and analyzed for their physicochemical properties. The manual gap center estimation method was adopted to establish the center of the canopy gap. Both descriptive and inferential statistics (Student's *t*-test) were used to analyze the data. The results revealed that the gaps have higher contents of silt (174.00 g kg⁻¹), clay (80.66 g kg⁻¹), soil organic matter (4.98 g kg⁻¹), soil organic carbon (2.89 g kg⁻¹), total nitrogen (0.27 g kg⁻¹), available phosphorus (0.79 mg kg⁻¹), magnesium (1.68 mg kg⁻¹), potassium (0.85 mg kg⁻¹), zinc (5.31 mg kg⁻¹), copper (3.39 mg kg⁻¹), and iron (150.40 mg kg⁻¹), indicating their positive impacts. In contrast, the canopy gaps influenced sand (697.50 g kg⁻¹), pH (5.71), effective cation exchange capacity (12.50 cmol kg⁻¹), calcium (9.40 mg kg⁻¹), sodium (0.59 mg kg⁻¹), and manganese (71.86 mg kg⁻¹) negatively. However, the lower values of BD (1.32 Mg m⁻³) observed in the gaps denote their positive influence on the soil. The study concluded that canopy gaps do impact soil properties in tropical *Hevea brasiliensis* plantations, and that soil properties respond differently to canopy gaps. The outcomes of this research contribute to a better understanding of the role of canopy gaps as ecological drivers of soil properties dynamics in a monoculture tree plantation such as *Hevea brasiliensis*, which is crucial for its functioning and sustainability.

Keywords: Canopy Gap, *Hevea brasiliensis*, Tree Plantation, Soil Quality, Tree Fall

INTRODUCTION

Rubber, scientifically known as *Hevea brasiliensis*, is a perennial tree cultivated for harvesting natural rubber (Bhumiphan *et al.*, 2023). It is a member of the *Euphorbiaceae*, the spurge family, and of the subfamily of *Crotonoideae* (Raj *et al.*, 2022). *Hevea brasiliensis* tree is indigenous to South America (Bakewell-Stone, 2025) and there has been substantial commercial increase of *Hevea brasiliensis* in the tropics (Warren-Thomas *et al.*, 2018). Forest is

being converted to *Hevea brasiliensis* rubber plantations and it is one of the important species cultivated in monoculture plantations within the rainforest region of southern Nigeria (Ndakara & Ohwo, 2022). *Hevea brasiliensis* plantations are both environmentally and economically significant at global, national, and local scales (Orobator, 2025), and *Hevea brasiliensis* tree grows rapidly to a height of about 25-30 m with a commercial lifecycle

of 30-35 years. The trees have a trunk with a cylindrical shape, and a usually swollen base, a high canopy and distinctive conical shape crown (Wei & Razak, 2021).

Gaps are the fingerprints of disturbances in forest canopies (Jucker, 2022). Disturbances are relatively discrete events in time that disrupt the structure of a biome, community, or population and alter resources, substrate accessibility, or the physical ecosystem (Pickett & White, 1985). Canopy gaps are characteristic significant biogeographical features in tree ecosystems signifying areas where the tree canopy has been opened up, typically due to the mortality of one or more trees (Donald *et al.*, 2022). Strong winds, climate extremes, lightning, trunk breakage or uprooting, collapse of a large branch, canopy tree or a collection of canopy trees can result in individual tree death. The processes (natural or anthropogenic) in which one or more trees in a forest die, leaving a hole in the canopy and making available both light and nutrient resources for seedlings and saplings, are called gap dynamics (Brokaw & Busing, 2000). Canopy gaps considerably modify the microenvironment, influencing flora regeneration, and species diversity (Krüger *et al.*, 2023). Furthermore, they can alter soil quality (Kooch *et al.*, 2010) by affecting the physicochemical properties of soil, organic matter decomposition, and soil microorganisms' activity (Lyu *et al.*, 2021). After gaps form, the soils are exposed; consequently, the soil quality properties, decomposition and mineralization, the quantity and composition of soil fauna, and soil microbes and enzymes in soil would be altered. These changes could instigate multifaceted fluctuations of soil nutrient contents (Zhang & Zhao, 2007). Similarly, canopy gaps can impact soil moisture, nutrient cycling, nutrient availability and turnover (Bottero *et al.*, 2011). All of these factors, singularly or in groups, can affect the

growth, survival, and reproduction of trees (Orman *et al.*, 2021).

To date, notable empirical studies have investigated the effects of canopy gaps on soil properties across various woodland ecosystems and climatic zones. For instance, gaps and soil C dynamics in old growth northern hardwood-hemlock forests (Scharenbroch & Bockheim, 2008); effects of gap disturbance on soil chemical and biochemical properties in a mixed beech – hornbeam forest of Iran (Kooch *et al.*, 2010); effects of forest gaps on soil properties in *Castanopsis kawakamii* nature forest (He *et al.*, 2015b); impacts of forest gaps on soil properties and processes in old growth northern hardwood-hemlock forests (Scharenbroch & Bockheim, 2007); effects of small gaps on the relationship among soil properties, topography, and plant species in subtropical rhododendron secondary forest, southwest China (Tang *et al.*, 2019); influences of forest gaps on soil physicochemical and biological properties in an oriental beech (*Fagus orientalis* L.) stand of Hyrcanian forest, north of Iran (Amolikondori *et al.*, 2020); short-term effects in canopy gap area on the recovery of compacted soil caused by forest harvesting in old-growth Oriental beech (*Fagus orientalis* Lipsky) stands (Jourgholami *et al.*, 2021); forest gaps mediate the structure and function of the soil microbial community in a *Castanopsis kawakamii* forest (Wang *et al.*, 2021), forest gaps alter the soil bacterial community of weeping cypress plantations by modulating the understory plant diversity (Lyu *et al.*, 2022); effects of different forest gap ages on soil physical properties and stoichiometric characteristics in *Cryptomeria japonica* plantations (L.f.) D. Don, 1839 (Xiao *et al.*, 2022); influence of forest canopy gaps on soil properties and richness of understory vascular plants in 2-hectare long-term ecological research (LTER) Site in Mt. Musuan in Bukidnon, southern Philippine (Paquit *et al.*, 2023); canopy gap impacts

on soil organic carbon and nutrient dynamics: A meta-analysis (Tong *et al.*, 2024) etc. Despite the ecological importance of canopy gaps, studies in the tropics remain underexplored, particularly in a managed monoculture tree system such as *Hevea brasiliensis* plantation, one of the dominant perennial tree ecosystems in southern Nigeria (Orobator & Odjugo, 2024). This study gap has limited the scope of research, and our understanding of how canopy gaps influence soil properties. In addition, it remains largely unknown whether the response of soil properties to canopy gap is the same across different tropical perennial tree plantations. Therefore, there is a need to address this gap and advance knowledge in this area.

Investigating soil properties in canopy gaps within *Hevea brasiliensis* plantations provides valuable insights into the soil's capacity to supply essential nutrients to plant roots. Canopy gaps represent important top-down trophic interactions between vegetation and soil (Chapin *et al.*, 2002). This reference framework enhances our understanding of plant-soil interactions in canopy gaps (He *et al.*, 2015a). These ecological considerations, along with the existing knowledge gaps, highlight the significance of an in-depth study on the impacts of canopy gaps on soil nutrients in tropical *Hevea brasiliensis* plantations. In this research, we examined

the soil quality properties in under-canopy (non-gap) and canopy gap areas within a *Hevea brasiliensis* plantation. In the under-canopy, the stand is well covered by overstory, which causes less sunlight, resulting in fewer plant species (Wang *et al.*, 1980).

The current study may represent the first attempt to examine the influence of canopy gaps on soil properties in a *Hevea brasiliensis* plantation in southern Nigeria. Our findings will be significant to biogeographers, environmentalists, forest ecologists, and soil scientists not only for understanding the sustainability of *Hevea brasiliensis* plantations, soil fertility, and biome health but also for providing meaningful insights into the responses of soil properties to canopy gaps in tropical *Hevea brasiliensis* plantations. This will aid to identify nutrient hot spots or islands of fertility vital for the productivity and overall pedodiversity of *Hevea brasiliensis* plantations. The results will provide a theoretical basis for tree regeneration and population restoration contributing to the long-term functioning of *Hevea brasiliensis* plantations. The current study highlighted the interface between canopy gaps and soil quality in perennial tree biomes in the tropical ecological zone. Consequently, the study will serve as an ecological reference for supporting the sustainable management of other related perennial tree ecosystems.

MATERIALS AND METHODS

Study area

This research was conducted in Rubber Research Institute of Nigeria (RRIN), Iyanomo, located in Ikpoba Okha Local Government Area, Edo State, Nigeria. The study area lies between latitudes 6°9'0" N and 6° 18'0" N and longitudes 5°33'0"E and 5°42'0"E (Figure 1) covering an area of about 30.2 km². RRIN belongs to a typical humid tropical climate with an average annual

temperature of 11.6 C and an average annual precipitation of 2000 mm. The soils are the ferralitic type and RRIN is dominated by rubber tree plantations of varying ages (Orobator *et al.*, 2020; Orobator & Odjugo, 2023). The study site is a mature *Hevea brasiliensis* plantation characterized by large canopies and irregular gaps.

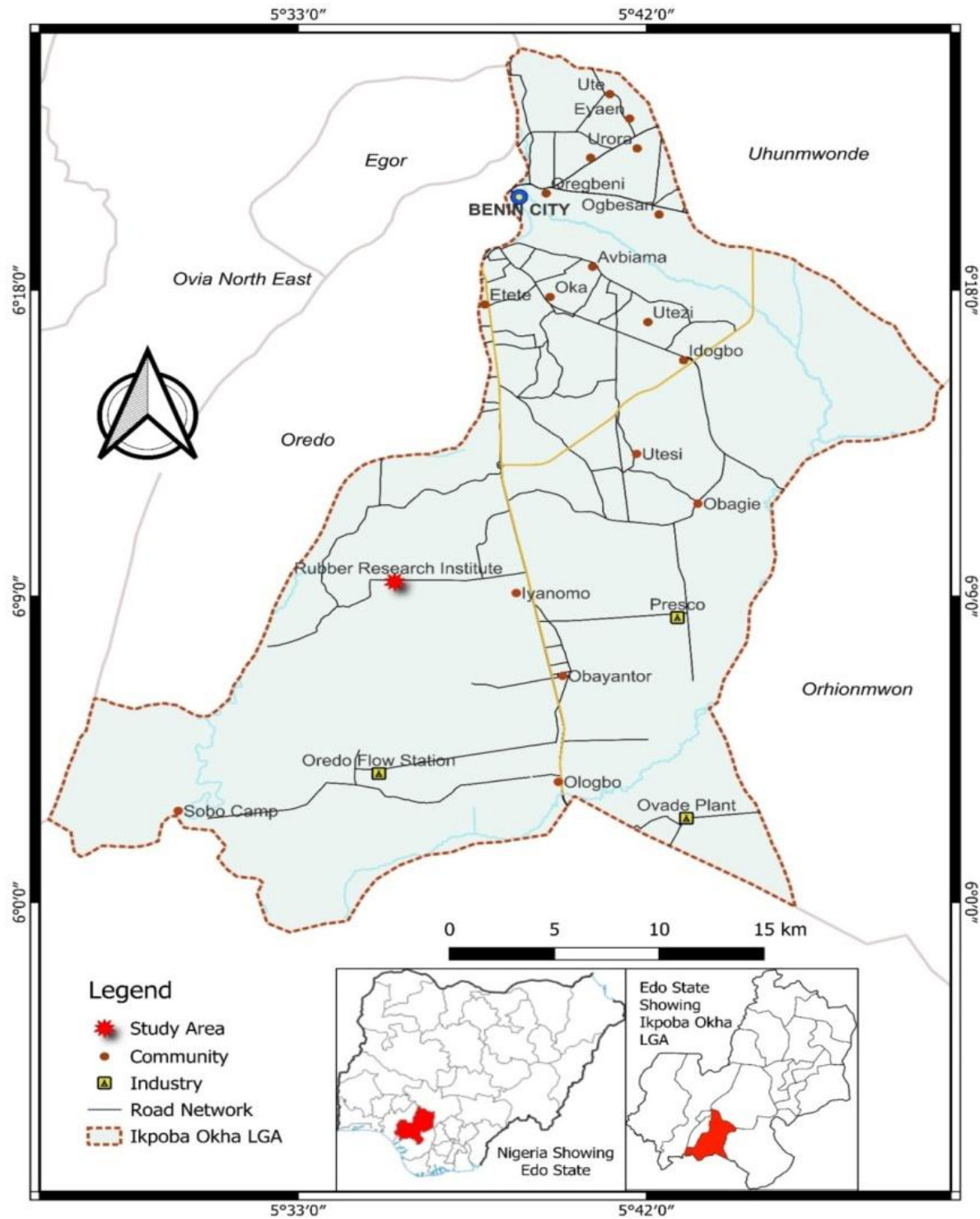


Figure 1: Ikpoba Okha Local Government Area showing the location of the Study Area (Rubber Research Institute of Nigeria)

Gap selection, characterization, center identification, and soil sampling

Due to the homogeneity of tree species in the *Hevea brasiliensis* plantation, and to eliminate any inconsistency linked with gap mode and closure, the examined gaps were those created from either trunk breakage, collapse of a large branch, or a dead individual tree. Fifteen (15) gaps were selected following the benchmarks of Runkle (1992), Tyrell and Crow (1994), and McClure *et al.*, (2000) cited in Scharenbroch and Bockheim (2007). Irregular canopy gaps (non-circular or complex gaps) (Figure 2) were selected for the study because they were the dominant gap types found in the *Hevea brasiliensis* plantation. To characterize the irregular gaps and establish the center, where soil samples were collected, the manual gap center estimation method was adopted.



Figure 2. Irregular canopy gap

This manual approach is typically accepted when gaps are irregular, and when high-precision tools (like GIS or LIDAR) are unavailable in the field (Van der Meer & Bongers, 2001). This method is hands-on in the field and it embraces identifying and measuring the longest and the widest diameters of the gap in the *Hevea brasiliensis* plantation, and the gap center was defined as the point of intersection of the two axes. Adopting the systematic

random sampling approach and with the aid of a hand auger, 15 soil samples were taken at a depth of 0-15 cm (referred to as topsoil; Adejuwon & Adesina, 1990) at intervals of 15 m, from both the center of the canopy gaps and the under-canopy of the adjacent trees, resulting in 30 samples in total. The technique of sampling at a consistent soil depth is necessitated by the desire to warrant comparability between the soils (Aweto, 1981). The approach adopted in the study was to sample the soil under-canopy and canopy gap of *Hevea brasiliensis* trees, and compare their properties in order to evaluate the impacts of the tree gaps on the soil. This method has been adopted by Aweto & Dikinya (2003) and Alo & Aweto (2018) to study the effects of trees on soil under their canopies. The number of soil samples collected is based on the similarity of soil type, vegetation, and climatic characteristics of both the under-canopy and canopy gap areas (Ozgedinova *et al.*, 2025). Each soil sample was air dried and sieved to 2 mm mesh size; also any living plant material was removed manually from the sieved soil.

Laboratory analysis

Soil samples were analyzed based on the standard methods of soil nutrients analysis (Page 1992). Soil texture (sand, silt and clay) was determined by Bouyoucos hydrometer method. Soil bulk density (BD) was measured by the soil core method. Soil pH was determined using a pH meter after shaking the soil: water (1:1, w/v) suspension for 1 hour. Soil organic carbon (SOC) was determined by the chromate acid oxidation method whereas soil organic matter (SOM) was obtained by multiplying percent soil organic carbon by a factor of 1.724. The micro-Kjedahl procedure was used to extract total nitrogen (TN) while available phosphorous (Avail. P) was measured following the Bray II method using 0.03 M

NH₄F and 0.10 M HCl solution. Effective cation exchange capacity (ECEC) was determined using sodium acetate at a pH of 8.2. Exchangeable cations (Ca, Mg, K and Na) were extracted in 1N NH₄OAc at pH 7. Zinc (Zn), Copper (Cu), Iron (Fe), and Manganese (Mn) were determined by diethylenetriaminepentaacetic acid (DTPA) extraction.

Statistical analyses

The study adopted both descriptive and inferential statistics. Descriptive statistics provided basic significant

information (range, mean, standard deviation and coefficient of variation) about the values of the soil nutrients in the under-canopy and canopy gap areas. Student t-test was used to compare the means of soil nutrients in the under-canopy and canopy gap, and to also ascertain significant differences. Differences were considered statistically significant at $p < 0.05$. The effect of the canopy gap was attained by comparing each soil quality parameter between the under-canopy and the canopy gap.

under-canopy cushions raindrop effect and reduce topsoil detachment (Ma *et al.*, 2014). The higher value of sand in under-canopy may be connected to the accrual of aeolian materials in their canopy (Isichei & Muoghalu, 1992). However, the results inferred that canopy gaps negatively influenced

RESULTS AND DISCUSSION

The summary of soil quality properties under the canopy and canopy gap areas are presented in Table 1. The mean value of sand in the under-canopy (780.00 g kg⁻¹) was higher than in the canopy gap (697.50 g kg⁻¹). The findings indicated that

Table 1: Soil physicochemical concentrations in under-canopy and canopy gap areas

Soil nutrient	Under-canopy				Canopy gaps				p-value
	Range	Mean	Std.	CV (%)	Range	Mean	Std.	CV (%)	
Sand (g kg ⁻¹)	650 - 900	780.00	67.61	8.67	400 - 800	697.50	156.36	22.42	0.39
Silt (g kg ⁻¹)	50 - 200	143.33	41.69	29.08	10 - 400	174.00	102.10	58.68	0.15
Clay (g kg ⁻¹)	0 - 150	76.67	45.77	59.70	10 - 200	80.66	55.09	68.29	0.39
BD (Mg m ⁻³)	1.21 - 1.47	1.34	0.07	5.50	1.11 - 1.47	1.32	0.11	8.84	0.13
pH	4.7 - 6.4	5.75	0.54	9.38	5.00 - 6.50	5.71	0.45	7.96	0.37
ECEC(cmolk g ⁻¹)	4.27 - 82.14	14.31	19.19	134.08	4.23 - 50.27	12.50	11.48	91.82	0.18
SOM (g kg ⁻¹)	1.40 - 8.60	4.65	2.03	43.78	1.60 - 13.60	4.98	2.99	60.11	0.36
SOC (g kg ⁻¹)	0.81 - 5.00	2.70	1.18	43.89	0.93 - 7.90	2.89	1.74	60.21	0.36
TN (g kg ⁻¹)	0.09 - 0.48	0.25	0.10	40.06	0.10 - 0.75	0.27	0.16	58.29	0.31
Avail. P (mg kg ⁻¹)	0.10 - 1.52	0.74	0.42	57.08	0.10 - 1.62	0.79	0.41	52.32	0.34
Ca (cmol kg ⁻¹)	3.00 - 71.00	11.20	16.86	150.58	3.00 - 40.00	9.40	9.34	99.37	0.36
Na (cmol kg ⁻¹)	0.34 - 1.24	0.64	0.22	34.85	0.14 - 1.24	0.59	0.27	46.88	0.27
Mg (cmol kg ⁻¹)	0.52 - 8.40	1.66	1.91	115.24	0.55 - 7.41	1.68	1.68	99.90	0.48
K (cmol kg ⁻¹)	0.41 - 1.50	0.81	0.28	35.40	0.38 - 1.62	0.85	0.35	42.17	0.34
Zn (mg kg ⁻¹)	3.40 - 8.70	5.10	2.20	41.56	3.50 - 11.80	5.31	2.20	41.56	0.37
Cu (mg kg ⁻¹)	1.80 - 4.62	3.19	0.71	22.40	2.50 - 4.91	3.39	0.72	21.28	0.27
Fe (mg kg ⁻¹)	78.00 - 330.00	136.00	63.15	46.43	76.00 - 320.00	150.40	78.13	51.95	0.11
Mn (mg kg ⁻¹)	34.40 - 210.00	76.76	58.36	76.03	28.5 - 200.00	71.86	53.27	74.13	0.41

Source: Author's Analyses

sandy soils by contributing to sand loss due to rain splash effect on the soil. No significant differences were found between under-canopy and canopy gap. In contrast to the findings of the study, Amolikondori *et al.*, (2020) reported higher values of sand (709.00 g kg^{-1}) in the gaps of oriental beech (*Fagus orientalis L.*) stand.

Silt contents were higher in canopy gaps (174.00 g kg^{-1}) than soil under-canopy (143.33 g kg^{-1}), suggesting that canopy gaps positively impacted silt. The redistribution of soil particles owing to reduced root and soil fauna activity in the gaps leads to accretion of silt particles (Wardle *et al.*, 2004), and this may be ascribed to the higher silt values in the canopy gaps. This outcome agreed with Jourgholami *et al.*, (1999) findings which showed higher contents of silt (554.60 g kg^{-1}) in canopy gap. Similarly, in line with the current study, Jourgholami *et al.*, (1999) detected no significant difference between under-canopy and canopy gap.

Higher mean value of clay was observed for canopy gaps (80.66 g kg^{-1}) than under-canopy (76.67 g kg^{-1}), demonstrating that canopy gaps have a positive impact on clay. This may be due to altered microtopography and increased soil moisture retention. This can stimulate clay particle accumulation and immobilization, resulting in localized clay enrichment (Bronick & Lal, 2005). However, in old-growth Oriental beech (*Fagus orientalis Lipsky*) stands, Jourgholami *et al.*, (2021) reported lower clay values (30.13 g kg^{-1}) compared to the non-gap area (31.39 g kg^{-1}). This may be due to enhanced rates of evaporation and soil drying in that tree biome. These will instigate clay particles to scatter or aggregate inversely, potentially decreasing the clay concentrations (Le Bissonnais & Arrouays, 1997).

Soil BD value was higher in under-canopy (1.34 Mg m^{-3}) than canopy gaps (1.32 Mg m^{-3}), indicating a loosening of soil structure of canopy gaps resulting to improving soil porosity composition and

moisture. This may lead to seedling recruitment (Muscolo *et al.*, 2010). BD is a significant physical property of soil, indicating the compactness of soil structure, and can influence soil water permeability and root extension (Tracy *et al.*, 2011). This result coincided with Zhang & Zhao (2007), who reported that soil BD under-canopy was slightly higher than in gaps, and had no significant difference.

As regards soil pH, in the under-canopy (5.75), a higher value was observed compared to the canopy gaps (5.71). The results demonstrate that canopy gaps have a negative influence on pH, resulting in a higher acidity level. This may be ascribed to the influence of decomposed foliage on the soils in canopy gaps. Most foliage is acidic, which can result in increased soil acidity after the leaves decompose (Geng *et al.*, 2002). The accrual of organic matter in canopy gaps can result in soil acidification. This was observed in the study, where a higher soil organic matter value was detected in canopy gaps (4.98 g kg^{-1}). The findings of the study aligned with Zhang and Zhao (2007), who reported that the soil pH value in canopy gaps was lower (5.80), while higher value (5.85) was observed for under-canopy. Similarly, they reported that the differences were not significant.

Higher mean value of ECEC was observed for under-canopy ($14.31 \text{ cmol kg}^{-1}$) than in canopy gaps ($12.50 \text{ cmol kg}^{-1}$). In addition, although the value of ECEC under canopy gaps was not significant compared to under-canopy soils, the findings showed a potential negative influence of canopy gaps on ECEC. This could be due to the higher acidity observed in gaps. Soil pH influences ECEC by altering the charge density on soil particles. At lower pH levels, the abundance of hydrogen ions (H^+) can occupy cation exchange sites, thus decreasing the ECEC (Warino, 2024). This was observed in the current study, where a lower pH value was observed for gaps (5.71). Similarly, Scharenbroch and Bockheim (2007) reported

lower contents of ECEC in canopy gaps.

Higher SOM value was observed in canopy gaps (4.98 g kg^{-1}) than under-canopy (4.65 g kg^{-1}). The observed higher value of SOM indicates a positive impact of canopy gaps on SOM. This implies that the soils in the canopy gaps have a higher potential to permit the growth of flora than in the under-canopy. This could be ascribed to increased litter decomposition (Bongiorno *et al.*, 2019). Canopy gaps receive more sunlight, which raises both temperature and soil humidity (Arunachalam *et al.*, 1996), resulting in an increased rate of litter decomposition and, consequently, more organic matter in the soil. Additionally, the presence of higher clay content in the soil may contribute to greater organic matter accumulation in the gaps. This was observed in the current study, where a higher clay value was detected in canopy gaps (80.66 g kg^{-1}). Higher SOM can influence the availability of other soil nutrients, as it is a primary source of nutrients in the soil. The result of this study is consistent with Zhang and Zhao (2007), who reported that organic matter content of soil in gaps was higher than that under-canopy.

Canopy gaps (2.89 g kg^{-1}) had a higher SOC value compared to under-canopy (2.70 g kg^{-1}). Although, the values of SOC in the soil under gaps relative to under-canopy levels were not significant, the results revealed a positive influence of canopy gaps on SOC. As a stable and long-term carbon source, SOC plays a vital role in sustaining soil fertility; its concentration influences the soil potential productivity (Xiong *et al.*, 2022). The decomposition of foliage and dead roots produces organic carbon (Zhang & Zhao, 2007). This process contributes to the increased organic carbon content in the soil in canopy gaps. In contrast to the results from *Castanopsis kawakamii* Nature Forest, He *et al.*, (2015b) reported lower value of SOC in the canopy gaps.

Higher mean value of TN was observed for gaps (0.27 g kg^{-1}) than under-

canopy (0.25 g kg^{-1}), suggesting that canopy gaps positively influenced TN. This demonstrated that there was an improvement in soil nitrogen availability ensuing gap creation. Organic matter is the main source of soil nutrients, as most nitrogen in the soil exists in organic form (Zhang & Zhao, 2007). The concentration and distribution of TN in the soil are closely linked to its organic matter content. Consequently, the observed higher soil organic matter value (4.98 g kg^{-1}) in the gaps resulted in higher TN value in the canopy gaps. The higher concentration level of TN may also be attributed to a reduction in nutrient uptake by vegetation (Tong *et al.*, 2024). Additionally, the observed TN concentration in the gaps may be due to a delayed response to the disturbance (Ritter & Vesterdal, 2006). In contrast, Amolikondori *et al.*, (2020) reported that TN indicated a significant decrease in the gaps in an oriental beech (*Fagus orientalis L.*) stand of Hyrcanian forest.

Canopy gaps (0.79 mg kg^{-1}) had higher Avail. P value than under-canopy (0.74 mg kg^{-1}). The higher value of Avail. P in canopy gaps indicated its positive impact. Despite the non-statistically significant differences in Avail. P between canopy gaps and under-canopy areas, the findings indicate a positive impact of canopy gaps on Avail. P. This may be due to the higher amount of clay observed in the soils of canopy gaps (80.66 g kg^{-1}). Clay has very strong attraction to immobile P (Sha & Cao, 1999). Equally, Chen *et al.*, (1995) observed higher phosphorus contents in canopy gaps. Contradictorily, the findings of the study are not consistent with He *et al.*, (2015b), who observed lower values of phosphorus in gaps of *Castanopsis kawakamii* Nature Forest.

Ca (9.40 mg kg^{-1}) and Na (0.59 mg kg^{-1}) had lower values in canopy gaps, whereas Mg (1.68 mg kg^{-1}) and K (0.85 mg kg^{-1}) showed higher concentrations. The findings demonstrated the varied impacts of gaps on exchangeable cations. Higher K

values observed in the gaps may be credited to increased litter decomposition and nutrient cycling (Kaspari *et al.*, 2008). Zhang and Zhao (2007) reported that the decomposition of foliage and dead roots would produce organic C that can effectively increase the concentrations of K. Enhanced SOM decomposition, resulting to quicker Mg mineralization from plant litter and dead wood can be ascribed to the higher value of Mg (Forrester *et al.*, 2023). Canopy gaps permit more rainfall to unswervingly reach the soil owing to reduced canopy interruption resulting to the leaching of soluble cations (Ca and Na) down into the soil profile or completely out of the root zone (Likens *et al.*, 1998). This may be credited to the lower Ca and Na values observed in the canopy gaps.

The concentrations of Zn (5.31 mg kg⁻¹), Cu (3.39 mg kg⁻¹), and Fe (150.40 mg kg⁻¹) were higher in gaps, except for Mn (76.76 mg kg⁻¹), which showed lower levels. The results indicated that whereas gaps had a negative impact on Mn, it was positive for Zn, Cu, and Fe. The lower value of Mn in the gaps may be due its slow release in foliar litter during plantation regeneration (He *et al.*, 2015a). In contrast, the higher values of the other micronutrients in the gaps could be attributed to increased organic matter decomposition which promotes nutrient mineralization (Prescott, 2002).

CONCLUSION AND RECOMMENDATION

The impacts of canopy gaps on soil properties are a complex and multifaceted process. Our research demonstrated that canopy gaps do influence soil properties in tropical *Hevea brasiliensis* plantation ecosystems. Specifically, BD, silt, clay, SOM, SOC, TN, Avail. P, Mg, K, Zn, Cu, and Fe were positively affected by canopy gaps. However, canopy gaps had a negative impact on sand, pH, ECEC, Ca, Na, and Mn. This study highlights the varied responses of

specific soil quality indicators to canopy gaps in *Hevea brasiliensis* plantations in the tropics. The findings will have significant implications for formulating soil quality management strategies in *Hevea brasiliensis* plantations. The study recommended that future research should focus on the influence of canopy gaps on soil microbial properties in tropical *Hevea brasiliensis* plantations.

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