

Soil properties and tree diversity along elevational gradients in a tropical agroforestry landscape in the Philippines

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ABSTRACT

The Philippines is known for its archipelagic geography and tropical climate, which support a wide range of organisms. However, determining the relationship between soil physicochemical properties and tree diversity in agricultural landscapes has been less explored. This study assessed whether soil physicochemical characteristics influence tree species diversity in various agricultural regions of Tagnote Falls in Barangay San Antonio, Remedios T. Romualdez (RTR), Agusan del Norte across different elevation ranges, specifically in low (0–200 masl), moderate (201–400 masl), and high (401–600 masl) elevation ranges. The researchers collected soil samples to analyze their soil physicochemical properties: soil texture, soil pH, and macronutrient content (Nitrogen, Phosphorus, and Potassium). A total of 16 tree species were recorded across these areas. The study results showed that the Shannon diversity index reached 1.7042, indicating very low species richness, while Pielou's evenness index averaged 0.7832, indicating that organisms were distributed evenly among species. The Kendall's tau correlation analysis showed no significant relationship between tree species diversity and soil texture or soil macronutrients (Nitrogen, Phosphorus, and Potassium). Pearson's correlation analysis also found that tree diversity was not significantly related to soil pH. The distribution of tree species in the area is more influenced by environmental and ecological factors, including microclimate differences, landscape topography, biotic interactions, and historical land-use practices, rather than by soil physicochemical properties. Overall, the findings suggest that sustainable agroforestry and biodiversity conservation strategies should consider broader ecological drivers beyond soil physicochemical properties.

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1. INTRODUCTION

Elevational gradients provide natural laboratories for testing ecological theories explaining biodiversity patterns, particularly environmental filtering and niche differentiation (Rahbek et al., 2019). According to environmental filtering theory, systematic abiotic transitions along altitudinal gradients—such as changes in temperature, humidity, sunlight exposure, and edaphic traits as selective mechanisms that determine which species can successfully establish and persist. Concurrently, soil–plant feedback theory highlights a dynamic, multi-directional interplay: tree communities actively modify their localized edaphic environments through litterfall composition, root exudates, and specialized microbial activities, while those changing soil conditions reciprocally govern tree vegetative growth, nutrient uptake, and overall community dynamics (Augusto et al., 2015; Beugnon et al., 2021). Globally, tropical forests serve as critical cornerstones for carbon storage, microclimate

regulation, and soil stabilization, highlighting the urgent need to model these complex ecological gradients to sustain essential ecosystem functions against intensifying climate change impacts (IPCC, 2022).

While numerous studies have examined elevation–diversity relationships in tropical natural forests, limited attention has been given to agroforestry landscapes and human-modified ecosystems where anthropogenic planting decisions may override environmental controls. In natural mountain systems, plant diversity patterns are heavily co-structured by soil matrices, slope, and altitude, with woody species richness frequently exhibiting systematic declines as environmental filters intensify at higher elevations (Loiola et al., 2023). However, within rural tropical landscapes, active agricultural mosaics introduce a powerful anthropogenic filter. Smallholder farmers choose, manage, and introduce vegetation based primarily on economic yield, cash crop utility, and rapid growth performance, which can completely mask or suppress natural ecological sorting rules.

Understanding whether underlying soil physicochemical properties still actively structure tree diversity under the pressure of human agricultural management remains an unresolved question and a critical gap in landscape ecology.

The Philippines provides a vital setting for addressing this theoretical gap. As one of the world's 17 megadiverse nations, its complex archipelagic topography hosts immense floristic endemism alongside high vulnerability to land-use modification (Posa et al., 2008; DENR, 2024). Despite growing global momentum in elevational ecology, localized, data-driven studies targeting the precise soil-diversity dynamics inside rural Philippine agroecosystems remain comparatively scant. This study addresses this lack of empirical data by focusing on the unique, understudied ecological mosaic surrounding Tagnote Falls in Barangay San Antonio, Remedios T. Romualdez (RTR), Agusan del Norte. This landscape features a distinct topographical transition composed of interacting agricultural plots and fractured forest remnants, making it a valuable setting for biodiversity assessments.

To evaluate whether traditional ecological gradient principles hold true under human management, this study assessed the relationship between tree species diversity and soil physicochemical properties—specifically soil texture, pH, and macronutrient availability (nitrogen [N], phosphorus [P], and potassium [K])—across an elevational gradient in the managed farmlands around Tagnote Falls. The specific objectives were to: 1) Identify and inventory the tree species across each distinct elevational range; 2) Determine which elevational zone exhibits the highest taxonomic tree diversity and evenness; 3) Characterize the key soil physical and chemical parameters across the gradient; and 4) Assess whether there is a statistically significant relationship between the soil properties and tree diversity metrics.

By testing the limits of environmental filtering within a human-dominated matrix, these findings are intended to provide a clear theoretical contribution to tropical landscape ecology, while offering practical guidance for local smallholders on sustainable land use and supporting regional conservation planning in upland agroforestry systems.

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted around Tagnote Falls, located in Barangay San Antonio, Remedios T. Romualdez (RTR), Agusan del Norte. Tagnote Falls, located at around 9.05°N, 125.65°E, is a two-level waterfall often visited by local people, not only for its views but also as a natural landmark of the area. Now the mix around the falls includes areas of forest

and farmland. Some areas are closer to the forest edge, while nearby communities have more influence on others. Due to changes in elevation and land use within the area, it appeared suitable for studying the relationship between soil physicochemical properties and tree species diversity.

2.2. Research design

The study used a quantitative research design to collect and analyze data on tree species diversity and its relationship to soil physicochemical properties across three elevation ranges: low (0–200 masl), moderate (201–400 masl), and high (401–600 masl).

2.3. Sampling design and plot layout

A quadrant sampling method was employed to assess tree diversity along an elevational gradient. Three 20 m × 20 m plots were randomly established across low-, moderate-, and high-elevation ranges. The researchers randomly established three sampling plots per elevation range, each measuring 20m x 20m, spaced 250 meters apart, depending on the structure of the tree community and the terrain.

While a total of nine plots ($n = 9$) represents a localized sample size, comparable plot-based vegetative inventories across topographically complex tropical environments have relied on similar sampling intensities when restricted by terrain and accessibility constraints (Proctor et al., 1983; Homeier et al., 2010). It is worth noting, however, that this limited sampling design may reduce overall statistical power; hence, future ecological studies should prioritize expanded sampling grids to enhance statistical generalization.

All trees with a diameter of $\geq 5\text{cm}$ were also recorded. DBH was measured 1.3 meters above ground using a diameter tape. Although tree heights were also measured using a tape measure where possible, it was not used in the computation of diversity indices.

Data collected per plot focused on:

- Species identification
- Number of individuals per species

These data were used to calculate:

- Shannon's Diversity Index (H'), representing species richness and abundance distribution
- $H' = -\sum(p_i \cdot \ln p_i)$, where p_i is the proportion of individuals of species i in the plot (Shannon & Wiener, 1963).
- Evenness Index, reflecting how evenly individuals are distributed among species.
- $E = H' / \ln S$, where S is the total number of species in the plot (Magurran, 2004).

This sampling design provided a standardized basis for comparing species diversity and evenness as measures of biodiversity across the three elevational gradients. The landscape around the falls comprises areas of forest and farmland. In the lower and mid-elevation portions, residents cultivate crops such as sweet potatoes and corn, while rice fields predominate in the low-lying areas. Additionally, many households nearby raise livestock, including pigs, cows, and goats.

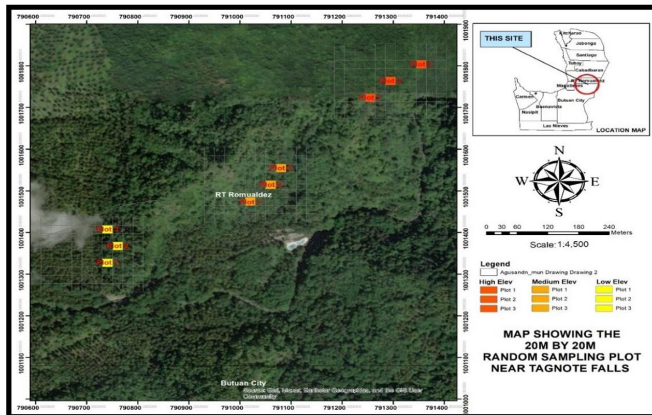


Figure 1: Map of the study area indicating sampling plots

2.4. Soil sample collection and analysis

Soil samples were collected in a zigzag pattern across each elevation range within each established 20 m × 20 m plot to minimize spatial bias and assess the influence of soil physicochemical properties on tree diversity. At each elevation range, nine (9) subplots were identified, and soil samples were collected at 0–30 cm depth within a 20 cm × 20 cm soil pit.

Samples per plot were homogenized to create one composite sample per plot, yielding 1 kilogram of soil. These samples were placed in labeled, sterile polyethylene bags to prevent contamination and then transported to the Department of Agriculture Soil Testing Laboratory in Taguibo, Butuan City, Caraga Region, for analysis.

The following soil physicochemical parameters were analyzed:

- Soil Texture – determined by the relative proportions of sand, silt, and clay
- Soil pH – measures the soil acidity or alkalinity
- Macronutrient Content – assessed the Nitrogen (N), Phosphorus (P), and Potassium (K)

Soil moisture and organic carbon were not included in the analysis due to time and resource constraints. However, these parameters are considered important factors in influencing nutrient dynamics and soil pH. These should be considered in future studies to provide a comprehensive understanding of the relationships between soil conditions and tree diversity.

GPS coordinates were also recorded at the center of each plot using a handheld Global Positioning System (GPS) device to geo-reference the sampling locations. The spatial distribution of sampling plots across the study area is shown in Figure 1.

2.5. Tree species identification and diversity analysis

The trees within the plots were taxonomically identified and classified in real time. The tree species diversity was calculated using Shannon Wiener's Diversity Index (Shannon & Wiener, 1963) and evenness (Pielou, 1966), which provides a quantitative description of tree species in terms of species richness and evenness, with the help of Paleontological Statistics Software (PAST) developed by Hammer et al. (2001). Biodiversity levels were interpreted based on the following index ranges, as presented in Table 1:

Table 1: Classification scheme for Shannon diversity index (H') and evenness index (J')

Relative Interpretation	Shannon's (H') Index	Evenness Index (J')
Very high	≥ 3.5	0.75–1.00
High	3.00–3.49	0.50–0.74
Moderate	2.50–2.99	0.25–0.49
Low	2.00–2.49	0.15–0.24
Very low	≤ 1.99	0.05–0.14

2.6. Statistical analysis

To investigate the relationship between tree species diversity metrics and soil physicochemical properties across the elevational gradient, data processing followed a structured, sequential workflow based on distributional assumptions. The choice of correlation coefficients was determined by the underlying characteristics of the data collected:

Parametric Approach: For continuous variables that exhibited a normal distribution (such as soil pH), Pearson's correlation coefficient (r) was applied to measure linear relationships. **Non-Parametric Approach:** For continuous or ranked variables exhibiting non-normal distributions (including soil texture and macronutrient concentrations of N, P, and K), Kendall's Tau tau correlation was deployed. Kendall's Tau was selected over Spearman's rho because it provided a more robust, distribution-free parameter estimation and greater statistical validity when dealing with smaller sample sizes and potential data ties.

The application of these targeted correlation methods provided an appropriate statistical framework, ensuring a valid interpretation of the interacting dynamics between edaphic traits and tree diversity. All statistical modeling sequences were executed using SPSS (Statistical Package for the Social Sciences), with the statistical

significance threshold established *a priori* at $p < 0.05$. To interpret the mathematical magnitude and direction of the resulting correlation coefficient, the following standardized evaluation guidelines were implemented:

Strong Correlation: Coefficient values falling between +0.50 and +1.00 (or -0.50 and -1.00);

Moderate Correlation: Coefficient values falling between +0.30 and +0.49 (or -0.30 and -0.49);

Weak Correlation: Coefficient values falling below ± 0.29 , indicating a weak correlation; and

No Correlation: A coefficient value exactly equal to 0, indicating no correlation at all.

3. RESULT AND DISCUSSION

3.1. Species composition at each elevation range

The analysis of tree species composition in the selected farmland areas of Tagnote Falls in Barangay San Antonio, Remedios T. Romualdez (RTR), Agusan del Norte, is shown in Table 2. Four species were found to be common across all elevation ranges, including low (0–200 masl), moderate (201–400 masl), and high (401–600 masl): *Falcataria falcata*, *Gmelina arborea*, *Lansium domesticum*, and *Artocarpus heterophyllus*.

Among all recorded species, *Gmelina arborea* (Gmelina) had the highest number of individuals (12), followed by *Durio zibethinus* (11). In terms of relative frequency, *Gmelina arborea* accounted for 16.7% of all recorded trees, while *Durio zibethinus* represented 15.3%. Thus, these species were ecologically dominant in this locality due to their adaptability to local conditions and their value to humans, who preferred species with high economic value or fast growth metrics. Duke et al. (1983) reported that *Gmelina arborea* was widely cultivated in tropical and subtropical Asia for wood production and landscaping, explaining its abundance in the studied farmlands. In the Philippines, the Forest Products Research and Development Institute (FPRDI, 2020) highlighted *G. arborea* as one of the most planted industrial tree species due to its rapid biomass accumulation and commercial utility, supporting its widespread cultivation in smallholder and managed plantations.

Smallholder farm surveys supported the observation that *Gmelina arborea* functioned as a widely cultivated, fast-growing timber species with strong adaptability to managed and altered landscapes. In northern Mindanao, Philippines, smallholder farmers planted *Gmelina arborea* in block plantations and hedgerow systems, integrating it into farmland uses to produce timber for construction materials and market sale, reflecting the species' economic value for local wood

products and farmers' livelihoods (Magcale-Macandog, Menz, Rocamora, & Predo, 1999/2021). *G. arborea* was commonly cultivated in 2–3 ha farms, ranging from a few hundred to over a thousand trees, and was harvested for both domestic use and local sawmills, signifying its structural importance in small-scale timber production systems.

In comparison, *Syzygium aqueum* (Tambis) and *Cananga odorata* (Ilang-ilang) were among the least abundant species observed in the farmlands, suggesting that specific cultivation practices rather than widespread agroforestry integration drove their occurrence. *Syzygium aqueum* was commonly grown for its edible fruit and aesthetic appeal, frequently occurring in home gardens, orchards, and smaller agricultural settings rather than in larger managed timber fields, thriving best in humid tropical climates for optimal fruit yields (NParks, 2025). *Cananga odorata* was primarily valued for its aromatic flowers and essential oil, which are widely used in the perfume and aromatherapy industries, rather than for timber and agroforestry (Tan et al., 2015; Silalahi, 2023).

Table 2: Tree Species Distribution, Frequency, and Relative Abundance Across Elevation Ranges in the Selected Farmland of Tagnote Falls, RTR, Agusan del Norte.

Elevation Range	Common Name	Scientific Name	Frequency	Relative abundance
Low (0–200 masl)	Antipolo	<i>Artocarpus blancoi</i>	3	4.05%
	Datiles	<i>Muntingia calabura</i>	2	2.70%
	Falcata	<i>Falcataria falcata</i>	3	4.05%
	Gmelina	<i>Gmelina arborea</i>	4	5.41%
	Hauli	<i>Ficus septica</i>	3	4.05%
	Lanzones	<i>Lansium domesticum</i>	2	2.70%
	Mahogany	<i>Swietenia macrophylla</i>	5	6.76%
	Nangka	<i>Artocarpus heterophyllus</i>	2	2.70%
	Santol	<i>Sandoricum koetjape</i>	2	2.70%
Moderate (201–400 masl)	Antipolo	<i>Artocarpus blancoi</i>	1	1.35%
	Avocado	<i>Persea americana</i>	1	1.35%
	Binunga	<i>Macaranga tanarius</i>	2	2.70%
	Durian	<i>Durio zibethinus</i>	4	5.41%
	Falcata	<i>Falcataria falcata</i>	1	1.35%
	Gmelina	<i>Gmelina arborea</i>	3	4.05%
	Lanzones	<i>Lansium domesticum</i>	2	2.70%
	Mahogany	<i>Swietenia macrophylla</i>	3	4.05%
	Nangka	<i>Artocarpus heterophyllus</i>	1	1.35%
	Tambis	<i>Syzygium aqueum</i>	1	1.35%
High (401–600 masl)	Tibig	<i>Ficus nota</i>	5	6.76%
	Avocado	<i>Persea americana</i>	2	2.70%
	Durian	<i>Durio zibethinus</i>	7	9.46%
	Falcata	<i>Falcataria falcata</i>	2	2.70%
	Gmelina	<i>Gmelina arborea</i>	5	6.76%
	Ipil-ipil	<i>Leucaena leucocephala</i>	2	2.70%
	Ilang-ilang	<i>Cananga odorata</i>	1	1.35%
	Lanzones	<i>Lansium domesticum</i>	2	2.70%
	Nangka	<i>Artocarpus heterophyllus</i>	3	4.05%
TOTAL			74	100.00%

3.2. Tree species diversity across elevation ranges

Shannon's diversity index quantified species richness along with relative abundance. An index close to 2.0 generally indicated low diversity (see Table 1) in plant communities composed of multiple species, with no single species excessively dominating the others (Magurran, 2004). Values close to 1.0 for evenness suggested that individuals were distributed uniformly among species, which occurred when competitive exclusion was minimized or when human intervention limited the prevalence of a single species.

The slightly increased diversity observed in Plot 3 at the lower elevation (see Table 3) corresponded with broader ecological trends documented in tropical ecosystems. Tropical lowlands generally exhibited greater tree species diversity due to stable temperatures, higher productivity, and reduced abiotic stress compared to cooler, higher-elevation areas (Rahbek, 2005). Recent research along tropical elevational gradients indicated a decline in tree species diversity with increasing elevation, a pattern observed in both natural forests and human-altered systems as environmental filters (e.g., temperature, moisture) intensified at higher altitudes (Song et al., 2021; Torres et al., 2024). Collectively, these results indicated that elevation still influenced tree diversity patterns, even within agroforestry or agricultural landscapes, as lowland regions typically harbored greater baseline diversity.

Table 3: Tree Species Diversity Indices Across Elevation Ranges and Plots in Tagnote Falls, RTR, Agusan del Norte.

Elevation Range	Plots	Shannon's (H) Richness Index	Interpretation	Evenness Index	Interpretation
Low (0–200 masl)	Plot 1	1.831	Very low	0.8333	Very high
	Plot 2	1.8867	Very low	0.8194	Very high
	Plot 3	2.0198	Low	0.8423	Very high
Moderate (201–400 masl)	Plot 1	1.4942	Very low	0.7185	High
	Plot 2	1.5498	Very low	0.7965	Very high
	Plot 3	1.7351	Very low	0.7897	Very high
High (401–600 masl)	Plot 1	1.5498	Very low	0.7965	Very high
	Plot 2	1.7481	Very low	0.7592	Very high
	Plot 3	1.523	Very low	0.6931	High

3.3. Soil physicochemical properties

3.3.1. Soil texture

Soil texture analysis in Table 4 indicated differences across elevation ranges within the farmlands near Tagnote Falls. At low elevation (0–200 masl), soils were classified as light to medium, with textures ranging from sandy to loamy. Soils with higher sand content and well-balanced loam textures were generally well to moderately drained, characterized by larger pore spaces and improved aeration compared to finer-textured soils (Vereecken et al., 2016; Brady & Weil, 2016). These properties improved the effective

movement of water in the soil profile while providing sufficient moisture for plants, creating an environment that supported root development, gas exchange, and microbial activity (Araya et al., 2019; Zhao et al., 2022). Light to medium textured soils often gave roots better access to water and nutrients than very coarse or very fine textures because soil textures directly affected aeration and moisture retention (Smith & Mullins, 2019; Vereecken et al., 2016).

In contrast, plots located at higher elevations (401–600 masl) and moderate elevations (201–400 masl) exhibited greater variation in soil texture. Soils with high clay content were observed in both moderate and elevated ranges, particularly in Plots 1 and 3. In contrast to coarser soil textures, clay soils possessed a greater percentage of fine particles, enhancing water retention and increasing total surface area (Vereecken et al., 2016). However, high clay content in soils reduced pore space and particle connectivity, leading to more compacted conditions that slowed drainage (Irshad et al., 2024). Root elongation was impeded by clay soils, which reduced aeration, restricted flow, and limited nutrient uptake under saturated conditions (Smith & Mullins, 2019).

Topographic processes likely contributed to these variations in texture across elevation ranges. Clay and silt, classified as finer soil particles, were more easily transported by overland flow and accumulated in mid-slopes and concave areas (Brady & Weil, 2016; Vereecken et al., 2016). Because hydrological flow and erosion patterns were controlled in part by landscape configuration, variations in soil texture with elevation reflected both particle redistribution and the influence of slope on soil genesis and deposition patterns. Variations in soil texture along the elevation gradient influenced soil physical characteristics, such as porosity, hydraulic conductivity, and moisture dynamics, which affected plant root growth conditions, water retention capacity, and mechanical resistance (Araya et al., 2019; Zhao et al., 2022).

Table 4: Soil Texture Across Elevation Gradients in Tagnote Falls, RTR, Agusan del Norte.

Elevation Range	Plot	Soil Texture
Low (0–200 masl)	Plot 1	Light
	Plot 2	Medium
	Plot 3	Medium
Moderate (201–400 masl)	Plot 1	Heavy
	Plot 2	Light
	Plot 3	Heavy
High (401–600 masl)	Plot 1	Heavy
	Plot 2	Medium
	Plot 3	Heavy

3.3.2. Soil pH

Soil pH functioned as a critical chemical property that influenced nutrient solubility, microbial activity, and overall soil fertility (Akram et al., 2023). It determined the availability of essential elements, such as phosphorus, micronutrients, and secondary nutrients, by modifying chemical reactions and ion

solubility in the soil solution (Barrow & Hartemink, 2023). In many mineral soils, nutrient availability was optimized within a near-neutral to slightly acidic pH range (6.0–7.0) because both macro- and micronutrients tended to remain in more plant-available forms within this window (Khaled & Sayed, 2023).

The pH of Plot 1 at low elevation was 8.13, as shown in Table 5, which classified it as a moderately alkaline soil. Soils with high pH values that exceeded the neutral range resulted from the presence of basic cations, which originated from parent materials containing carbonate minerals, functioning as a buffer for acidity by raising soil pH to alkaline levels (Muzaffar, 2026). Alkaline environments reduced the solubility of various micronutrients including iron (Fe), manganese (Mn), and zinc (Zn), which hindered plant absorption (Muzaffar, 2026). Plot 2 at the same elevation showed a pH of 6.26, indicating slightly acidic soil that sat closer to the range where nutrients are readily available for plants. The pH value of Plot 3 was 6.76, which fell within the very slightly acidic range, approaching the neutral pH of 7.0.

This pH level enabled the growth of numerous plant species by maintaining proper nutrient distribution and beneficial microbial processes (Muzaffar, 2026). The soil pH values at moderate elevation (201–400 masl) showed only minor differences among the different plots. Plot 1 had a pH of 6.83 (very slightly acidic), and Plot 2 measured 6.42 (slightly acidic), both within the range where nutrient availability remained favorable for many plant species. Plot 3 exhibited a pH of 7.19 (very mildly alkaline), which lay just above the neutral pH range (7.0). Most tropical crops could still absorb nutrients from it except when specific micronutrients became inadequate. Soil pH influenced nutrient availability not only by affecting chemical reactions and soil solubility but also by modifying nutrient uptake, with higher pH levels decreasing micronutrient solubility and leading to localized nutrient deficiencies that required soil management interventions (Muzaffar, 2026); Barrow & Hartemink, 2023).

At high elevation (401–600 masl), both plots 1 and 2 possessed mildly alkaline soils, with Plot 1 showing a pH of 7.87 and Plot 2 showing a pH of 7.66. Plot 3 had very mild alkaline soils with a pH of 7.36. The values exceeded neutral pH yet remained within acceptable limits for most tropical tree species because mildly alkaline soils typically provided enough macronutrients for growth (Khaled & Sayed, 2023). However, higher pH reduced micronutrient availability in some areas (Barrow & Hartemink, 2023). Differences in soil pH across elevation ranges arose from variations in parent material composition, organic matter decomposition, and leaching intensity, which determined soil chemical properties (Muzaffar, 2026).

Table 5: Soil pH Levels and Interpretations Across Elevation Gradients in Tagnote Falls, Barangay San Antonio, RTR, Agusan del Norte.

Elevation range	Plot	Soil pH	Interpretation
Low (0–200 masl)	Plot 1	8.13	Moderately alkaline
	Plot 2	6.26	Slightly acid
	Plot 3	6.76	Very slightly acid
Moderate (201–400 masl)	Plot 1	6.83	Very slightly acid
	Plot 2	6.42	Slightly acid
	Plot 3	7.19	Very mildly alkaline
High (401–600 masl)	Plot 1	7.87	Mildly alkaline
	Plot 2	7.66	Mildly alkaline
	Plot 3	7.36	Very mildly alkaline

3.3.3. Soil nutrients (N, P, K)

Nitrogen levels across different elevation ranges showed significant changes throughout the study area (see Table 6). The moderate elevation range of Plot 1, spanning 201 to 400 masl, showed the highest nitrogen concentration of 0.374 ppm, while the low elevation range of 0 to 200 masl showed 0.019 ppm. Soil nitrogen content changes arose from variations in organic matter input and decomposition rates, which depended on vegetation cover, microclimate, and soil biological activity (Jiang et al., 2019). Research conducted along elevation gradients showed that nitrogen distribution patterns did not follow a linear relationship with altitude because localized organic inputs, microbial transformations, and plant uptake determined its distribution (Nie et al., 2023).

Phosphorus concentrations across Plots 1 and 2 ranged from 3 ppm to 32 ppm (see Table 6) in both high and low elevation zones, and did not show a specific pattern with elevation. Research findings showed that phosphorus availability depended on three main factors: parent material composition, microbial immobilization, and sorption processes, rather than solely on elevation (Jiang et al., 2019; Springmann et al., 2023). The ability of soils to retain and make phosphorus available depended on soil pH and mineral composition (Penn & Camberato, 2019; Amadou et al., 2022).

Potassium concentrations also varied across the elevation zones (see Table 6). Plot 2, at low elevation, recorded the highest potassium level of 332 ppm, while the same plot recorded 48 ppm as its lowest potassium level at high elevation. The primary source of soil potassium was the weathering process, which broke down potassium-bearing minerals in parent materials. The distribution of the material changed due to leaching, cation exchange, and topographic redistribution, which affected its movement through the landscape (Springmann et al., 2023). Nutrient movement and landscape accumulation processes depended on how elevation affected rainfall patterns, water runoff, and slope location (Nie et al., 2023).

The distribution patterns of N, P, and K across different elevation zones showed that multiple environmental

factors interacted to shape soil nutrient dynamics, rather than elevation being the sole determining factor. Factors that determined nutrient availability to plants included soil-forming processes, vegetation inputs, microbial activity, and landscape characteristics. The low and moderate elevations showed higher nitrogen and potassium levels because these areas experienced greater accumulation of organic matter, leading to lower nutrient loss than in high-elevation areas with steeper terrain (Jiang et al., 2019; Springmann et al., 2023). Overall, results implied that intricate interactions between biotic and abiotic variables, rather than elevation alone, controlled soil nitrogen dynamics. The mineral composition of soil and its ability to absorb nutrients determined phosphorus availability more than any other factor. The study results demonstrated that soil nutrient distribution operated through a complex system that responded to environmental gradients that affected both ecosystem soil fertility and nutrient cycling processes.

Table 6: Soil nutrient concentrations (ppm) across different plots and elevations in Tagnote Falls.

Elevation range	Plot	Nitrogen (ppm)	Phosphorus (ppm)	Potassium (ppm)
Low (0–200 masl)	Plot 1	0.019	3	41
	Plot 2	0.254	32	332
	Plot 3	0.234	17	225
Moderate (201–400 masl)	Plot 1	0.374	7	205
	Plot 2	0.045	4	112
	Plot 3	0.261	12	245
High (401–600 masl)	Plot 1	0.167	5	225
	Plot 2	0.062	3	48
	Plot 3	0.257	7	175

3.4. Relationship between soil physicochemical properties and tree diversity

3.4.1. Soil texture and tree diversity

The correlation assessments executed across the Tagnote Falls gradient revealed a stark, uniform absence of statistically significant relationships between the evaluated edaphic parameters and tree diversity indices. Kendall's Tau correlation matrices showed that soil texture did not significantly influence tree species richness ($p = 0.141$) or evenness ($p = 0.089$; Table 7). Similarly, Pearson's r modeling confirmed that soil pH operated entirely independently of taxonomic richness ($r = -0.111$, $p = 0.776$) and community evenness ($r = -0.063$, $p = 0.873$; Table 8). This total lack of statistical predictive power extended into macronutrient profiles (Table 9), where soil nitrogen concentration was negatively but non-significantly linked to richness ($\tau = -0.310$, $p = 0.249$) and evenness ($\tau = -0.366$, $p = 0.173$), while phosphorus and potassium exhibited weak, decoupled trends.

In natural, undisturbed tropical forest ecosystems,

environmental filtering typically structures woody communities along clear edaphic gradients, forcing species to systematically sort into specialized micro-habitats based on fine-scale chemical niches (Loiola et al., 2023; Rahbek et al., 2019). However, the data gathered at Tagnote Falls clearly demonstrated that traditional, natural soil–vegetation feedback loops were suppressed. Within this active human-dominated landscape, the selective filters imposed by agricultural management, such as targeted species selection, manual landscape fragmentation, and localized fertilization, effectively override the natural abiotic selective mechanisms described by environmental filtering theory (Bañares de Dios et al., 2022; Majuakim et al., 2024). This pattern reveals a clear shift where active land management, rather than underlying soil chemistry, is the primary force shaping what grows across the landscape.

Table 7: Soil texture and tree species diversity (Correlation matrix).

		Texture
Species Richness	Kendall's Tau	-0.431
	p-value	0.141
Species Evenness	Kendall's Tau	-0.497
	p-value	0.089

3.4.2. Soil pH and tree diversity

Pearson's correlation assessments revealed that soil pH possessed weak, non-significant relationships with both tree species richness ($r = -0.111$, $p = 0.776$) and community evenness ($r = -0.063$, $p = 0.873$; Table 8). While soil pH typically operates as a master variable in natural ecosystems by governing nutrient solubility, microbial kinetics, and root elongation, the statistical results demonstrated that tree diversity patterns across the Tagnote Falls gradient occurred independently of shifting soil chemistry. This decoupling suggested that macro-vegetation communities within human-altered mosaics develop in response to a multi-layered matrix of environmental conditions, spatial distributions, and anthropogenic elements rather than soil chemistry alone (Majuakim et al., 2024).

The primary driver of this observed edaphic decoupling was the continuous override of natural environmental filters by human intent. Within these managed agroforestry systems, smallholder farmers intentionally selected, planted, and maintained economically lucrative species such as *Gmelina arborea* and *Durio zibethinus* across all plots, completely bypassing structural adjustments to baseline soil conditions. Furthermore, active agricultural management practices, including localized liming, ash deposition from burning, or organic fertilization, periodically altered topsoil pH levels without altering the established woody canopy, thereby severing the long-term co-evolutionary feedback loops between soil acidity and plant

community assembly.

This lack of structural sorting along the pH gradient was further aggravated by the functional traits and broad phenotypic plasticity of the dominant vegetation. The local agroforestry matrix was heavily dominated by highly adaptable generalist species and widely cultivated exotics that possessed broad physiological tolerances. These species maintained optimal nutrient absorption and cellular function across a wide pH spectrum, meaning that minor or moderate fluctuations in soil chemical properties failed to trigger competitive exclusion or taxonomic sorting, leaving Shannon diversity metrics (H') unchanged.

Such aboveground independence from soil chemistry aligns with broader tropical ecology trends, where fine-scale chemical variations exert a far more immediate selective pressure on short-lived soil microbes than on long-lived, deeply rooted tree species (Tripathi et al., 2016). Global macroclimatic frameworks confirm that soil pH accounts for only a minor portion of the variation in aboveground tree species richness, whereas multi-layered interactions between macro-climate, topography, and solar radiation operate as far more robust predictors of tree diversity trends (Shi et al., 2024).

Ultimately, systematic reviews have established that no single soil parameter, such as pH, can reliably predict floristic composition across shifting topographies because multiple environmental factors interact to shape landscape-scale plant distributions (Bañares de Dios et al., 2022). At Tagnote Falls, severe landscape fragmentation, slope variations, and historical land-use patterns exerted a dominant control over forest-area species distribution and natural vegetation regeneration processes. Intense localized variations in canopy openness and microclimate overrode belowground edaphic factors, confirming that human-driven interactions and spatial heterogeneity, rather than soil pH, dictated aboveground tree community architecture.

Table 8: Soil pH and tree species diversity (Correlation Matrix).

		pH
Species Richness	Pearson's r	-0.111
	p-value	0.776
Species Evenness	Pearson's r	-0.063
	p-value	0.873

3.4.3. Soil nutrients (N, P, K) and tree diversity

The analysis of Kendall's Tau correlations in Table 9 revealed no significant relationship between tree diversity and soil macronutrients. Nitrogen (N) showed a negative relationship with species richness ($\tau = -0.310$, $p = 0.249$) and evenness ($\tau = -0.366$, $p = 0.173$), whereas phosphorus (P) and potassium (K) showed weak, non-significant relationships

with both metrics. The findings indicate that N, P, and K concentrations do not reliably predict tree diversity patterns in Tagnote Falls agricultural areas. The species composition of an area is influenced more by factors such as light availability, seed dispersal, interspecific competition, and land-use history than by other ecological elements (Majuakim et al., 2024; Yaseen et al., 2022).

This severe decoupling of soil nutrient profiles from aboveground community architecture can be interpreted through the lens of environmental filtering theory interacting directly with the neutral theory of biodiversity. In a completely natural, undisturbed setting, environmental filtering selectively permits the establishment of only those species whose functional traits align with localized soil nutrient capabilities. However, within these active smallholder farmlands, human intervention introduced a powerful selective filter that effectively overrode this process. Smallholder farmers systematically bypassed natural nutritional constraints by intentionally selecting and planting economically profitable timber and fruit crops like *Gmelina arborea* and *Durio zibethinus*. Consequently, because the spatial arrangement of the overstory vegetation was dictated by socioeconomic valuation and human preferences rather than natural edaphic suitability, the expected correlation signals between soil nutrients and tree diversity indices broke down completely.

Furthermore, severe seed dispersal limitations within the fragmented agricultural matrix heavily restricted the capacity of native forest trees to colonize ideal soil niches. As articulated by neutral theory, structural sorting along nutrient gradients requires uninhibited regional seed flow so that highly specialized species can naturally find and occupy their preferred chemical boundaries (Hubbell, 2001). In the open, human-dominated mosaic surrounding Tagnote Falls, the conversion of natural forest into fragmented farm units disrupted natural wildlife vectors and created steep dispersal barriers (Wright, 2002). Because wild seed recruitment was minimized and largely replaced by the active and deliberate transportation of specific seedlings by humans, natural ecological sorting along nitrogen, phosphorus, and potassium gradients was prevented.

The absence of an observable correlation between tree diversity metrics and nutrient concentrations was also heavily supported by the phenomenon of functional redundancy among the dominant vegetation. As noted by Kunstler et al. (2016), when multiple coexisting plant species possess highly overlapping nutrient-use strategies, the statistical link between taxonomic diversity indicators (H') and soil fertility becomes entirely masked. The highly adaptable exotics and fast-growing fruit trees that dominated the Tagnote Falls landscape exhibited remarkable environmental

plasticity, allowing them to thrive uniformly across both nutrient-deficient and nutrient-rich pockets without undergoing localized competitive exclusion. This broad systemic tolerance meant that even stark variations in soil macronutrients failed to alter aboveground tree richness or distribution evenness.

Additionally, ongoing, active agroforestry management practices functioned as a continuous confounding variable that destabilized natural soil-plant feedback loops. In native tropical forests, tree species modify their surrounding soil properties over decades via species-specific litter fall decomposition and root exudate chemistry. Within the managed plots of Tagnote Falls, however, artificial inputs such as targeted organic or inorganic fertilization, undergrowth clearing, and ash deposition from burning periodically disrupted the natural baseline distribution of nitrogen, phosphorus, and potassium. This continuous manual alteration of soil chemistry, coupled with the systematic mechanical removal of wild recruits, severed the predictive relationship between soil fertility profiles and vegetative diversity patterns.

These findings align closely with broader tropical montane syntheses, which demonstrate that soil nutrients alter tree diversity unpredictably across human-altered landscapes. While nitrogen and phosphorus elements successfully drive clear species distribution boundaries in primary tropical forests, their ecological influence becomes highly erratic or entirely negligible in managed, cleared, or disturbed systems (Bañares de Dios et al., 2022). The results from Tagnote Falls reinforce the understanding that no single soil macronutrient consistently governs floristic composition in tropical agricultural matrices, highlighting instead the dominant influence of human management as an overriding landscape filter.

Table 9: Soil nutrients (N, P, K) and tree species diversity (Correlation Matrix).

		N	P	K
Species	Kendall's Tau	-0.310	0.087	0.057
Richness	p-value	0.249	0.751	0.833
Species	Kendall's Tau	-0.366	0.087	0.114
Evenness	p-value	0.173	0.751	0.673

4. CONCLUSION

The assessment of tree diversity across the studied elevational gradient in the farmlands surrounding Tagnote Falls revealed consistently low overall Shannon-Wiener diversity values ($H' = 1.49$ to 2.02). Rather than exhibiting a clear linear pattern across the terrain, higher individual species counts and localized structural diversity were concentrated within specific pockets, notably where agroforestry species such as *Durio zibethinus* (Durian) and

Gmelina arborea were actively maintained. Crucially, statistical evaluations using correlation matrices demonstrated that individual edaphic factors including soil texture, pH, and primary macronutrients (nitrogen, phosphorus, and potassium) exhibited no statistically significant relationship with tree species diversity parameters in these active agricultural plots.

Although tree diversity may vary along elevational gradients, these patterns are shaped by multiple interacting ecological and environmental drivers that extend far beyond basic soil-chemistry variables. These findings indicate that soil physicochemical properties alone do not act as the primary structural determinant governing tree community distribution patterns within localized, human-modified agroforestry ecosystems. Because these sites function as active agricultural domains, anthropogenic preferences (such as species selection, crop spacing, and historic land-use choices) overwrite natural edaphic-vegetation feedback loops. Furthermore, the presence of functional redundancy where diverse tree species utilize similar nutrient-acquisition strategies across varying soil matrices weakens the detectable influence of localized soil properties on overall botanical composition in tropical farmlands.

These findings hold essential practical value for sustainable agroforestry planning and local reforestation initiatives within the watershed. Because soil nutrient profiles alone do not dictate tree community patterns, administrative land-use strategies and restoration practices should emphasize structural species diversification and the deliberate maintenance of canopy heterogeneity, rather than relying exclusively on soil nutrient management. To build climate resilience, buffer economic shocks for local farmers, and protect the ecological integrity of the Tagnote Falls system, future landscape interventions must merge organic soil enrichment methods with multi-strata crop systems and the systematic reintroduction of native timber species.

To maintain scientific transparency and offer clear boundaries for interpreting these outcomes, several core limitations of this study are acknowledged. First, the investigation relied on a localized sampling layout confined to designated elevation zones within selected farmlands, where a broader geographic sampling distribution would improve generalizability. Second, because the study sites operate as active, managed agricultural lands, the tree community composition is heavily modified by human interference, crop choice, and active clearing, which masks natural ecological successional patterns. Third, edaphic property testing was restricted to texture, pH, and primary macronutrients (N, P, K), meaning that the absence of Soil Organic Carbon (SOC) and Soil Organic Matter (SOM) parameters limits the interpretation

of deeper microbial activities and overall soil structural health. Finally, the structural evaluation relied entirely on taxonomic counts and diversity indices rather than incorporating functional plant traits such as specific leaf area (SLA), wood density, and root architectures which would provide a more mechanistic view of environmental adaptation.

To build upon these insights, future investigations should incorporate long-term or seasonal monitoring to track temporal soil-vegetation interactions across shifting environmental conditions. Furthermore, future research should expand into functional trait analysis of both dominant and coexisting species, focusing on leaf and root traits, tissue nutrient composition, and specific resource-acquisition characteristics. Uncovering these functional dynamics alongside detailed crop distribution mapping will yield more effective conservation frameworks and highly sustainable land-use solutions for tropical agricultural interfaces.

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