Malaysian Journal of Soil Science 2026 Vol. 30: 1-15

Characteristics of Yellow-Brown Ferralitic Soil Beneath the Canopy of Tropical Semi-Moist Evergreen Closed Forests in the Hoa Binh Hydropower Reservoir Area, Hoa Binh Province, Vietnam

Cuong, L.V.[1]; Chien, L.H.[2]; Karam, D.S.[3]; Bao, T.Q.[4]; Quy, N.V.[5]; Thanh, N.M.[6]*; Hoan, L.N.[7] & Tam, P.M.[2]

[1]*Faculty of Forestry, Vietnam National University of Forestry - Dongnai Campus, Dongnai 76000, Vietnam*
[2]*Institute of Land Management and Rural Development, Vietnam National University of Forestry, Hanoi 100000, Vietnam*
[3]*Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, Serdang 43400, Selangor, Malaysia*
[4]*Department of Forestry and Forest Protection, Hanoi 100000, Vietnam*
[5]*Southern Branch of Joint Vietnam-Russia Tropical Science and Technology Research Center, Hochiminh 700000, Vietnam*
[6]*Faculty of Forestry, Vietnam National University of Forestry, Hanoi 100000, Vietnam*
[7]*Academic Affairs Office, Vietnam National University of Forestry, Hanoi 100000, Vietnam*

**Corresponding author: thanhnm@vnuf.edu.vn*

ABSTRACT
Assessing soil properties across different forest types is a critical aspect of silviculture. This study aimed to investigate the variations in the characteristics of yellow-brown ferralitic soil beneath the canopy of tropical semi-moist evergreen closed forests subjected to varying intensities of selective logging in the Hoa Binh Hydropower Reservoir area, Hoa Binh Province, Vietnam. Twelve 1000 m² plots representing rich, medium, poor, and mixed wood–bamboo forests were sampled. At each plot, soil sample was collected at two depths from five random points along an S-shaped transect, then composited by depth for physical and chemical analysis. The results showed that: (1) The characteristics of yellow-brown ferralitic soil varied significantly based on the forest types. Soil water content was higher in the rich and medium forests compared to the poor and mixed wood-bamboo forests. Soil clay content progressively increased from the rich forest to the poor forest, with the lowest levels found in the mixed wood-bamboo forest. Conversely, soil silt content tended to increase with forest degradation, while soil sand content decreased significantly as degradation intensified. (2) An increase in stand timber volume is linked to a decrease in soil bulk density and particle density. In contrast, it is associated with higher levels of soil pHKCl, as well as greater concentrations of soil organic matter, organic carbon and essential nutrients such as total nitrogen, phosphorus, and potassium. (3) Organic matter content in yellow-brown ferralitic soil was most strongly influenced by standing tree volume, followed by soil pHKCl, microbial community, and water content. The findings of this study not only contribute to a deeper understanding of soil dynamics under the influence of logging but also offer a scientific basis for the development of silvicultural practices and sustainable forest management strategies.

Keywords: Yellow-brown ferralitic soil, stand, forest types, forest litter, soil microorganisms

INTRODUCTION
Soil serves as the foundation of forest ecosystems, providing essential minerals and water for their growth (Jia *et al*., 2020; Qiu *et al*., 2018; Wang *et al*., 2012). Throughout their life cycles, forests release the minerals they have absorbed back into the soil (Trung, 1999; Sam & Binh, 2000). The relationship between forests and soil is closely intertwined, which forms what is known as the forest-soil system (Thanh & Cuong, 2015; Cuong *et al*., 2017). The characteristics of the soil beneath a forest canopy are influenced not only by the parent material but also by the specific type of forest (Them & Toai, 2024). Therefore, studying the interactions between

forests and soil is crucial for developing theories related to forestry, silvicultural practices, and sustainable forest management.

According to the forest classification system developed by Trung (1999), the natural forest surrounding the Hoa Binh hydropower reservoir area in Hoa Binh Province is classified as a tropical semi-moist evergreen closed forests (Rkn). The soil beneath this Rkn canopy is yellow-brown ferralitic soil, which originates from shale parent rock. In the past, this Rkn type in the region underwent selective logging at various intensities (Dien, 2016). As a result of these logging activities, the soil conditions beneath the Rkn canopy have changed. Nonetheless, there is still a lack of research in forestry exploring the relationship between soil properties and Rkn type after selective logging at different intensities. This knowledge gap complicates the assessment of the impact of logging on soil properties.

The primary objective of this study is to analyze the differences in the traits of yellow-brown ferralitic soil on shale parent rock beneath the Rkn canopy, which has been restored after selective logging at various intensities in the Hoa Binh hydropower reservoir area, Hoa Binh Province, Vietnam. The hypothesis being tested is that the properties of yellow-brown ferralitic soil on shale do not change based on the forest condition following selective logging. To investigate this hypothesis, soil properties will be compared under the Rkn canopy in four different forest types: (1) Rich forest, (2) medium forest, (3) poor forest, and (4) mixed wood-bamboo forest. These four forest types are classified according to Circular No. 16/2023/TT-BNNPTNT issued by the Ministry of Agriculture and Rural Development, which outlines guidelines for forest survey, inventory, and forest transition monitoring (MARD, 2023). The findings from this study will not only enhance our understanding of soil changes due to logging but also provide a scientific basis for developing effective silvicultural practices and sustainable forest management strategies.

MATERIALS AND METHODS

Study area

The study focuses on the characteristics of yellow-brown ferralitic soil beneath the canopy of restored tropical semi-moist evergreen closed forests (Rkn) after selective logging. The research site is located around the Hoa Binh hydropower reservoir area, Hoa Binh Province, Vietnam. The geographic coordinates are 20°36′51″–21°42′57″ North latitude and 103°45′34″–105°25′43″ East longitude (**Figure 1**). The study area is situated in a tropical monsoon climate zone. The average annual air temperature ranges from 22.5°C to 23.2°C. The average annual rainfall is between 1,300 mm and 2,200 mm, with approximately 85% occurring during the rainy season from May to September. The average air humidity is also around 80%–85%. The terrain elevation varies from 300 m to 1,000 m above sea level, with slopes ranging from 10° to over 50° (Dien, 2016).

Determining forest characteristics of forest types

The stand characteristics of the four forest types, including rich forest, medium forest, poor forest, and mixed wood-bamboo forest (**Figure 2**) were determined based on six criteria: Tree species and stand density (N, trees$\cdot$ ha^{-1}); Diameter at breast height (DBH, cm) at 1.3 meters above the ground; Total height (H, m) of the trees; Basal area (G, m$^{2}\cdot$ ha^{-1}); Stand timber volume (M, m^3 $\cdot$ha^{-1}). For each forest type, data were collected from three temporary sample plots with dimensions of 1,000 m² (each measuring 40 × 25 m). Thus, for the four forest types, a total of twelve sample plots were sampled. Within each sample plot, the circumference at breast height (CBH, cm) of each tree with a DBH ≥ 6 cm was measured using a tape measure with an accuracy of 0.1 cm, and then converted to DBH (cm). Tree height (H) was measured using a Blume-Leiss altimeter. In each sample plot, five sub-plots with dimensions of 4 m² (each 2 m

× 2 m) were established at the four corners and center of the sample plot to determine the mass of forest litter (FL, kg), and the average value was calculated. The fresh FL was weighed in place. For each type of fresh FL, approximately 250 g was collected and dried at 75°C until constant weight. The dried FL was then converted to dry FL per hectare. The basic characteristics of the four forest types are summarized in **Table 1**.

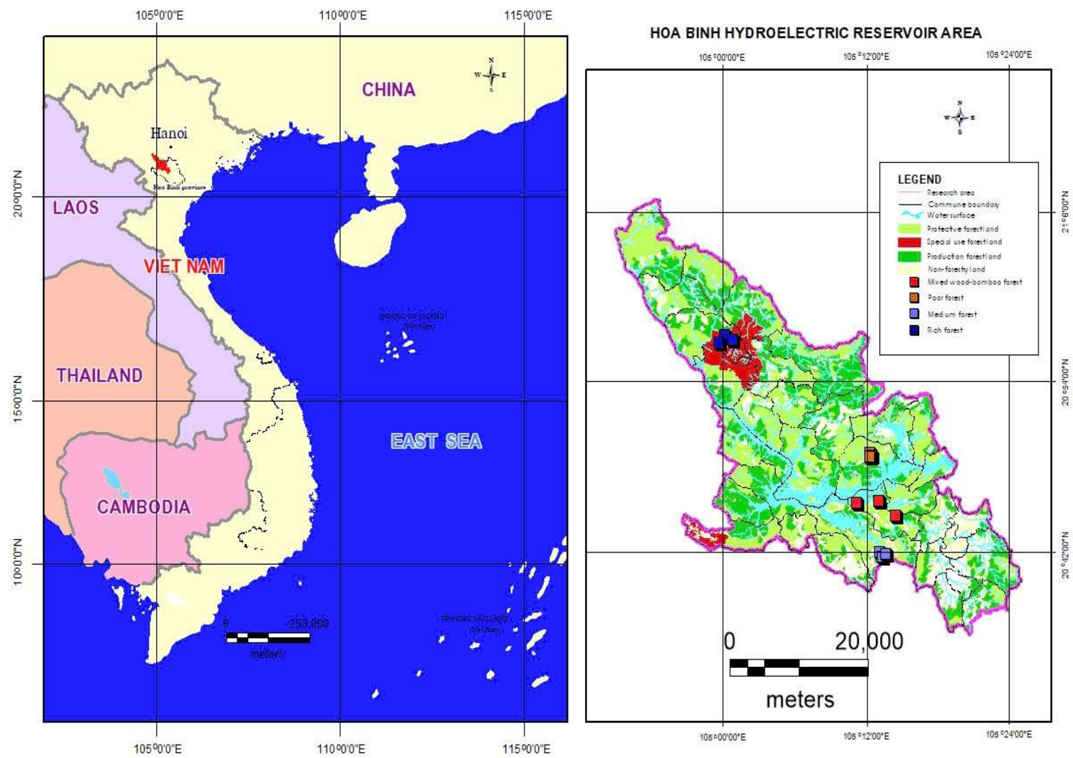

Figure 1: Map showing the locations of sampling points in the Hoa Binh hydropower reservoir area, Hoa Binh province, Vietnam

Soil sample collection

Soil samples were collected from September 21st, 2024 to April 30th, 2025. In each standard plot, five soil profiles were randomly sampled along an S-shaped transect, covering two depth layers: 0–20 cm, and 20–40 cm. Soil samples from each depth layer within the same plot were thoroughly mixed in equal proportions to create a composite sample. These composite samples were then air-dried at room temperature (25°C), ground, and passed through a 0.15 mm mesh sieve to remove roots, gravel, and other debris before analyzing the soil's physical and chemical properties. For bulk density determination, undisturbed soil cores were collected from different layers using a stainless steel sampling ring with a volume of 100 cm³. The samples were then transported to the laboratory for bulk density measurement using the core method.

Laboratory analysis

Soil bulk density (BD, $g \cdot cm^{-3}$) was determined by oven-drying undisturbed core samples at 105°C until a constant weight was achieved, following the method of Blake and Hartge (1986). Soil particle density (PD, $g \cdot cm^{-3}$) was determined using the pycnometer method (Thanh & Cuong, 2015). To determine soil water content (SW, %), a 20 g subsample of fresh soil was oven-dried at 105°C for 24 hours, following the procedure described by Chau *et al*. (2023). The percentage of soil particle size fractions (soil clay < 0.002 mm, soil silt = 0.002–0.02 mm, and soil sand = 0.02–2 mm) was analyzed using the pipette method (Van Reeuwijk, 2002).

Table 1: Stand characteristics of four different forest types

Characteristics parameters	Forest Types	Mean	Min	Max	SEE	CV(%)
Stand density (N, trees· ha^{-1})	Rich forest	450	400	490	41.0	9.1
	Medium forest	440	410	470	26.8	6.1
	Poor forest	393	360	420	27.3	6.9
	Mixed wood-bamboo forest	214	180	250	31.3	14.6
Mean diameter at breast height (DBH, cm)	Rich forest	26.0	24.7	27.3	1.16	4.5
	Medium forest	23.2	21.8	24.7	1.3	5.6
	Poor forest	19.9	18.3	22.1	1.78	8.9
	Mixed wood-bamboo forest	13.6	12.8	14.6	0.82	6.0
Mean height (H, m)	Rich forest	19.2	18.5	19.8	0.58	3.0
	Medium forest	14.1	13.5	14.9	0.64	4.6
	Poor forest	15.5	14.8	16.2	0.62	4.1
	Mixed wood-bamboo forest	13.7	13.4	14.2	0.39	2.8
Basal area (G, m^{2}· ha^{-1})	Rich forest	23.8	23.4	24.6	0.6	2.5
	Medium forest	18.6	17.2	21.1	1.94	10.4
	Poor forest	12.2	10.5	13.8	1.48	12.1
	Mixed wood-bamboo forest	3.1	2.5	3.6	0.5	16.1
Standing timber volume (M, m^{3} ·ha^{-1})	Rich forest	205.5	202.9	208.6	2.6	1.3
	Medium forest	118.5	104.4	141.4	17.9	15.1
	Poor forest	85.0	70.1	100.7	13.7	16.1
	Mixed wood-bamboo forest	19.2	15.3	22.7	3.3	17.3

Note: Min = Minimum; Max = Maximum; SEE = Standard Error of Estimate; CV% = Coefficient of Variation

The pH of the soil solution (pHKCl) was determined by mixing 10 g of air-dried soil with 25 mL of 1 M KCl solution at a soil-to-solution ratio of 1:2.5, followed by measurement using a pH meter (Sartorius PB-10) (Van Reeuwijk, 2002). Soil total organic carbon (SC, g· kg^{-1}) content was determined using the H_2SO_4–$K_2Cr_2O_7$ oxidation procedure as described by Nelson & Sommers (1982). The total nitrogen, total phosphorus, and total potassium contents in the soil were analyzed according to the Vietnamese National Standard methods, as approved by the studies (Chau *et al*., 2023; Cuong*et al*., 2024), as follows: (i) Method for determining soil total nitrogen (SN, g· kg^{-1}) content: TCVN 6498:1999 (SN concentration was measured using a modified Kjeldahl method, which involved digestion with a mixture of salicylic acid and sulfuric acid); (ii) Method for determining soil total phosphorus (SP, g· kg^{-1}) content: TCVN 8940:2011 (SP content was determined through a colorimetric method following digestion with a combination of sulfuric acid and perchloric acid); (iii) Method for determining soil total potassium (SK, g· kg^{-1}) content: TCVN 8660:2011 (SK concentration was assessed using flame photometry after digestion with a mixture of perchloric acid and hydrofluoric acid). Soil organic matter (SM, g· kg^{-1}) content was calculated by multiplying the SC content by a conversion factor of 1.724 (Cuong*et al*., 2024). The enumeration of total soil microbial abundance (TSM, CFU· g^{-1}) was performed using the colony-forming unit (CFU) counting method on specific agar plates formulated for each microbial group (bacteria, actinomycetes, and fungi) (Hien *et al*., 2017).

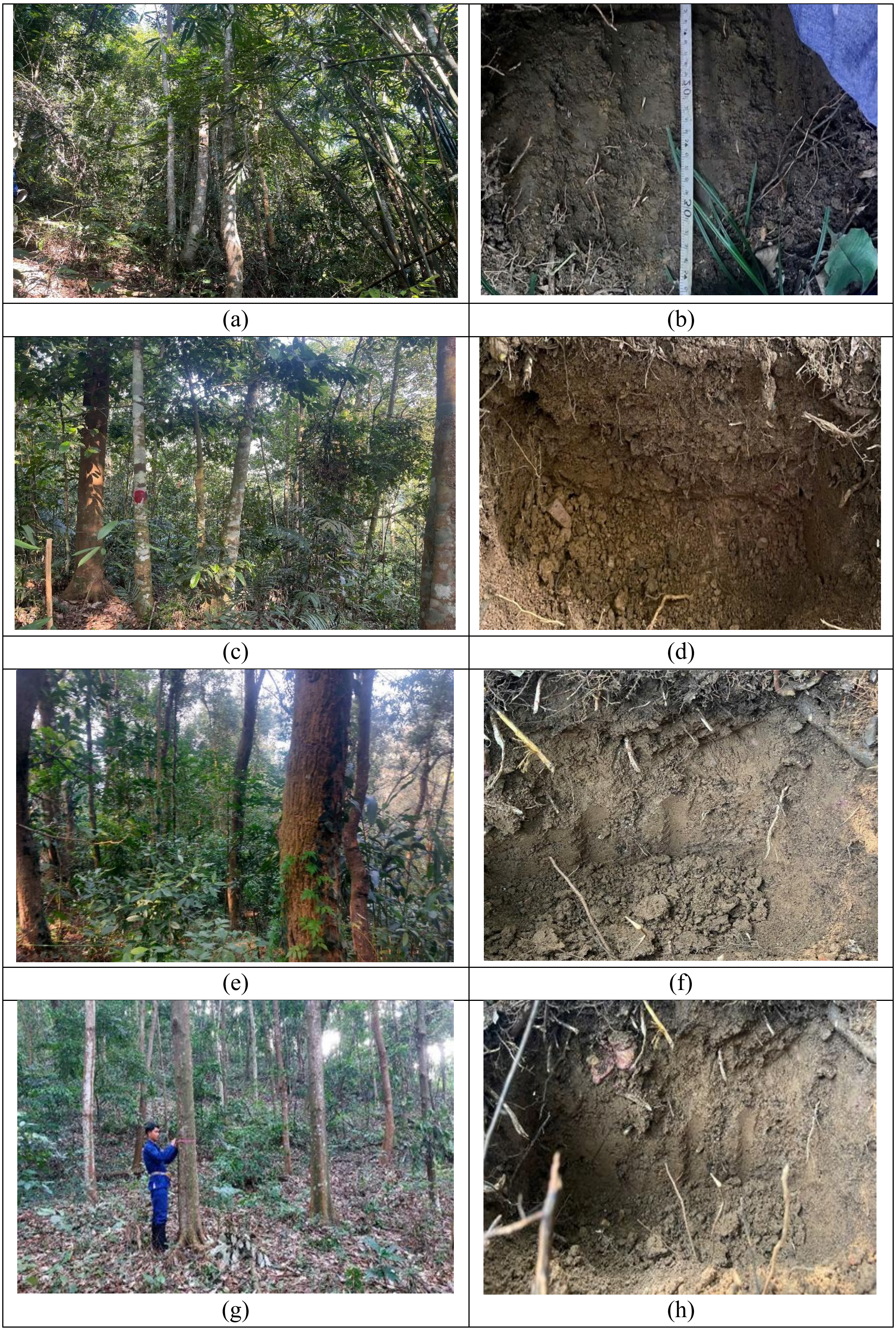

Figure 2. Some pictures of four forest types and their corresponding soil profiles: mixed wood–bamboo forest (a–b), poor forest (c–d), medium forest (e-f), and rich forest (g-h).

Analysis of the characteristics of stand and soil according to different forest types
Determining the stand characteristics in four different forest types (**Step 1**). First, collect the data of DBH, H, N, and M from the sample plots for each of the four forest types.

The N (trees· ha^{-1}) index for stand is defined by Equation 1, as outlined by Cuong *et al*. (2020):

$$\mathrm{N} = \frac{10000}{s} \times \mathrm{n} \qquad \text{(Equation 1)}$$

where *s* is the area of the sample plots and *n* is the number of trees per sample plot.

The volume of the trees is calculated using Equation 2 (Chau *et al*., 2024; Khoa *et al*., 2024):

$$\mathrm{V} = \mathrm{g} \times \mathrm{H} \times \mathrm{F} \qquad \text{(Equation 2)}$$

where g (m^{2}· tree^{-1}) is the cross-sectional area of each tree ($\mathrm{g} = 0.00007854 \times DBH^2$), DBH and H are the diameter and height of each tree, and F is the tree form factor). The research adopted a value of F = 0.45 for natural forests.

The timber volume (M, m^{3} ·ha^{-1}) of the stand is calculated using Equation 3 (Chau *et al*., 2024; Khoa *et al*., 2024):

$$\mathrm{M} = \sum \mathrm{V} \times \frac{10000}{s} \qquad \text{(Equation 3)}$$

where $\sum$V (m^{3}· sample plot^{-1}) is the total volume of trees in the sample plot and *s* is the area of the sample plot.

Calculating descriptive statistics for soil properties across different forest types (**Step 2**). The indices calculated include the mean, minimum (Min), maximum (Max), standard error (SEE), and coefficient of variation (CV%).

Analysis of the relationship between soil properties and forest types
The relationship between soil properties at the 0–40 cm depth (Yi = BD, PD, SM, clay, silt, sand, pH, SM, SC, SN, SP) and timber volume (M) across the four forest types was analyzed using Pearson's correlation coefficient (r). The null hypothesis (H_0) posits that soil properties are not related to timber volume (M) within the four forest types. The decision rule is as follows: if the significance level (P) > 0.05, H_0 is accepted; if P < 0.05, H_0 is rejected. The direction and strength of the relationships are interpreted based on the sign (+/-) and magnitude of the correlation coefficient (r). To assess differences in soil properties among the four forest types, a one-way ANOVA was performed under the General Linear Model (GLM) (Equation 4) (Them *et al*., 2021):

$$\mathrm{Y_i} = \mathrm{a} + \mathrm{b} \times \mathrm{M_i} + \mathrm{e} \qquad \text{(Equation 4)}$$

where Yi represents each soil property (BD, PD, clay, silt, sand, pH, SM, SC, SN, SP), Mi is the timber volume, and e is the error term. The model's significance was evaluated at a P-value threshold of 0.05. Differences among treatments were further assessed using Tukey's post-hoc test at the same significance level (P = 0.05).

Analysis of the relationship between soil organic matter (SM) and soil features and forest types
Soil organic matter (SM) plays a crucial role in forest growth (Thanh & Cuong, 2015; Cuong *et al*., 2024). Therefore, this study examined the multivariate linear relationship: SM = f(BD, PD, SM, pHKCL, M, FL, TSM). The null hypothesis (H_0) was: (1) SM content is not influenced by BD, PD, SM, pHKCL, M, FL, TSM. The decision rule was as follows: when the significance level P < 0.05, the null hypothesis is rejected. The reliability of the regression models was assessed using the coefficient of determination (R^2; Equation 5), standard error of estimate

(SEE; Equation 6), mean absolute error (MAE; Equation 7), and mean absolute percentage error (MAPE; Equation 8) (Them *et al*., 2021). The most influential factors affecting SM content were identified through standardized multiple regression and correlation analysis. The relative importance of each factor was evaluated by the absolute value of the standardized regression coefficient (Beta; Equation 9) (Them *et al*., 2021).

$$R^2 = \left[1 - \frac{\sum(SM_i - SM_j)^2}{\sum(SM_i - SM_{BQ})^2}\right] \times 100 \qquad \text{(Equation 5)}$$

$$SEE = \sqrt{\sum \frac{(SM_i - SM_j)^2}{n-p}} \qquad \text{(Equation 6)}$$

$$MAE = \left|\left(\frac{SM_i - SM_j}{n}\right)\right| \qquad \text{(Equation 7)}$$

$$MAPE = \frac{MAE \times 100}{n} \qquad \text{(Equation 8)}$$

$$Beta = B_k \times \frac{SEE_k}{SEE_{SM}} \qquad \text{(Equation 9)}$$

In Equation 5–9, SM_i and SM_j represent the observed and predicted SM values, respectively; SM_{BQ} is the mean observed SM; n is the sample size; p is the number of regression parameters; B_k is the partial regression coefficient of the k-th independent variable; SEE_k and SEE_{SM} are the standard deviations of the k-th independent variable and SM, respectively.

Statistical analysis

The data processing tools used in this study were Microsoft Excel 2019 and IBM SPSS Statistics 26.0. Microsoft Excel 2019 served to compile and manage intermediate datasets, while IBM SPSS Statistics 26.0 was utilized to conduct descriptive statistics and perform one-way analysis of variance (ANOVA) within the General Linear Model (GLM) (Them *et al*., 2021). Before conducting the statistical analysis, all data were tested for normality using the Kolmogorov–Smirnov test and for homogeneity of variances using Levene's test.

RESULTS

Characteristics of yellow-brown ferralitic soil of the four different forest types

The soil physical features of the four forest types are summarized in **Table 2**. The average BD ranged from 0.81 g·cm^{-3} in the rich forest to 1.16 g·cm^{-3} in the mixed wood-bamboo forest, with an overall mean of 1.07 g·cm^{-3} and a CV of 22.1%. PD showed less variability, ranging from 2.24 g·cm^{-3} in the rich forest to 2.41 g·cm^{-3} in the mixed wood-bamboo forest, with an overall mean of 2.37 g·cm^{-3} and a CV of 4.0%. SW varied from 3.4% in mixed wood-bamboo forest to 4.8% in rich forest, averaging 4.1% across all forest types and exhibiting a CV of 15.9%. Regarding soil texture, soil clay content ranged between 26.0% in mixed wood-bamboo forest and 37.8% in poor forest, with an overall mean of 31.4% and a CV of 15.6%. Soil silt content varied less, from 43.9% in rich forests to 46.4% in mixed wood-bamboo forests, with an overall mean of 46.6% and a CV of 5.4%. Soil sand content showed the greatest variation, ranging from 16.0% in poor forest to 27.7% in rich forest, with an overall mean of 22.1% and a relatively high CV of 28.0%. Overall, the four soil physical indicators (BD, PD, SW, and particle size distribution) exhibit significant variability among forest types, reflecting the influence of Rkn forest stand characteristics on the soil development processes of yellow-brown ferralitic soils.

Table 3 presents the statistical characteristics of soil chemical properties under the four forest types. Soil pHKCl values indicated strongly acidic conditions, ranging from 3.1 in mixed wood-bamboo fores to 4.5 in rich forest, with an overall mean of 3.6 and a CV of 15.1%. SM content varied considerably, with the highest mean value observed in rich forest (46.9 g·kg^{-1}) and the lowest in poor forests (23.9 g·kg^{-1}). The overall mean SM concentration across all forest types was 34.0 g·kg^{-1}, with a CV of 26.7%. SC followed a similar trend, ranging from 18.8 g·kg^{-1} in mixed wood-bamboo forest to 27.2 g·kg^{-1} in rich forest, and an overall mean of

19.8 g·kg⁻¹ (CV = 26.7%). SN content varied between 0.18 $g \cdot kg^{-1}$ in medium forest and 0.33 $g \cdot kg^{-1}$ in rich forest, averaging 0.25 $g \cdot kg^{-1}$ with a CV of 26.8%. SP showed values ranging from 1.22 $g \cdot kg^{-1}$ in poor forest to 1.70 $g \cdot kg^{-1}$ in rich forest, with a mean of 1.43 $g \cdot kg^{-1}$ and a CV of 20.2%. SK exhibited the greatest variability, ranging from 11.62 $g \cdot kg^{-1}$ in poor forest to 41.42 $g \cdot kg^{-1}$ in rich forest, with an overall mean of 24.68 $g \cdot kg^{-1}$ and a CV of 44.8%. In summary, yellow-brown ferralitic soil's chemical properties varied significantly among the forest types, reflecting the impact of Rkn forest stand characteristics and logging activities on soil nutrient dynamics and acidity

Table 2: Statistical characteristics of soil physical properties of the four forest types

Soil indices	Forest Types	Mean	Min	Max	±SEE	CV (%)
Soil bulk density (BD, $g \cdot cm^{-3}$)	Rich forest	0.81	0.06	0.98	0.37	45.4
	Medium forest	1.11	1.02	1.20	0.08	7.2
	Poor forest	1.18	1.10	1.25	0.07	5.8
	Mixed wood-bamboo forest	1.16	1.12	1.20	0.04	3.1
	Average	**1.07**	**0.06**	**1.25**	**0.24**	**22.1**
Soil particle density (PD, $g \cdot cm^{3}$)	Rich forest	2.24	2.13	2.32	0.09	3.9
	Medium forest	2.44	2.37	2.52	0.07	2.8
	Poor forest	2.38	2.35	2.41	0.03	1.1
	Mixed wood-bamboo forest	2.41	2.38	2.43	0.03	1.1
	Average	**2.37**	**2.13**	**2.52**	**0.10**	**4.0**
Soil water content (SW, %)	Rich forest	4.8	3.9	5.3	0.6	11.8
	Medium forest	4.5	4.4	4.7	0.1	2.1
	Poor forest	3.7	3.4	3.9	0.2	5.0
	Mixed wood-bamboo forest	3.4	3.2	3.6	0.2	5.1
	Average	**4.1**	**3.2**	**5.3**	**0.7**	**15.9**
Soil clay (%)	Rich forest	28.4	26.8	31.2	1.7	6.0
	Medium forest	33.3	30.7	35.7	2.0	6.1
	Poor forest	37.8	36.7	40.5	1.5	3.9
	Mixed wood-bamboo forest	26.0	24.7	27.3	1.0	3.8
	Average	**31.4**	**24.7**	**40.5**	**4.9**	**15.6**
Soil silt (%)	Rich forest	43.9	42.6	44.6	0.8	1.8
	Medium forest	49.9	47.5	52.5	2.1	4.2
	Poor forest	46.1	44.9	48.3	1.2	2.7
	Mixed wood-bamboo forest	46.4	45.3	47.5	0.7	1.6
	Average	**46.6**	**42.6**	**52.5**	**2.5**	**5.4**
Soil sand (%)	Rich forest	27.7	25.0	29.2	1.7	6.1
	Medium forest	16.8	12.8	20.7	3.8	22.6
	Poor forest	16.0	12.9	18.4	2.1	13.2
	Mixed wood-bamboo forest	27.6	25.9	29.6	1.4	5.1
	Average	**22.1**	**12.8**	**29.6**	**6.2**	**28.0**

Table 4 presents data on forest floor litter biomass and soil microbial abundance under different forest types. The average FL ranged from 11.5 tons· ha^{-1} in the mixed wood-bamboo forest to 18.4 tons· ha^{-1} in the rich forest. The overall average across the four forest types was 14.9 tons· ha^{-1}, with a CV of 18.5%. For TSM, the average ranged from 1.75 x 10^6 CFU g^{-1} in the mixed wood-bamboo forest to 2.66 x 10^6 CFU g^{-1} in the rich forest. The average across the four forest types was 2.12 x 10^6 CFU g^{-1}, with a CV of 18.5%. These differences in FL and TSM reflect the influence of forest structure and degradation levels on litter input and microbial activity in yellow-brown ferralitic soil following logging disturbance.

Table 3: Statistical characteristics of soil chemical features of the four forest types

Soil indices	Forest Types	Mean	Min	Max	±SEE	CV (%)
pHKCl	Rich forest	4.5	4.1	4.7	0.2	4.9
	Medium forest	3.6	3.5	3.8	0.1	2.5
	Poor forest	3.3	3.1	3.5	0.1	4.3
	Mixed wood-bamboo forest	3.1	3.0	3.4	0.2	5.1
	Average	**3.6**	**3.0**	**4.7**	**0.5**	**15.1**
Soil organic matter (SM, $g \cdot kg^{-1}$)	Rich forest	46.9	39.9	51.3	4.6	9.9
	Medium forest	32.9	26.7	36.2	3.5	10.5
	Poor forest	23.9	17.1	27.2	3.9	16.4
	Mixed wood-bamboo forest	32.4	30.5	34.3	1.4	4.3
	Average	**34.0**	**17.1**	**51.3**	**9.1**	**26.7**
Soil organic carbon (SC, $g \cdot kg^{-1}$)	Rich forest	27.2	23.1	29.8	2.7	9.9
	Medium forest	19.1	15.5	21.0	2.0	10.5
	Poor forest	13.8	9.9	15.8	2.3	16.4
	Mixed wood-bamboo forest	18.8	17.7	19.9	0.8	4.3
	Average	**19.7**	**9.9**	**29.8**	**5.3**	**26.7**
Soil total nitrogen (SN, $g \cdot kg^{-1}$)	Rich forest	0.33	0.32	0.35	0.01	3.8
	Medium forest	0.18	0.17	0.20	0.01	4.4
	Poor forest	0.19	0.18	0.20	0.01	3.0
	Mixed wood-bamboo forest	0.30	0.28	0.32	0.01	4.3
	Average	**0.25**	**0.17**	**0.35**	**0.07**	**26.8**
Soil total phosphorus (SP, $g \cdot kg^{-1}$)	Rich forest	1.70	1.50	2.00	0.18	10.5
	Medium forest	1.32	1.00	1.80	0.35	26.5
	Poor forest	1.22	1.00	1.50	0.20	16.8
	Mixed wood-bamboo forest	1.47	1.30	1.70	0.16	11.1
	Average	**1.43**	**1.00**	**2.00**	**0.29**	**20.2**
Soil total potassium (SK, $g \cdot kg^{-1}$)	Rich forest	41.42	39.90	45.30	1.98	4.8
	Medium forest	21.24	20.10	22.30	0.81	3.8
	Poor forest	11.62	10.90	12.80	0.75	6.4
	Mixed wood-bamboo forest	24.44	22.20	26.50	1.50	6.1
	Average	**24.68**	**10.90**	**45.30**	**11.06**	**44.8**

Table 4: Statistical characteristics of forest litter biomass and total soil microbial abundance of the four forest types

Indices	Forest Types	Mean	Min	Max	±SEE	CV (%)
Forest litter biomass (tons $\cdot ha^{-1}$)	Rich forest	18.4	17.9	18.9	0.45	2.4
	Medium forest	16.2	15.7	16.7	0.45	2.8
	Poor forest	13.3	12.9	13.8	0.41	3.1
	Mixed wood-bamboo forest	11.5	10.5	12.3	0.83	7.2
	Average	**14.9**	**10.5**	**18.9**	**2.74**	**18.5**
Total soil microbial abundance ($x10^6$ CFU $\cdot g^{-1}$)	Rich forest	2.66	2.58	2.74	0.07	2.7
	Medium forest	2.23	2.10	2.40	0.14	6.1
	Poor forest	1.82	1.62	1.92	0.15	8.5
	Mixed wood-bamboo forest	1.75	1.62	1.87	0.11	6.4
	Average	**2.12**	**1.62**	**2.74**	**0.39**	**18.5**

Relationship between the characteristics of yellow-brown ferralitic soil and various forest types

The properties of yellow-brown ferralitic soil varied significantly across the four forest types ($P < 0.01$; **Table 5**). As stand timber volume increased from the mixed wood–bamboo forest to the rich forest, there was a marked decline in BD, PD, and silt content. In contrast, SW, soil clay and sand fractions, pHKCl along with SM, SM, SC, SN, SP, and SK concentrations, exhibited increasing trends (**Figures 3–4**).

Table 5: Relationship between the characteristics of yellow-brown ferralitic soil and the four forest types

No.	Soil indicators	r	Pα	Sample Size (n)
1	Soil bulk density (BD, g·cm⁻³)	-0.58	0.01	24
2	Soil particle density (PD, g·cm³)	-0.65	0.01	24
3	Soil water content (SW, %)	0.80	0.01	24
4	Soil clay content (%)	0.03	0.98	24
5	Soil silt content (%)	-0.30	0.16	24
6	Soil sand content (%)	0.10	0.65	24
7	Soil pH (pHKCl)	0.92	0.01	24
8	Soil organic matter (SM, $g \cdot kg^{-1}$)	0.64	0.01	24
9	Soil organic carbon (SC, $g \cdot kg^{-1}$)	0.64	0.01	24
10	Soil total nitrogen (SN, $g \cdot kg^{-1}$)	0.87	0.01	24
11	Soil total phosphorus (SP, $g \cdot kg^{-1}$)	0.52	0.01	24
12	Soil total potassium (SK, $g \cdot kg^{-1}$)	0.76	0.01	24

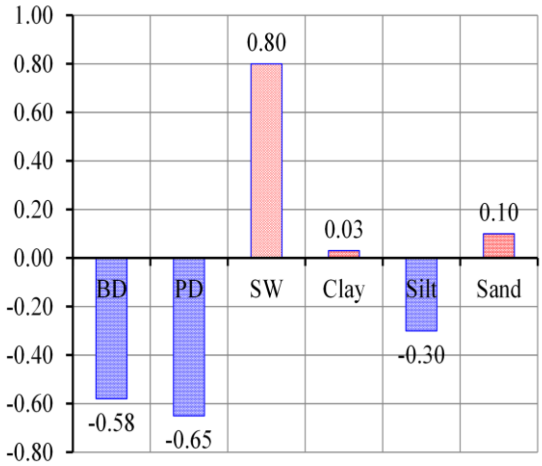

Figure 3. Relationship between physical properties of yellow-brown ferralitic soil and four different forest types

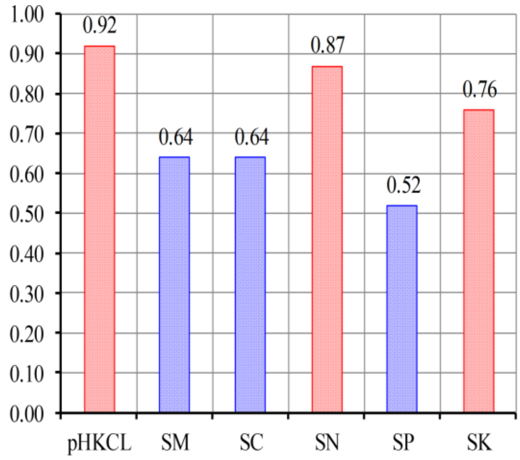

Figure 4. Relationship between chemical properties of yellow-brown ferralitic soil and four different forest types

Notes: BD, soil bulk density ($g \cdot cm^{-3}$); PD, soil particle density ($g \cdot cm^{-3}$); SW, soil water content (%); SM, soil organic matter ($g \cdot kg^{-1}$); SC, soil organic carbon ($g \cdot kg^{-1}$); SN, Soil total nitrogen($g \cdot kg^{-1}$); SP, Soil total phosphorus ($g \cdot kg^{-1}$); SK, Soil total potassium ($g \cdot kg^{-1}$);

One-way ANOVA analysis (X = Forest types) revealed that the physical properties of the soil (Y = BD, PD, SW, and soil texture) differed significantly ($P < 0.01$) among the four forest types (**Table 6**). The BD under rich forest (0.81 g/cm^3) and medium forest (BD = 1.11 g/cm^3) did not differ significantly ($P = 0.06$) (**Table 2)**. Likewise, the difference in BD between poor forest (1.18 g/cm^3) and mixed wood-bamboo forest (1.16 g/cm^3) was not statistically significant ($P = 0.92$). In general, the BD in rich and medium forest soils was lower than in poor and mixed wood-bamboo forest soils. A similar trend was found for PD (**Table 2)**. SW content in rich forest (4.8%) and medium forest (4.5%) did not differ significantly ($P = 0.39$) (**Table 2)**. The difference between poor forest (3.7%) and mixed wood-bamboo forest (3.4%) was also not significant ($P = 0.60$). Overall, SW content was higher in rich and medium forests compared to poor and mixed wood-bamboo forests. Soil clay content increased from 28.4% in rich forest to 37.8% in poor forest, while the lowest soil clay content was recorded in mixed wood-bamboo forest (26.0%). Soil silt content tended to increase with the degree of forest degradation, whereas soil sand content significantly decreased with the degree of forest deterioration (**Table 2)**.

Table 6: Analysis of the effect of forest types on soil physical properties

Variation source	Soil Properties	SSE	df	MS	F	P
Model Y = a + b×X	Soil bulk density (BD, $g·cm^{-3}$)	0.53	3	0.18	4.8	0.01
	Soil particle density (PD, $g·cm^3$)	0.14	3	0.05	13.8	0.01
	Soil water content (SW, %)	7.83	3	2.61	26.8	0.01
	Soil clay content (%)	498.78	3	166.26	64.9	0.01
	Soil silt content (%)	111.76	3	37.26	20.9	0.01
	Soil sand content (%)	760.52	3	253.51	42.6	0.01
Intercept (a)	Soil bulk density (BD, $g·cm^{-3}$)	27.35	1	27.35	735.0	0.01
	Soil particle density (PD, $g·cm^3$)	134.52	1	134.52	39181.0	0.01
	Soil water content (SW, %)	404.01	1	404.01	4151.4	0.01
	Soil clay content (%)	23597.15	1	23597.15	9204.8	0.01
	Soil silt content (%)	52102.53	1	52102.53	29292.7	0.01
	Soil sand content (%)	11671.51	1	11671.51	1961.9	0.01
Forest types (X)	Soil bulk density (SB, $g·cm^{-3}$)	0.53	3	0.18	4.8	0.01
	Soil particle density (SP, g/cm^3)	0.14	3	0.05	13.8	0.01
	Soil water content (SW, %)	7.83	3	2.61	26.8	0.01
	Soil clay content (%)	498.78	3	166.26	64.9	0.01
	Soil silt content (%)	111.76	3	37.26	20.9	0.01
	Soil sand content (%)	760.52	3	253.51	42.6	0.01

Note: SSE, Sum of squares of errors; df, Degrees of freedom; MS, Mean square; F, Fisher's statistic; P, Statistical significance level

The chemical properties of the soil (Y = pHKCl, SM, SC, SN, SP, SK) differed significantly ($P < 0.01$) among the four forest types (**Table 7**). The ferralitic yellow-brown soil exhibited a strongly acidic reaction, with pHKCl values decreasing from 4.5 in the rich forest to 3.3 in the poor forest and 3.1 in the mixed wood–bamboo forest (**Table 3)**. The SM and SC concentrations were highest in the rich forest (46.9 and 27.2 $g·kg^{-1}$, respectively), and lowest in the poor forest (23.9 and 13.8 $g·kg^{-1}$, respectively) (**Table 3)**. SN, SP, and SK contents also reached their highest values in the rich forest (0.33; 1.70; and 41.42 $g·kg^{-1}$, respectively) and their lowest in the poor forest (0.19; 1.22; and 11.62 $g·kg^{-1}$, respectively) (**Table 3**). Overall, all six soil chemical properties decreased as the degree of forest degradation increased.

Table 7: One-way ANOVA of the effect of forest types on soil chemical properties

Variation source	Soil properties	SSE	df	MS	F	P
Model Y = a + b×X	pHKCl	6.4	3	2.1	84.1	0.01
	Soil organic matter (SM, $g·kg^{-1}$)	1643.4	3	547.8	43.1	0.01
	Soil organic carbon (SC, $g·kg^{-1}$)	552.7	3	184.2	43.1	0.01
	Soil total nitrogen (SN, $g·kg^{-1}$)	0.1	3	0.03	322.8	0.01
	Soil total phosphorus (SP, $g·kg^{-1}$)	0.8	3	0.27	4.8	0.01
	Soil total potassium (SK, $g·kg^{-1}$)	2776.0	3	925.3	502.3	0.01
Intercept (a)	pHKCl	318.4	1	318.4	12497.1	0.01
	Soil organic matter (SM, $g·kg^{-1}$)	27811.4	1	27811.4	2190.0	0.01
	Soil organic carbon (SC, $g·kg^{-1}$)	9355.2	1	9355.2	2189.8	0.01
	Soil total nitrogen (SN, $g·kg^{-1}$)	1.5	1	1.5	14334.8	0.01
	Soil total phosphorus (SP, $g·kg^{-1}$)	48.7	1	48.7	878.1	0.01
	Soil total potassium (SK, $g·kg^{-1}$)	14617.5	1	14617.5	7934.3	0.01
Forest types (X)	pHKCl	318.4	1	318.4	12497.1	0.01
	Soil organic matter (SM, $g·kg^{-1}$)	27811.4	1	27811.4	2190.0	0.01
	Soil organic carbon (SC, $g·kg^{-1}$)	9355.2	1	9355.2	2189.8	0.01
	Soil total nitrogen (SN, $g·kg^{-1}$)	1.5	1	1.5	14334.8	0.01
	Soil total phosphorus (SP, $g·kg^{-1}$)	48.7	1	48.7	878.1	0.01
	Soil total potassium (SK, $g·kg^{-1}$)	14617.5	1	14617.5	7934.3	0.01

Note: SSE, Sum of squares of errors; df, Degrees of freedom; MS, Mean square; F, Fisher's statistic; P, Statistical significance level

Factors influencing organic matter content in yellow-brown ferralitic soil

Statistical analysis revealed that SM concentration in yellow-brown ferralitic soil was significantly correlated ($P < 0.01$) with BD, PD, SW, pHKCl, M, FL, and TSM (**Table 8**). SM content was found to increase significantly with rising levels of SW, pHKCl, M, FL, and TSM, whereas it decreased notably with increasing values of BD and PD.

Table 8: Correlation coefficients between soil organic matter content and soil properties and forest types

Parameters	BD	PD	SW	pHKCl	M	FL	TSM
SM	-0.414	-0.501	0.702	0.795	0.637	0.663	0.743
BD	1	0.731	-0.213	-0.637	-0.582	-0.525	-0.589
PD		1	-0.295	-0.723	-0.653	-0.490	-0.546
SW			1	0.752	0.804	0.879	0.812
pHKCl				1	0.921	0.879	0.883
M					1	0.952	0.920
FL						1	0.935

Notes: SM, soil organic matter ($g \cdot kg^{-1}$); BD, soil bulk density ($g \cdot cm^{-3}$); PD, soil particle density ($g \cdot cm^{-3}$); SW, soil water content (%); M, standing timber volume ($m^3 \cdot ha^{-1}$); FL, forest litter ($tons \cdot ha^{-1}$); TSM, total number of soil microorganisms ($x10^6$ $CFU \cdot g^{-1}$)

Multivariate linear regression and correlation analyses demonstrated that the estimation function for SM content can be expressed as SM = f(BD, PD, SW, pHKCl, M, FL, TSM), corresponding to the forms presented in Equations 10 and 11 (**Table 9**). In these equations, the partial correlation coefficient (R) represents the strength of the relationship between SM and each independent variable after accounting for the linear effects of the other variables. The variance inflation factor (VIF) is used to evaluate the degree of multicollinearity among the predictors. Analysis based on Equation 11 indicated that SM content in the 0–40 cm soil layer is positively correlated with four variables: BD, SW, pHKCL, and TSM. In contrast, negative correlations were observed with PD, M, and FL. Ranking the standardized regression coefficients (Beta) revealed that M exerted the strongest influence on SM content (|−1.237|), followed by soil pHKCL (|1.078|) and TSM (|0.728|). SW had the weakest effect, with a Beta coefficient of |0.505|.

Table 9: Regression equation for estimating organic matter content based on soil properties and forest types

Variable	Unstandardized Coefficient	Standardized Coefficient	Part R	VIF	Rank
Constant	-29,370				
BD	2,524	0,065	0,032	4,1	7
PD	-15,972	-0,168	-0,074	5,2	6
SW	7,035	0,505	0,178	8,1	4
pHKCl	17,829	1,078	0,342	9,9	2
M	-0,162	-1,237	-0,249	24,6	1
FL	-0,912	-0,276	-0,049	31,3	5
TSM	16,825	0,724	0,229	10,0	3
	(Equation 10)	(Equation 11)			

Notes: SM, soil organic matter ($g \cdot kg^{-1}$); BD, soil bulk density ($g \cdot cm^{-3}$); PD, soil particle density ($g \cdot cm^{-3}$); SW, soil water content (%); M, Standing timber volume ($m^3 \cdot ha^{-1}$); FL, forest litter ($tons \cdot ha^{-1}$); TSM, total number of soil microorganisms ($x10^6$ $CFU \cdot g^{-1}$)

DISCUSSION

This study analyzes the physical and chemical properties of yellow-brown ferralitic soil at a depth of 0–40 cm beneath the canopy of tropical semi-moist evergreen closed forests recovering after selective logging in the Hoa Binh hydropower reservoir area. The results indicate that the physical and chemical properties of the soil vary across different forest recovery conditions (**Tables 2–4**). These properties are closely related to M, FL, and TSM (**Table 5**). Generally, SW is higher in rich and medium forests compared to poor and mixed broadleaf-bamboo forests. Soil clay content tends to increase from rich to poor forest, and is lowest in mixed broadleaf-bamboo forest. Soil silt content shows an increasing trend with forest degradation, while sand content decreases significantly with the same gradient. An increase in M is associated with a decrease in BD and PD, while it corresponds with an increase in pHKCl, SM, SC as well as SN, SP, and SK contents. These findings aligned with the results of previous studies on the influence of forest types on soil properties (Thanh & Duyen, 2014; Cuong *et al*., 2017; Chau *et al*., 2024). For example, Thanh and Duyen (2014) and Cuong *et al*. (2017) reported that soil organic matter and nutrient (SN, SP, SK) concentrations were significantly higher in low- to medium-intensity selective logging forests due to greater plant litter and root input. Similarly, Chau *et al*. (2024) found that as standing timber volume and canopy density increased, BD and PD decreased. An increase in soil porosity and nutrient retention capacity accompanied this change. These findings are consistent with the observed relationships between standing timber volume and the physical and chemical characteristics of the soil in the current study. The above analyses indicate that the degree of forest recovery after logging has a significant impact on the properties of yellow-brown ferralitic soil.

Univariate correlation analysis showed that the SM content in yellow-brown ferralitic soil at the depth of 0–40 cm under the canopy of tropical evergreen humid closed forests recovering after selective logging in the area surrounding the Hoa Binh hydropower reservoir depended on various soil and stand characteristics (**Table 8**). The SM content is primarily influenced by four key factors: M, pHKCl, TSM, and SW (**Table 9**). Among these factors, M exerts the most significant impact, followed by pHKCl, TSM, and SW. The M is a key factor in determining the content and stability of SM in forest ecosystems. It influences both the quantity and quality of organic inputs, such as litterfall, root turnover, and woody debris, which all contribute to the formation of SM (Sam & Binh, 2000). Moreover, M affects decomposition rates and the overall chemical and physical properties of the soil (Sam *et al*., 2006; Qiu *et al*., 2018). Numerous studies have shown that soil pH is closely related to SM (Cuong *et al*., 2024). Specifically, soil pH influences microbial activity within the soil, which directly affects the decomposition of organic matter (Ngaba *et al*., 2020). Low soil pH has been suggested to reduce microbial activity, and it may also contribute to the accumulation of SM (Chen *et al*., 2004). Soil microbial communities are vital for enhancing soil fertility, as noted in previous studies (Sun *et al*., 2017; Liu *et al*., 2018). These microorganisms play a crucial role in both the decomposition and stabilization of soil organic matter, as well as in regulating nutrient cycling processes. SM content is also impacted by SW, as it can modulate the input of organic matter and microbial activity (Vasques *et al*., 2010), affecting the accumulation, decomposition, and stability of SM.

CONCLUSION

The features of yellow-brown ferralitic soil vary based on forest types. SW is higher in rich and medium forest areas compared to poor and mixed wood-bamboo forests. Soil clay content progressively increases from rich to poor forest types, being lowest in the mixed wood-bamboo forest areas. The proportion of soil silt tends to rise with the level of forest degradation, while soil sand content significantly decreases as degradation increases. An increase in M results in lower BD and PD, along with increased pHKCL, SM, SC, SN, SP, and SK levels. In the Hoa Binh hydropower reservoir area, the amount of SM in yellow-brown ferralitic soil at a depth of 0–40 cm beneath the canopy of selectively logged recovering forests is most strongly influenced by M, followed by soil pHKCl and TSM, with SW having the least effect. To prevent further degradation of the yellow-brown ferralitic soils beneath the canopy of tropical semi-moist evergreen closed forests recovering after selective logging in this region, we recommend that forestry management agencies in the Hoa Binh hydropower reservoir area adopt restoration measures for poor forest types, avoid clear-cutting of low-layer vegetation, and maintain the litter layer under the forest canopy.

ACKNOWLEDGEMENTS

We would like to acknowledge the financial support from the Provincial Science and Technology Task Foundation as per Decision No. 1560/QĐ-UBND of Hoa Binh Province.

REFERENCES

Blake, G.R., & Hartge, K.H. (1986). Bulk density. In: Klute, A., Ed., Methods of Soil Analysis, Part 1 - Physical and Mineralogical Methods, 2nd Edition, Agronomy Monograph 9. *American Society of Agronomy - Soil Science Society of America*, *Madison* 363-382.

Chau, M., Quy, N., Hung, D., Xu, X., Cuong, L., Ngoan, T., & Dai, Y. (2023). Soil nitrogen storage and associated regulation factors in an Acacia hybrid plantation chronosequence in Southern Vietnam. *Applied Ecology and Environmental Research* 22(1): 145-162.

Chau, M., Quy, N., Cuong, L., Hieu, N., Ngoan, T., Hung, D., Hung, B., & Phu, N. (2024). Soil organic carbon stocks in natural forests of Dongnai Culture and Nature Reserve, Southeastern Vietnam. *Applied and Environmental Microbiology* 22(4): 3815-3834.

Chen, C.R., Xu, Z.H. & Mathers, N.J. (2004). Soil Carbon Pools in Adjacent Natural and Plantation Forests of Subtropical Australia. *Soil Science Society of America Journal* 68: 282-291.

Cuong, L., Hung, B., Bolanle-Ojo, O., Xu, X., Thanh, N., Chai, L., Nebiyou, L., Wang, J., & Thang, B., (2020), Biomass and carbon storage in an age-sequence of *Acacia mangium* plantation forests in Southeastern region, Vietnam. *Forest Systems* 29(2): e009.

Cuong, L., Quy, N., Hung, B., Chau, M., & Doan, P. (2024). The relative importance of stand and soil properties parameters on soil organic matter content of *Acacia* hybrid forests in the South Central Coast Region of Vietnam. *Malaysian Journal of Soil Science* 28: 134-146.

Cuong, L., Thanh, N., Long, L., Trang, B. & Hieu, N. (2017). Some soil physical and chemical properties under natural forest canopy in Tanphu protective forest board, Dongnai Province, Vietnam. *Journal of Forest Science and Technology* 6: 17-24.

Dien, P. (2016). How much is the value of forest hydrological services for electricity production: Case study at Hoa Binh Hydropower Reservoir area. *Journal of Forestry Science and Technology* 3: 30-38.

Hien, P., Phuong, N., Khieu, L. & Hoa, N. (2017). Characteristics of soil organisms under experimental forest canopy of luot mountain, Vietnam National University of Forestry. *Journal of Forestry Science and Technology* 10: 65-75.

Jia, X., Zhou, J., Su, T., Zhou, Y., Chen, J., Ma, H., Ma, J. & Wang, X. (2020). Effects of different cropping densities on the habitat of artificial Caragana intermedia in desert steppe. *Acta Ecologica Sinica* 40: 4126-4136.

Khoa, P., Hung, B., Dell, B., Vinh, N., Kurbanov, E., Cuong, L. & Phuong, N. (2024). Multivariate Spatial Structure of Secondary Forests in Tuyen Quang Province, Vietnam. *Biology Bulletin* 51: 396-409.

Liu, D., Huang, Y., Sun, H. & An, S. (2018). The restoration age of Robinia pseudoacacia plantation impacts soil microbial biomass and microbial community structure in the Loess Plateau. *CATENA* 165: 192-200.

Nelson, D.W. & Sommers, L.E. (1982). Methods of soil analysis. Part 2 chemical and microbiological properties. Madison: Soil Science Society of America, Inc: pp 539-579.

Ngaba, M.J.Y., Ma, X.Q. & Hu, Y.L. (2020). Variability of soil carbon and nitrogen stocks after conversion of natural forest to plantations in Eastern China. *PeerJ* 8: e8377.

Qiu, X., Peng, D., Li, W. & Jiang, H. (2018). Soil physicochemical properties of Pinus tabuliformis plantations of different ages in Yanqing, Beijing. *Chinese Journal of Applied & Environmental Biology* 24: 0221-0229.

Sam, D. & Binh, N. (2000). Assessment of Potential Productivity of Forest Lands in Vietnam. Hanoi Agriculture Publishing House, Vietnam.

Sam, D., Que, D., Siem, T. & Binh, N. (2006). Forest soils, nutrition, and management. Hanoi Agriculture Publishing House, Vietnam.

Sun, Y., Zhang, Y., Feng, W., Qin, S., Liu, Z., Bai, Y., Yan, R. & Fa, K. (2017). Effects of xeric shrubs on soil microbial communities in a desert in northern China. *Plant and Soil* 414: 281-294.

Thanh, N. & Cuong, L. (2015). Soil characteristics under vegetation types at Donhan Commune, Tanlac District, Hoabinh Province. *Science and Technology Journal of Agriculture & Rural Development* 257: 116-122.

Thanh, N. & Duyen. H. (2014). Principal soil properties under recovery natural forest at Con Cuong Forestry Company, Nghe An Province. *Science and Technology Journal of Agriculture & Rural Development* 232: 115-120.

Them, N., Duong, D., Ngoan, T. & Hung, N. (2021). Statistical Methods and Data Processing Techniques in Forestry. Hanoi: Agriculture Publishing House.

Them, N., & Toai, P. (2024). Forest ecology. Science and Technology Publishing House, Hanoi.

Trung, T. (1999). Tropical forest ecosystems in Vietnam. Science and Technology Publishing House, Hanoi.

Van Reeuwijk, L.P. (2002). Procedures for soil analysis. ISRIC, FAO, Wageningen.
Vasques, G., Grunwald, S., Comerford, N. & Sickman, J. (2010). Regional modelling of soil carbon at multiple depths within a subtropical watershed. *Geoderma* 156: 326-336.
Wang, H.X., Sun, X.M., Chen, D.S., Shen, Y.Z. & Ma, J. (2012). Changes of soil physical and chemical properties at different developmentalstages of *Larix kaempferi* plantations in Xiaolongshan, Gansu Province. *Forest Research* 25(3): 294-301.