Variation In Soil Organic Carbon Stock In The Deciduous Forest Of Yok Don National Park Of Vietnam

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ABSTRACT

Assessment of soil organic carbon (SOC) in terrestrial ecosystems, particularly in tropical deciduous forests is one of the global imperative tasks in order to better comprehend its contribution in regulating the regional and global carbon cycles. Yok Don National Park is dominated by deciduous forest with smaller areas of evergreen forest, particularly on hills and along watercourses. The objectives of this study were to investigate the impacts of various environmental factors on the density of soil organic carbon (SOC) in the deciduous forest areas of Yokdon National Park and analyzed the effects of soil type, components in soil, forest status, steepness, altitude on %OC as well as estimation of total SOC stock using the Normalized Difference Vegetation Index (NVDI) and Factor Analysis for Mixed Data (FAMD). The results showed that soil type and soil texture had the most significant impacts on %OC, accounting for over 50% of the variation in OC% and closely linked to changes in %OC. The total storage of SOC in the dipterocarp forest of Yok Don National Park is estimated to be approximately 7,644,080 tons across an area of 95,955.23 ha. The SOC stock shows a large fluctuation range from 14.3 tons/ha to 246.8 tons/ha with an average of 84 tons/ha, respectively. The effective protection and management practices implemented in Yok Don National Park have played a significant role in enhancing SOC storage in the forest soils of this region. Our findings in this study may provide useful information for forest conservation and management as pertaining to strategies for the preservation and augmentation of carbon storage within forest ecosystems.

Keywords: Soil organic carbon, deciduous forest, CO_2, Yok Don National Park

Introduction

Soil is the second largest carbon reservoir in nature after the ocean. It contains twice as much carbon as the atmosphere and three times that accumulated in plants within terrestrial ecosystems (Batjes, 1996; Houghton, 2007). Approximately, 10% change in soil organic carbon is equivalent to the total amount of CO_2 emission generated by human activities over the past few decades (Kirschbaum, 2000). The impact of land use changes on carbon can either release or sequester carbon depending on soil and environmental characteristics as well as land management practices (Baldock, 2007). Carbon sequestration in soil is a slow process, but it is a strategic natural reservoir that offsets the amount of CO_2 emissions from human activities related to living and production (Jandl et al., 2007; Lal, 2004). The identification of carbon storage in ecosystems is a necessary requirement for national measurement, reporting, and verification systems (Huy et al., 2016). In recent years, SOC has received much significant attention from worldwide researchers. Since the 1960s, numerous scientific publications have explored two main research directions concerning SOC. The first direction considers soil as a potential storage area for greenhouse gases (Al-Adamat et al., 2007; Eswaran et al.,1993; Fontaine et al.,2007; Paul et al., 2002; Stockmann et al., 2013). The second direction focuses on soil function (Batjes, 1996; Cantú Silva & Yáñez Díaz, 2018; McBratney et al., 2014; Pandey et al., 2019; Tung et al., 2018; Sultan et al., 2014). Researchers worldwide have increasingly emphasized the quantification of SOC storage in different ecosystems and scales using mathematical models. Notably, Baldock (2007) presented dynamic SOC models that consider both spatial and temporal dimensions. Several factors have been identified as influential in SOC dynamics, including land-use systems (Al-Adamat et al., 2007; Vaccari et al., 2012; Von Fromm et al., 2021), total clay content (Amelung et al., 1998; Kahle et al., 2002; Rasmussen et al., 2018; Schmidt et al., 2011), slope aspect, vegetation cover, soil formation, and micro-topography (Hoffmann et al., 2012). Other factors encompass soil structure, climate, farming practices (Burke et al., 1989), changes in cropping patterns and fallow cycles (Ando et al., 2014), climate and forest type (Paul et al., 2002), temperature, altitude, rainfall, and land use (Liu et al., 2011), as well as soil type and land cover (Dengiz et al., 2015). However, one inevitable issue with all dynamic SOC models is the existence of errors resulting from two main causes: the number of factors included in the model and the simultaneous existence of qualitative and quantitative factors. The implemented Factor Analysis for Mixed Data (FAMD) method using open-source R software (R Core Team, 2021) is considered a potential solution to address these issues.

To date, some studies have been conducted on dipterocarp forest ecosystems in the Central Highlands. For instance, ecological studies of dipterocarp forests (Brearley et al., 2016), analysis and management of forest carbon dynamics (Nguyen et al., 2012), relationships between logging intensity and carbon stocks (Stas et al., 2020), modeling of growth rates and productivity of dipterocarp forests in the Central Highlands of Vietnam (Nguyen, 2009), structure and composition of deciduous dipterocarp forests in Central Vietnam (Nguyen & Baker, 2016), analysis and management of forest carbon dynamics (Nguyen et al., 2012), forest restoration (Do et al., 2019), and dipterocarp enrichment planting with *Tectona grandis* (Huy et al., 2018). However, there have been no reports on the effects of environmental factors on SOC content and estimation of total SOC storage in this forest ecosystem. Therefore, the objective of this study is: (i) To determine the degree of influence of environmental factors including soil type, mechanical composition, NDVI index, forest condition, slope, and altitude on SOC density (%OC); (ii) To estimate total SOC storage in the dipterocarp forest ecosystem at Yok Don National Park, Vietnam.

Research site

The Yok Don National Park was established on October 29, 1991, according to Decision No. 352/CT of the Council of Ministers, with the aim of protecting a 58,200-ha lowland forest ecosystem. By Decision No. 39/2002/QD of the Prime Minister in 2002, the total natural area managed by the Yok Don National Park was expanded to 115,545 ha, located in two provinces of Dak Lak and Dak Nong (Figure 1), including a strict protection zone of 80,947 ha, an ecological restoration zone of 30,426 ha, and an administrative service zone of 4,172 ha. The Yok Don National Park was established to conserve the genetic resources of animal and plant species in the lowland forest ecosystem.

The Yok Don National Park is situated on the Southern edge of the Central Highlands in the districts of Buon Don and Ea Sup, characterized by a flat and slightly undulating terrain with an average elevation of 200-300 m. The terrain slopes gradually from the east (400-500 m) to the west (with a height of only about 140 m), where the Srepok River flows into Cambodia. Due to the low elevation and the surrounding highlands, the climate of the Yok Don National Park is very dry and hotter than other regions. The climate of the region is characterized by a tropical highland monsoon with two distinct seasons: the rainy season from May to November, accounting for about 76% of the total annual rainfall, and the dry season from December to April of the following year.

Field sampling, laboratory analysis and total SOC calculation

The study conducted soil sampling at 187 locations in the field. Sampling locations were randomly sampled and the coordinates were transferred to a handheld GPS for approaching the sampling point in the field site. Soil samples were collected from a depth of 30 cm, both at the center of each sampling point and at four additional points distributed diagonally within a 10 m radius, mixed, and sieved to remove particles larger than 2 mm. The samples were air-dried, placed in sealed bags, and labeled before being taken to the laboratory. The samples were passed through a 0.25 mm mesh sieve to determine the organic carbon (OC) content using the Walkley-Black method. In addition, soil cores were taken at the sampling points using a 100 cm^3 volumetric cylinder to determine soil bulk density and stored properly. The SOC stock in 1 ha of soil with a depth of 30 cm was calculated using the formula (Pearson, 2007).

$$SOC\ (tons/ha) = \rho \times d \times \%OC \times 100$$

where ρ is the soil bulk density (g/cm3), d is the soil depth with significant organic carbon content (30 cm), and %OC is the percentage of carbon in the soil.

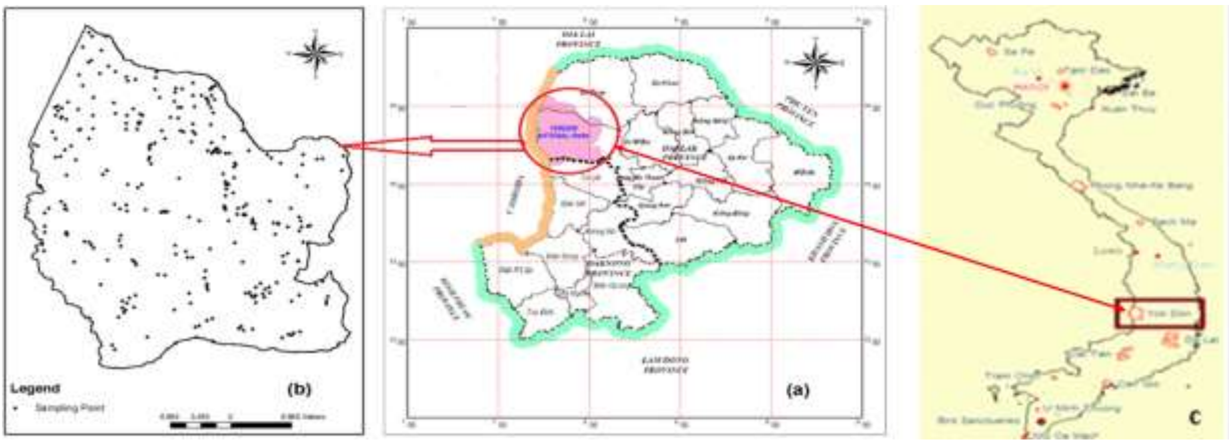


Figure. 1. Locations of (a) YokDon National Park and (b) the sampling sites; (c) Vietnam map

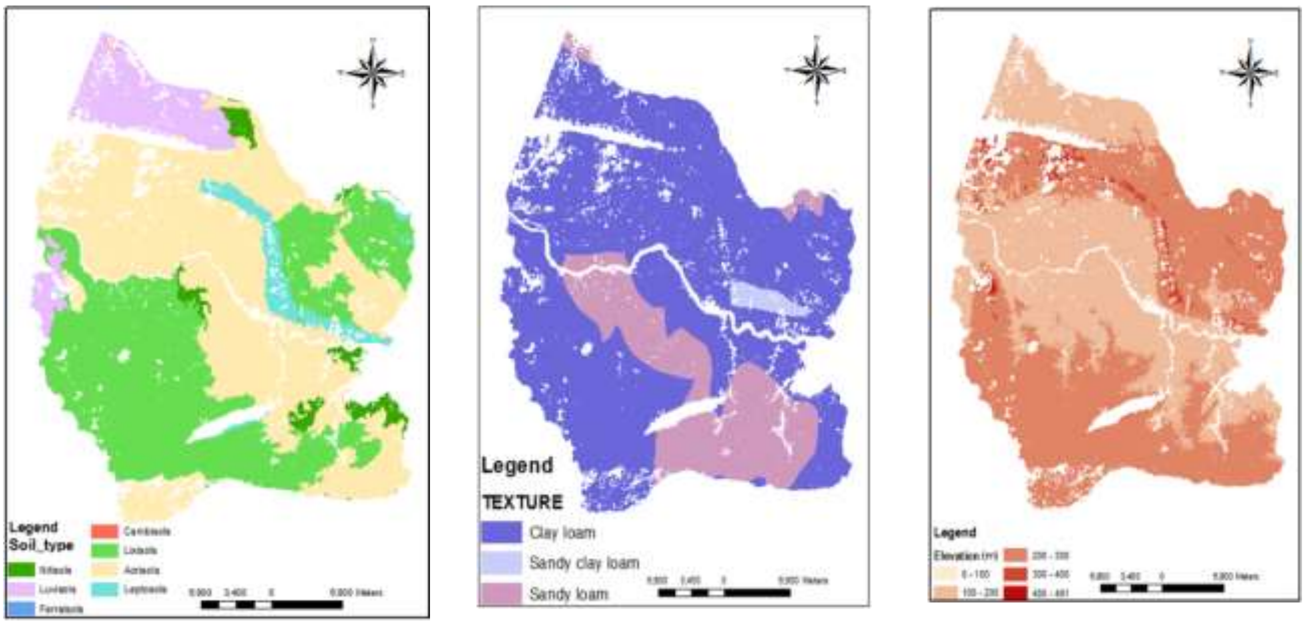
Constructing environmental factors maps and classification

In order to establish the factor maps, the spatial analysis software ArcGIS 10.5 was used, incorporating various factors such as soil type, mechanical composition, NDVI index, forest status, slope and elevation zone. The data used for the factor maps were developed from specific sources, including a soil map at a scale of 1:250,000, which was updated in 2019 as part of the project titled: "*Assessment of Soil Degradation for Dak Lak and Dak Nong Provinces*". The NDVI map was generated using NDVI images with a resolution of 30m x 30m, while the slope and elevation zone maps were developed using DEM images with a resolution of 30m x 30m. Additionally, the slope and elevation zone maps were developed using DEM images with the same resolution, acquired from Google Earth Engine (GEE) in 2020. To ensure consistency, all maps and images were converted to the WGS84 coordinate system and projected in the UTM zone N48, respectively.

The forest status map for the study area was classified from Sentinel-2 satellite imagery with a resolution of 10m x10m in 2020, consisting of 10 image channels (02, 03, 04, 05, 06, 07, 08, 8A, 11, and 12), which were downloaded through the GEE application. The images used for classification were the median of 367 cloud-filtered images downloaded from 01/06/2019 to 31/05/2020 and transformed to the WGS84 coordinate system, UTM projection, and N48 projection zone. The Maximum Likelihood classification method (Khouangvichit et al., 2020; Mensah et al., 2019) was used to classify the images based on a sample set of 1056 ROI points, with 6 types of land cover classes of interest, including 126 ROI of degraded forests, 398 ROI of poor forests, 286 ROI of average and rich forests, 57 ROI of water bodies, 44 ROI of other lands, and 145 ROI of evergreen forests. The sample set was built based on checking the status at the standard forest inventory plots (OTC) established during the 2014 forest inventory, comparing the color and image structure at the OTC positions that had been checked, selecting coordinates for each type of classification status, and combining ground-truthing using the quick measurement method of Bitterlich prism with the advice and support of technical staff from the forest garden. The sample set was split in a 70:30 ratio for classification and validation. The classification accuracy was evaluated using various indices, including Kappa, Overall accuracy, Producer accuracy, and User accuracy (Congalton, 2001; Khouangvichit et al., 2020). Based on the characteristics of the study area and references to environmental factors classification methods in some published studies (Hoffmann et al., 2012; Jahn et al., 2006; Liu et al., 2011; Tung et al., 2018), the environmental factors of interest were classified as shown in Table 1 and Figure 2.

Table 1. Description of class divisions the Environmental factors considered to affect soil organic carbon density (%OC)

Environmental factors	**Class**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Soil Type	Nitisols	Luvisols	Cambisols	Lixisols	Acrisols	Leptosols	Ferralsols
Soil Texture	Clay loam	Sandy clay loam	Sandy loam				
Elevation	0 – 100m	100m – 200m	200m – 300m	300m – 400m	400m – 491m		
Slope	$0^0 – 3^0$	$3^0 – 8^0$	$8^0 – 15^0$	$15^0 – 20^0$	$20^0 – 25^0$	$25^0 – 35^0$	$>35^0$
NDVI	(-0.4) - 0	0 – 0.2	0.2 – 0.4	0.4 – 0.6	0.6 – 0.8		
Forest State	Medium and Rich	Poor	Impoverished				



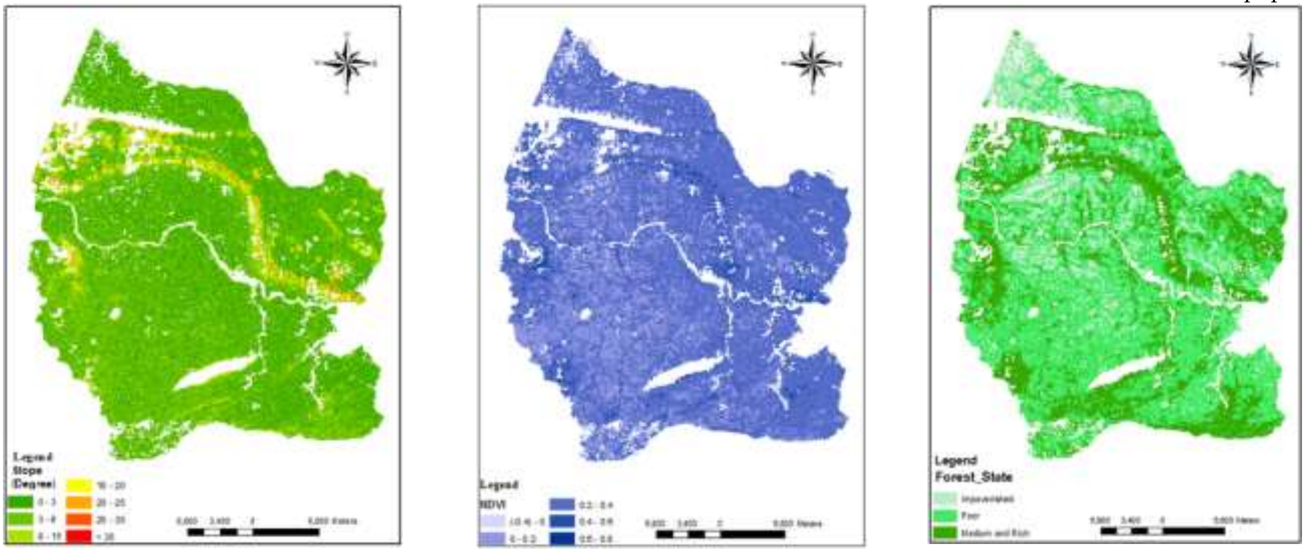


Figure 2. Environmental Factor Maps

Method for estimating total reserves of SOC

In order to determine the factors that have the highest impact on SOC content, we used Factor Analysis for Mixed Data (FAMD) on mixed data in the open-source R software (R Core Team, 2021). FAMD was applied to reduce weakly influential variables and increase the ability to collect and select the key factors affecting SOC. FAMD is a part of the Principal Component Analysis (PCA) method and is suitable for processing datasets that include both numerical and categorical variables. FAMD is used to test the correlation between both numerical and categorical variables, and it is an approach that combines PCA and Multiple Correspondence Analysis (MCA) (Pages, 2004; R Core Team, 2021). During the analysis, the variables were normalized, numerical variables were scaled to the same variance unit, and categorical variables were encoded and then scaled proportionally using MCA. This ensures a balance of the influence of both numerical and categorical variables in the analysis (R Core Team, 2021; Huy et al., 2022). Based on FAMD, we selected the factors that contributed to variability and had a strong relationship with SOC, and then analyzed the impact of each combination of factors on SOC content using Statgraphics Centurion XV software.

Statistical analyses

To evaluate the influence of environmental factors on the %OC in the soil of the forest, we applied evaluation standards in Statgraphics Centurion XV based on the following principles: accepting a standard sample experiment (n = 178>30); checking for independence and homogeneity of variance using Levene's criteria; performing ANOVA with equal variances; and performing non-parametric Kruskal Wallis tests with unequal variances. Additionally, Fisher's Least Significant Difference (LSD) method was used to group environmental factors according to their variability in influencing %OC. Mean values, standard deviation, maximum and minimum values were used to assess the amount of SOC in the studied areas.

Results

Relationships between SOC density (OC%) and environmental factors

In this study, the percentage of organic carbon (%OC) was influenced by multiple factors. Our investigation focuses on exploring the relationships between %OC and various factors, including soil type, soil structure, slope, altitude, NDVI index, and forest status. To examine the significance of these factors in relation to %OC, we employed One-way ANOVA and non-parametric Kruskal

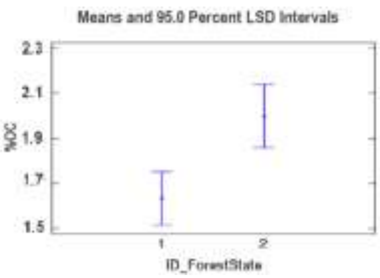
Wallis tests. Additionally, Fisher's Least Significant Difference (LSD) test, based on the minimum significant difference standard, was used to determine significant differences at a 95% significance level between each independent factor and %OC. The results presented in Tables 2, 3, and Figure 3 revealed notable findings. Firstly, %OC exhibited variation across different elevation ranges, specifically between 100m - 300m and 300m - 400m (P-Value ≈ 0.03). At an elevation of 300m - 400m, %OC was higher compared to the 100m - 300m range, with mean values of 2.29% and 1.71%, respectively. Additionally, considerable differences in %OC were observed when considering three slope levels: 0° - 15°, 15° - 25°, and 25° - 35°. %OC was the lowest at an elevation of 250m - 350m, measuring 0.84%, and gradually increased with the slope from 0° - 15° (1.74%) to 15° - 25° (2.62%).

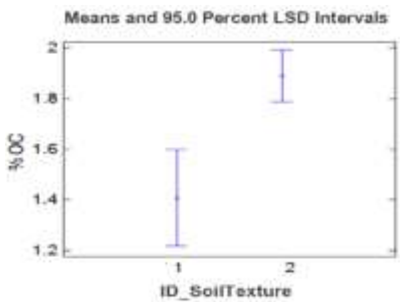
Soil type demonstrates a significant influence on %OC, as indicated by a P-value of 0.006. The experimental findings reveal that Lixisols and Nitisols soils exhibit lower %OC compared to Leptosols, Ferralsols, Luvisols, Acrisols, and Cambisols soils. The corresponding mean values were measured at 1.49% and 1.93%, respectively. Another influential factor on %OC was soil texture. The statistical analysis reveals that %OC decreases from Clay Loam (1.89%) to Sandy Clay Loam and Sandy Loam (1.41%). Furthermore, %OC varies based on different forest statuses. The %OC in impoverished dipterocarp forests and poor dipterocarp forests was lower than in medium and rich dipterocarp forests, respectively. Among the six environmental factors considered, only the NDVI index did not demonstrate a significant difference in relation to %OC in the dipterocarp forest soil.

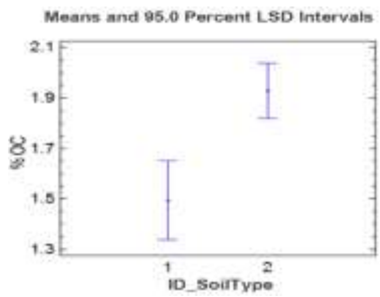
Table 2. Variance Check, ANOVA and Kruskal-Wallis Test for SOC by environmental factors

Environmental Factors	**Factor**			**Factor Group**		
	P- Value for Levene's Variance Check	**P- Value According to ANOVA**	**P- Value According to Kruskal-Wallis Test**	**P- Value for Levene's Variance Check**	**P- Value According to ANOVA**	**P- Value According to Kruskal-Wallis Test**
Elevation	0.00666488	-	0.07494395942	0.00997351	-	0.0256979
Slope	0.497325	0,0043	-	0.0982942	0.0003	-
Soil Type	0.0437137	-	0.065532	0.00824674	-	0.00554135
Soil Texture	0.132239	0.0086	-	0.07515632627	0.0022	
Forest Status	0.406809	0,0151	-	0.2137468079	0.0060	-
NDVI Index	0.606943	0.6682				

Encoding environmental factors according to the direction of variation of %OC; Forest State Group Code 1: Impoverished dipterocarp forest and Poor dipterocarp forest; Forest status Group Code 2: Medium and Rich dipterocarp forest; Soil Texture Group Code 1: Sandy clay loam and Sandy loam; Soil Texture Group Code 2: Clay Loam; Soil Type Group Code 1: Lixisols and Nitisols; Soil Type Group Code 2: Leptosols, Ferralsols, Luvisols, Acrisols, Cambisols; Slope Group Code 1: 250 – 350; Slope Group Code 2: 00 – 30; 30 - 80; 80 – 150; Slope Group Code 3: 150 - 200; 200 – 250; Elevation Group Code 1: 100m – 200m; 200m – 300m; Elevation Group Code 2: 300m – 400m







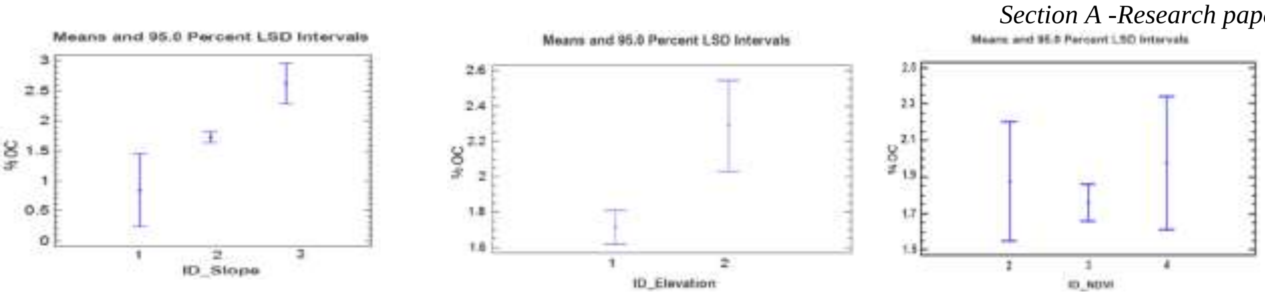


Figure 3. Graph of Mean and 95.0 Percent LDS Intervals Box – Whishker of the Environmental factor Groups considered to affect soil organic carbon density.

Table 3. Multiple Range Tests for %OC by environmental factors

Environmental Factor	**Factor/Factors Group**	**Count**	**Mean**	**Homogeneous Groups**
Elevation	1	164	1.71	X
	2	23	2.29	X
Slope	1	4	0.84	X
	2	170	1.74	X
	3	13	2.62	X
Soil Type	1	62	1.49	X
	2	125	1.93	X
Soil Texture	1	41	1.41	X
	2	146	1.89	X
Forest State	1	110	1.63	X
	2	77	2.00	X
NDVI	3	160	1.76	X
	2	15	1.87	X
	4	12	1.98	X

Encoding environmental factors according to the direction of variation of %OC. Forest State Group Code 1: Impoverished dipterocarp forest and Poor dipterocarp forest. Forest State Group Code 2: Medium and Rich dipterocarp forest; Soil Texture Group Code 1: Sandy clay loam and Sandy loam; Soil Texture Group Code 2: Clay Loam; Soil Type Group Code 1: Lixisols and Nitisols; Soil Type Group Code 2: Leptosols, Ferralsols, Luvisols, Acrisols, Cambisols; Slope coding in the direction of variation SOC; Slope Group Code 1: 25 0 - 35 0; Slope Group Code 2: 0 0 – 3 0 ; 3 0 - 8 0; 8 0 - 15 0; Slope Group Code 3: 15 0 - 20 0; 20 0 - 25 0; Elevation Group Code 1: 100m – 200m; 200m – 300m; Elevation Group Code 2: 300m – 400m.

Assessment of soil organic carbon content (SOC/ha) and SOC stock

The Walkley-Black method was used to process 187 sampling points, resulting in an average %OC of 89.9845 tons/hectare and a range of 14.3 to 246.8 tons/hectare. The standard deviation was 47.3463 tons/hectare, indicating that the SOC stock value has a right-skewed distribution, as confirmed with 95% accuracy (Figure 4). The FAMD analysis yielded five dimensions, but dimension two was specifically selected due to its significant involvement in the SOC. The dataset includes four numerical variables, including the density of SOC, NDVI index, slope, and elevation, as well as categorical variables such as soil types, soil composition, and forest status. Table 5 and Figure 5 present the contribution of each variable toward changes in SOC density. The dataset includes 7 variables, of which 4 are numerical variables: SOC/ha, NDVI, slope, and altitude relative to sea level, and the remaining variables are categorical, such as land group, soil mechanical composition, and state of the forest.

Table 4. Summary Statistics for SOC

Count	187
Average	83.9845
Standard deviation	47.3463
Coeff. of variation	56.375%
Minimum	14.3
Maximum	246.8
Range	232.5
Stnd. skewness	5.95834
Stnd. kurtosis	2.05194

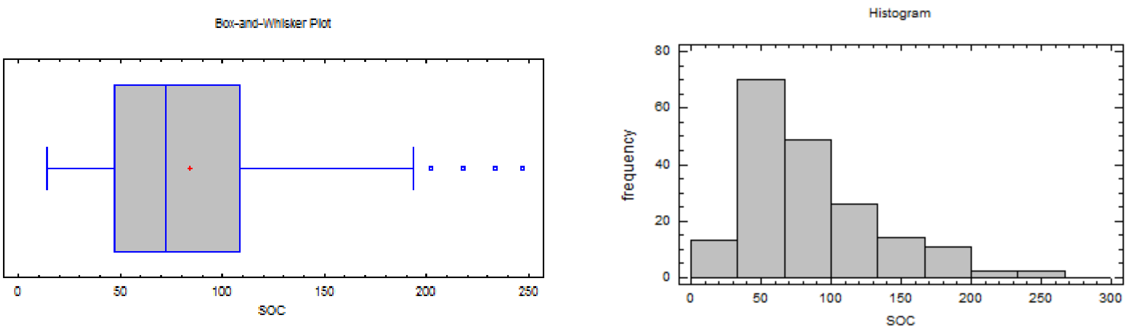


Figure 4. SOC content distribution chart. The red dot on the graph above indicates the average SOC value

The results of FAMD applied to the mixed data yielded 5 dimensions. Among them, Dimension 2 was selected for the study because SOC/ha had a higher variability compared to the other dimensions. The contribution of the factors and variables to the common variability and their relationship with SOC/ha are shown in Figure 5. There are 3 factors studied in this study showing significantly and dominantly affected SOC density: soil group, soil composition, and SOC itself. The other factors, such as the NDVI index, forest status, slope, and elevation, have a lesser impact on the SOC content. To gain a more comprehensive understanding, we further investigated the relationship between soil type, soil composition, and SOC by creating four combinations of two types of soil groups and two types of soil composition. ANOVA analysis showed that the SOC content varied significantly from 59.2408 to 98.5723 tons/hectare (P-value = 0.0008 << 0.05) (Table 7). Furthermore, combining the second soil type with the second type of texture resulted in the highest amount of SOC, while the combination of the first type in both groups resulted in the lowest.

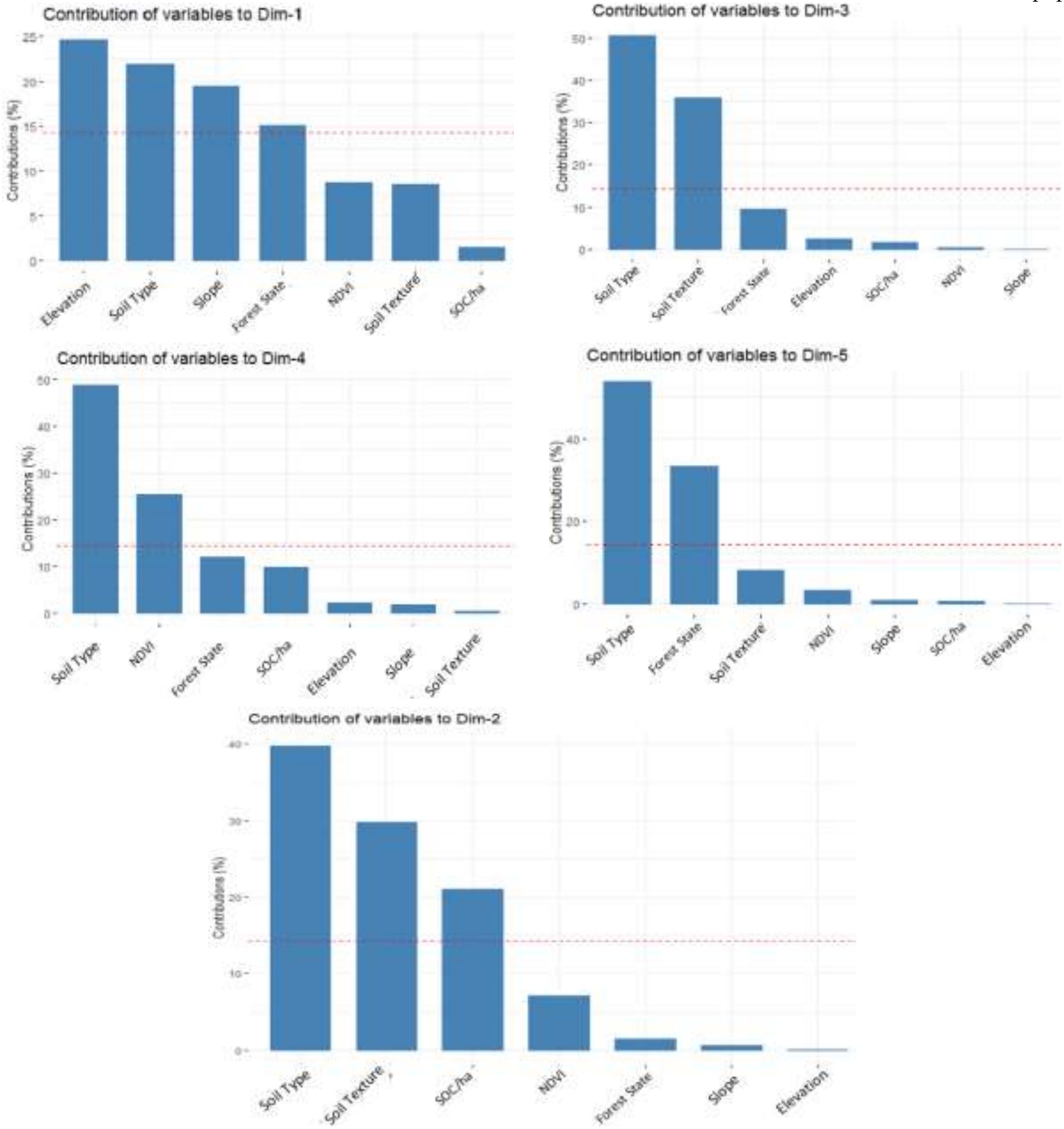


Figure 5. Contribution of factors and variables according to FAMD with dimensions, the red line is the average value of the contribution of variables, factors

As indicated by ANOVA analysis results, the 4 combinations of soil type and soil mechanical components significantly influenced the amount of SOC/ha (P-Value = 0.0008 << 0.05) (Table 7). Examining the combinations of soil type and soil mechanical components found that the SOC content varied between 59.2408 t/ha and 98.5723 t/ha. Among these combinations, soil type 2 and mechanical component 2 had the highest SOC content, followed by soil type 2 and mechanical component 1, soil type 1 and mechanical component 2, and the lowest content was in soil type 1 and mechanical component 1 (Table 7).

Table 7: ANOVA Table for SOC/ha using a combination of two-factor groups

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	36417.4	3	12139.1	5.84	0.0008
Within groups	380582	183	2079.68		
Total (Corr.)	416999	186			

Using the LSD with a significance level of 95%, the 4 combinations of land group and soil mechanical component that affected SOC/ha were grouped into two homogeneous groups (Table 8 and Figure 6): Homogeneous group 1 includes: land group 1 and soil mechanical component 1, land group 1 and soil mechanical component 2. Homogeneous group 2 includes land group 2 and soil mechanical component 1, land group 2 and soil mechanical component 2 (Table 8).

Table 8. Multiple Range Tests for SOC/ha using a combination of two-factor groups

Level	Count	Mean	Homogeneous Groups
Soil Type Group 1 & Texture Group 1	26	59.2408	X
Soil Type Group 1 & Texture Group 2	66	77.0382	X
Soil Type Group 2 & Texture Group 1	15	79.5874	XX
Soil Type Group 2 & Texture Group 2	80	98.5723	X

Based on the results grouped from the homogeneous combination, the average SOC/ha for the two homogeneous groups was calculated and used as a basis to estimate the total amount of SOC stored in the natural forests (Table 9).In order to predict the total amount of SOC stored in the Yok Don National Park forest, the study conducted a mapping of soil and mechanical composition groups. Overlaying resulted in units with homogeneous SOC values according to the homogeneous combination groups. After providing the mean SOC values for the 4 homogeneous combination groups in the map data, the SOC storage map was formed and the total SOC storage in the Yok Don National Park forest was estimated. The results show that the estimated total SOC storage in the Yok Don National Park forest is about 7,644,080 tons over 95,955.23 hectares, with a large variation range from 14.3 tons/ha to 246.8 tons/ha, with an average of nearly 84 tons/ha (Tables 9).

Table 9. SOC reserves stored in Dipterocarp forest land Yok Don National Park

Combination of Factor Group	Areas (ha)	SOC Average (Tons/ha)	Total of SOC (Tons)
Soil Type Group 1 & Texture Group 1	40.177,96000	68.1	2736119,076
Soil Type Group 1 & Texture Group 2	2.942,54000	68.1	200386,974
Soil Type Group 2 & Texture Group 1	52.834,73000	89.1	4707574,443
Total	95.955,23000		7.644.080,493

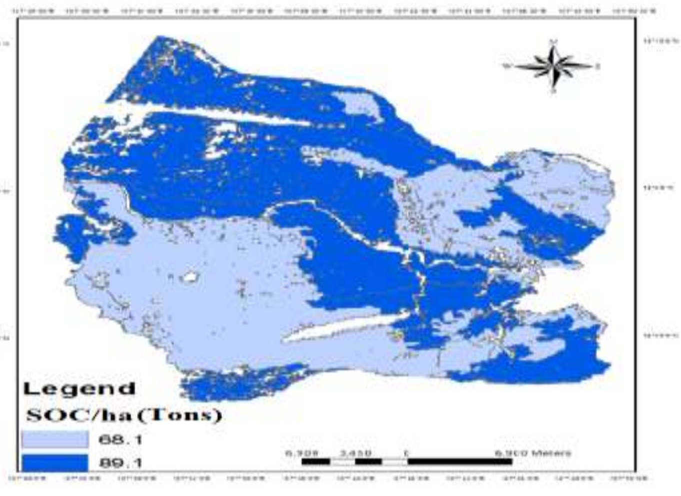


Figure 5. Map of the distribution of SOC (ton/ha) in deciduous forest soil at Yok Don National Park

Discussion

The influences of environmental variables on SOC stock

In this study, the relationship between %OC and environmental factors was observed, it was found that %OC in the forest soil at Yok Don National Park changed with variations in soil type, soil structure, slope, elevation, and forest state. Among these factors, the slope had the greatest impact on %OC, while the effects of soil texture, soil type, and forest status were almost equal. Elevation had the lowest influence on %OC in the soil. These relationships have also been documented in some previous studies. Intanil et al. (2016) found that soil texture affected soil organic carbon when studying carbon stock in dry dipterocarp forests in Northern Thailand. The relationship between clay content and organic matter in tropical soils was also reported by Birch & Friend (1956) and Jones (1973). When investigating the composition and turnover of soil organic carbon, Baldock (2007) reported that soil structure was one of the environmental factors affecting OC decomposition. Stockmann et al. (2013) proposed a curve of soil organic carbon saturation limit as a function of soil structure and suggested that the ability to store SOC in the soil is greater when the ratio of clay to sand is high. Pham et al. (2018) also reported the influence of soil structure on SOC content when evaluating soil quality in Central Vietnam. The reason may be that clay has a high ability to bond with organic matter. (Bot and Benites, 2005; Power and Prasad, 1997). In this study, seven soil groups were considered, and their average SOC content was determined. The soil groups with high average SOC content were: newly converted land with 143.3 tons/ha and black soil with 108.968 tons/ha. The group with average SOC content included: gray soil with 90.0887 tons/ha, yellow and red soil with 85.4 tons/ha, and soil with a compacted clay layer with 81.1 tons/ha. The soil groups with low SOC content were brown soil with 70.7513 tons/ha and severely eroded soil with 66.031 tons/ha. Spain et al. (1983) also reported similar findings that the organic carbon content of soils in Australia, where soils with low carbon content included some important types of soils for dryland agriculture, such as red and brown soils, gray clay soils, brown and red soils. Other important agricultural soils, such as black earth with moderate organic content and mountain peat soil, had the highest carbon values. Moreover, Orhan et al. (2015) also observed a profound influence of soil type on %OC in the Mandendere watershed in Turkey. When studying soil organic matter in Australia through the ratio of N and C, Northcote et al. (1975) also noted differences in soil organic matter content among large soil groups. Differences in the physicochemical properties of the soil groups may be considered the cause of the variation in %OC in soils (Spain et al., 1983).

Globally, soil organic matter (SOM) contains three times more carbon than the atmosphere or terrestrial vegetation. Recent advancements in analysis and experimentation have shown that molecular structure alone could not control the stability of SOM, as environmental and biological controls are dominant (Schmidt et al., 2011). Topography indirectly affects %OC in soil by influencing precipitation, temperature, solar radiation, and relative humidity (Tsui et al., 2004). SOC increases with elevation (Tsui et al., 2004). The relationship between %OC in the forest soil at YokDon National Park and elevation levels with no remarkable correlation was observed. However, significant correlations were found when subgrouping by the LSD (95%). Nonetheless, this correlation was not high compared to other environmental factors of interest. This relationship was also observed in a study on SOC reservoirs in Taiwan (Tsui et al., 2013), where a significant linear regression was found between the mean SOC stock and the mean value of elevation layers. As elevation changes lead to changes in climate, vegetation type, and soil minerals, the study's results demonstrated that elevation is a simple and effective predictor for SOC reservoirs. The relationship between elevation and SOC in the forest soil of Yok Don National Park is not high, likely due to the fact that this area is located on the flat basin of Buon Don and Ea Sup districts, with a gently undulating terrain and an average elevation of 200-300 meters (YokDon, 2021).

In the study area, %OC in soil showed a strong correlation ($P = 0.006$) with forest conditions. Average and rich forest conditions had higher %OC than poor and depleted forest conditions. The main reason for this relationship may be due to the amount of litterfall (Miao et al., 2019; Nadelhoffer et al., 2004). Litterfall on the forest floor and its decomposition are the pathways through which plant carbon enters the soil (Vitousek & Andariese, 1986). The addition or removal of litterfall can increase or decrease soil respiration in most forest ecosystems (Li et al., 2004; Nadelhoffer et al., 2004; Wang et al., 2013), including deciduous forests in Central Europe (Fekete et al., 2014). However, this work did not find any significant impact of the NDVI index on %OC in soil. Nevertheless, this relationship was observed in a study on the influence of environmental factors on %OC in the soil in the Heihe River Basin, China (Song et al., 2016; Li et al., 2019; Li et al., 2016), and in the Ranthambhore Tiger Reserve Forest in Sawai Madhopur and Karauli district of Rajasthan (Kumar et al., 2016). The reason for this difference may be due to the small study area and the consideration of only one forest type. Therefore, expanding the study areas and considering different forest types would provide meaningful evidence for this relationship.

The distribution of SOC content and SOC stock

The estimated global amount of organic carbon stored in forest soils is 580 Pg (Eswaran et al., 2000), with 40% located in forest ecosystems (Hudson et al., 1994). At YokDon National Park, the average amount of soil organic carbon (SOC) stored in the forest floor was nearly 84 tons per hectare (Table 4), and the total amount of SOC stored in the forest soils of the 95,955.23-hectare forest was estimated to be 7,644,080.493 tons (Table 9). Compared to the average SOC content in dry dipterocarp and dry forest soils reported in previous studies (Table 10), the amount of SOC stored in the forest floor at Yok Don National Park was found to be higher. This could be due to differences in the factors considered in previous studies and those in the study area. Some of these differences include the protection and management of the National Park, which has helped maintain forest quality and promote a diverse range of species and plant density. The relationships between tree density, vegetation characteristics, and carbon in the soil have been recognized in previous studies (Dar & Sundarapandian, 2013; Li et al., 2010; Solomon et al., 2018), and in the study area, the relationship between forest condition and SOC% was also observed. The relatively stable slope of the terrain is another factor that impacts SOC storage (Li et al., 2010; Liu et al., 2006).

The diversity of soil types and soil structure in the study area is also a contributing factor to these differences (Stockmann et al., 2013). The high average temperature and concentrated seasonal rainfall are also factors that may contribute to the differences in SOC/ha storage compared to similar forest types in other regions. In summary, the protection and management of YokDon National Park have likely contributed to the higher SOC storage in the forest soils of this area, along with the other factors mentioned above. These findings highlight the importance of forest conservation and management in maintaining and promoting carbon storage in forest ecosystems.

Table 10. Comparison of carbon content (Mg C ha^{-1}) in the soil of tropical dry deciduous forests

Forest type/region	SOC (Tons/ha)	Source
Tropical Dry Deciduous Forests, Himachal Pradesh	36.04 tonnes/ha (30 cm)	(Panwar & Gupta, 2013)
Tropical Dry Deciduous Forests, Indian Forest	37.5 ±3.4 tons/ha (50cm) 69. 9 ±10.1 tons/ha (1m)	(Chhabra et al., 2003)
Yok Don National Park, VietNam	78.6 tons/ha (30cm)	Present study

Conclusions

In summary, our findings reveal soil organic carbon (SOC) in the deciduous forest at Yok Don National Park is significantly influenced by environmental factors, including soil type, soil texture, forest condition, slope, and elevation on %OC in the soil. At a significance level of 95%, when each factor was considered separately, slope, soil texture, soil type, and forest condition showed a stronger influence on %OC than elevation. However, no significant differences in %OC were observed in relation to changes in the NDVI index. The SOC stock per hectare varied considerably, ranging from 14.3 tons/ha to 246 tons/ha, with an average of almost 84 tons/ha. With a total area of deciduous forest of 95.955,23 ha, the estimated total SOC stock was 7.644.080,49 tons. However, further research is needed with expanded input variables, aiming to build a predictive model of SOC stocks that can be applicable to all deciduous forest areas.

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