

VARIABILITY IN SOIL CARBON AND NITROGEN STORAGE ACROSS A CHRONOSEQUENCE OF *PINUS KESIYA* PLANTATIONS IN THE CENTRAL HIGHLAND, VIETNAM

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(Received 17th Oct 2024; accepted 16th Jan 2025)

Abstract. Plantations play a crucial role in the global nutrient cycle by accumulating soil carbon (C) and nitrogen (N). However, the relationship between stand features, soil physicochemical properties, and soil C and N storage in plantations of various ages has not been clearly understood. This study aims to clarify these complex relationships by investigating soil C and N stocks at three soil depths (0–20, 20–40, and 40–60 cm) across a chronosequence of *Pinus kesiya* Royale ex. Gordon plantations aged 5, 11, 15, 25, and 35 years in the Central Highland region of Vietnam. The results demonstrated that the contents of soil organic carbon (Sc) and total soil nitrogen (Sn), as well as the soil C:N ratio, all increased during forest development. The contents of Sc and Sn, along with the soil C:N ratio, significantly decreased as soil depth increased throughout forest development. Stocks of total Sc (SSc) and total Sn (SSn) also increased during forest development, rising from 101.20 Mg ha⁻¹ to 226.83 Mg ha⁻¹ and from 5.43 Mg ha⁻¹ to 8.76 Mg ha⁻¹, respectively. SSc and SSn appear to respond to afforestation by predominantly aggregating just beneath the ground surface. SSc and SSn decreased with increasing soil depth. SSc demonstrated a significant positive association with SSn. The results from the structural equation model (SEM) analysis indicated that SSc and SSn were significantly influenced by soil variables such as bulk density, pH, and clay content, as well as forest stand traits like plant biomass. In general, SSc and SSn were more significantly affected by soil traits than by stand traits. Our findings contribute substantially to the scientific knowledge necessary for developing sustainable management strategies and techniques for *P. kesiya* forests to enhance their productivity.

Keywords: *Pinus kesiya* forests, soil carbon and nitrogen stocks, soil traits, stand traits, structural equation modeling

Introduction

Global warming and the greenhouse effect are becoming increasingly important concerns as concentrations of carbon dioxide (CO₂) and other greenhouse gases rise. It is vital to identify some strategies to reduce the amount of greenhouse gases in the atmosphere (Chau et al., 2024d). The global organic C concentration in the 0–100 cm soil layer is significantly higher than that in the atmosphere, plants, or deeper soil reservoirs (Gautam et al., 2017). Even slight variations in the soil organic carbon (Sc) stock (SSc)

can major impacts on the amount of C present in the atmosphere (Wang et al., 2016). In most ecosystems, nitrogen (N) is a key variable constraining plant net primary productivity, which in turn regulates the rate of Sc accumulation (Deng et al., 2016). Hence, since Sc and soil total nitrogen (Sn) are important components of the global C and N cycles, they interact to influence atmospheric concentrations of greenhouse gases and global climate change, and identifying their respective amounts and how they are changing has become a hot topic in research on global climate change (Wang et al., 2019a; Duan et al., 2020; Ngaba et al., 2020; He et al., 2022; Zhang et al., 2022; Rahman et al., 2022; Yu et al., 2024). Accurate assessment of Sc and Sn stocks is crucial for sustainable land management and predicting future C and N cycles.

The age of the stand has a significant impact on the amount of C and N stored in various forest components such as trees, coarse woody debris, forest floor, and mineral soil (Noh et al., 2010). Moreover, stand age is a good indicator of how a forest ecosystem will be structured and function, which may impact the C and N density across C and N pools (Vangi et al., 2024). Additionally, a forest's multiple C and N pools respond to stand age in different ways (Li et al., 2012). Thus, it is crucial to comprehend how stand age links to Sc and Sn and sequestration rate. Although several studies have documented Sc and Sn across stand ages, the patterns in forest Sc and Sn driven by stand ages remain highly debated (Mao et al., 2010; Noh et al., 2010; Deng et al., 2017; Wang et al., 2019b). For instance, Deng et al. (2017) demonstrated that Sc and Sn rose with rising stand age, but additional studies reported that Sc and Sn declined first and then increased with increasing stand age (Noh et al., 2010; Wang et al., 2019b). The divergent findings from the individual studies may be depending on multiple other factors such as tree species planted, previous land use, climate, soil physicochemical properties, stand factors, and nutrient management (Li et al., 2012; Chau et al., 2024a). This strongly indicates the requirement for a mechanistic comprehension of how soil ecosystems in plantation ecosystems change with stand development stages.

Pinus kesiya Royale ex. Gordon is a prominent coniferous species in the afforestation efforts of Vietnam's Central Highlands. Its rapid growth rate, high-quality raw materials, and significant resin yield have made *P. kesiya* an important source of timber and resin. Recently, the area dedicated to *P. kesiya* plantations has increased steadily (MARD, 2023). In the context of multifunctional forest management and global climate change, numerous studies have explored various aspects of *P. kesiya* forests, including growth characteristics, biomass yield predictions, carbon sequestration capacity, and soil physical and chemical properties (Phuc, 1996; Phuong, 2011; Phuong and Hai, 2011; Baishya and Barik, 2011; Lapitan, 2017; Them, 2017). However, the dynamics of carbon (C) and nitrogen (N) in the soil during the development of *P. kesiya* forests, particularly in Vietnam's Central Highlands, have not been extensively documented. This gap constrains the scientific understanding of the geochemical cycles of essential nutrients in these forests. Therefore, a comprehensive assessment of soil C and N content and storage in relation to stand age (5, 11, 15, 25, and 35 years) in *P. kesiya* plantations is warranted. The specific objectives of this study are: (i) to determine the soil C and N content and stocks across five distinct stand ages of *P. kesiya* forests, and (ii) to identify the environmental factors influencing soil C and N stocks in these ecosystems. The findings of this study will significantly enhance the scientific knowledge required to formulate sustainable management practices and strategies aimed at improving the productivity of *P. kesiya* forests.

Materials and methods

Study area description and experimental design

This study was carried out in the Baolam Forestry Company, Bao Lam County (107°50'08"-107°42'30"E; 11°52'30"-11°38'02"N), Lamdong Province, Central Highland Region, Vietnam (Fig. 1). The climate of this region is characterized by a tropical monsoon climate, with an average annual precipitation of 3300 mm (mostly occurring from April to October) and an average annual temperature of 22°C (BFC, 2022; Quy et al., 2024). The elevation of the investigation's area ranges from 905 to 918 m *a.s.l.*, with slope angles ranging from 8° to 10°. According to the FAO-UNESCO soil classification system, the soil in the research area is categorized as Ferralsols soil. *P. kesiya* is the dominant tree species in the area. Other woody plants are also found in the area, the most common species are *Pinus caribaea* Morelet, and *Acacia mangium* Wild. Plantations occupy 19.78% of the total forest area (BFC, 2022). The dominant species of shrubs and herbs included *Lygodium microphyllum* (Cav.) R. Br., *Sonerila* Roxb., *Mimosa diplotricha* C. Wright ex Sauvalle, *Dicranopteris linearis* (Burm.f.) Underw. var. *Linearis*, *Chromolaena odorata* (L.) R.M. King & H. Rob., *Imperata cylindrica* (L.) Beauv., and (*Cynodon dactylon* (L.) Pers).

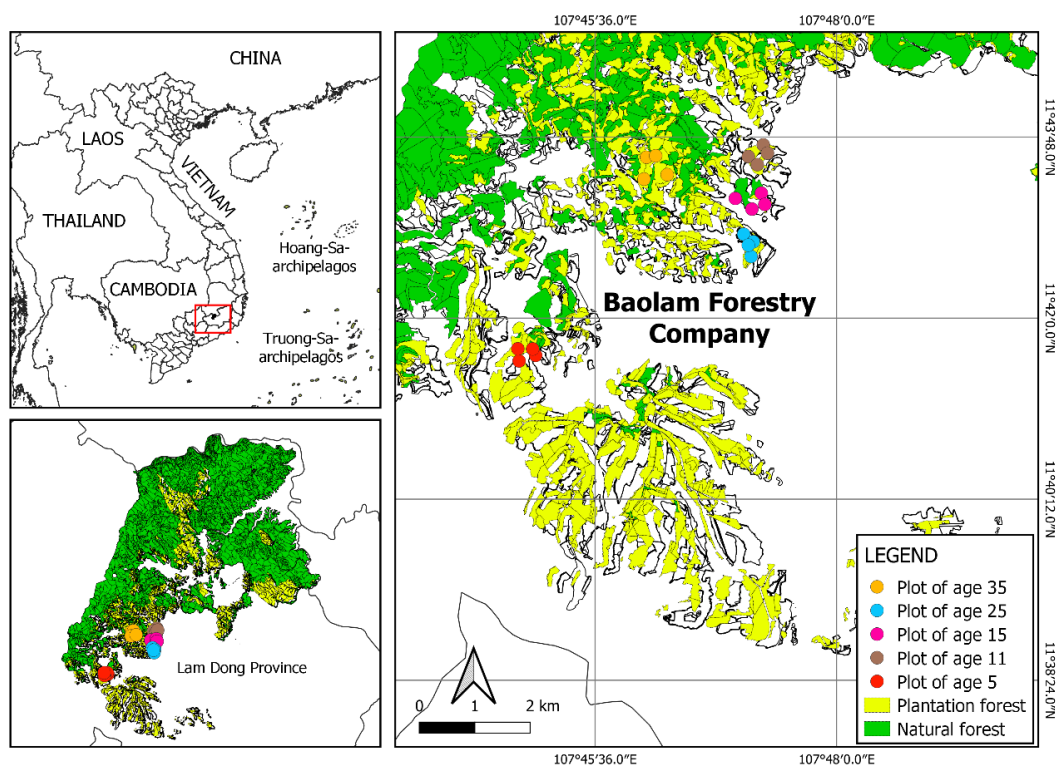


Figure 1. Map of experimental plots in the Baolam Forestry Company (Lamdong Province, Central Highland Region, Vietnam)

Field sampling was carried out in five sites with stand ages of 5, 11, 15, 25, and 35 years (Fig. A1 in the Appendix). Five various stand ages were situated within a 5 km radius of each other (Fig. 1). Twenty experimental plantings of various ages were chosen for the study after the first rotation was cleared of all tree stumps and branches. These

plantations were established on the same soil type and texture with a comparable disturbance and topography. Furthermore, following planting, no fertilizer was applied to these forest stands. In *P. kesiya* stands, thinning is a significant and frequent silvicultural technique. These three management operations, conducted three times following stand establishment, are intended to improve tree growth, vitality, and stem and wood quality. The experimental stands had an initial density of 3330 trees/ha (with an initial spacing of 3 m × 1.0 m). The stands were thinned once for the 11-year-old stands, twice for the 15-year-old stands, and three times for the 25- and 35-year-old stands. We realized that the vertical distribution characteristics, soil structure, and mineral composition of the planted forest stands were nearly the same after investigating the forest soil. Hence, forest development may be the primary cause of differences in soil traits among forest stands. This implies that all forest stands' requirements are acceptable for our chronosequence evaluation.

Data collection

Four 20 m x 25 m plots were established in each stand from April 7th to May 30th, 2024 (Table A1 in the Appendix). The diameter at breast height (Dbh) and tree height (H) of each tree and canopy closure were determined and documented. A diameter tape was used to measure the tree's Dbh, and a Blume-Leiss altimeter was used to determine the tree's H. To measure the canopy density, hemispherical images of the canopy were taken at the center of each plot and twenty equally spaced spots. These photographs were then processed using the GLAMA program (Gap Light Analysis mobile application). For the calculation of shrub and herb biomass, five randomly allocated 2 m × 2 m and 1 m × 1 m subplots were used to collect plant biomass for the understory and litter layers within a 20 m × 25 m plot. Following harvesting the biomasses of understory plants and forest litter from the sampling plots, they were weighted using a digital scale to estimate their fresh weight. They were subsequently transported to the lab and oven-dried at 65°C until a constant weight was achieved. The dry weights of understory plants and forest litter were used to quantify the biomasses of understory plants and litter per unit area. The forestry survey procedures are followed in the establishment of sampling plots and the measurement of stand indicators (Chau et al., 2023). Comprehensive site information of the sites and plant biomass measurements are presented in Table 1.

Table 1. Basic information of sampling plots in different stand ages in Baolam Forestry Company

Measured factors	Forest age (years)				
	5	11	15	25	35
Average diameter at breast high (cm)	7.25 ^a	15.18 ^b	21.25 ^c	27.03 ^d	30.10 ^e
Average tree height (m)	3.26 ^a	10.91 ^b	16.77 ^c	19.02 ^d	21.08 ^e
Tree density (Individual ha ⁻¹)	2935 ^d	1700 ^c	610 ^b	365 ^a	355 ^e
Canopy density	0.55 ^a	0.69 ^b	0.80 ^c	0.85 ^d	0.89 ^d
Understory plant biomass (Mg ha ⁻¹)	2.17 ^a	3.49 ^b	4.55 ^c	6.76 ^d	9.60 ^e
Litter biomass (Mg ha ⁻¹)	6.62 ^a	8.16 ^b	10.17 ^c	12.08 ^d	15.18 ^e
Slope (°)	8	9	9	10	8
Elevation (m a.s.l.)	907	905	912	918	910
Soil type	Ferralsols soil	Ferralsols soil	Ferralsols soil	Ferralsols soil	Ferralsols soil

Note: Data display the mean ± standard deviation (SD). Divergent lowercase letters represent a substantial variation among distinct stands (p<0.05)

Soil sampling and laboratory analysis

Five points were randomly chosen in each sample plot, and using a soil drilling sampler with a 5 cm inner diameter, soil samples were gathered at depths of 0–20, 20–40, and 40–60 cm after removal of plant residues, gravel, or other debris. Five random samples were taken from each plot using the S-shaped sampling procedure, and to preserve the major structure during transportation to the laboratory, the samples were stored in an aluminum specimen box. A total of 300 soil samples (5 forest age groups $\times$ 4 replicate plots $\times$ 5 points $\times$ 3 soil depths) were collected in the research. Soil samples were taken using a cutting ring with volume of 100 cm³ at each soil depth to analyze the soil bulk density. Soil bulk density (g cm⁻³) at each depth was ascertained by drying core soil samples at 105°C for more than 24 hours until a constant weight was obtained (Chau et al., 2024c). Before analyzing the physicochemical characteristics of the soil, any small rocks, plant roots, and coarse debris were eliminated from the samples using a 0.25 mm screen and laid out to dry. Using the pipette method, the soil particle size proportions were determined, including the clay content (<0.002 mm), silt content (0.02–0.002 mm), and sand content (0.02–2 mm) (Van Reeuwijk, 2002). A portable pH meter (PB-10, SARTORIUS, Germany) was used to analyze the soil pH at a soil-to-water mass ratio of 1:2.5, following the techniques proposed by Chau et al. (2024c). Utilizing the H₂SO₄-K₂Cr₂O₇ oxidation method, the concentration of Sc was determined (Nelson and Sommers, 1982). We applied the methods described in our previously published study (Cuong et al., 2022) to assess soil total nitrogen (Sn, g kg⁻¹), soil total phosphorus (Sp, g kg⁻¹), and soil available phosphorus (Svp, mg kg⁻¹). The Kjeldahl digestion method, colorimetric method, and molybdenum antimony colorimetric method were utilized to estimate the contents of Sn, Sp, and Svp, respectively.

Computation of soil C and N storage

The Sc and Sn storage (measured in Mg ha⁻¹) were computed as follows (Yu et al., 2024):

$$Storage_{Sc} = \sum_{i=1}^n Sc_i \times BD_i \times D_i \times 10^{-1} \quad (\text{Eq.1})$$

$$Storage_{Sn} = \sum_{i=1}^n Sn_i \times BD_i \times D_i \times 10^{-1} \quad (\text{Eq.2})$$

In *Equations 1 and 2*, Storage_{Sc} and Storage_{Sn} are soil C storage and soil N storage in layer *i* (Mg ha⁻¹); *Sc_i* and *Sn_i* are soil C concentration and soil N concentration in layer *i* (g kg⁻¹); *BD_i* is the bulk density of soil in layer *i* (g cm⁻³); *D_i* is the depth of soil layer *i* (cm); and 10⁻¹ is unit conversion coefficient.

Statistical data analyses

One-way analysis of variance (ANOVA) followed by the Least Significant Difference (LSD) test (*p*<0.05) was used to assess the differences in Sc and Sn contents and their corresponding stocks, and other soil properties among different stand ages and soil layers. The data normality (Kolmogorov-Smirnov test) and homogeneity of variance (Levene's test) were assessed before statistical analysis. Pearson correlation analysis was carried out to analyze the relationship between the Sc and Sn stocks and environmental factors. The structural equation model (SEM), which integrates path and factor analysis, has been used mostly with maximum-likelihood methods for causal inference in ecology (Xing et al.,

2023). We first used the variance inflation factor (VIF) threshold to remove highly correlated variables to prevent multicollinearity (Cuong et al., 2024a). Then, utilizing the connections and established consequences between the drivers of Sc and Sn stocks, we designed an a-prior model. Using the maximum likelihood chi-square (χ^2) and the standardized root means square residual (SRMR), the path coefficients relating to the variables were fitted. The model's excellent fit was defined through the comparative fit index (CFI), nonsignificant chi-square test, and root-mean-square errors of approximation (RMSEA). An acceptable fit is represented by CFI > 0.90, a nonsignificant chi-square test ($p > 0.05$), RMSEA < 0.08, and SRMR < 0.05 (Chi et al., 2022). The 'lavaan' package for R software version 4.4.1 (R Core Team, 2024) was implemented to carry out the SEM analysis (Rosseel, 2012). For all statistical analyses and figures in the study, R version 4.4.1 (R Core Team, 2024) statistical software program was utilized.

Results

Changes in stand features under different stand ages

Table 1 represents the stand characteristic parameters for the *P. kesiya* sampling stands. Stand trait variables differed among stands of varying ages considerably ($p < 0.05$). Stand tree density showed a declining tendency as stand age rose, while Dbh, H, and canopy density variables displayed a rising trend. Over time, the undergrowth (shrubs and herbs) biomass and litter biomass amount increased significantly.

Changes in soil physicochemical features under different stand ages

Figures 2 and 3 represent the statistical analysis of the physicochemical characteristics of soil for five differently aged stands at three different soil depths. The soil bulk density varied greatly among the five stand ages as well as the three soil layers ($p < 0.05$, Fig. 2a), ranging from 1.02 to 1.27 g cm⁻³. The soil bulk density in the 0-20, 20-40, and 40-60 cm soil layers decreased across time, with the 35-year-old stand exhibiting the lowest soil bulk density ($p < 0.05$). The profile distribution showed that the soil bulk density increased as soil depth increased, lowest in the 0–20 cm layer, followed by the 20–40 cm layer, and highest in the 40–60 cm layer. The study area's soil textural characteristic parameters displayed that, in stands of all ages, the sand content significantly reduced as soil depth increased, while the amounts of clay and silt rose ($p < 0.05$, Fig. 2b-d). Soil clay, silt, and sand concentrations varied considerably among three soil depths at the same forest age ($p < 0.05$), except for clay content in soil depths 20-40 and 40-60 cm at the 25-year-old stand ($p > 0.05$). For every soil depth, the 5-year-old stand exhibited the largest amount of sand ($p < 0.05$), whereas the 35-year-old stand displayed the highest proportions of silt and clay across all soil depths ($p < 0.05$). The soil pH value decreased significantly at each soil layer as stand age increased ($p < 0.05$; Fig. 3a). At a depth of 0-20 cm, the pH value of the soil in the 35-year-old stand was significantly lower than that of the other four stand ages (25-, 15-, 11-, and 5-year-old). This implies that surface soil acidification was increased later in the forest development process. The soil pH increased in the vertical direction as the soil's depth increased, demonstrating that the degree of acidity declined as soil depth rose ($p < 0.05$). The Sp and Svp contents of the soil were greatly impacted by stand age ($p < 0.05$, Fig. 3b-c). At the 0–60 cm layer, the annual mean values of Sp content in 35-year-old stand were 1.83, 1.53, 1.17, and 1.08 times greater than in 5-, 11-, 15-, and 25-year-old stands, respectively. Additionally, the annual mean value of Svp content (0 ~

60 cm) demonstrated a tendency as follows through the following order: 35-year-old stands > 25-year-old stands > 15-year-old stands > 11-year-old stands > 5-year-old stands. Sp and Svp levels in all five stands were substantially greater at the 0-20 cm soil layer than at the other soil layers.

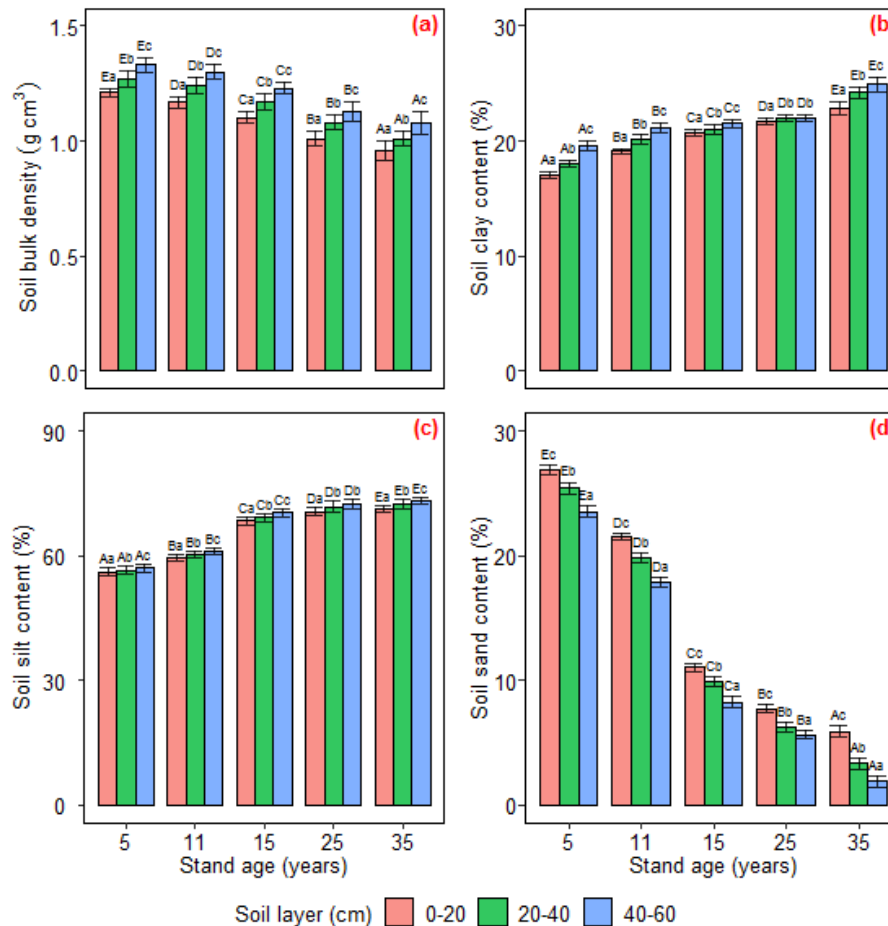


Figure 2. Soil bulk density (a), clay content (b), silt content (c), and sand content (d) at multiple soil depths in different-aged *Pinus kesiya* plantation stands. Error bars display standard deviation (SD). Divergent capital letters represent substantial variations among different stands on the same soil depth layer ($p < 0.05$). Divergent lowercase letters represent substantial variations among distinct soil depth layers on the same stand ($p < 0.05$)

Changes in soil organic carbon concentration, soil nitrogen concentration, and C/N ratio under different stand ages

Among stand ages or soil layers, there were notable differences in the concentrations of Sc and Sn ($p < 0.05$, Fig. 4a-b), except for the Sn content between the 15-, and 25-year-old stands at the 20–40 soil depth ($p > 0.05$). The 35-year-old stand exhibited the greatest Sc content in the 0-20, 20-40, and 40-60 cm layers ($p < 0.05$), with averages of 47.25, 34.86, and 30.21 g kg⁻¹, respectively. From the surface layer (0-20 cm) to the deep layer (40-60 cm), the Sc content declined drastically by 46.91%. The 35-year-old stand had the highest equivalent Sn concentration of those soil layers, at 1.66, 1.39, and 1.27 g kg⁻¹, respectively, which was substantially greater than any other younger stands ($p < 0.05$). The soil C:N ratio increased with time in all soil layers, with the 35-year-old stand exhibiting

the greatest ratio relative to all other stand ages ($p < 0.05$, Fig. 4c). The C:N ratio in the 60 cm deep soil profile varied 1.4 times across the chronosequence, from 18.10 to 25.81. Consistent variations in the Sc and Sn contents were observed in their vertical distribution, as both significantly declined as they went deeper into the soil profile ($p < 0.05$).

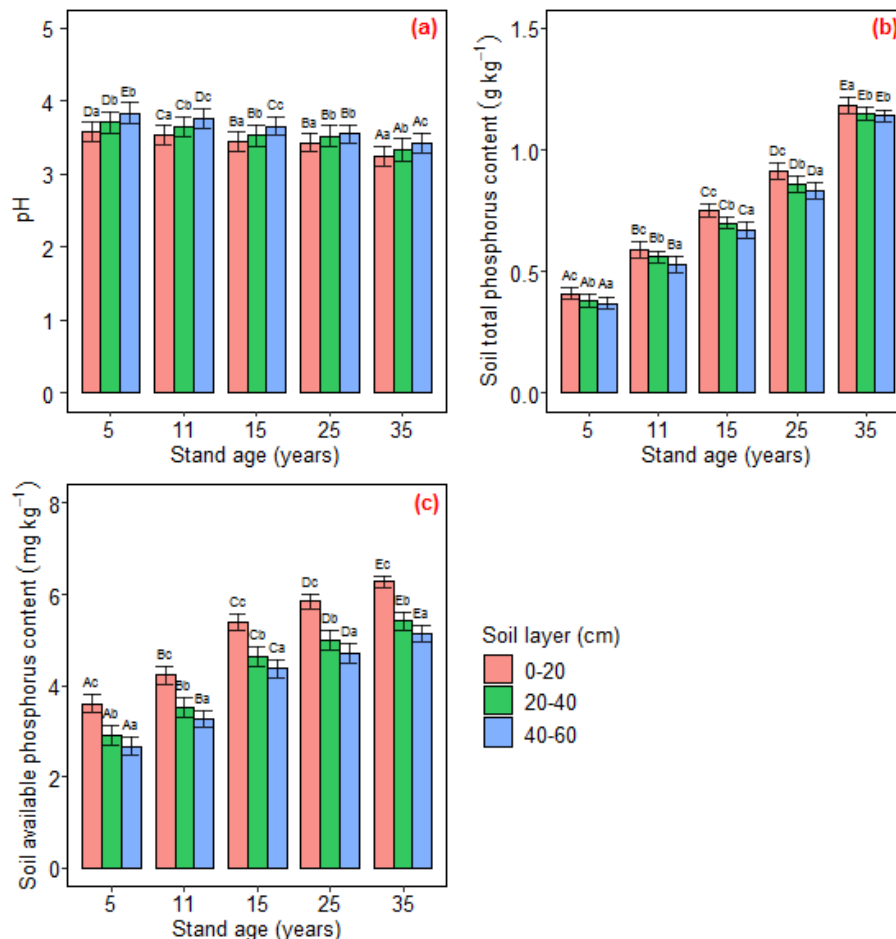


Figure 3. Soil pH (a), Soil total phosphorus content (b), and Soil available phosphorus content (c) at multiple soil depths in different-aged *Pinus kesiya* plantation stands. Error bars display standard deviation (SD). Divergent capital letters represent substantial variations among different stands on the same soil depth layer ($p < 0.05$). Divergent lowercase letters represent substantial variations among distinct soil depth layers on the same stand ($p < 0.05$).

Changes in soil organic carbon and soil nitrogen storage under different stand ages

The Sc and Sn stocks varied significantly during the sites' afforestation chronosequence ($p < 0.05$, Fig. 5a-b). The stocks of Sc and Sn increased over time, taking into account the entire 0–60 cm soil depth profile. As a result, they were ranked as follows: 5 < 11 < 15 < 25 < 35 years. The 35-year-old stand had Sc and Sn storage of 226.83 and 8.76 Mg ha⁻¹, respectively, substantially greater than those of the younger stands ($p < 0.05$). Upon vertical examination (Fig. 5c-d), the soil layers' respective contributions to Sc and Sn stocks throughout the afforestation chronosequence were found to be as follows: 40.01% to 50.20% and 36.45% to 41.26% for 0–20 cm, 29.35%

to 31.11% and 32.05% to 33.51% for 20–40 cm, and 18.88% to 28.88% and 25.23% to 31.50% for 40–60 cm. In general, as the stands developed older, a greater proportion of Sc and Sn storage was discovered just beneath the surface (0–20 cm) than in deeper soil (20–40 or 40–60 cm).

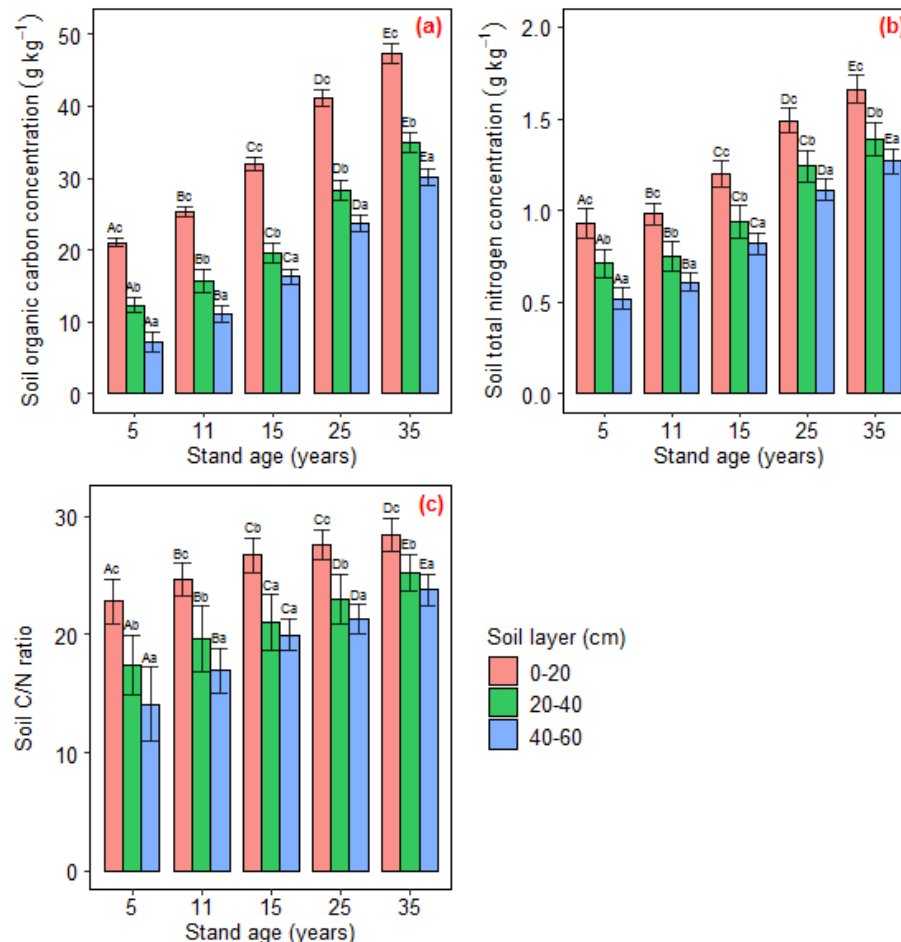


Figure 4. Soil organic carbon concentration (a), Soil total nitrogen concentration (b), and Soil C/N ratio (c) at multiple soil depths in different-aged *Pinus kesiya* plantation stands. Error bars display standard deviation (SD). Divergent capital letters represent substantial variations among different stands on the same soil depth layer ($p < 0.05$). Divergent lowercase letters represent substantial variations among distinct soil depth layers on the same stand ($p < 0.05$)

Effects of environmental parameters on soil organic carbon and soil nitrogen storage under different stand ages

Bd, Cy, St, Sd, pH, C/N ratio, Sp, and Svp in different soil layers, and Dbh, H, Ca, Ub, Lb, At, and Sl were measured to explain the variation of SSc and SSn among stand ages (Fig. 6). According to correlation analysis, the SSc and SSn substantially positively correlated with Cy, St, C/N ratio, Sp, Svp, Dbh, H, Ub, Lb, and At, while it obviously negatively connected with Bd, Sd, pH, Ds, and Sl ($p < 0.001$). However, there was no correlation found between SSc and SSn and Sl ($p > 0.05$). Additionally, there was a substantial positive connection between SSc and its SSn ($p > 0.05$).

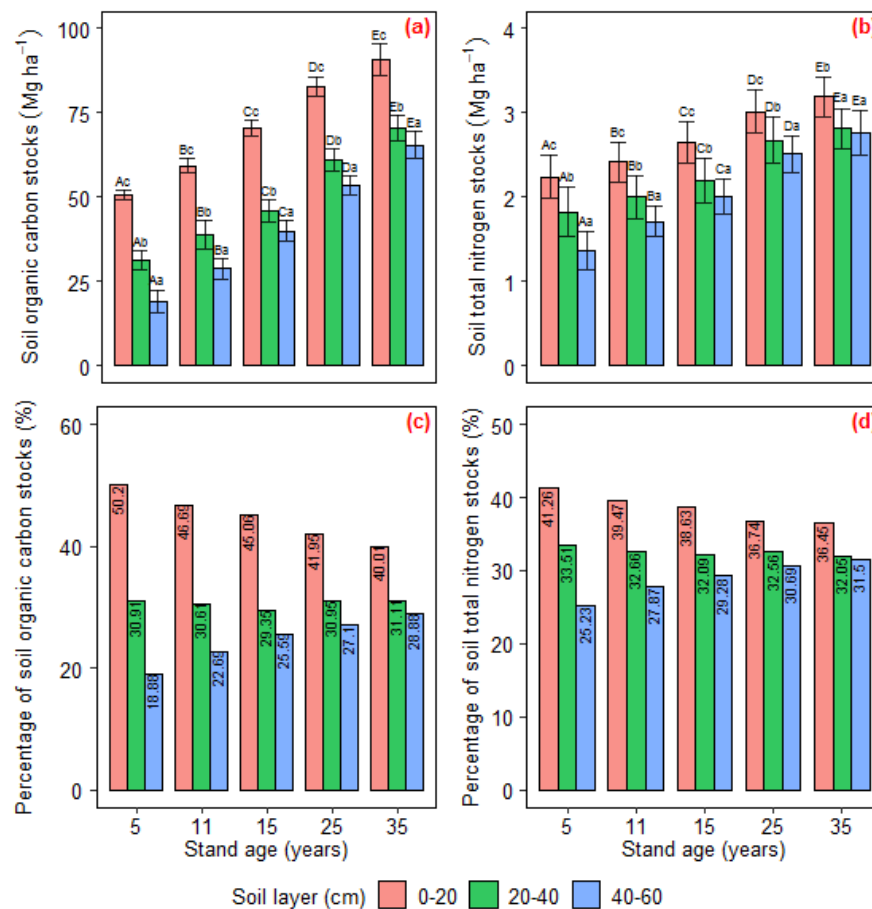


Figure 5. Soil organic carbon (a) and soil total nitrogen (b) storage across multiple soil depths, and their proportional contributions at five different locations in the afforestation chronosequence. Error bars display standard deviation (SD). Divergent capital letters represent substantial variations among different stands on the same soil depth layer ($p < 0.05$). Divergent lowercase letters represent substantial variations among distinct soil depth layers on the same stand ($p < 0.05$).

As revealed in Figure 6, The estimated CFI and SRMR values were 0.957 and 0.044, respectively, and the RMSEA value was 0.000. All of the values (CFI > 0.90, RMSEA < 0.08, and SRMR < 0.05) were within the allowed range, demonstrating additional the fact that the study model fit the data. Consequently, the findings showed that the SEM model accurately represents the interaction between the research area's soil C and N stocks and environmental variables, such as stand structural and soil features.

The degree of direct effect between the latent variables was assessed using standardized path coefficients (SPCs) (Fig. 7). Soil physicochemical traits, as a latent variable, had a substantial correlation with Bd, pH, and Cy. The corresponding SPCs values for these variables were 0.91, 0.91, and 0.71 respectively. The contributions of Bd, pH, and Cy to the soil properties latent variable were comparable. Stand structural features, as a latent variable, had a significant correlation with both Ub and Lb, with corresponding SPC values of 0.99 and 0.98, respectively. Similar contributions were made by Ub and Lb to the latent variable of stand structural traits. SSc exhibited the highest standardized path coefficient (0.99) with respect to the latent parameter associated with soil nutrient stocks.

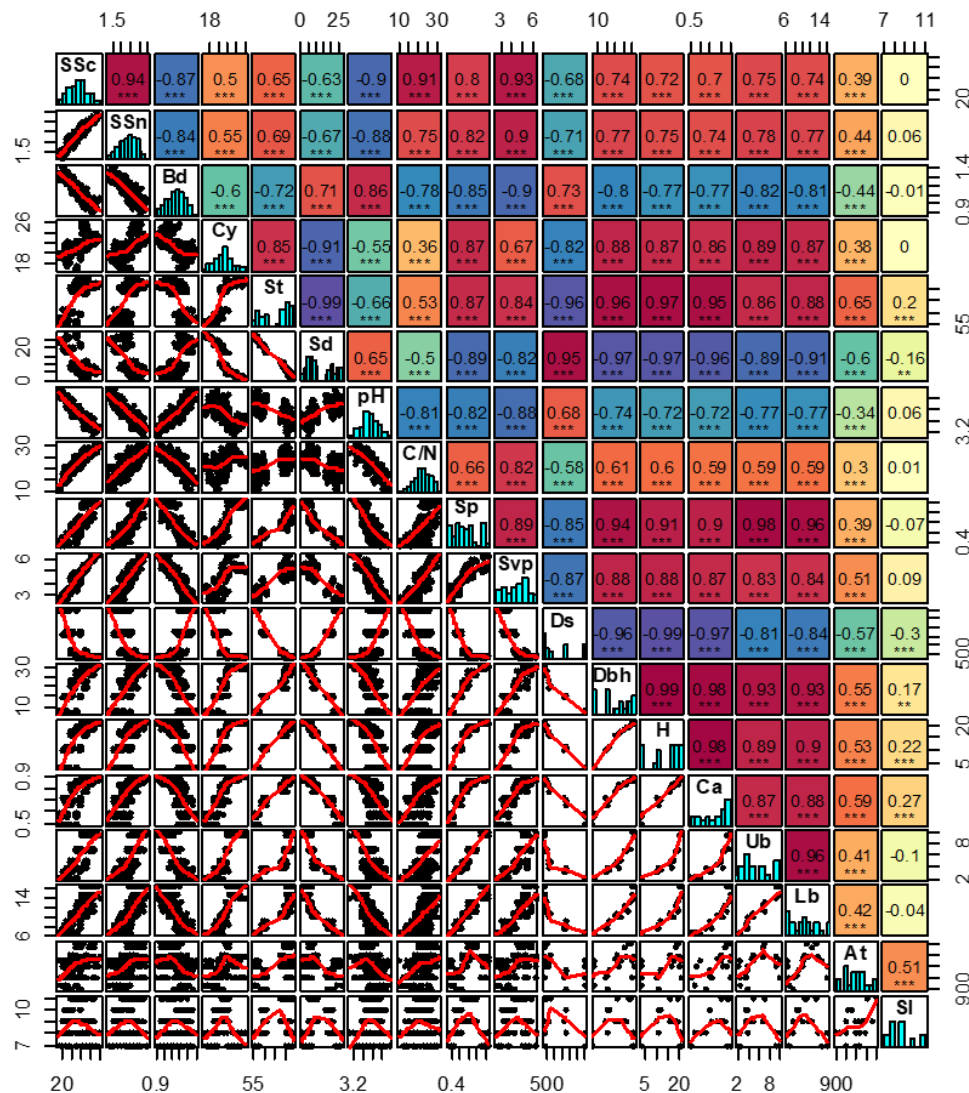


Figure 6. Correlation coefficients of soil organic carbon and soil total nitrogen storage with environmental parameters traits assessed across various forest ages. Note: SSc, soil organic carbon storage; SSn, soil total nitrogen storage; Bd, soil bulk density; Cy, soil clay content; St, soil silt content; Sd, soil sand content; Sp, soil total phosphorus concentration; Svp, soil available phosphorus concentration; Ds, stand density; Dbh, diameter at breast height (1.3 m); H, height; Ca, canopy density; Ub, understory plant biomass; Lb, litter plant biomass; El, Elevation; Sl, slope. Significance levels: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

Correlations between SSc and SSn and soil characteristics or stand features were significantly negative, and total effects of both factors on SSc and SSn were -0.85 and -0.07, respectively (*Table 2*). The results demonstrated that SSc and SSn are significantly more correlated with soil parameters than with stand structural attributes. Thus, SSc and SSn were significantly influenced by environmental factors, with soil characteristics having a greater impact.

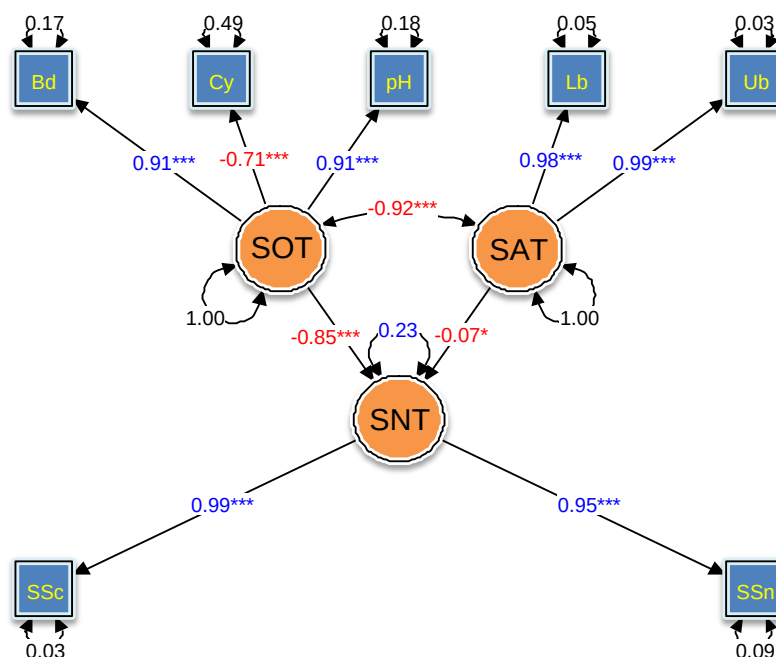


Figure 7. Environmental variables' impacts on soil organic carbon and total nitrogen storage were explored utilizing structural equation modeling (SEM). Note: The model's exogenous latent factors are soil traits (SOT) and stand characteristics (SAT), which characterize soil and stand indices, respectively. SNT is an endogenous latent parameter that denotes soil organic carbon and soil total nitrogen storage indices, while soil pH, soil bulk density (Bd), and soil clay (Cy) are measured indices related to soil features (SOT), and understory biomass (Ub), and litter biomass (Lb) are measured indices linked to stand features (SAT). Soil organic carbon (SSc) and soil total nitrogen (SSn) storage are measured indices related to SNT. The model's goodness-of-fit statistics are as follows: χ^2 -square = 231.830, p = 0.058, CFI = 0.957, RMSEA = 0.039, SRMR = 0.044. The arrows' direction depicts a connection among the values of the parameters. A factor loading coefficient value > 0 implies a positive association, whilst a value < 0 implies a negative correlation. Significance level: *: $p < 0.05$, ***: $p < 0.001$

Table 2. Impacts of soil and stand indicators on soil organic carbon and soil total nitrogen storage

Environmental variables	Path coefficients to SNT	
SOT	Total effect	-0.85***
SAT	Total effect	-0.07*

Note: SNT demonstrates soil organic carbon and soil total nitrogen storage. SOT demonstrates stand traits, and SAT demonstrates soil traits. levels of significance are presented as follows: *** $p < 0.001$, * $p < 0.05$

Discussion

Effects of stand age on soil C and N stocks

Sc and Sn are two of the most essential elements of soil nutrients and are crucial to the material cycle in forest ecosystems (Kang et al., 2023). Recent researches have demonstrated that afforestation can improve the soil's nutritional status (Deng et al., 2017; Chau et al., 2024b). In this research, the concentrations and stocks of Sc and Sn showed

a remarkable increasing trend with the forest stand development (*Fig. 4a-b, Fig. 5a-b*), as did the quantity of litter (*Table 1*). This suggests that the soil would have received more organic matter input over time. Zhang et al. (2022) demonstrated that increasing the afforestation duration advances soil microbial and enzymatic activities, which promotes the procedure of the soil's C and N accumulation. According to previously conducted studies, as stand ages rise, SSc and SSn have been shown to either decrease (Chi et al., 2022), increase continuously (Dou et al., 2013), initially decrease, and then increase (Wang et al., 2019b), or almost unchanged (Sartori et al., 2007). These results imply that the direct relationship between stand age and soil C and N stocks may not be strong and that stand age may influence soil C and N storage through other abiotic and biotic parameters (Mao et al., 2010). Hence, it was commonly claimed that the association between stand age and the soil C and N stocks varied across investigations.

Soil depth is an essential parameter controlling the concentrations and storage of Sc, and Sn (Rahman et al., 2022). Consistent with other reported study findings (Duan et al., 2020; Wang et al., 2019b), our study demonstrates that both the Sc and Sn contents and storage reduced significantly with increasing soil depth in all plantation ages and reached their highest in the topmost soil layer (0–20 cm depth) (*Fig. 4a-b, Fig. 5a-d*). This is probably because of the influence of surface aggregation. The governing variables and mechanism of Sc and Sn altered across soil layers as explained by the notable differences in the physical as well as chemical features of top soils and deep soils (Mobley et al., 2015). Surface SOC accumulation is typically the outcome of connections between biotic processes controlled by microbes and abiotic processes driven by environmental factors (Xing et al., 2023). Because there is plenty of plant litter and roots in the surface soil, as well as the fact that adequate air and water near the surface promote soil microbial activity (Gong et al., 2022).

Effects of environmental factors on soil C and N stocks

Soil C and N storage were influenced by various kinds of biotic and abiotic factors (Noh et al., 2010). The analysis results from SEM demonstrated that the distribution of SSc and SSn in the *P. Kesiya* forests was greatly affected by soil features, as indicated by the observed variables of Bd, pH, and Cy, and stand structural traits, as indicated by the observed variables of Ub and Lb. Additionally, SSc and SSn were more influenced by soil factors than by stand variables (*Fig. 7*). Our data showed that Bd and pH were negatively linked to soil C and N stocks (*Fig. 6*). This finding implies the Bd and pH distribution pattern in the soil has an impact on soil function, including the soil microbial community and microbial activity, which are directly linked to the Sc and Sn stocks of the soil (Rahman et al., 2022). It has been reported that soil acidification (low soil pH) can reduce microbial biomass and activities and might also lead to Sc and Sn accumulation since soil microbes prefer a neutral pH range of 6.5 to 7.5 (Xing et al., 2023). Additionally, soil texture can affect the distribution of SSc and SSn as it influences soil traits such as soil water and soils' capacity to hold nutrients (Kuśmierz et al., 2023). Our study's results showed that SSc and SSn were strongly correlated with the amount of Cy and St, while negatively correlated with Sd (*Fig. 6*). Some authors, such as those by Chau et al. (2023), and Su et al. (2023) have indicated that there was a positive link between SSc and SSn and the soil's silt and clay amounts because clay and fine silt particles help chemically stabilize and physically protect soil organic matter. Smaller particles should theoretically absorb organic material better and slow down its decomposition by microorganisms due to their bigger specific surface areas. Furthermore,

plant biomass factors including Ub and Lb can affect the distribution and availability of soil C and N stocks (Fig. 7). Typically, soil C and N ought to accumulate in ecosystems when equivalent inputs are higher or losses are lower (Chau et al., 2024b). According to Cuong et al. (2024b), soil C and N levels are mainly governed by aboveground plant litter and roots. Consequently, more plant litter and roots could lead to a greater accumulation of C and N in the soil (Sam and Binh, 2000). In line with that, we discover that the quantity of plant litter had a significant impact on soil C and N stocks (Fig. 6). As *P. kesiya* stands grew and developed older, the overall ecological environment enhanced, the plant community's biomass rose, and more dead leaves were generated. These leaves penetrated the soil through decomposition and mineralization, which contributed to retaining soil C and N stocks (Hai et al., 2009). Based on the determined SPCs, the strength of the influence of soil properties and structure features on SSc and SSn as ranked $SSc > SSn$.

Correlations between soil C and N

In alignment with previously reported findings (Wang et al., 2019b; Ngaba et al., 2020), we found a strong positive association between soil C and N stocks. Additionally, we identified an increase in N stock after a rise in C stock, suggesting that the availability of soil N restricts the C budget due to the coupling influence between C and N cycles in the forest ecosystem (Hungate et al., 2003). Numerous studies have suggested that N dynamics is a crucial factor in controlling terrestrial C sequestration. For instance, raising the input of N results contributes to over time C sequestration (Luo et al., 2004; Reich and Oleksyn, 2004). Hence, high soil N amounts promote the growth of trees, which may increase soil C inputs via litterfall and rhizodeposition, and they additionally increase soil organic C sequestration by reducing the rate at which old litter and recalcitrant soil organic matter decay through soil microbial inhibition and chemical stabilization (Ngaba et al., 2020). The C/N ratio of soil is a significant indication of soil quality that affects the equilibrium of Sc and Sn (Chau et al., 2024b). The results shown in Figure 6 demonstrate a notable correlation among the soil C/N ratio and SSc and SSn, corroborated by earlier findings (Duan et al., 2020). The most likely explanation for this is that the soil C/N ratio controls soil enzyme activity and nutrient availability at the same time, generating a higher C/N ratio beneficial for accumulating Sc and Sn (Weintraub et al., 2013). Globally, the average soil C/N ratio was found to be 14.30 (Cleveland and Liptzin, 2007). The soil C/N ratio in the present study area was significantly higher (between 18 and 26) than the global average (Fig. 4c), which probably stimulated the accumulation of Sn and Sc. This is due to the fact that raising the soil C/N of ecosystem constituents is a crucial step in increasing the ecosystem's soil C and N stocks (Yu et al., 2024).

Conclusion

Stand age had a significant impact on Sc and Sn content and storage in stands of *P. kesiya*. With the increase of stand ages, Sc and Sn content and storage in *P. kesiya* stands increased considerably, implying that they probably grew over time. Consequently, in response to afforestation, both Sc and Sn appear to predominantly focus just beneath the ground surface. Sc and Sn contents and stocks decreased with rising soil depth. The Sc and Sn storage are positively connected. The results from SEM analysis demonstrated the substantial influence of soil variables (i.e., soil pH, bulk density, and clay) and stand variables (i.e., plant biomass) on SSc and SSn. Overall, variables related to soil characteristics had a greater impact on SSc and SSn than those related to forest

stand characteristics. The results presented here have immediately noticeable and important significance for establishing effective management measures and approaches for *P. kesiya* forests to increase their productivity.

Acknowledgements. The authors would like to express their sincere gratitude to Dr. Nguyen Van Quy and Associate Professor Dr. Bui Manh Hung for their invaluable assistance with the statistical analysis. This research was funded by the Fundamental Scientific Research Foundation (No. 178/QD/PHDHLN-KHCN&HTQT) of the Vietnam National University of Forestry - Dongnai Campus.

REFERENCES

- [1] Baishya, R., Barik, S. K. (2011): Estimation of tree biomass, carbon pool and net primary production of an old-growth *Pinus kesiya* Royle ex. Gordon forest in north-eastern India. – *Annals of Forest Science* 68(4): 727-736.
- [2] BFC (2022): Sustainable forest management plan description. – Baolam Forestry Company, Lamdong Province, Vietnam, 84.
- [3] Chau, M. H., Quy, N. V., Hung, B. M., Xu, X. N., Cuong, L. V., Ngoan, T. T., Dai, Y. Z. (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.
- [4] Chau, M., Quy, N., Xu, X., Hung, B., Cuong, L. V., Ngoan, T., Nguyen, T. (2024a): Variations in soil carbon, nitrogen, and phosphorus concentrations and stoichiometry with stand age in *Acacia* hybrid plantations in Southern Vietnam. – *Biodiversitas Journal of Biological Diversity* 25(2): 76-87.
- [5] Chau, M. H., Hung, B. M., Cuong, L. V., Ruan, X., Xiaoniu, X., Thanh, N. M. (2024b): Variations in soil carbon, nitrogen, and phosphorus concentrations and stoichiometry with stand age in *Acacia* hybrid plantations in Southern Vietnam. – *Biodiversitas* 25(2): 565-573.
- [6] Chau, M. H., Quy, N. V., Cuong, L. V., Hieu, N. T., Ngoan, T. T., Hung, D. V., Hung, B. M., Phu, N. V. (2024c): Soil organic carbon stocks in natural forests of Dongnai Culture and Nature Reserve, Southeastern Vietnam. – *Applied and Environmental Microbiology* 22(4): 3815-3834.
- [7] Chau, M. H., Quy, N. V., Hung, B. M., Xu, X. N., Cuong, L. V., Ngoan, T. T., Dai, Y. Z. (2024d): 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.
- [8] Chi, G., Zeng, F., Wang, Y., Chen, X. (2022): Phosphorus dynamics in litter-soil systems during litter decomposition in larch plantations across the chronosequence. – *Front Plant Sci* 13: 1010458.
- [9] Cleveland, C. C., Liptzin, D. (2007): C:N:P stoichiometry in soil: is there a “Redfield ratio” for the microbial biomass? – *Biogeochemistry* 85(3): 235-252.
- [10] Cuong, L., Thang, B., Tope Bolanle-Ojo, O., Bao, T., Tuan, N., Sang, T., Xu, X., Thanh, N. (2022): Enhancement of Soil Organic Carbon by *Acacia Mangium* Afforestation in Southeastern Region, Vietnam. – *Agriculture and Forestry* 68(2): 133-155.
- [11] Cuong, L. V., Karam, D. S., Hung, B. M., Chau, M. H., Quy, N. V. (2024a): Variations in Soil Phosphorus Levels in *Acacia* Hybrid Plantations Across Different Ages in Southern Vietnam. – *Malaysian Journal of Soil Science* 28: 230-243.
- [12] Cuong, L. V., Quy, N. V., Hung, B. M., Chau, M. H., Doan, P. (2024b): 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.

- [13] Deng, L., Wang, G.-L., Liu, G.-B., Shangguan, Z.-P. (2016): Effects of age and land-use changes on soil carbon and nitrogen sequestrations following cropland abandonment on the Loess Plateau, China. – *Ecological Engineering* 90: 105-112.
- [14] Deng, L., Han, Q.-S., Zhang, C., Tang, Z.-S., Shangguan, Z.-P. (2017): Above-Ground and Below-Ground Ecosystem Biomass Accumulation and Carbon Sequestration with *Caragana korshinskii* Kom Plantation Development. – *Land Degradation & Development* 28(3): 906-917.
- [15] Dou, X., Deng, Q., Li, M., Wang, W., Zhang, Q., Cheng, X. (2013): Reforestation of *Pinus massoniana* alters soil organic carbon and nitrogen dynamics in eroded soil in south China. – *Ecological Engineering* 52: 154-160.
- [16] Duan, B., Man, X., Cai, T., Xiao, R., Ge, Z. (2020): Increasing soil organic carbon and nitrogen stocks along with secondary forest succession in permafrost region of the Daxing'an mountains, northeast China. – *Global Ecology and Conservation* 24: e01258.
- [17] Gautam, M. K., Lee, K.-S., Song, B.-Y., Bong, Y.-S. (2017): Site related $\delta^{13}\text{C}$ of vegetation and soil organic carbon in a cool temperate region. – *Plant and Soil* 418: 293-306.
- [18] Gong, S., Yang, X., Xu, X., Lai, Y., Zhang, Z., Kong, Y. (2022): Effect of stand age on the temporal dynamics of soil active carbon and nitrogen in Chinese cypress artificial forests. – *Soil Science and Plant Nutrition* 68(1): 64-71.
- [19] Hai, V. D., Trieu, D. T., Tiep, N. H., Bich, N. V., Duong, D. T. (2009): Biomass productivity and carbon absorption capacity of some major types of plantation forests in Vietnam. – Hanoi Agriculture Publishing House, Hanoi, Vietnam, 356.
- [20] He, J., Dai, Q., Xu, F., Yan, Y., Peng, X. (2022): Variability in Soil Macronutrient Stocks across a Chronosequence of Masson Pine Plantations. – *Forests* 13(1): 17.
- [21] Hungate, B. A., Dukes, J. S., Shaw, M. R., Luo, Y., Field, C. B. (2003): Nitrogen and Climate Change. – *Science* 302(5650): 1512-1513.
- [22] Kang, J., Deng, Z., Zhang, Z., Chen, S., Huang, J., Ding, X. (2023): Relative importance of soil properties and functional diversity to the spatial pattern of the forest soil nitrogen. – *Ecological Indicators* 146: 109806.
- [23] Kuśmierz, S., Skowrońska, M., Tkaczyk, P., Lipiński, W., Mielniczuk, J. (2023): Soil Organic Carbon and Mineral Nitrogen Contents in Soils as Affected by Their pH, Texture and Fertilization. – *Agronomy* 13(1): 267.
- [24] Lapitan, R. (2017): Carbon Stock Potential of Benguet Pine (*Pinus kesiya* Royle ex Gordon) Stands within a Mining Sire in Padcal, Benguet Province, Philippines. – *Ecosystems and Development Journal* 7(2): 28-36.
- [25] Li, D., Niu, S., Luo, Y. (2012): Global patterns of the dynamics of soil carbon and nitrogen stocks following afforestation: a meta-analysis. – *New Phytologist* 195(1): 172-181.
- [26] Luo, Y., Su, B., Currie, W. S., Dukes, J. S., Finzi, A., Hartwig, U., Hungate, B., McMurtrie, R. E., Oren, R., Parton, W. J. (2004): Progressive nitrogen limitation of ecosystem responses to rising atmospheric carbon dioxide. – *Bioscience* 54(8): 731-739.
- [27] Mao, R., Zeng, D.-H., Hu, Y.-L., Li, L.-J., Yang, D. (2010): Soil organic carbon and nitrogen stocks in an age-sequence of poplar stands planted on marginal agricultural land in Northeast China. – *Plant and Soil* 332(1): 277-287.
- [28] Mobley, M. L., Lajtha, K., Kramer, M. G., Bacon, A. R., Heine, P. R., Richter, D. D. (2015): Surficial gains and subsoil losses of soil carbon and nitrogen during secondary forest development. – *Glob Chang Biol* 21(2): 986-96.
- [29] Nelson, D. W., Sommers, L. E. (1982): Total carbon, organic carbon, and organic matter. – *Methods of soil analysis: Part 2 Chemical and Microbiological Properties* 9: 539-579.
- [30] 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.
- [31] Noh, N.-J., Son, Y., Lee, S.-K., Seo, K.-W., Heo, S.-J., Yi, M.-J., Park, P.-S., Kim, R.-H., Son, Y.-M., Lee, K.-H. (2010): Carbon and nitrogen storage in an age-sequence of *Pinus densiflora* stands in Korea. – *Science China Life Sciences* 53(7): 822-830.

- [32] Phuc, L. H. (1996): Evaluation of growth, biomass and productivity of *Pinus kesiya* royle ex Gordon planted forests in Da Lat city, Lam Dong Province, Viet Nam. – Vietnam National University of Forestry, Hanoi, Vietnam, 165.
- [33] Phuong, V. T. (2011): Biomass and carbon stocks of *Pinus kesiya* plantations in Hoangsuphi district, Hagiang Province. Science and Technology Journal of Agriculture & Rural Development. – Vietnam Journal of Forestry Science 2(1): 89-93.
- [34] Phuong, V. T., Hai, V. D. (2011): Biomass structure of *Pinus kesiya* plantation in Lamdong Province. – Vietnam Journal of Forest Science 2: 1812-1817.
- [35] Quy, N. V., Dien, P. V., Manh, V., Linh, N. V., Van, N. T., Hai, N. H. (2024): Neighborhood competition and spatial patterns of tree species in an evergreen broadleaved forest of Bidoup-Nui Ba National Park, southern Vietnam. – Israel Journal of Ecology and Evolution 1(aop): 1-13.
- [36] R Core Team (2024): R: A language and environment for statistical computing. – R Foundation for Statistical Computing, Vienna, Austria.
- [37] Rahman, M., Wang, Y., Zhang, K., Ahmad, B., Ali, A., Ahamd, A., Muhammad, D., Afzaal, M., Zhang, Z., Bohnett, E. (2022): Variations in Soil C, N, P Stocks and Stoichiometry with Soil Depth and Forest Types in Qilian Mountains of Northwest China. – Frontiers in Environmental Science 10.
- [38] Reich, P. B., Oleksyn, J. (2004): Global patterns of plant leaf N and P in relation to temperature and latitude. – Proceedings of the National Academy of Sciences 101(30): 11001-11006.
- [39] Rosseel, Y. (2012): lavaan: An R package for structural equation modeling. – Journal of Statistical Software 48: 1-36.
- [40] Sam, D. D., Binh, N. N. (2000): Assessment of Potential Productivity of Forest Lands in Vietnam. – Hanoi Agriculture Publishing House, Hanoi, Vietnam.
- [41] Sartori, F., Lal, R., Ebinger, M. H., Eaton, J. A. (2007): Changes in soil carbon and nutrient pools along a chronosequence of poplar plantations in the Columbia Plateau, Oregon, USA. – Agriculture, Ecosystems & Environment 122(3): 325-339.
- [42] Su, B., Zhang, H., Zhang, Y., Shao, S., Mouazen, A. M., Jiao, H., Yi, S., Gao, C. (2023): Soil C:N:P Stoichiometry Succession and Land Use Effect after Intensive Reclamation: A Case Study on the Yangtze River Floodplain. – Agronomy 13(4): 1133.
- [43] Them, N. V. (2017): Diameter distribution modelling of *Pinus kesiya* Royle ex Gordon plantations on II site class based on weibull and richards distribution functions. – Vietnam Journal of Forest Science 1: 42-51.
- [44] Van Reeuwijk, L. P. (2002): Procedures for soil analysis. – ISRIC, FAO, Wageningen.
- [45] Vangi, E., Dalmonech, D., Cioccolo, E., Marano, G., Bianchini, L., Puchi, P. F., Grieco, E., Cescatti, A., Colantoni, A., Chirici, G., Collalti, A. (2024): Stand age diversity (and more than climate change) affects forests' resilience and stability, although unevenly. – Journal of Environmental Management 366: 121822.
- [46] Wang, T., Kang, F., Cheng, X., Han, H., Ji, W. (2016): Soil organic carbon and total nitrogen stocks under different land uses in a hilly ecological restoration area of North China. – Soil and Tillage Research 163: 176-184.
- [47] Wang, X., Li, Y., Gong, X., Niu, Y., Chen, Y., Shi, X., Li, W. (2019a): Storage, pattern and driving factors of soil organic carbon in an ecologically fragile zone of northern China. – Geoderma 343: 155-165.
- [48] Wang, Y., Liu, L., Yue, F., Li, D. (2019b): Dynamics of carbon and nitrogen storage in two typical plantation ecosystems of different stand ages on the Loess Plateau of China. – PeerJ 7: e7708.
- [49] Weintraub, S. R., Wieder, W. R., Cleveland, C. C., Townsend, A. R. (2013): Organic matter inputs shift soil enzyme activity and allocation patterns in a wet tropical forest. – Biogeochemistry 114(1): 313-326.
- [50] Xing, G., Wang, X., Jiang, Y., Yang, H., Mai, S., Xu, W., Hou, E., Huang, X., Yang, Q., Liu, W., Long, W. (2023): Variations and influencing factors of soil organic carbon during

the tropical forest succession from plantation to secondary and old-growth forest. – *Frontiers in Ecology and Evolution* 10(3): 167.

- [51] Yu, S., Yang, J., Norghauer, J. M., Yang, J., Yang, B., Zhang, H., Li, X. (2024): Soil Carbon and Nitrogen Stocks and Their Influencing Factors in Different-Aged Stands of Sand-Fixing *Caragana korshinskii* in the Mu Us Desert of Northwest China. – *Forests* 15(6): 1018.
- [52] Zhang, K., Gao, D., Guo, H., Zeng, J., Liu, X. (2022): Forest structure characteristics on soil carbon and nitrogen storage of *Pinus massoniana* plantations in southern subtropic region. – *Frontiers in Forests and Global Change* 5(1): e2345.

APPENDIX

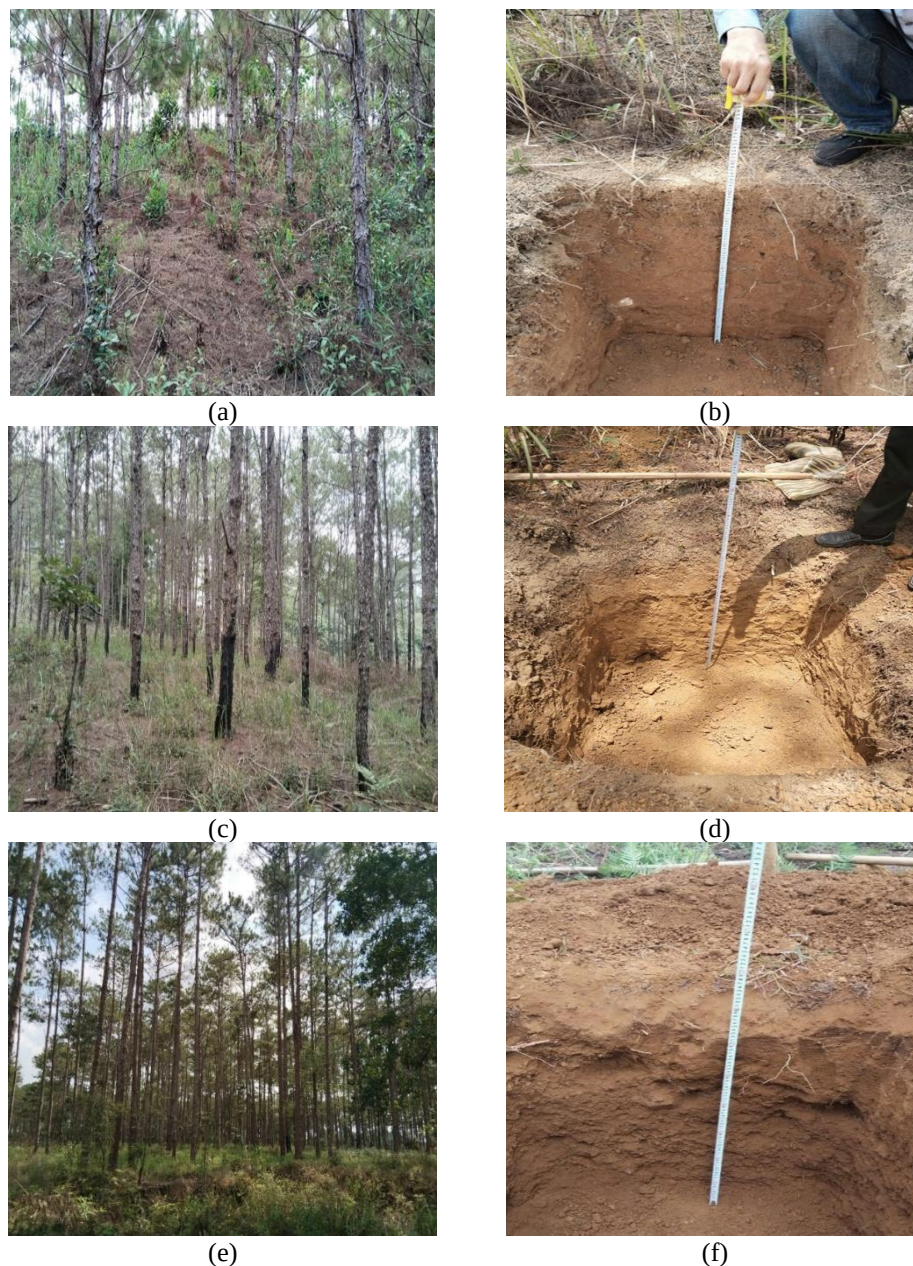


Figure A1. Some pictures of the 5-year-old (a-b), 15-year-old (c-d), and 35-year-old (e-f) *Pinus kesiya* plantation stands

Table A1. Summarizing the GPS coordinates for each sampling site in different stand ages in Baolam Forestry Company

Ages	Plots	Latitude	Longitude
5	1	11°41'33.8"N	107°44'53.2"E
	2	11°41'39.7"N	107°44'50.7"E
	3	11°41'42.7"N	107°44'58.7"E
	4	11°41'37.8"N	107°45'3.2"E
11	1	11°43'32.6"N	107°47'13.3"E
	2	11°43'36.0"N	107°47'9.2"E
	3	11°43'37.5"N	107°47'18.2"E
	4	11°43'42.5"N	107°47'17.3"E
15	1	11°43'5.0"N	107° 47' 9.8"E
	2	11°43'5.0"N	107°47'18.2"E
	3	11°43'10.4"N	107°47'59.7"E
	4	11°43'14.4"N	107°47'16.2"E
25	1	11°42'37.4"N	107°47'9.8"E
	2	11° 42' 43.3"N	107°47'8.2"E
	3	11°42'45.8"N	107°47'11.8"E
	4	11°42'50.2"N	107°47'5.2"E
35	1	11°43'21.8"N	107°46'4.3"E
	2	11°43'25.2"N	107°46'20.7"E
	3	11°43'37.1"N	107°46'7.2"E
	4	11°43'38.0"N	107°46'11.2"E