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Soil Nitrogen Content and Storage in Age Sequence *Acacia Mangium* Plantations in the Southeastern Region of Vietnam

Cuong, L.V.[1*], Sang, T.V.[2], Bolanle-Ojo, O.T.[3], Bao, T.Q.[1], Ngoan, T.T.[1], Tuan, N.T.[1], Hung, N.X.[1], Long L.V.[1], Duong D.T.T.[1] and Phu, N.V.[1]

[1] *Faculty of Forestry, Vietnam National University of Forestry, Hanoi 100000, Vietnam*
[2] *Institute of Ecology and Works Protection, Vietnam Academy for Water Resources*
Hanoi 100000, Vietnam
[3] *Forestry Research Institute of Nigeria, P.M.B. 5054, Ibadan, Nigeria*

**Corresponding author: cuongvfu.90@gmail.com*

ABSTRACT

To better understand soil nitrogen (N) sequestration by *Acacia mangium* Willd. in the plantations of the Southeastern region of Vietnam, a study was conducted to examine soil N content and storage in three different-aged *A. mangium* stands (4, 7 and 11 years old). Soil samples were collected at different depths from 0–50 cm. Field measurements were taken based on established national standard methods. We used the modified Kjeldahl method to determine soil total N concentration. Soil total N concentration at the various soil depths for each plantation decreased significantly with increasing depth, but increased significantly with plantation age. Soil total N stocks at the topsoil (0–50 cm) increased from 6.13 Mg N ha^{-1} in 4-year-old stands to 9.71 Mg N ha^{-1} in 11-year-old stands. Soil total N storage showed obvious topsoil aggregation with more than 60% of soil total N storage in the 0–30 cm depth for each stand. Hence, protection of total N stocks present in the topsoil of planted forests is very critical in the context of N sequestration. Furthermore, stand characteristic parameters (i.e., stand age, plant biomass, stand density, tree height and diameter at breast height, and canopy closure) significantly affected soil total N storage. The findings from this study indicate that taking stand age into consideration is greatly beneficial for forest soil N storage assessment and highlights the potential of *A. mangium* for N sequestration in plantation ecosystems.

Key words: ***Acacia mangium* plantations, nitrogen sequestration, age-sequence, plantation forestry, Vietnam**

INTRODUCTION

Soils constitute the main terrestrial reservoir for organic carbon (C) and approximately 1500 PgC are accumulated in the first meter of the soil (Batjes 1996; Scharlemann *et al*. 2014). Particularly in forest soil, C sequestration plays an important role in the global C cycle, and comprises about 73% of global soil organic C storage (Sedjo 1993). Soil organic C accumulation rate is greatly reliant on the net primary productivity of plants (Jobbágy and Jackson 2000; Reich *et al*. 2006), which is predominantly limited by nitrogen in most terrestrial ecosystems (Vitousek and Howarth 1991; Knops and Tilman 2000). Thus, soil nitrogen reservoir has been considered as an index of C sequestration potential (Luo *et al*. 2004; Vesterdal *et al*. 2008). Accurate assessment of soil total nitrogen (TN) storage in different stand ages is crucial to understanding the relationship between C cycles in terrestrial ecosystems and global climate change.

Acacia mangium Willd. is a principal tree species for afforestation in the Southeastern region of Vietnam and plays an important role in the global C cycle because its plantation area covers over 800,000 ha (MARD 2018), accounting for 19% of the total plantations in Vietnam (MARD 2020) and about 0.27% of all plantation forests in the world (FAO 2020). In addition to producing wood for industries, *A. mangium* planted forests also have a role in providing environmental service such as reducing negative impacts on C and N cycles through the uptake and storage of C and N.

Therefore a better knowledge of changes in soil and total nitrogen (TN) storage of *A. mangium* plantations is essential to improve the C storage of soils and reduce the emission of greenhouse gases. Several studies have been carried out on growth and wood properties, biomass and productivity, C sequestration, soil physico-chemical properties, biological nitrogen fixation and nutrient cycling in *A. mangium* plantations (Ribet and Drevon 1996; Xu *et al*. 1998; Dhamodaran and Chacko 1999; Saharjo and Watanabe 2000; Hai *et al*. 2009; Matali and Metali 2015; Paula *et al*. 2015; Cuong *et al*. 2020). However, soil nitrogen sequestration by *A. mangium* plantations in the Southeastern region of Vietnam is still unknown. Hence, the present study was designed to assess soil nitrogen of an *A. mangium* forest ecosystem in an age-sequence. The primary objective of this research was to explore soil TN content and storage in *A. mangium* plantations over three different ages along various soil depths.

MATERIALS AND METHODS

Description of Study Area

The study site is located in the Changriec Historical-Cultural Forest, Tayninh Province, Vietnam (11°00′30″ to 11°35′13″N and 106°00′00″ to 106°07′10″E) (*Figure* 1). The region has a tropical monsoon climate, including a rainy (May to November) and a dry season (December to April). The mean annual temperature is 26.9°C with the lowest temperature of 21°C in the month of December and the highest temperature of 35.2 °C in the month of April. Annual mean humidity is 78.3%, and the monthly sunshine hours average about 181-277 h (Tuan and Dinh 2020). The terrain of the research area is relatively flat, with an elevation of 28-53 m a.s.l. with slopes of 3-5°. The soil type is grey brown, developed on ancient alluvium, with a soil depth of above 100 cm. The soil is loamy in texture with a pH (H_2O) ranging from 5.10-5.54. The concentrations of soil sand, silt and clay are 41.19, 46.06, and 12.76%, respectively (Cuong *et al*. 2020). There are a large number of *A. mangium* plantation stands with different ages and densities. Other woody plants in this region include *Acacia hybrid (Acacia auriculiformis* A. Cunn. ex Benth. × *A. mangium* Willd.*), Hopea* sp., *Dipterocarpus obtusifolius* Teijsm. ex Miq. and *Tectona grandis* L.f. The plantation forests take up about 40% of the total forest area. The main shrub and herb plants include *Mallotus apelta* (Lour.) Müll. Arg., *Tetracera scandens* (L.) Merr., *Chromolaena odorata* (L.) R.M. King & H. Rob., *Saccharum arundinaceum* (Retz.), *Mimosa pudica var. tetrandra* (Willd.) D.C., *Chrysopogon aciculatus* (Retz.) Trin., *Maesa perlarius* (Lour.) Merr., *Lygodium microphyllum* (Cav.) R. Br., *Dryopteris parasitica* (L.) Kuntze, *Helicteres angustifolia* var. *obtusa* (Wall. ex Kurz) Pierre and *Cynodon dactylon* (L.) Pers. In this study, we selected three different-aged (4, 7, 11 years) *A. mangium* plantation forests, which were all covered by cassava under agriculture before the afforestation. Subsequently pure *A. mangium* forests were planted in similar slope, direction and elevation. No treatments such as fertilization and irrigation were carried out after afforestation. From February to April 2019, four plots (40 m × 25 m in size) were selected in each stand. All the sampling plots were less than 1.0 km apart (*Figure* 1). Within each plot, tree height (H) and diameter at breast height (DBH) were recorded for every tree. Other descriptive details of the sites are given by Cuong *et al*. (2020) and are reproduced in Table 1.

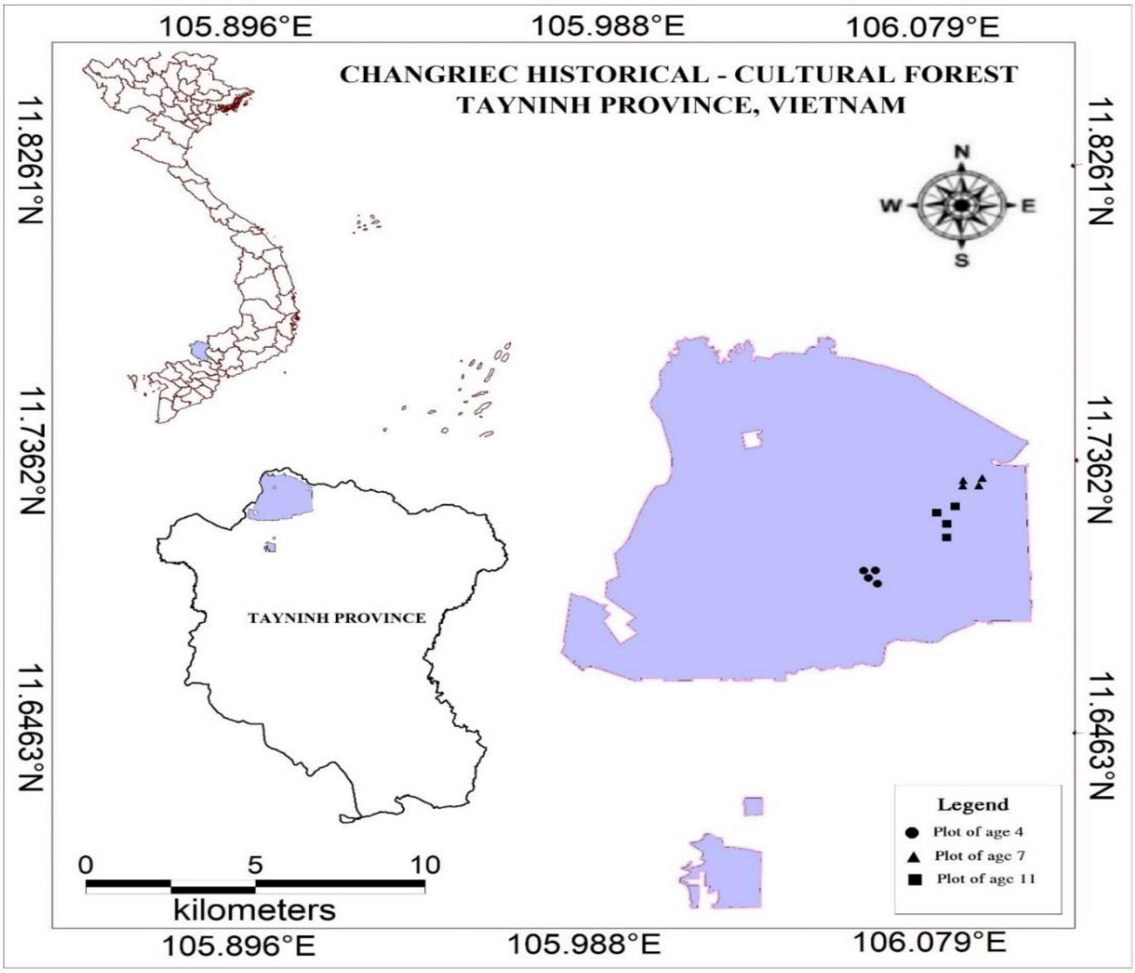

Figure 1. Map of experimental plots in Changriec Historical-Cultural Forest (Tayninh Province, Southeastern region, Vietnam)

TABLE 1
Characteristics of the sampled stands of *Acacia mangium* plantations in Changriec Historical - Cultural Forest (Southeastern region, Vietnam)

Measured variables			Stand age (years)		
			4	7	11
Plants		Stand area (ha)	2.6	2.2	3.6
		Mean DBH (cm)	13.78 ±0.38^{a}	17.94 ± 0.86^{b}	21.78 ± 0.85^{c}
		Mean Hvn (m)	14.72 ± 0.17^{a}	17.29 ± 0.56^{b}	18.60 ± 0.21^{c}
		Stand density (tree· ha^{-1})	888 ± 30^{a}	728 ± 22^{b}	610 ± 29^{c}
		Canopy closure	0.83 ± 0.01^{a}	0.81 ± 0.01^{b}	0.79 ± 0.03^{b}
		Elevation (m a.s.l.)	38	40	40
		Soil depth (cm)	>100	>100	>100
	Above–ground biomass	Trees (Mg· ha^{-1})	55.08 ± 3.98^{a}	109.18 ± 4.44^{b}	175.17 ± 5.11^{c}
		Understory (Mg· ha^{-1})	4.05 ± 0.05^{a}	4.31 ± 0.05^{b}	4.80 ± 0.11^{c}
		TAB (Mg· ha^{-1})	59.1 ± 3.98^{a}	113.4 ± 4.46^{b}	179.96 ± 5.07^{c}
	Below–ground biomass	Trees (Mg· ha^{-1})	17.64 ± 0.68^{a}	34.38 ± 1.43^{b}	35.40 ± 1.87^{b}
		Understory (Mg· ha^{-1})	0.82 ± 0.02^{a}	0.92 ± 0.02^{b}	1.19 ± 0.02^{c}
		TBB (Mg· ha^{-1})	18.46 ± 0.67^{a}	35.30 ± 1.41^{b}	36.59 ± 1.87^{c}
	Litter biomass (Mg· ha^{-1})		11.43 ± 0.91^{a}	11.90 ± 0.55^{ab}	13.29 ± 1.16^{b}

Note: Data represent the mean ± standard deviation (SD). Different capital letters indicate a significant difference between different stands ($p < 0.05$). DBH, diameter at breast height (1.3 m); H, tree height; TAB, total above-ground biomass; TBB total below-ground biomass.

Soil Sampling and Laboratory Analyses

A soil corer (5 cm inner diameter) was used to dig to a depth of 50 cm from the four corners and the center of each sample plot. Following the removal of understory vegetation and litter, samples were taken from four depths (0-10, 10-20, 20-30 and 30-50 cm). Soil samples from the same depth layer in the same plot were mixed in equal volume proportions, air-dried naturally and stored at room temperature. Soil samples were analysed at the Centre of Forestry Research and Climate Change Laboratory at the Vietnam National University of Forestry (VNUF). Soil bulk density (BD) of different soil layers (0-10, 10-20, 20-30 and 30-50 cm) was determined by collecting samples from a stainless steel cylinder (100 cm^3) and oven drying the cored soil at 105°C to a constant weight. Soil BD was calculated by dividing the mass of oven-dried soil by the volume of the core (Blake and Hartge 1986). The other soil samples were sieved through a 2-mm screen to remove plant roots and other debris before soil TN analysis. The content of soil TN was measured according to the Vietnam National Standard method (TCVN 6498:1999 - ISO 11261:1995) adopted by Thanh and Cuong (2016; 2017) and Cuong *et al.* (2017). TN concentration in the soil was determined by the modified Kjeldahl method after digestion with a mixture of $C_7H_6O_3$ and H_2SO_4.

Calculation of Soil Total Nitrogen Storage

Total nitrogen storage (NS) in each soil layer was computed according to the TN content of the soil layer, its soil BD and sampling depth. Coarse fractions (>2 mm) were very rare in the soil samples. Thus, Eqn. 1 was used to compute soil TN storage (Deng *et al.* 2013; Thanh and Cuong 2016; Wang *et al.* 2019; Xu *et al.* 2019):

$$NS_i = TN_i \times BD_i \times d_i \times 10^{-1} \quad [1]$$

where NS_i, total nitrogen storage in the soil layer i (Mg$^{\cdot}$ N$^{\cdot}$ ha^{-1}); i represents the 0–10 cm, 10–20 cm, 20–30 cm, and 30–50 cm soil layers; TN_i, the total nitrogen concentration of the soil layer i (g$^{\cdot}$ kg^{-1}); BD_i, the bulk density of the soil layer i (g$^{\cdot}$ cm^{-3}); and d_i, the thickness of the soil layer i (cm).

Statistical Analyses

The data were checked for normality and homogeneity of variances using the Kolmogorov-Smirnov test and the Levene’s test, respectively. The difference between the stand means and within-stand variations was examined by one-way ANOVA (analysis of variance) followed by Fisher’s Least Significant Difference (LSD) test at $p<0.05$. Pearson's correlation coefficients were calculated to characterise the relationships between soil total nitrogen storage and environmental variables (e.g., TAB, TBB, litter biomass, stand density, DBH, H_{vn}, canopy closure, and stand age). Statistical analysis, including mean value, standard deviation, Pearson's correlation, and ANOVA were carried out using SPSS 25.0 software package (IBM Corp 2017).

RESULTS

Soil Nitrogen Concentration in Three Differently Aged A. mangium Stands

Figure 2 demonstrates the soil TN concentration at layers of 0-10, 10-20, 20-30 and 30-50 cm in the 4-, 7-, and 11-year-old stands. Statistically significant differences were observed among different aged stands of different soil layers for soil TN values (p<0.05). Irrespective of stand age, soil TN content significantly decreased with increasing soil depth, being greater in the top layer (0–10 cm) than in deeper layers (10-20, 20-30 and 30-50 cm) (p<0.05). Mineral soil TN concentration at all soil depths increased significantly with increasing stand age (p<0.05). At depths of 0-10, 10-20, 20-30 and 30-50 cm, soil TN concentrations of the 4-year-old stand were 1.10, 0.97, 0.82, and 0.51, respectively; soil TN contents of the 7-year-old stand were 1.33, 1.24, 1.15, and 0.91, respectively; and soil TN concentrations of the 11-year-old stand were 1.54, 1.45, 1.37, and 1.25, respectively.

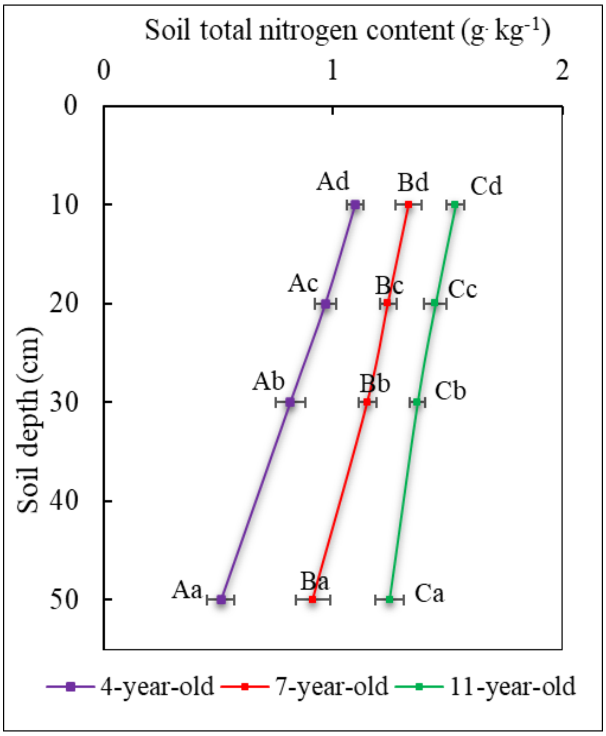

Figure 2. Total nitrogen content in different depths in Acacia mangium plantations of three different ages.

Note: Different uppercase letters indicate a significant difference between stand ages at the same horizon (p < 0.05); different lowercase letters indicate a significant difference between different soil depths in the same stand (p < 0.05). Error bars represent standard deviation (SD).

Soil Bulk Density in A. mangium Stands

As described in *Figure 3*, the soil BD value in a 4-year-old stand was the highest among all stand ages at four soil depths (0–0.1, 0.1–0.2, 0.2–0.3 and 0.3–0.5 m) (p < 0.05). Nevertheless, there was no distinguishable difference in soil BD between 11- and 7-year-old stands at 0–10 and 10–20 cm soil layers (p > 0.05). The average soil BD value in 4-, 7-, and 11-year-old stands at the depth of 0–10 cm was 1.46, 1.33 and 1.31 g· cm^3, respectively (Figure 3). The mean soil BD value in 4-, 7- and 11-year-old stands at the depth of 10–20 cm was 1.50, 1.38 and 1.35 g· cm^3, respectively (*Figure 3*). The average soil BD value in 4-, 7- and 11-year-old stands at the depth of 20–30 cm was 1.64, 1.44 and 1.39 g· cm^3, respectively (*Figure 3).* Soil BD increased significantly as soil depth increased across all stand ages (*Figure 3, p* < 0.05). Soil BD value in the upper 0–10 cm soil layer was 1.7 – 1.9 times significantly lower than that present in the 30–50 cm soil layer.

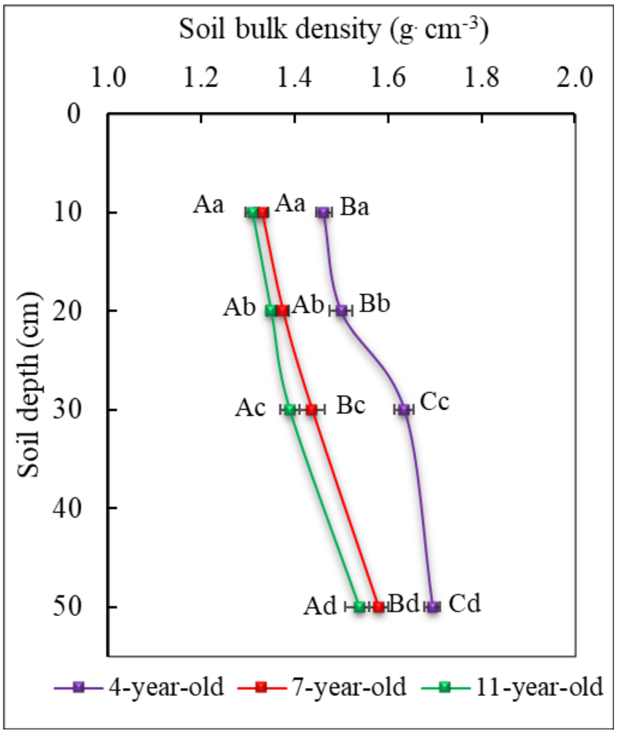

Figure 3. Soil bulk density at various depths in Acacia mangium plantations of three different ages

Note: Different uppercase letters indicate a significant difference between stand ages at the same horizon (p < 0.05); different lowercase letters indicate a significant difference between different soil depths in the same stand (p < 0.05). Error bars represent standard deviation (SD).

Soil Nitrogen Storage in A. mangium Stands

Figure 4 summarizes the soil layer nitrogen stocks over an age-sequence of three *A. mangium* stands. The NS in the four soil layers (0–10 cm, 10-20, 10–30, and 30–50 cm) followed a significant increasing trend with stand age ($p < 0.05$). The soil nitrogen stocks (all Mg· N· ha^{-1}) were 1.61, 1.77, and 2.01 in 0–0.1 m soil depth; 1.45, 1.71, and 1.95 in 0.1–0.2 m soil depth; 1.33, 1.65, and 1.90 in 0.2–0.3 m soil depth; and 1.74, 2.88, and 3.84 in 0.3–0.5 m soil depth in the 4-, 7-, and 11-year-old stands, respectively. The NS observed in the 0–50 cm soil layer at different stand ages was 6.13, 8.01, and 9.71 Mg· N· ha^{-1} for the 4-, 7-, and 11-year-old stands, respectively. The uppermost 30 cm of soil stocked a large proportion of nitrogen with the NS in the 0–30 cm soil layer accounting for 60.43%, 64.01%, and 71.65% of the total nitrogen storage in the 0–50 cm soil layer for the three stands *(Figure 5).*

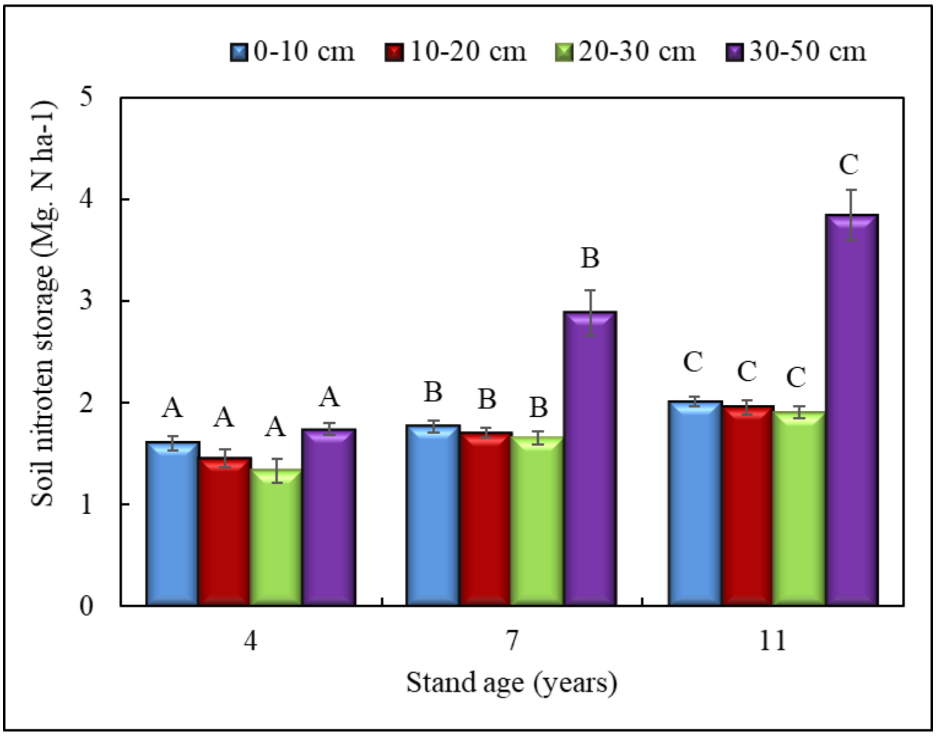

Figure 4. Soil total nitrogen storage (Mg· N· ha^{-1}) in different depths in 4-, 7- and 11-year-old Acacia mangium plantations.

Note: Data represent the mean ± standard deviation (SD). Different capital letters indicate a significant difference between different stands at the same horizon ($p < 0.05$).

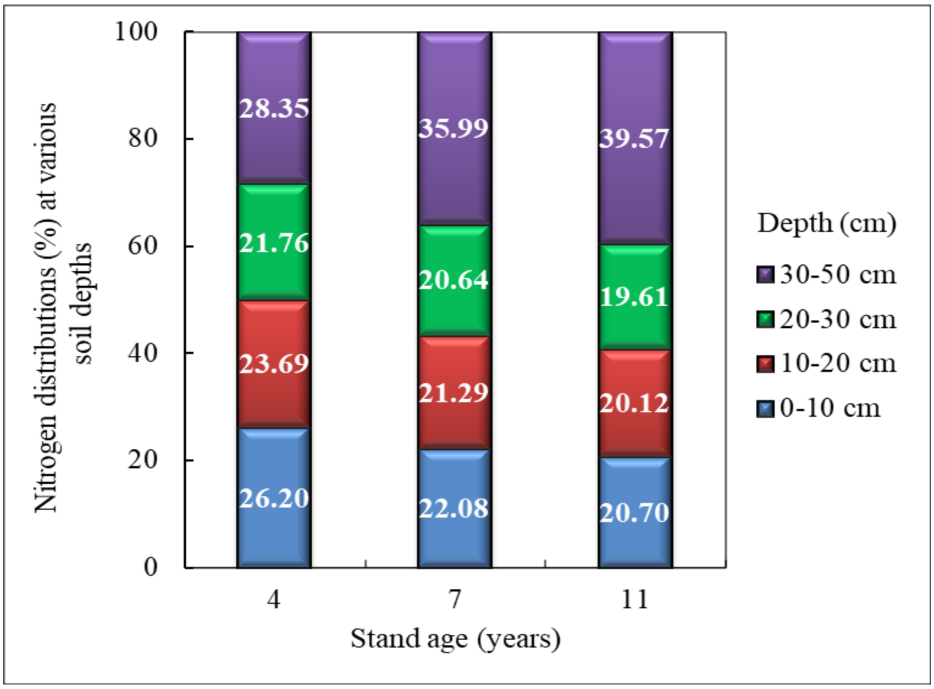

Figure 5. Nitrogen distributions (%) at different soil depths in the 4-, 7- and 11-year-old Acacia mangium stands

Relationships between Soil Total Nitrogen Storage and Environmental Variables

Table 2 presents the correlation analyses between the NS and the various influential environmental factors. It can be seen that NS strongly and positively correlates with DBH (r = 0.509, $p < 0.01$), *H* (r = 0.505, $p < 0.01$), and stand age (r = 0.534, $p < 0.01$) but is significantly negatively associated with stand density (r = -0.511, $p < 0.01$), and canopy closure (r = -0.363, $p < 0.05$). Plant biomass variables including TAB (r = 0.527, $p < 0.01$), *TBB* (r = 0.477, $p < 0.01$), and litter biomass (r = 0.316, $p < 0.05$) are also significantly positively correlated with NS.

TABLE 2

Pearson Correlation Coefficient values (r) between soil total nitrogen storage and environmental variables at different stand ages of *Acacia mangium* plantations

Environmental factors	*NS* ($Mg^{\cdot} N^{\cdot} ha^{-1}$)
TAB ($Mg^{\cdot} ha^{-1}$)	0.527^{**}
TBB ($Mg^{\cdot} ha^{-1}$)	0.477^{**}
Litter biomass ($Mg^{\cdot} ha^{-1}$)	0.316^{*}
Stand density ($tree^{\cdot} ha^{-1}$)	-0.511^{**}
DBH (cm)	0.509^{**}
H_{vn} (m)	0.505^{**}
Canopy closure	-0.363^{*}
Stand age	0.534^{**}

Note. NS- soil total nitrogen storage; TAB- total above-ground biomass; TBB - total below-ground biomass; DBH - diameter at breast height; H_{vn}*, tree height. *, ** show significant effects at* $p < 0.05$ *and* $p < 0.01$*, respectively.*

DISCUSSION

Changes in NS following afforestation and stand age have been widely reported in several studies. Interestingly, the results on changes in NS after afforestation have been varied in these studies. Some studies did not show any significant increase in NS with increasing forest age (Markewitz *et al*. 2002; Sartori *et al*. 2007) while other studies have reported an initial decline in NS during the early stage after afforestation, followed by a gradual increase with stand development (Noh *et al*. 2010; Wang *et al*. 2019). This phenomenon may be ascribed to numerous factors such as climate, soil properties, tree species, management operations (such as thinning and felling), N_2 fixation by free-living organisms, atmospheric nitrogen deposition, and previous land use, all of which may independently or jointly overshadow the effect of stand age on NS (Berthrong *et al*. 2009; Mao *et al*. 2010). In our study, we found a very significant positive correlation between soil total nitrogen storage and stand age (Table 2) as in the case of studies carried out by Mao *et al*. (2010), Miao *et al*. (2014) and Ngaba *et al*. (2020). The remarkable increase in NS with age of *A. mangium* plantation may be related to the higher inputs of plant biomass in the older forests. There is a significantly positive correlation between plant biomass and NS (Table 2) indicating the accumulation of NS with increasing plant biomass due to the crucial control of plant litter and roots on NS (Li *et al*.2019). Liu *et al*. (2020) also found that plant litter and roots were the primary factors for the accumulation of soil N because variations in the quality and quantity of plant litter and roots can impact soil organic matter decomposition mechanisms, regulate the decomposition of soil organic matter, and finally affect the storage of soil N (Manuel *et al*. 2015). Additionally, other stand parameters such as stand density, canopy closure, mean DBH, and H may also impact the change in NS in forests at different ages (Table 1). Our study found that stand density, DBH, H_{vn} and canopy closure had a significant effect on the NS (Table 2). In our previous study, stand features such as stand density, DBH, H_{vn} and canopy closure were found to have significant effects on plant biomass in this study area (Cuong *et al*. 2020), which could have created variations in NS along with stand development. Finzi *et al*. (1998) reported that the forest canopy structure can alter the NS because it may influence the soil temperature, soil moisture content and growth of understory vegetation. Besides, other N sources and mechanisms may also impact NS. For instance, atmospheric N deposition, biological N fixation capacity, and release of nitrogen from bedrock are often cited to explain NS increase during forest development (Morford *et al*. 2011; Yang *et al*. 2011; Hou *et al*. 2016).

Soil TN storage is mainly measured by TN content, BD and soil depth. In this study, soil depth was fixed at 0–10 cm, 10-20, 20–30, and 30–50 cm. Therefore, TN content and BD determine soil TN storage. Our study found an inverse relationship between soil BD and soil T (*Figures 2, 3* and *4*). Lower soil BD is closely connected with greater soil porosity and tends to enhance soil microbial activity, tree root growth, and other underground biological activities, thereby increasing soil organic matter formation and soil nitrogen content (Anh *et al*. 2014; Miao *et al*. 2014; Duan *et al*. 2020). Our findings demonstrate that the change in soil BD partially reflected soil TN trend.

In the three age-sequence *A. mangium* stands of the current study, soil TN content was highest in the 0–10 cm surface soil layer and demonstrated a decreasing trend with increasing depth (*Figure 2*). This result is congruent with most existing studies (Jobbágy and Jackson 2001; Zhang *et al*. 2018; Mahdavi *et al*. 2019). The is because surface soil is impacted strongly by external environmental factors, soil microorganisms, and nutrient return from the surface litter which leads to a high concentration of N in the surface soil (Xu *et al*. 2019). With increasing soil depth, the input of organic matter is restricted by soil permeability, microbial decomposition activity and root absorption (Berger *et al*. 2002) which reduces the N content of deep soil. For the 4-, 7-, and 11-year-old stands, the soil TN concentration of the 0-10, 10-20, 20-30 and 30-50 cm soil layers increased with increasing stand age (*Figure 2*), showing an obvious accumulation process of nitrogen in the mineral soil layers after afforestation. This might be due to slow decomposition and litter productivity in high older stands (Noh *et al*. 2010). Additionally, since most litter and fine roots are distributed in the surface soil, the NS accumulates in the surface soil. In our current research, approximately 60.43–71.65% of NS was observed in the top 30 cm soil in all three *A. mangium* stands (*Figure 5*). This means that, although it is vulnerable to human disturbance and soil erosion, the top soil in the study area is the main nitrogen pool. Thus, these findings suggest that protection of nitrogen in the topsoil from human disturbances and soil erosion is necessary to promote nitrogen sequestration.

CONCLUSION

The results obtained in this study show changes in soil TN concentration and stock for the plantation ecosystem across an age sequence of *A. mangium* stands (from 4- to 11-years old) on Changriec Historical - Cultural Forest, Southeastern region, Vietnam. Soil TN content in the mineral soil at different depths for each plantation decreased significantly with increasing soil depth and and this decrease was increasingly significant with plantation age. Soil TN storage at the top soil (0–50 cm) increased significantly with stand age, from 6.13 $Mg^{\cdot} N^{\cdot} ha^{-1}$ in 4-year-old stand to 9.71 $Mg^{\cdot} N^{\cdot} ha^{-1}$ in a 11-year-old stand. Soil TN stocks indicated an obvious topsoil aggregation trend, with more than 60% NS being in 0–30 cm depth for each stand. The study results suggest that protection of the NS present in the topsoil of plantations is very crucial in the context of nitrogen sequestration. Moreover, stand features like stand age, plant biomass, stand density, tree height and diameter at breast height, and canopy closure significantly influence NS. Our findings provide new insights that will significantly improve our knowledge of soil nitrogen stocks in *A. mangium* forests and can be used in forest management activities to enhance nitrogen sequestration function. Nevertheless, long-term monitoring of changes in NS is necessary to improve the assessment of NS across the *A. mangium* lands of the Changriec Historical - Cultural Forest in Southeastern region, Vietnam.

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REFERENCES

Anh, P.T.Q., T. Gomi, L.H. MacDonald, S. Mizugaki, P.V. Khoa and T. Furuichi. 2014. Linkages among land use, macronutrient levels, and soil erosion in Northern Vietnam: A plot-scale study. *Geoderma* 232-234: 352-362.

Batjes, N.H. 1996. Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science* 47: 151-163.

Berger, T.W., C. Neubauer and G. Glatzel. 2002. Factors controlling soil carbon and nitrogen stores in pure stands of Norway spruce (*Picea abies*) and mixed species stands in Austria. *Forest Ecology and Management* 159: 3-14.

Berthrong, S.T., E.G. Jobbágy and R.B. Jackson. 2009. A global meta-analysis of soil exchangeable cations, pH, carbon, and nitrogen with afforestation. *Ecological Applications* 19: 2228-2241.

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

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

Cuong, L.V., N.M. Thanh, L.V. Long, B.T.T. Trang and N.T. Hieu. 2017. Some soil physical and chemical properties under natural forest cover in Tanphu protective forest, Dongnai Province. *Journal of Forest Science and Technology* 6: 17-24.

Manuel, D.B., G.P. Pablo, R. Milla, A. Gallardo and F.T. Maestre. 2015. Soil characteristics determine soil carbon and nitrogen availability during leaf litter decomposition regardless of litter quality. *Soil Biology and Biochemistry* 81: 134–142.

Deng, L., Z.P. Shangguan and S. Sweeney. 2013. Changes in soil carbon and nitrogen following land abandonment of farmland on the Loess Plateau, China. *PLOS ONE* 8: e71923.

Dhamodaran, T.K. and K.C. Chacko. 1999. *Growth and Wood Characteristics of Acacia mangium Grown in Kerala*. Research Report No.174, Kerala Forest Research Institute, Peechi, p. 60.

Duan, B., X. Man, T. Cai, TR. Xiao and Z. Ge. 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.

FAO. 2020. Global Forest Resources Assessment 2020 – Key findings. Rome.

Finzi, A.C., N. Van Breemen and C.D. Canham. 1998. Canopy tree–soil interactions within temperate forests: species effects on soil carbon and nitrogen. *Ecological Applications* 8: 440-446.

Hai, V.D., D.T. Trieu, N.H. Tiep, N.V. Bich and D.T. Duong. 2009. *Research on Carbon Sequestration Potential and Commercial Value of Some Major Types of Plantation Forests in Vietnam*. Final Project Report No. VAFS2009; Vietnamese Academy of Forest Sciences: Hanoi, Vietnam, p. 190.

Hou, H., S.Z. Zhang, J.H. Guan and S. Du. 2016. Accumulation of soil organic carbon and total nitrogen in *Quercus aliena* var. *acuteserrata* forests at different age stages in the Xiaolongshan Mountains, Gansu Province. *Acta Ecologica Sinica* 36: 8025–8033.

IBM Corp. 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.

Jobbágy, E.G. and R.B. Jackson. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications* 10: 423-436.

Jobbágy, E.G. and R.B. Jackson. 2001. The distribution of soil nutrients with depth: Global patterns and the imprint of plants. *Biogeochemistry* 53: 51-77.

Knops, J.M.H. and D. Tilman. 2000. Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment. *Ecology* 81: 88-98.

Li, Q., D. Yang, Z. Jia, L. Zhang, Y. Zhang, L. Feng, L. He, K. Yang, J. Dai, J. Chen and X. Zhao. 2019. Changes in soil organic carbon and total nitrogen stocks along a chronosequence of *Caragana intermedia* plantations in alpine sandy land. *Ecological Engineering* 133: 53-59.

Liu, Y., Y. Fang and S. An. 2020. How C:N:P stoichiometry in soils and plants responds to succession in *Robinia pseudoacacia* forests on the Loess Plateau, China. *Forest Ecology and Management* 475: 118394.

Luo, Y., B. Su, W.S. Currie, J.S. Dukes, A. Finzi, U. Hartwig, B. Hungate, R.E. McMurtrie, R. Oren, W.J. Parton, D.E. Pataki, R.M. Shaw, D.R. Za and C.B. Field. 2004. Progressive nitrogen limitation of ecosystem responses to rising atmospheric carbon dioxide. *BioScience* 54: 731-739.

Mahdavi, A., A. Maleki and M. Bazgir. 2019. Soil properties and carbon sequestration in Persian oak (*Quercus brantii* var. *persica*) forests, Iran. *Journal of Forest Science* 65: 247-255.

Mao, R., D.H. Zeng, Y.L. Hu, L.J. Li and D. Yang. 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: 277-287.

MARD. 2018. Promulgating a list of major forestry tree species, recognition of varieties and seed sources, and management o main forestry tree seed materials. No. 30/2018/TT-BNNPTNT. Ministry of Agriculture and Rural Development (MARD), Hanoi, Vietnam.

MARD. 2020. *Promulgation of the State of National Forests*. No. 1558/QD-BNN-TCLN. Ministry of Agriculture and Rural Development (MARD), Hanoi, Vietnam.

Markewitz, D., F. Sartori and C. Craft. 2002. Soil change and carbon storage in *Longleaf pine* stands planted on marginal agricultural lands. *Ecological Applications* 12: 1276-1285.

Matali, S. and F. Metali. 2015. Selected soil physicochemical properties in the *Acacia mangium* plantation and the adjacent heath forest at Andulau Forest Reserve. *Malaysian Journal of Soil Science* 19: 45-58.

Miao, J., C.Y. Zhou, S.J. Li and J.H. Yan. 2014. Accumulation of soil organic carbon and total nitrogen in *Pinus yunnanensis* forests at different age stages. *Chinese Journal of Applied Ecology* 25: 625-631.

Morford, S.L., B.Z. Houlton and R.A. Dahlgren. 2011. Increased forest ecosystem carbon and nitrogen storage from nitrogen rich bedrock. *Nature* 477: 78-81.

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

Noh, N.J., Y. Son, S.K. Lee, K.W. Seo, S.J. Heo, M.J. Yi, P.S. Park, R.H. Kim, Y.M. Son and K.H. Lee. 2010. Carbon and nitrogen storage in an age-sequence of *Pinus densiflora* stands in Korea. *Science China Life Sciences* 53: 822-830.

Paula, R.R., J.P. Bouillet, P.C. Ocheuze Trivelin, B. Zeller, J. Leonardo de Moraes Gonçalves, Y. Nouvellon, J.M. Bouvet, C. Plassard and J.P. Laclau. 2015. Evidence of short-term belowground transfer of nitrogen from *Acacia mangium* to *Eucalyptus grandis* trees in a tropical planted forest. *Soil Biology and Biochemistry* 91: 99-108.

Reich, P, S. Hobbie, T. Lee, D. Ellsworth, J. West, D. Tilman, J.Knops, S. Naeem and J. Trost. 2006. Nitrogen limitation constrains sustainability of ecosystem response to CO_2. *Nature* 440: 922-925.

Ribet, J. and J.J. Drevon. 1996. The phosphorus requirement of N_2-fixing and urea-fed Acacia mangium. *New Phytologist* 132: 383-390.

Saharjo, B.H. and H. Watanabe. 2000. Estimation of litter fall and seed production of *Acacia mangium* in a forest plantation in South Sumatra, Indonesia. *Forest Ecology and Management* 130: 265-268.

Sartori, F. , R. Lal, M.H. Ebinger and J.A. Eaton. 2007. Changes in soil carbon and nutrient pools along a chronosequence of *Poplar* plantations in the Columbia Plateau, Oregon, USA. *Agriculture, Ecosystems & Environment* 122: 325-339.

Scharlemann, J.P.W., E.V.J. Tanner, R. Hiederer and V. Kapos. 2014. Global soil carbon: understanding and managing the largest terrestrial carbon pool. *Carbon Management* 5: 81-91.

Sedjo, R.A. 1993. The carbon cycle and global forest ecosystem. *Water, Air, and Soil Pollution* 70: 295-307.

Thanh, N.M. and L.V. Cuong. 2016. Soil characteristics under natural forest canopy in Dongnai Cultural and Natural Reserve, Dongnai Province, South Vietnam. *Science and Technology Journal of Agriculture & Rural Development* 5: 99-104.

Thanh, N.M. and L.V. Cuong. 2017. Effects of plantation forest types to soil physical and chemical properties in Socson district, Hanoi city. *Science and Technology Journal of Agriculture & Rural Development* 2: 133-139.

Tuan, N.T. and T.T. Dinh. 2020. Growth performance of *Dipterocarpus alatus* and *Hopea odorata* in degraded secondary forest land in Southern Vietnam. *Dendrobiology* 83: 60-67.

Vesterdal, L., I. K. Schmidt, I. Callesen, L.O. Nilsson and P. Gundersen. 2008. Carbon and nitrogen in forest floor and mineral soil under six common European tree species. *Forest Ecology and Management* 255: 35-48.

Vitousek, P.M. and R.W. Howarth. 1991. Nitrogen limitation on land and in the sea: How can it occur? *Biogeochemistry* 13: 87-115.

Wang, Y, L. Liu, F. Yue and D. Li. 2019. Dynamics of carbon and nitrogen storage in two typical plantation ecosystems of different stand ages on the Loess Plateau of China. *Peer J* 7: e7708.

Xu, D, Z. Z. Yang and Q. He.1998. Above ground biomass production and nutrient cycling of middle-age plantation of *Acacia mangium*. *Forest Research* 11: 592-598.

Xu, H, Q. Qu, P. Li, Z. Guo, E. Wulan and S. Xue. 2019. Stocks and stoichiometry of soil organic carbon, total nitrogen, and total phosphorus after vegetation restoration in the Loess hilly region, China. *Forests* 10: 27.

Yang, Y., Y. Luo and A.C. Finzi. 2011. Carbon and nitrogen dynamics during forest stand development: a global synthesis. *New Phytologist* 190: 977–989.

Zhang, H., H. Duan, M. Song and D. Guam.. 2018. The dynamics of carbon accumulation in eucalyptus and acacia plantations in the Pearl River delta region. *Annals of Forest Science* **75**: 40.