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Soil Texture, Organic Matter and Nutrients Affect Production of *Acacia* in Northeast Vietnam

Pham Tien Dung[1], Do Van Ban[2], Pham Quang Tuyen[1], Phung Dinh Trung[1], Nguyen Huy Hoang[1], Luu Quoc Thanh[2], Ninh Viet Khuong[1], Nguyen Van Tuan[1], Tran Hai Long[1], Bui Thanh Tan[1], Nguyen Huu Thinh[1], Bui Huu Thuong[2], Pham Thi Quynh[3] and Tran Van Do[1*]

[1]Silviculture Research Institute, Vietnamese Academy of Forest Sciences, Hanoi, Vietnam.
[2]Research Institute of Forest Industry, Vietnamese Academy of Forest Sciences, Hanoi, Vietnam.
[3]Vietnam National University of Forestry, Xuan Mai Town, Hanoi, Vietnam.

Authors' contributions

This work was carried out in collaboration among all authors. Author TVD performed data analysis and wrote the first draft of the manuscript. Authors PTD, DVB, PQT, PDT, NHH, LQT, NVK, NVT, THL, BTT, NHT, BHT and PTQ conducted fieldwork. All authors read and approved the final manuscript.

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ABSTRACT

Soil provides nutrients, water, and growing space for plants, and thus is the basis for life on earth. Soil nutrient availability impacts productivity of terrestrial ecosystems i.e. forest. However, support for this phenomenon in the tropics remains elusive. In this study, the effects of soil properties including texture, organic matter and nutrients on production of *Acacia hybrid* and *A. mangium* plantations in Northeast Vietnam were studied. Thirtythree sample plots of 500 m^2 (20 m × 25 m) each were established in plantations of 1–14 years old for measuring stem diameter at breast height and height for all *Acacia* trees. In each plot, a 0–30 cm depth soil sample was taken for analyzing soil texture, organic matter, and nutrients. While allometry was used to estimate standing volume (production) of all measured stems. The results indicated that both species had rapid growth until 8^{th} year after planting, then growth speed decreases as age increasing. The ratio of loam particles in soil controls production of both species, as higher loam ratios lead to lower

**Corresponding author: Email: dotranvan@hotmail.com;*

production in terms of the standing volume. While higher phosphorous availability in the soil will lead to higher production of *A. mangium* but not *A. hybrid*. There weren't any relationships between production and soil nitrogen and potassium for both species. It is concluded that *A. hybrid* and *A. mangium* should be logged at the age earlier than 8 years old for pulpwood to maximize production, rapid reinvestment, and benefit return. Fertilizing phosphorus to *acacia* plantations should be conducted to increase production, while potassium and nitrogen should not be applied.

Keywords: Density; growth; nutrients; production; soil texture.

1. INTRODUCTION

Soil provides nutrients, water, and growing space for plants, and thus is the basis for life on earth [1]. Soil nutrients determine structure and function at all levels of biological organization and also play an important role in ecosystem functioning [2,3]. The mineral nutrients influence plant growth, biodiversity, and ecosystem processes [4-7]. Soil differs in its properties such as mineral composition, nutrient contents, pH, and organic matter [8]. Soil properties and plants interact with each other [9-11]. Soil pH, nutrients, base saturation may change relatively quickly, which relate to biological processes, vegetation cover, and management practices [12]. While the basic site properties as grain size, the mineralogical composition may change over a long time due to biotic activities at ecological time scales [13]. Soil properties as texture, organic matter, and pH control the total nutrients in soil solution, ion exchange sites, unavailable pools of soil nutrients, and fluxes among these three [14]. A high clay fraction corresponds to a high cation exchange capacity, while soil organic matterhas a positive influence on nutrient availability [15] and provides cation as well as anion exchange sites [16]. Soil pH strongly influences the availability of phosphorous (P) and base cations as Ca_2C and Mg_2C [17,18].

There is aclear evidence that soil nutrient availability impacts forest productivity [19-21]. However, support for this phenomenon in the tropics remains elusive [22]. The deeper soil layers are, the less their effects on plants. As they have different properties [23,24], reducing nutrients in deeper soil layers. Decrease of soil organic matter, N, P Ca, Mg, Na, and K with increasing soil depth is the main pattern in most forest soils [11,25,26]. Soil properties driver biotic functions such as productivity in terrestrial ecosystems [21,22]. It is clear that abiotic site conditions affect individual tree growth, then community and ecosystem levels [27,28]. Furthermore, soil characteristics impact the herbivore population and therefore affect plant's development and productivity, especially in pure plantations [29-31]. Therefore, studying the effects of soil characteristics on production capacity is useful for managers in a forest plantation. The objective of this study is to quantify the impacts of soil properties on the growth of *Acacia* plantations in Northeast Vietnam.

2. MATERIALS AND METHODS

2.1 Study Site

The study was conducted in Northeast Vietnam including six provinces i.e. TuyenQuang, Yen Bai, Bac Giang, QuangNinh, Phu Thu, and VinhPhuc. The plantations of *A. hybrid* and *A. mangium* have been widely established in these provinces and contributed considerably to poverty reduction and economic developments, especially for local people in those provinces.

The study plantations were in the age ranges of 3–14 years old, which were established by local people themselves, forest enterprises, and government bodies. The plantations were established in diverse climate and edaphic conditions. *A. mangium* plantations were established by seedlings produced from selected seed sources, while *A. hybrid* plantations were established by cuttings of best cultivars. Both acacias were established with an initial planting density of 1,660 trees/ha (3 m × 2 m). The planting holes had sizes of 20 cm × 20 cm × 20 cm or 30 cm × 30 cm × 30 cm. The seedlings had sizes of 25–40 cm height and 4–7 mm in stumpdiameter. At planting, NPK was widely applied with doses of 50–100 g/tree. After planting, tending by weeding and cutting linear was applied in the first and second years.

2.2 Data Collection

By interviewing responsible staff of the Provincial Department of Forest Development, representative plantations of age (3–14 years old), planting density (1,660 trees/ha), techniques (planting holes, fertilization, tending), and seedling sources were selected for field data collection. At the time of field survey, plantation age was confirmed by interviewing owners for establishment year.

In each selected plantation, a representative plot of 500 m^2 (20 m × 25 m) was established for data collection. All *acacia* stems in the plot were measured for diameter at breast height (DBH) and stem height (H).

2.3 Soil Sampling and Analysis

In each survey plot, the soil was taken in 0–30 cm depth from five positions (four corners and one in the middle) by soil coring vertically. Which was then mixed carefully for one sample of around 300 g. Samples were then transferred to lab for analysis.

The sample was air-dried, grind, and sieved. Soil texture was analyzed first by hydrometer method. Then, the <2 mm fraction was used for soil organic matter and nutrient analysis. The determination of soil organic carbon is based on the Walkley-Black chromic acid wet oxidation method [32]. Oxidisable matter in the soil is oxidized by 1 N $K_2Cr_2O_7$ solution. The reaction is assisted by the heat generated when two volumes of H_2SO_4 are mixed with one volume of the dichromate. The remaining dichromate is titrated with ferrous sulphate. The titre is inversely related to the amount of C present in the soil sample. Nitrogen (N) and phosphorus (P) were determined on 20 mL sulfuric acid/hydrogen peroxide digested material, which was filtered through a fine paper filter to remove particulate matter. While exchangeable potassium (K) was determined by atomic absorption spectrometry after shaking soil in a reciprocating shaker with 1-M ammonium chloride (soil: solution ratio of 1:30) for 2 hours [33].

2.4 Data Analysis

Current stem density, DBH, H, basal area (m^2/ha), and standing volume (m^3/ha) were generated for each survey plot, representing for that plantation. Standing volume (V) of each stem was estimated as V =G•H•f, where G is basal area equaling (3.14•DBH^2)/4 with DBH in centimeter, H is stem height in meter, and f is stem form equaling 0.453 for *A. hybrid* and 0.458 for *A. mangium* [34]. The equation was established based on plantations in Northeast Vietnam. Therefore, it ascertains estimation of standing volume in the present study.

Regressions for ages, and DBH and H; and for soil properties (organic matter, nitrogen/N, P_2O_5, K_2O, and loam particles) and standing volume were established by the best-fitted model. All statistical analyses were conducted using SAS 9.2 at p = 0.05 (SAS Institute Inc., Cary, NC, USA).

3. RESULTS

Thirteen *A. hybrid* plantations and twenty *A. mangium* plantations were surveyed (Table 1). The current densities ranged 600–1,580 trees/ha compared to planting density of 1,660 trees/ha, DBH of 6.1–18.9 cm, H of 6–19.4 m, basal area of 2.4–29.6 m^2/ha, and standing volume of 8.3–314.7 m^3/ha. The oldest plantation of *A. hybrid* was 14 years old with a density of 720 trees/ha, DBH of 18 cm, H of 18.6 m, basal area of 19.8 m^2/ha, and standing volume of 203.5 m^3/ha. While theoldest plantation of *A. mangium* was 13 years old with a density of 980 trees/ha, DBH of 18.9 cm, H of 19.3 m, basal area of 19.6 m^2/ha, and standing volume of 314.7 m^3/ha. Even denser and younger plantations, growths of *A. mangium* were better than that of *A. hybrid* (Table 1).

The relationships between ages, and DBH and H of both species (Fig. 1) also indicated faster growth of *A. mangium* compared to *A. hybrid*. Growth of both species were fast when trees were less than 8 years old. Then, growth still increased but the speed was reducing with tree age (Fig. 1).

For *A. hybrid* plantations, the relationships between standing volume, and organic matter, N, phosphorus and potassium did not exist (Fig. 2). While the relationship between volume and loam particle percentage existed in the form of linear. This existed relationship indicates that a higher ratio of loam particles in soil texture will lead to lower plantation production.

For *A. mangium* plantations, the relationships between standing volume, and N and potassium did not exist (Fig. 3). While relationship between standing volume, and organic matter (exponential form), phosphorous (linear) and loam particle percentage (linear) existed. These existed relationships indicated that higher organic matter will lead to lower production of *A. mangium*, higher soil phosphorous will lead to higher production, and a higher ratio of loam particles in soil texture will lead to lower production.

Table 1. Tree growths of *A. hybrid* and *A. mangium* in different ages and densities

No.	Age (years)	Current density (trees/ha)	DBH (cm)	H (m)	Basal area (m^2/ha)	Volume (m^3/ha)
Acacia hybrid						
1	3	1,500	9.1	11.1	9.9	57.0
2	4	860	9.7	10.9	6.6	38.5
3	4	900	10.7	12.0	8.5	53.8
4	4	1,020	9.4	10.2	7.4	41.1
5	4	1,120	10.7	12.1	10.4	67.0
6	5	1,000	13.7	15.6	15.4	126.7
7	5	1,240	10.8	11.9	11.7	73.0
8	6	680	13.3	14.0	9.9	74.2
9	6	1,580	11.7	14.1	17.5	131.5
10	7	600	16.9	17.1	14.1	128.3
11	7	760	16.6	18.3	16.7	156.4
12	11	1,040	16.9	19.4	24.0	242.7
13	14	720	18.0	18.6	19.8	203.5
Acacia mangium						
1	3	680	6.8	7.1	2.6	10.1
2	3	740	6.4	6.5	2.4	8.3
3	3	980	6.1	6.0	3.0	9.4
4	3	1,040	7.2	7.1	4.3	16.3
5	4	1,120	9.0	10.1	7.5	41.8
6	4	1,220	9.3	10.7	8.7	50.4
7	6	720	18.0	19.4	18.8	188.6
8	6	900	14.6	16.3	15.5	132.2
9	6	1,060	12.0	13.8	12.3	89.8
10	6	1,180	11.2	12.7	12.2	84.2
11	6	1,280	12.7	14.0	17.2	131.9
12	6	1,320	13.5	15.5	19.8	164.7
13	7	700	13.2	13.9	10.0	72.6
14	7	1,200	11.4	12.5	12.9	87.1
15	9	680	12.7	14.4	9.2	72.9
16	9	960	14.1	15.6	15.6	128.4
17	11	820	17.6	18.8	21.5	222.5
18	11	1,040	17.5	18.2	27.3	275.5
19	12	600	16.2	16.6	12.9	113.9
20	13	980	18.9	19.3	29.6	314.7

4. DISCUSSION

Older plantations had even lower growth parameters compared to younger ones, which were found in the present study (Table 1). For example, 6-year-old *A. hybrid* plantations had DBH (11.7 cm) and H (14.1 m) lower than that of 5-year-old plantations (DBH = 13.7 and H = 15.6). Similar cases were also found in 6-, 7-, and 9-year-old *A. mangium* plantations. Such differences resulted from the difference of current density, as generally lower density had higher growth parameters. However, the main reason for such difference may come from the difference in soil properties [19,27]. In addition, higher densities (Fig. 4) did not lead to higher production. Therefore, soil properties especially soil nutrients play an important role in the production of both *acacia* species.

In both study species, the ratio of soil loam particles (0.002–0.02 mm) negatively linear relates to standing volume (Figs. 2, 3). This could be explained that loam particles play an important role in soil density and porosity [27,28]. Higher loam particles will lead to compacted soil, which limits root growth because of the difficulty of root penetrating and limitation of soil oxygen. In addition, nutrients in the soil may be in the status of unavailability for trees to uptakes, leading to reducing production in higher loam particle ratios [5]. However, too low loam particle ratios may also be not good for plant's production especially trees, as it is not good for root anchoring, nutrient and water absorbing, and the ability for remaining soil nutrients and organic matter.

The exponential shape was fitted for standing volume and organic matter relationship and positive linear was fitted for standing volume and phosphorous relationship for *A. mangium* (Fig. 3), but not for *A. hybrid*. Such differences could result from internal factors of different species other than surrounding environments as plantations were established in similar sites. The negative standing volume and organic matter relationship for *A. mangium* could be explained by the fact that high organic matter are not yet decomposed to release soluble nutrients for

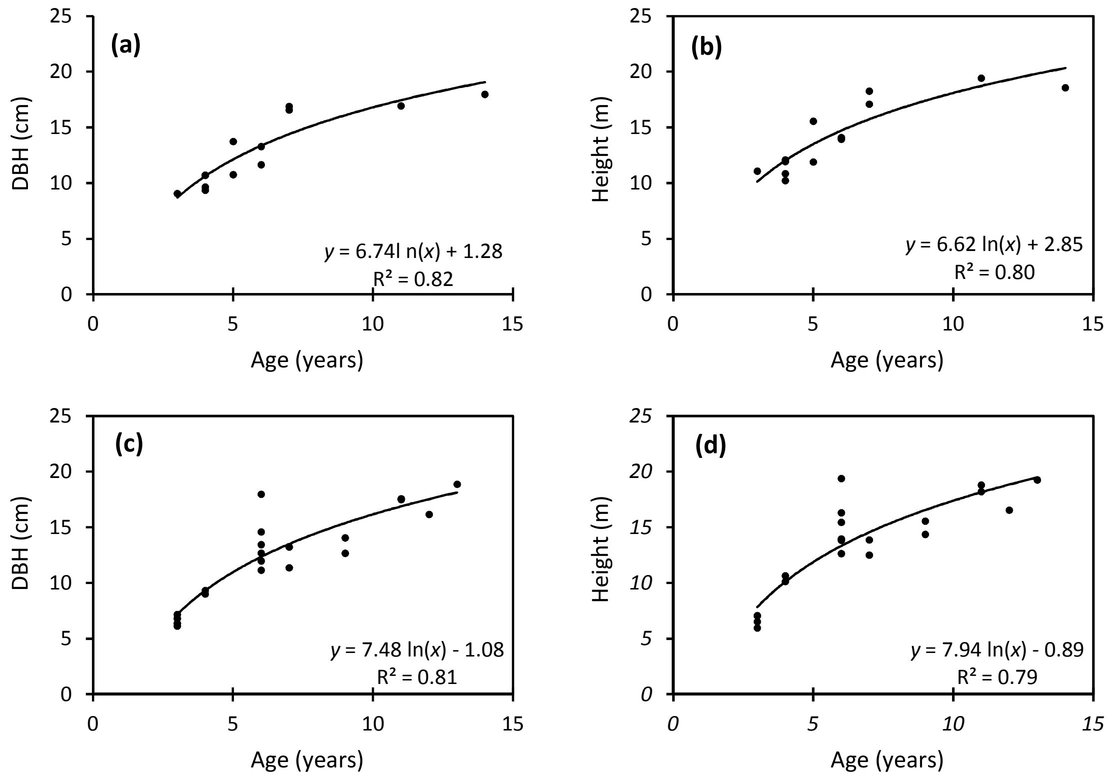

Fig. 1. Relationship between ages, and DBH (diameter at breast height) and height of *A. hybrid* (a, b) and *A. mangium* (c, d)

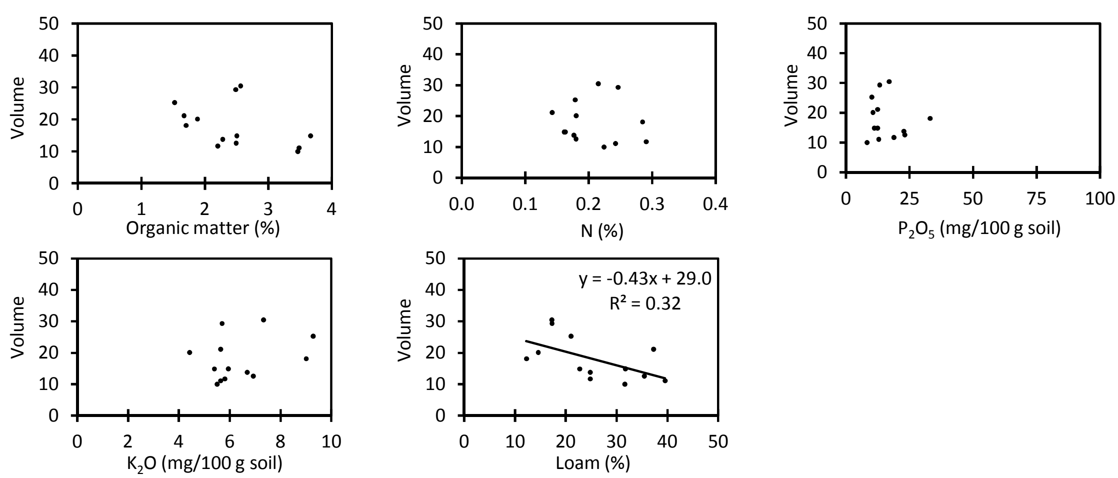

Fig. 2. Relationship between soil properties and volume of *A. hybrid* trees (dm^3/tree/year)

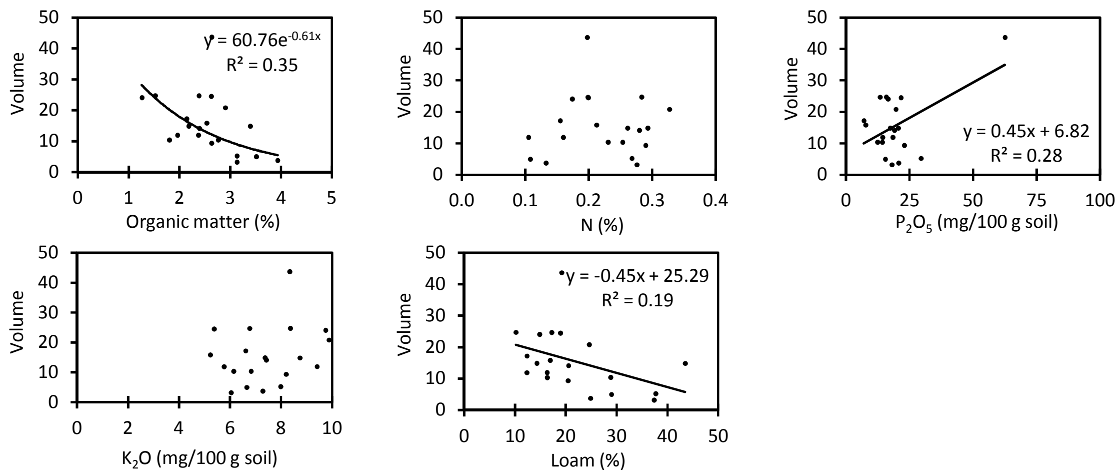

Fig. 3. Relationship between soil properties and volume of *A. mangium* trees (dm^3/tree/year)

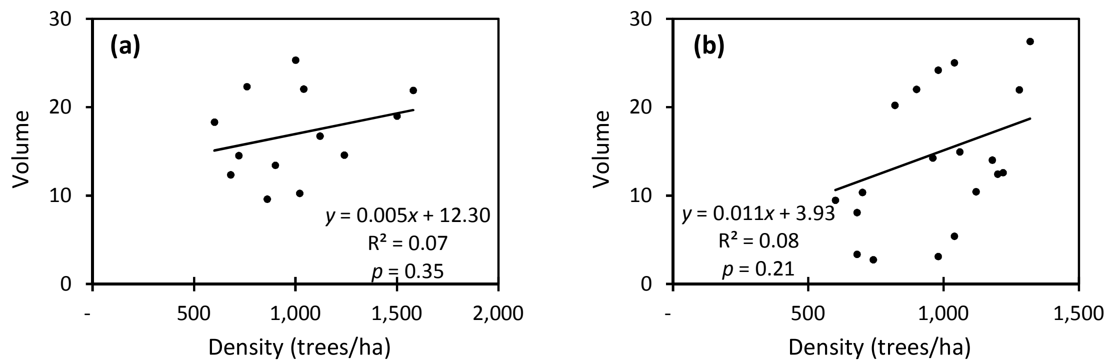

Fig. 4. Relationship between density, and volume (m^3/ha/year) of *A. hybrid* (a) and *A. mangium* (b)

tree's uptake. Meanwhile, a positive linear relationship between standing volume and phosphorous indicates the importance of phosphorous for *A mangium* in Northeast Vietnam. Other studies also indicated the importance of fertilizing phosphorous for *acacia* plantations in Vietnam [35-38].

Acacias are legume plants, which can fix nitrogen themselves [39]. Therefore, soil nitrogen did not impact on the production of both study acacias (Fig. 2, 3). While potassium also did not impact production in the present study, similar results were also reported in others [37,38]. This could be explained by 1) the much availability of potassium in the present study site like in tropics and potassium is efficiency for acacias, and 2) the requirement of acacias on potassium is not so high compared to other plants especially crops [40,41]. These again indicated that fertilizing nitrogen and potassium for *acacia* plantations may not be necessary.

Rapid production of both study acacias occurs in the ages of less than 8 years old (Fig. 1). Therefore, if plantations are established for biomass production, then it could be logged after planting less than 8 years for maximizing productivity in the time unit [35-38]. However, for timber production, it must require a much longer time to achieve merchantable timber standards. Many studies indicated that *acacia* is a fast-growing tree, it is true in short-rotation [35-38]. While *acacia* plantations of > 8 years old grow quite slow (Table 1), it can only reach less than 1 cm DBH/year. Therefore, establishing *acacia* plantations for timber production or pulp production must be considered carefully in terms of cost-benefit analysis for further recommendations.

5. CONCLUSION

Acacia plantations have been widely established in Vietnam, contributing considerably to poverty reduction and local economic development. Both *A. hybrid* and *A. mangium* plantations established in Northeast Vietnam have fast growths in the first 8 years after planting, and then growths reduce in the later ages. Therefore, short rotations should be applied for plantation establishment to produce pulpwood, which can maximize production per time unit, and speeding up reinvestment and return rates.

Soil could play an important role in the production of *acacia* plantations. Soils with a low ratio of loam particles (0.002–0.02) should be selected for growing acacias. While the availability of phosphorous in the soil is important for higher production. Therefore, fertilizing phosphorous should be applied to *acacia* plantations, while potassium and nitrogen are not necessary.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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