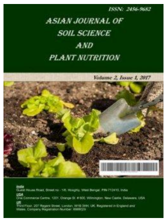

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Effect of Planting Density on Production of Acacia Plantations in Northeast Vietnam

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Authors' contributions

This work was carried out in collaboration among all authors. Author TVD managed the literature searches and wrote the first draft of the manuscript. Authors DVT, NTT, PDT, LTTH, NTTP, DHH, NVT, LTH, HTN and THV designed the study and performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Acacia plantations have been contributing to national economic and livelihood of millions people living in rural areas of Vietnam. It has been widely planted and accounted for nearly 50% areas of plantations in Vietnam. In this study, different planting densities including 1,110 trees ha^{-1} (3 × 3 m), 1,330 trees ha^{-1} (2.5 × 3 m), and 1,660 trees ha^{-1} (2.5 × 2.5 m) were tested for *Acacia hybrid* and *Acacia auriculiformis*. The growth parameters (diameter at breath height/DBH and stem height/H) were measured, and dry biomass was estimated for 4-year-old plantations. The results indicated that a 4-year-old plantation of *A. hybrid* had most massive DBH (11.3 cm) at planting density of 1,100 tree ha^{-1}, while highest dry biomass (57.9 Mg ha^{-1}) was observed in planting density of 1,660 trees ha^{-1}. In case of a 4-year-old plantation of *A. auriculiformis*, highest DBH (10.0 cm) and highest dry biomass (50.4 Mg ha^{-1}) at planting density of 1,330 trees ha^{-1} were recorded. At the planting densities of 1,110 trees ha^{-1} and 1,660 trees ha^{-1}, a 4-year-old plantation of *A. hybrid* had

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significantly higher dry biomass as compared to that of a 4-year-old plantation of *A. auriculiformis*. However, the difference of dry biomass between 4-year-old plantations of two species at planting density of 1,330 trees ha^{-1} was not significant. This study concluded that to grow *A. hybrid* planting density of 1,660 trees ha^{-1} should be used, while density of 1,330 trees ha^{-1} is encouraged for planting *A. auriculiformis* for pulpwood production.

Keywords: Acacia hybrid; Acacia auriculiformis; economic contribution; growing space; rural areas; survival rate.

1. INTRODUCTION

Plantations of exotic trees are assuming an increasingly significant role in landscape management and the rural economy in many tropical regions [1]. In Vietnam, plantation of acacias is becoming increasingly important in contributing to the national economy and livelihood of million people in rural areas [2], when logging timber from natural forest is prohibited. By 2013, 51% of total plantation areas in Vietnam were planted with acacias.

To protect natural resources and the environment for the sustainable development, plantation has become the major source of timber supply for timber industry such as solid wood, plywood pulping, and paper [3]. A good plantation species can produce not only high timber yield, but also the desired properties of wood for highly valued end products. Accelerating tree growth or shortening the rotation could potentially affect wood quality [4].

Acacias are the major raw material of the pulp and paper industries in Vietnam and for export, so it is imperative that planting stock of high genetic quality is important to increase productivity for acacia plantations. Silviculture techniques as selecting optimum densities and fertilization application are important management considerations to increase overall productivity for any plantation [5]. Planting density is a very important tool of silvicultural treatment, which affects the growing conditions of planted trees and the stem wood production [6].

The objective of this study is to examine the effects of planting density on growth of acacia plantations in Northeast Vietnam.

2. MATERIALS AND METHODS

2.1 Study Site

This study was conducted in Quang Ninh Province in Northeast Vietnam, on the altitude of 85–100 m above sea level. The site has mean annual temperature of 23°C and total annual precipitation of 1,850–1,900 mm. Soil in the study site is known as Ferralic Acrisol with average pH of 3.5–3.6, organic matter of 3.2–4.3%, and nitrogen of 0.069–0.164% [7].

2.2 Plantation Establishment

Two wide-planted acacia species including *Acacia auriculiformis* and *Acacia hybrid* were experimented in this study. Seedlings of 3-month old were used, which was 0.3-0.5 cm in diameter at stump and 40-50 cm in height. Seedlings were planted in June as it is rainy season in the study site.

The experiment on planting density included three treatments as (a) 1,110 trees ha^{-1} (3 × 3 m), (b) 1,330 trees ha^{-1} (2.5 × 3 m), and (c) 1,660 trees ha^{-1} (2.5 × 2.5 m). At planting, each tree was fertilized with 150 g NPK (ratio of 5:10:3) + 150 g compost.

Experiment was conducted in a randomized complete block with three replicates. Each treatment was conducted in a plot of 20 × 20 m, which included 36 trees in planting density of 1,110 trees ha^{-1}, 42 trees in planting density of 1,330 trees ha^{-1}, and 49 trees in planting density of 1,660 trees ha^{-1}. Totally, there were two blocks for two study species.

2.3 Data Collection and Analysis

Data included survival rate (%), diameter at breast height (DBH in cm) and stem height (H in m) were measured in June after planting four years. All surviving stems in plots were measured.

Total dry biomass of each stem (B in kg) was estimated as following [8]:

A. hybrid	$B = 0.2255*DBH^{2.1661}$
A. auriculiformis	$B = 0.3116*DBH^{2.1069}$

Comparison among treatments in each species was conducted with ANOVA one-factor and posthoc test. While, comparing between two species in each planting density was conducted by pair-comparison. Statistical analysis was conducted by using SAS 9.2.

3. RESULTS

Survival rates of *A. hybrid* plantation were higher than 94% in all treatments (Table 1) after planting four years. The highest survival rate was 95.3% in planting density of 1,330 trees ha^{-1}, and the lowest (94%) belonged to planting density of 1,110 trees ha^{-1}. However, the difference of survival rates among three planting densities was not statistically significant. The highest mean stem height (13.6 m) was found in planting density of 1,330 trees ha^{-1} and the shortest mean stem height (13.4 m) was found in planting density of 1,110 trees ha^{-1}. Similar with survival rates, planting densities did not significantly effect on height growth of *A. hybrid* (Table 1). Meanwhile, planting density significantly effect on DBH growth and dry biomass. The largest mean DBH (11.3 cm) was found in planting density of 1,110 trees ha^{-1}, reducing to 10.9 cm in planting density of 1,330 trees ha^{-1}, and to 10.5 cm in planting density of 1,660 trees ha^{-1}. Even with lesser mean DBH, a 4-year-old plantation of planting density of 1,600 trees ha^{-1} had highest dry biomass (57.9 Mg ha^{-1}). The lowest dry biomass (44.9 Mg ha^{-1}) belonged to planting density of 1,110 trees ha^{-1} (Table 1).

Survival rate of a 4-year-old *A. auriculiformis* plantation was highest (95%) in planting density of 1,330 trees ha^{-1}, reducing 94.7% in planting density of 1,660 trees ha^{-1}, and to 94% in planting density of 1,100 trees ha^{-1} (Table 2). However, planting density did not significantly effect on survival rates after planting four years. Mean DBH (10 cm) was largest at planting density of 1,300 trees ha^{-1} and the smallest mean DBH (8.4 cm) was found in planting density of 1,660 trees ha^{-1}. The difference of mean DBH among three planting densities was statistically significant. Planting densities also significantly effect on height growth and dry biomass of a 4-year-old *A. auriculiformis* plantation. Mean height was tallest (10.3 m) in planting density of 1,300 trees ha^{-1}, reducing to 8.8 m in planting density of 1,110 trees ha^{-1}, and to 7.8 m in planting density of 1,660 trees ha^{-1}. Resulted from largest mean DBH, plantation with planting density of 1,330 trees ha^{-1} had highest dry biomass of 50.4 Mg ha^{-1}, and the lowest dry biomass (34.9 Mg ha^{-1}) belonged to planting density of 1,100 trees ha^{-1}.

At the planting density of 1,330 trees ha^{-1}, a 4-year-old *A. auriculiformis* plantation had dry biomass of 50.4 Mg ha^{-1} and that of a 4-year-old *A. hybrid* plantation was 50.5 Mg ha^{-1}. The difference of dry biomass between two species at this planting density was not significant (Fig. 1). Meanwhile, the difference of dry biomass between two species was statistically significant at planting densities of 1,100 trees ha^{-1} and 1,660 trees ha^{-1}. The study indicated that dry biomass of a 4-year-old plantation of *A. hybrid* was significantly higher than that of a 4-year-old plantation of *A. auriculiformis*. The difference was 10 Mg ha^{-1} at planting density of 1,110 trees ha^{-1} and 14.5 Mg ha^{-1} at planting density of 1,660 trees ha^{-1}.

Table 1. Effects of planting density on survival rate, growth, and dry biomass of a 4-year-old *A. hybrid* plantation (means ±SD)

Planting density (trees ha^{-1}) [spacing]	Survival rate (%)	DBH (cm)	H (m)	Dry biomass (Mg ha^{-1})
1,110 [3 × 3 m]	94.0 ±0.57	11.3 ±0.81^{a}	13.4 ±0.65	44.9 ±1.3^{a}
1,330 [2.5 × 3 m]	95.3 ±2.08	10.9 ±0.79^{ab}	13.6 ±0.71	50.5 ±2.8^{a}
1,660 [2.5 × 2.5 m]	95.0 ±0.57	10.5 ±0.85^{bc}	13.5 ±0.59	57.9 ±1.8^{b}

In a column, the different letters $^{a, b, c}$ indicated the significant difference of mean at $p = 0.05$

Table 2. Effects of planting density on survival rate, growth, and dry biomass of a 4-year-old *A. auriculiformis* plantation (means ±SD)

Planting density (trees ha^{-1}) [spacing]	Survival rate (%)	DBH (cm)	H (m)	Dry biomass (Mg ha^{-1})
1,110 [3 × 3 m]	94.0 ±0.58	9.2 ±0.85^{a}	8.8 ±0.69^{a}	34.9 ±0.4^{a}
1,330 [2.5 × 3 m]	95.0 ±0.58	10.0 ±0.88^{a}	10.3 ±0.72^{b}	50.4 ±0.5^{b}
1,660 [2.5 × 2.5 m]	94.7 ±0.33	8.4 ±0.71^{b}	7.8 ±0.59^{c}	43.4 ±0.3^{c}

In a column, the different letters $^{a, b, c}$ indicated the significant difference of mean at $p = 0.05$

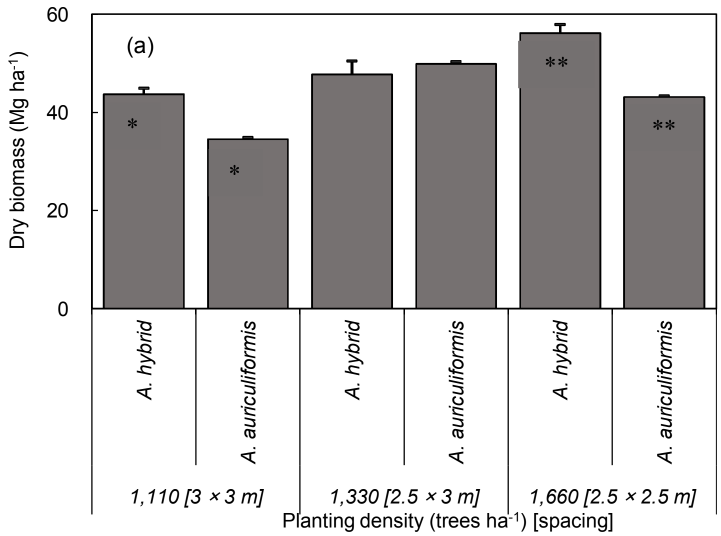

Fig. 1. Comparison of dry biomass between a 4-year-old plantation of *A. hybrid* and that of *A. auriculiformis* at different planting densities

Vertical bars indicated ±SD. Asterisks indicated the significant difference of dry biomass in corresponding planting density at p = 0.05

4. DISCUSSION AND CONCLUSION

Each tree requires a growing space of both belowground and aboveground. Requirement of growing space is increasing with tree's age and/or growth of crown and root's system. When there is no competition for growing space as no-cross growth of crown and/or root's system, trees grow freely and tend to have larger crown and DBH but shorter stem height. The planting density represents growing space of planted trees. The denser planting density is, the less growing space trees have. It is obviously that growing space for planted trees of both *A. hybrid* and *A. auriculiformis* is largest at planting density of 1,110 trees ha^{-1} (9 m^2 $tree^{-1}$), reducing to 1,330 trees ha^{-1} (7.5 m^2 $tree^{-1}$), and to 1,660 trees ha^{-1} (6.25 m^2 $tree^{-1}$). Dang [7] indicated that at the same age, crown diameter of *A. hybrid* is larger than that of *A. auriculiformis*, when both were planted at the same site. Therefore, in this study the growing space is more available for *A. auriculiformis* tree than that for *A. hybrid* tree at the same planting density.

The larger growing space at planting density of 1,110 trees ha^{-1} led to less competition among planted trees of *A. hybrid*. Therefore, mean DBH was more in planting density of 1,110 trees ha^{-1} and less in planting density of 1,660 trees ha^{-1} (Table 1). This pattern was not found for *A. auriculiformis* (Table 2), which had largest mean DBH at planting density of 1,330 trees ha^{-1}. However, mean DBH at both planting densities of 1,110 trees ha^{-1} and 1,330 trees ha^{-1} was not significantly different. This may be explained by small crown diameter of both planting density [7] which led to no completion among planted trees and by species characteristics of *A. auriculiformis* [9]. While, there was cross-crown of planted trees at planting density of 1,660 trees ha^{-1}, leading to significant smaller mean DBH in this planting density of *A. auriculiformis* (Table 2).

There was no significant difference of stem height among planting densities for *A. hybrid* (Table 1), while it was for *A. auriculiformis* (Table 2). Even it was mentioned that crown diameter of *A. hybrid* is much larger than that of *A. auriculiformis* [7], leading to higher competition of *A. hybrid* compared to that of *A. auriculiformis* at the same planting densities [10]. This is explained by species characteristics. Of which, *A. auriculiformis* is usually taller in stem height and thinner in DBH [9] compared to *A. hybrid* when they are planted in the same site with the same silvicultural techniques.

Dry biomass of individual stem is function of DBH. Therefore larger DBH stem has higher biomass [8,11]. In addition, dry biomass per area unit is function of both stem DBH and planting density [8]. However, mean DBH and planting density have negative relationship; higher planting density leads to smaller mean DBH. Such correlation resulted in difference of dry biomass of plantation [12]. Smallest mean DBH with highest planting density of 1,660 trees ha^{-1}

for *A. hybrid* led to highest biomass of a 4-year-old plantation (Table 1). Meanwhile, largest mean DBH with medium planting density of 1,330 trees ha^{-1} resulted in highest dry biomass of a 4-year-old *A. auriculiformis* plantation (Table 2).

If anyone plans to grow *A. hybrid* and *A. auriculiformis* for pulp wood production, planting density of 1,660 trees ha^{-1} is best applied for *A. hybrid* and that is 1,330 trees ha^{-1} for planting *A. auriculiformis*. However, higher planting density requires higher inputs as costs for seedlings, soil preparation, and fertilization *etc*. Therefore, cost-benefit analysis should be considered before practicing.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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