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Importance of Fertilization on Growth and Biomass of Acacia Plantations in 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, VTL, TDM, PDS, VVT, NQH, PTD, NHT, NVK, THQ, NHH, DHD, TAH, DQT, HVT, HTL and DTD designed the study and performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

To increase productivity of forest plantation, fertilization has been widely applied, especially in poor soil condition, of which Nitrogen (N), Phosphorous (P), Potassium (K) and compost are usually used. The amount is decided basing mainly on species and soil condition. The objective of this study is to examine the effects of fertilization on growth of acacia plantations. Four fertilization treatments (100 g NPK+200 g compost, 150 g NPK+150 g compost, 200 g NPK+100 g compost, and control) were applied at planting for *Acacia hybrid* and *Acacia auriculiformis* plantations with planting density of 1,330 trees ha^{-1} (spacing 2.5 × 3 m) in Northeast Vietnam at 21°38'N and 107°32'E. Data included survival rate, diameter at breast height (DBH), stem height, and crown diameter (D_c) were collected, and then dry biomass was calculated basing on available allometries.

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The results indicated that fertilizations had significant effects on DBH, D_c, and dry biomass of 4-year-old plantations of both species. Meanwhile, fertilization did not affect on survival rate. A 4-year-old *A. hybrid* plantation had largest DBH (12.4 cm) and highest dry biomass (66.1 Mg ha^{-1}) in the treatment of 200 g NPK+100 g compost, and smallest DBH (11.3 cm) and lowest dry biomass (53.3 Mg ha^{-1}) in control. A 4-year-old *A. auriculiformis* had largest DBH (8.6 cm) and highest dry biomass (36.6 Mg ha^{-1}) in treatment of 100 g NPK+200 g compost, and smallest DBH (5.1 cm) and lowest dry biomass (12.3 Mg ha^{-1}) in treatment of 200 g NPK+100 g compost. In all fertilization treatments, dry biomass of a 4-year-old *A. hybrid* plantation was significant higher than that of a 4-year-old *A. auriculiformis* plantation; ranging from the highest of 537% in treatment of 200 g NPK+100 g compost to the lowest of 178% in treatment of 100 g NPK+200 g compost. To grow *A. hybrid*, 200 g NPK+100 g compost should be applied, while 100 g NPK+200 g compost should be applied for *A. auriculiformis*.

Keywords: Fertilizer requirement; growing stages; soil condition; sustainable yield; wind damage.

1. INTRODUCTION

Acacias are fast growing tree species, which could meet the growing demands of pulp wood and timber. For optimum growth and development, planted trees require large amount of nutrients [1]. Nitrogen, phosphorous, and potassium play an important role in growth and development of plants [2-4], especially when trees are planted in poor soil [5]. As more high-yielding materials are planted, therefore nutrient requirement becomes more intense due to the close relationship between biomass and nutrient supply [6]. Knowledge of nutrient relations in acacia plantations is therefore imperative for the application of nutrient to maintain nutrient contents within limits that ensure the yield sustainability.

Different growth stages of the forest control nutrient demand, storage, and distribution in trees. In the beginning stage after planting, the gross productivity proportion of the forest is highest in the crown, with high nutrient concentrations in leaves and branches. Redistribution of nutrients by leaf senescence is small during this period, and great amount of nutrients are absorbed from the soil. This stage is characterized by increased nutrient accumulation rates, which peak during the crown closing phase [7,8]. Growth may be restricted by a limited soil nutrient supply due to the high demand. Therefore, fertilization for planted trees is widely applied.

In Vietnam, plantation of acacias is becoming increasingly important in contributing to the national economy and livelihood of million people in rural areas [9], when logging timber from natural forest is prohibited. Acacias are the major raw material of the pulp and paper industries in Vietnam and for export, so it is imperative that fertilization is important to increase productivity for acacia plantations. The objective of this study is to examine the effects of fertilization on growth of acacia plantations in Vietnam.

2. MATERIALS AND METHODS

2.1 Study Site

This study was conducted in Quang Ninh Province in Northeast Vietnam at 21°38'N and 107°32'E. 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 soil with average pH of 3.5–3.6, organic matter of 3.2–4.3%, and N of 0.069–0.164% [10].

2.2 Plantation Establishment

This study was conducted for two acacia species, which have been widely planted in Vietnam, including *Acacia auriculiformis* and *Acacia hybrid*.

The fertilization experiment included four treatments as (*1*) 100g NPK+200g compost/tree, (*2*) 150g NPK+150g compost/tree, (*3*) 200g NPK+100g compost/tree, and (4) control (no fertilization). In all fertilization treatments, planting density of 1,330 trees ha^{-1} (spacing 2.5 × 3 m) was used. Fertilization was applied at planting manually. After planting, no further silvicultural techniques were applied.

The experiment was conducted in a randomized complete block with three replicates. Each replicate was conducted in a plot of 20 × 20 m, which included 36 trees. Totally, there were two blocks for two species.

2.3 Data Collection and Analysis

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

Total dry biomass of each stem (B in kg) was estimated as following [11]:

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

Comparison among treatments was conducted with ANOVA one-factor and post-hoc test, while, comparing between two species was conducted by pair-comparison. Statistical analysis was conducted using SAS 9.2.

3. RESULTS

There was no significant difference of survival rate of a 4-year-old *A. hybrid* plantation among treatments (Table 1). Which ranged from lowest 93% in control to highest 94.6% in treatment of 100g NPK+200g compost. The difference of mean stem height among treatments was also not significant. Which was tallest (14.1 m) in treatments of 150 g NPK+150 g compost and 200 g NPK+100 g compost, while the shortest mean stem height (13.6 m) belonged to control.

Means DBH and D_c were statistically significant different among treatments (Table 1). The largest mean DBH (12.4 cm) belonged to treatment of 200 g NPK+100 g compost and the smallest mean DBH (11.3 cm) belonged to control (Table 1). Meanwhile, the largest mean D_c (5.8 m) belonged to treatment of 100 g NPK+200 g compost, and the smallest mean D_c (5.2 m) belonged to control.

The significant difference of DBH led to significant difference of dry biomass of a 4-year-old *A. hybrid* plantation among treatments (Table 1). The highest dry biomass of 66.1 Mg ha^{-1} belonged to treatment of 200 g NPK+100 g compost, reducing to 65.1 Mg ha^{-1} in treatment of 100 g NPK+200 g compost, to 58.3 Mg ha^{-1} in treatment of 150 g NPK+150 g compost, and to 53.3 Mg ha^{-1} in control.

There was no significant difference of survival rate of a 4-year-old *A. auriculiformis* plantation among treatments (Table 2), ranging from lowest 93.7% in control to highest 95.7% in treatment of 200 g NPK+100 g compost. The difference of mean stem height among treatment was significant. Treatment of 100 g NPK+200 g compost had tallest mean stem height of 8.4 m, much taller than that of 150 g NPK+150 g compost (6.0 m), 200 g NPK+100 g compost (6.0 m), and control (6.2 m).

Means DBH and D_c were statistically significant different among treatments (Table 2). The largest mean DBH (8.6 cm) and D_c (2.1 m) belonged to treatment of 100 g NPK+200 g compost. Meanwhile, the smallest mean DBH (5.1 m) belonged to treatment of 200 g NPK+100 g compost, and the smallest mean D_c (1.5 m) belonged to control.

The significant difference of mean DBH led to significant difference of dry biomass of a 4-year-old *A. auriculiformis* plantation among fertilization treatments (Table 2). The highest dry biomass of 36.6 Mg ha^{-1} belonged to treatment of 100 g NPK+200 g compost, reducing to 20.4 Mg ha^{-1} in treatment of 150 g NPK+150 g compost, to 13.0 Mg ha^{-1} in control, and to 12.3 Mg ha^{-1} in treatment of 200 g NPK+100 g compost.

Comparing dry biomass between a 4-year-old *A. hybrid* plantation and a 4-year-old *A. auriculiformis* plantation in each fertilization treatment indicated that *A. hybrid* plantation had much higher dry biomass than that of *A. auriculiformis* plantation (Fig. 1). The comparison was 537% in treatment of 200g NPK+100 g compost, reducing to 410% in control, to 286% in treatment of 150 g NPK+150 g compost, and to 178% in treatment of 100 g NPK+200 g compost.

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

Fertilization treatment	Survival rate (%)	DBH (cm)	H (m)	D_c (m)	Dry biomass (Mg ha^{-1})
100 g NPK+200 g compost	94.6 ±0.33	12.3 ±0.91^{a}	14.0 ±0.91	5.8 ±0.62^{a}	65.1 ±1.0^{a}
150 g NPK+150 g compost	94.3 ±0.88	11.7 ±0.85^{ab}	14.1 ±1.01	5.6 ±0.51^{a}	58.3 ±2.3^{b}
200 g NPK+100 g compost	94.3 ±0.33	12.4 ±0.87^{a}	14.1 ±0.99	5.7 ±0.56^{a}	66.1 ±1.7^{c}
Control	93.0 ±0.58	11.3 ±0.79^{b}	13.6 ±0.92	5.2 ±0.51^{b}	53.3 ±0.9^{b}

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

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

Fertilization treatment	Survival rate (%)	DBH (cm)	H (m)	D_c (m)	Dry biomass (Mg ha^{-1})
100 g NPK+200 g compost	95.0 ±0.58	8.6 $\pm0.76^a$	8.4 $\pm0.71^a$	2.1 $\pm0.15^a$	36.6 $\pm0.4^a$
150 g NPK+150 g compost	95.3 ±0.88	6.5 $\pm0.45^b$	6.0 $\pm0.64^b$	1.8 $\pm0.17^a$	20.4 $\pm0.3^b$
200 g NPK+100 g compost	95.7 ±1.20	5.1 $\pm0.41^c$	6.0 $\pm0.59^b$	1.5 $\pm0.13^b$	12.3 $\pm0.2^c$
Control	93.7 ±0.88	5.3 $\pm0.44^c$	6.2 $\pm0.61^b$	1.5 $\pm0.11^b$	13.0 $\pm0.3^c$

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

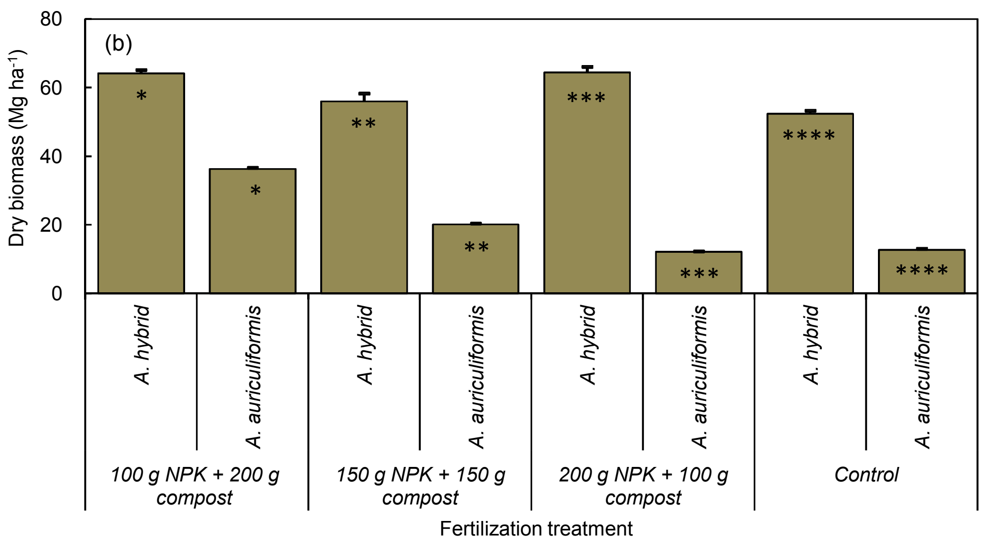

Fig. 1. Comparison of dry biomass between 4-year-old *A. hybrid* and *A. auriculiformis* plantations in different fertilization treatments

Bars indicated ±SD. Asterisks indicated the significant difference of dry biomass in corresponding fertilization treatment at p = 0.05

4. DISCUSSION

Like any other crops, the response to fertilization in acacia plantations depends on degree of mismatch between nutrient supply and nutrient demand. Water supply is similarly a strong driver of growth [12,13]. However, this experiment was conducted in the same site with high annual precipitation of 1,850–1,900 mm, assuming the same water supply for all treatments. Therefore, nutrient supply is the main determinant of growth of acacia plantations in this study. Nutrient did not affect on survival rate for both species at all treatments, as seedlings were planted in rainy season with enough water supply for initial growth. Generally, survival rate of trees planted in moderate and rich soil condition is controlled mainly by water supply other than availability of nutrient [10]. Therefore, there was no significant difference of survival rates in both species among four fertilization treatments (Tables 1 and 2).

It seems that compost fertilizer is much better supporting growth of both *A. auriculiformis* and *A. hybrid* as they had better growth of DBH and D_c in treatment with the higher amount of compost (Tables 1 and 2). Water holding capacity of compost is better than NPK, leading to stabilizing soil moisture. In addition, NPK loses easier than compost by rainfall, which causes leaching and soil erosion. Further activities of soil microorganisms are required to decompose compost for nutrient availability, while this process is not required for NPK. Therefore, in poor soil both compost and NPK are encouraged to be supplied at planting; NPK is immediately available for planted trees in initial growth, while compost will be decomposed gradually for later growth. In medium soil condition, compost is encouraged at planting other than NPK. Planted trees can get enough nutrients already available in soil for initial growth, therefore supporting NPK may lead to loss through leaching other than absorbing by planted trees.

Crown diameter represents Leaf Area Index (LAI) of plantation. At the same planting density of 1,330 trees ha^{-1}, D_c of a 4-year-old *A. hybrid* plantation was much larger than that of a 4-year-old *A. auriculiformis* plantation, leading to higher LAI in *A. hybrid* plantation. There is positive relationship between LAI and growth of plantation when LAI increases up to 7 [13,14], as higher photosynthesis capacity leads to higher Net Primary Production [15]. In this study, the difference of D_c between two plantations led to difference of DBH, which was much larger in *A. hybrid* plantation than that in *A. auriculiformis* plantation, and finally resulted in much higher dry biomass in *A. hybrid* plantation (Fig. 1). With the mean D_c of less than 2.1 m in a 4-year-old *A. auriculiformis* plantation, generally there was no crown closure, indicating growing space is still available in this plantation as less competition among planted trees. To increase biomass of *A. auriculiformis* plantation, increasing planting density is possible to fully use available resource in the site. Meanwhile, for *A. hybrid* plantation there may be high competition among planted trees in the next ages as high level of crown closure from larger D_c (Table 1). Thinning should be conducted to support growth of remaining trees or it should be planted with planting density of less than 1,330 trees ha^{-1} as applied in the present study to reduce competition when plantation gets older than 4 years old.

One may prefer growing *A. hybrid* other than *A. auriculiformis*, because of its higher productivity (Fig. 1) [16]. However, Vietnam is a monsoon country, where there may have more than 15 storms passing a year and wind speed may reach >12 m s^{-1}. Those have been causing fall down of many acacia plantations, especially for *A. hybrid*. Seedlings of *A. hybrid* used for plantation are produced by cuttings, which usually have no tap root of planted tree. Only lateral roots could not support the planted trees against strong wind. Therefore, planting *A. hybrid* is not encouraged for areas close to coasts or where there may have many storms crossing every year. Such areas should be planted with *A. auriculiformis*. Even lower productivity, it may bring higher benefit to forest growers as its stability to harsh environment condition of storming wind. In addition, *A. auriculiformis* should be planted in denser density of >1,330 trees ha^{-1}, which will help plantation in reducing wind momentum and standing firmly.

5. CONCLUSIONS

Acacia plantations have contributed to poverty reduction in Vietnam. To increase its productivity, NPK fertilizer has been applied widely. This study indicated that applying 200g NPK+100g compost per tree at planting to *A. hybrid* plantation of 1,330 trees ha^{-1} resulted in highest dry biomass of 66.1 M g ha^{-1} at the age of 4-years old. Meanwhile, the best fertilization treatment is 100 g NPK+200 g compost per tree at planting for *A. auriculiformis* plantation of 1,330 trees ha^{-1}, resulting in highest dry biomass of 36.6 Mg ha^{-1} at the age of 4-years old.

In any fertilization treatments and control, *A. hybrid* grew better than *A. auriculiformis*, indicating much higher dry biomass of *A. hybrid* plantation. Even *A. hybrid* plantation in control experiment (no fertilization) had significant higher dry biomass compared to that of *A. auriculiformis* plantation in any fertilization treatments.

Plantation of *A. hybrid* should not be established in areas close to the coasts or where there are storms passing. Because they will cause trees falling down, leading to low benefit. Meanwhile, planting *A. auriculiformis* in those areas should be conducted in denser density of >1,330 trees ha^{-1} to reduce wind momentum and therefore number of falling-down trees.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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