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Aboveground Net Primary Production at *Acacia mangium* Plantation in Northern Vietnam

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Authors' contributions

This work was carried out in collaboration among all authors. Authors TVD, NTT, VTL, DVT, PDT, PDS, THQ, NTTP, LTTH, NHT, NVT, DTD, DTHH, DQT, HTL, NTHA and MTL designed the study and conducted field works. Author TVD managed the literature searches, performed the statistical analysis, and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Net primary production (NPP) is an important index for understanding carbon cycling in forest ecosystems. In this study, aboveground NPP at *Acacia mangium* plantation was estimated basing on allometry for aboveground biomass increment (ΔM) and litter trap technique for litterfall (Lf). The experiment was conducted in two plots of 300 m^2 each (15 × 20 m), established at a 21-month old plantation. Data were collected five times of 3-month intervals in a total duration of 357 days. The results indicated that Lf and ΔM were seasonal-dependent. Litterfall was highest (4.06 g m^{-1} day^{-1}) during Sep-Jan (late rainy season, early winter) and lowest (1.10 g m^{-1} day^{-1}) during Mar-Jun (early rainy season, early summer). While, ΔM was highest (13.51 g m^{-1} day^{-1}) during Jun-Sep (rainy

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season, summer) and lowest (3.10 g m^{-1} day^{-1}) during Jan-Mar (dry season, winter). Total Lf in a duration of 357 days was 9.69 tons ha^{-1} and ΔM was 27.71 tons ha^{-1}, leading to total aboveground NPP of the present study plantation of 37.40 tons ha^{-1}. It is concluded that aboveground NPP of acacia plantation was much higher than other forests of different types and ages around the world. Such difference indicates the importance of acacia plantation in soil nutrient cycling through litterfall decomposition and carbon sequestration through aboveground biomass increment.

Keywords: Aboveground biomass; acacia plantation; carbon cycle; litterfall; nutrient return.

1. INTRODUCTION

Net primary production (NPP) and heterotrophic respiration represent fluxes of carbon exchange between ecosystems and the atmosphere. NPP is an important index for the evaluation of patterns, processes, and dynamics of carbon cycling in forest ecosystems [1]. NPP of forest ecosystem drives heterotrophic activities and controls net ecosystem production. Changes in NPP could have global significance and change ecosystem function and structure [2-3], therefore estimating NPP of forests around the world is necessary. NPP of forest includes aboveground NPP (ANPP) and belowground NPP (BNPP). ANPP includes increment of aboveground biomass (AGB) and litterfall [4-5]. While, BNPP includes increment of coarse roots and production of fine roots [6]. ANPP is estimated mainly basing on available allometries for AGB increment and litter trap technique for litterfall [7].

Many studies have been conducted for NPP of evergreen broadleaved forests [8-10]. Such studies for ANPP in plantations were also conducted [11-14]. ANPP of forests is depending on forest types, geographical locations, and species. It could be low as 0.49 g m^{-2} d^{-1} in an old-growth *Larix gmelinii* stand, central Siberia [15], 1.59 g m^{-2} d^{-1} in an old-growth *Cryptomeria japonica* plantation, central Japan [16], and 4.41 g m^{-2} d^{-1} in an old-growth *Pinus kesiya* forest, northeastern India [17]. While, in natural forest it could be 1.92 g m^{-2} d^{-1} in a cool-temperate broadleaved deciduous forest, central Japan [18], 3.53 g m^{-2} d^{-1} in tropical forest in central Amazon [4], and 5.41 g m^{-2} d^{-1} in tropical rain forests on Mount Kinabalu, Borneo, Malaysia [19].

ANPP changes locally, regionally, and globally. Therefore, estimating ANPP of any forest ecosystem locally will provide us more understanding on forest carbon cycling and its function against increase of atmospheric carbon causing global warming and climate change. The aim of the present study is to estimate ANPP of *Acacia mangium* plantation in Northern Vietnam.

2. METHODS

2.1 Site Description

This study was conducted at the Forest Experiment Station (FES), College of Agriculture and Forestry Northeast, located in Quang Ninh province Vietnam. The site has monsoon climate conditions with an annual temperature of 22.2°C and air humidity of 81% [20]. A total annual precipitation ranges 1.600–2.200 mm with 153 annual rainy days.

The site for the experiment in this study locates on flat land with a slope of <3°. The site was classified as bared land with some trees of pines and other shrubs which were shorter than 3 m. It was cleared and burnt to prepare the site for planting *A. mangium*. The soil is classified as Ferralic Acrisol with a depth of 60–80 cm. Soil sample analysis indicated a pH of 3.7, organic matter of 2.7%, N of 0.18%, P of 2.2 mg P_2O_5/100 g soil, K of 3.5 mg K_2O/100 g soil.

A. mangium plantation was 21 months old at the time of experiment start. The plantation was established with density of 1,100 trees/ha (3 × 3 m) and had the survival rate of >98%. The plantation had mean diameter at breast height (DBH) of 7.2 cm, stem height of 6.2 m, and crown diameter of 4.0 m.

Two plots of 300 m^2 each (15 × 20 m) containing 30 *A. mangium* trees (total 60 trees in two plots) were established for measuring diameter at breast height (DBH) and letter trap setting.

2.2 ANPP Estimation

Two compartments were included in the ANPP estimation as ANPP = ΔM + Lf (ΔM is aboveground biomass increment, Lf is litterfall). Herbivore loss due to insects and wildlife was assumed to be negligible.

2.2.1 Aboveground biomass increment estimation

ΔM at each time interval was estimated basing on measured DBH at times t_i and t_j. First aboveground biomass (AGB) of each stem was estimated as AGB = 0.223*$DBH^{2.251}$ [21], then ΔM = AGB_j - AGB_i. Where, AGB_i is aboveground biomass basing on DBH measured at time t_i and AGB_j is aboveground biomass basing on DBH measured at time t_j. DBH was measured at three month intervals in Mar, Jun and Sep 2018, and Jan and Mar 2019 in a total duration of 357 days.

2.2.2 Aboveground litterfall

Lf (including all fallen materials, such as leaves, branches and productive organs) was estimated based on 10 square litter traps of 1 m^2 each, distributed randomly in two plots (five litter traps per plot). Litter was collected at three month intervals in Jun and Sep 2018, and Jan and Mar 2019, the same dates of DBH measurement. The litter was then oven dried at 105°C to a constant mass and weighed to obtain the dry mass.

2.3 Statistical Analysis

Mean litterfall and its spatial variation as standard errors were estimated basing on all ten litter traps. While, mean DBH, basal area, AGB, and ΔM and their spatial variations as standard errors were estimated basing on all 60 measured trees. Univariate analysis of variance (ANOVA) and post-hoc test were used to evaluate effects of collected intervals/season on litterfall and ΔM. SAS 9.2 was employed for statistical analysis.

3. RESULTS

3.1 Growth and AGB of *A. mangium* Plantation

Mean DBH of *A. mangium* plantation increased with stand age increase (Fig. 1). There were low spatial variations (SE) of the mean DBH, indicating the homogeneity of planted trees. At 21 months (Mar, 2018) after planting, stand achieved 7.2 cm in DBH. It increased to 9.97 cm at 33 months (Mar, 2019) after planting (Fig. 1).

As results of increasing DBH, stand basal area also increased (Fig. 1). It was 4.82 m^2 ha^{-1} at 21 months (Mar, 2018) after planting, increasing to 7.60 m^2 ha^{-1} after planting 27 months (Sep, 2018) and to 9.04 m^2 ha^{-1} after planting 33 months (Mar, 2019).

The similar pattern with basal area, AGB of *A. mangium* plantation increased with stand ages (Fig. 2). It was 23.3 Mg ha^{-1} at 21 months (Mar, 2018) after planting, increasing to 27.5 Mg ha^{-1} after planting 24 months (Jun, 2018), to 38.8 Mg ha^{-1} after planting 27 months (Sep, 2018), to 44.5 Mg ha^{-1} after planting 30 months (Jan, 2019), and to 47.0 Mg ha^{-1} after planting 33 months (Mar, 2019).

3.2 Aboveground Litterfall

Litterfall was seasonal-dependent (Fig.3), which was highest duration Sep-Jan, 2019 (4.06 g m^{-2} day^{-1}), reducing to 3.36 g m^{-2} day^{-1} during Jan-Mar, 2019, to 2.29 g m^{-2} day^{-1} during Jun-Sep, 2018, and to 1.10 g m^{-2} day^{-1} during Mar-Jan, 2018.

3.3 Aboveground Biomass Increment

AGB increment was also seasonal-dependent, however the pattern was litter different from litterfall (Fig. 3). The highest ΔM occurred during Jun-Sep, 2018 (13.5 g m^{-2} day^{-1}), reducing to 6.76 g m^{-2} day^{-1} during Sep-Jan, 2019; to 4.93 g m^{-2} day^{-1} during Mar-Jun, 2018; and to 3.01 g m^{-2} day^{-1} during Jan-Mar, 2019 (Fig.3).

3.4 Total ANPP

Total litterfall in the present study *A. mangium* plantation was 9.69 Mg ha^{-1} in a duration of 357 days (Table 1). While, total ΔM was 27.71 Mg ha^{-1}, nearly three times of litterfall. Total ANPP of the present study plantation was 37.40 Mg ha^{-1} in a duration of 357 days.

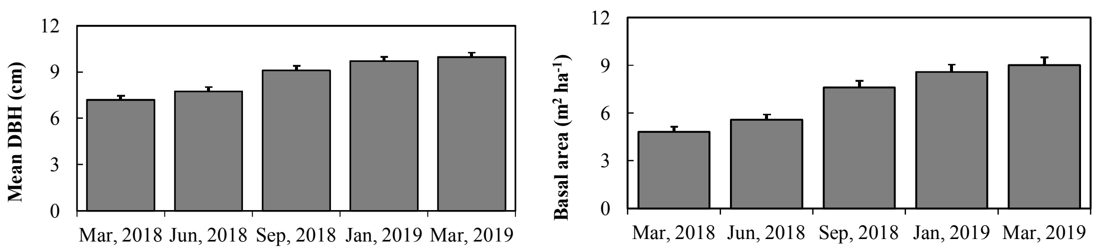

Fig. 1. Diameter at breast height (DBH) and basal area of an *A. mangium* plantation. Bars indicate +SE

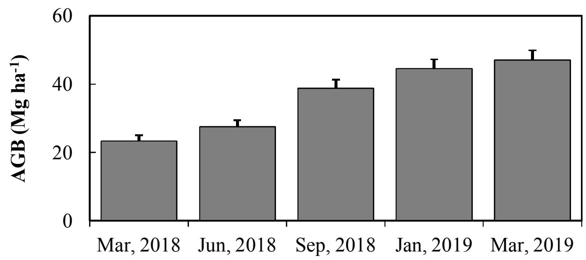

Fig. 2. Aboveground biomass (AGB) of an *A. mangium* plantation. Bars indicate +SE

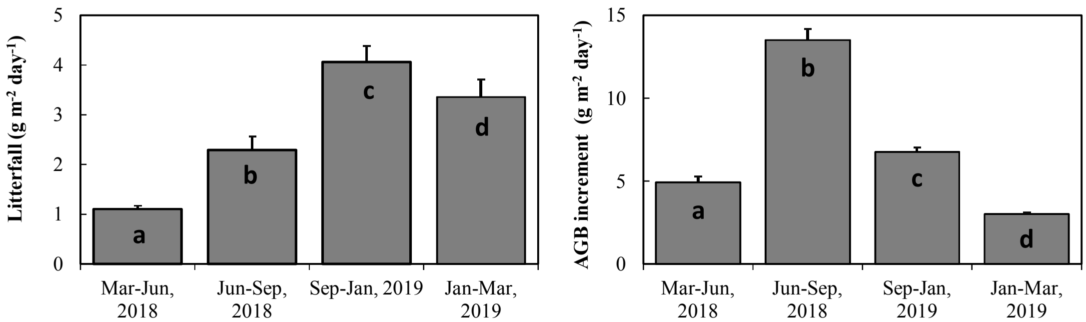

Fig. 3. Litterfall and aboveground biomass (AGB) increment of an *A. mangium* plantation. Bars indicate +SE. Different letters (a, b, c, and d) indicate significant difference of means at p <0.1

Table 1. Litterfall, aboveground biomass (AGB) increment, and total aboveground NPP (±SE, Mg ha^{-1}) at an *A. mangium* plantation

Time interval	Number of days	Litterfall	AGB increment	Total aboveground NPP
Mar-Jun, 2018	84	0.93 ±0.06	4.14 ±0.28	5.07 ±0.34
Jun-Sep, 2018	108	2.48 ±0.30	14.59 ±0.71	17.06 ±1.01
Sep-Jan, 2019	107	4.34 ±0.35	7.24 ±0.28	11.58 ±0.63
Jan-Mar, 2019	58	1.95 ±0.20	1.75 ±0.07	3.70 ±0.2
Total	**357**	**9.69 ±0.91**	**27.71 ±1.34**	**37.40 ±2.25**

4. DISCUSSION

Acacias are well-known as fast-growing tree species, which can grow well in poor nutrient soil and promote soil fertility through huge amount of litterfall and biological nitrogen fixation. In a duration of nearly one year, an *A. mangium* plantation in the present study returned 9.69 Mg ha^{-1} of litterfall, which will be soon decomposed to return nutrient to the soil. The ANPP of the present study plantation is much higher than other forests around the world, including tropical natural forests [19] (19.75 tons ha^{-1} year^{-1}); [22] (13.58 tons ha^{-1} year^{-1}); [4] (12.88 tons ha^{-1} year^{-1}), temperature natural forests [6] (10.38 tons ha^{-1} year^{-1}); [18] (7.01 tons ha^{-1} year^{-1}), temperature plantations [17] (16.1 tons ha^{-1} year^{-1}); [23] (17.56 tons ha^{-1} year^{-1}); [16] (5.80 tons ha^{-1} year^{-1}), and boreal forest [15] (1.79 tons ha^{-1} year^{-1}). This again indicates the important of acacia trees in soil fertility improvement and carbon cycling.

Litterfall is seasonal-dependent (Fig. 3). Jun-Sep is known as rainy/summer season in the present study site, therefore it had highest AGB increments (Fig. 3), but low litterfall. In this duration, to support high AGB increment trees had to speed up photosynthesis, therefore litterfall must be low. In addition, it is summer with high radiation supporting higher photosynthesis rate. In duration of late rainy season (Sep-Jan) and winter (Jan-Mar), trees slow their growths and photosynthesis, leading to much higher litterfall to balance energy. Therefore, generally higher litterfall leads to lower AGB increment (Fig. 3). Lowest litterfall during Mar-Jun could be explained by spring and easily growing season, when new leaves are formed to prepare for the following growing season, and by falling of old leaves during Sep-Jan and Jan-Mar (Fig. 3). Again, AGB increment was lowest during Jan-Mar known as winter/dry season in the present study. Therefore, growths of *A. mangium* are much affected by climate conditions as temperature and soil moisture.

High amount of litterfall can improve soil in short time through decomposition, which returns nutrients (N, P, and K) to the soil and increases water holding capacity through higher soil organic carbon. However, decomposition also returns carbon to atmosphere, reducing net ecosystem production of forest ecosystem [9]. Therefore, any silvicultural techniques, which can improve AGB increment and reduce litterfall, are important for carbon sequestration of *A. mangium* plantation. Besides litterfall, there is huge amount of dead fine roots [9, 24], which are also decomposed to release carbon. Vogt et al. [25] indicated that fine root production may account up to 50% of the total NPP in forest ecosystem. In addition, longevity of fine roots are short compared to tree life [24, 26-27]. Therefore, total litterfall and dead fine roots in the present study forest must be very high (e.g., double of litterfall, equaling 20 tons ha^{-1} $year^{-1}$).

Net primary production includes both aboveground and belowground compartments [6] and BNPP may contribute to total NPP more than ANPP. Therefore, to fully understand the role of acacia plantation on forest carbon cycle, estimating BNPP is necessary and should be conducted. Several new and simple methods for estimating BNPP were recently initiated [9, 14, 27], which can be applied in any forest types including plantations.

5. CONCLUSION

Net primary production (NPP) is important to understand forest carbon cycling and atmospheric carbon controlling. Aboveground NPP (ANPP) was estimated for *A. mangium* plantation in Northern Vietnam. The AGB increment and litterfall, two components of ANPP, were seasonal-dependent. The AGB increment was highest in rainy/summer season and lowest in winter/dry season. While, litterfall was highest in late rainy season and lowest in early growing/rainy season.

In a duration of 357 days, a plantation of *A. mangium* in Northern Vietnam increased 27.71 tons ha^{-1} for AGB, and amount of litterfall was 9.69 tons ha^{-1}. Total ANPP of the present study plantation was 37.40 tons ha^{-1}. Such amount is much higher than other forests around the world, including old and young plantations, and natural forests in tropics, temperatures and boreal.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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