Contribution of Litterfall to Aboveground Net Primary Production in *Acacia hybrid* Plantation, Northeast Vietnam

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Authors’ contribution

Author TVD designed the experiment, gathered the initial data, performed data analysis and wrote the manuscript.

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ABSTRACT

Carbon input to forest ecosystem is mainly from Net Primary Production (NPP), therefore estimating NPP becomes important to understand the global carbon cycle. In this study, allometry for aboveground biomass increment (ΔAGB) and litter trap technique for litterfall (LF) were used for estimating aboveground NPP in *Acacia hybrid* plantation, Northeast Vietnam. The experiment was conducted in a plot of 300 m² (15×20 m) established in a 21 month old plantation and conducted in a duration of one year. Data were collected in 3 month intervals with a total of five field-measurements. The results indicated that LF and ΔAGB were seasonally dependent. Litterfall was highest (3.38 g m⁻² day⁻¹) during September-January (winter) and lowest (0.61 g m⁻² day⁻¹) during March-June (early summer). While ΔAGB was highest (7.7 g m⁻² day⁻¹) during June-September (summer) and lowest (2.3 g m⁻² day⁻¹) during January-March (winter). Total LF was 7.27 tones ha⁻¹ year⁻¹ and ΔAGB was 18.94 tones ha⁻¹ year⁻¹. The total aboveground NPP of *Acacia hybrid* plantation was 26.31 tones ha⁻¹ year⁻¹. It is concluded that LF plays an important role in soil nutrient cycling in *Acacia hybrid* plantation.

Keywords: Carbon cycle; litterfall; nutrient return; seasonality; summer season.

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1. INTRODUCTION

Plantation of exotic trees has been contributing significantly to the rural economy in many regions [1]. *Acacia* plantations are increasingly important to the national economy of Vietnam and contribute significantly to livelihood of million people in rural areas [2]. More than 50% of total plantation areas in Vietnam were established with *Acacias* by 2013. Understanding litterfall in a plantation is important for sustainable management because litterfall contributes significantly to the nutrient cycle in the plantation ecosystem [3,4].

Litterfall plays an important role in nutrient cycling in forest ecosystems [5]. The maintenance of fertility in tropical forests has long been attributed to the recycling of nutrients through decomposition of litterfall as a large proportion of available nutrients in soils is tied up in the living biomass and recycled with the decomposition of litter [6,7]. Nutrients in leaves and litter may directly reflect soil fertility [8] and consequently, litterfall and its nutrients have been used as a measure of site fertility in forest [9].

Net Primary Production (NPP) is important in evaluating the pattern, process, and dynamic of the carbon cycle and nutrient cycling [10]. Heterotrophic respiration is derived by litterfall and other soil organic carbon, which control carbon sequestration in a forest [11]. The NPP change will affect ecosystem function and structure [12], therefore estimating NPP is necessary to understand the role of forest on atmospheric carbon [13]. Litterfall and increment of aboveground biomass (AGB) are two components of aboveground NPP (ANPP) [14]. Forest types, ages, climate conditions, geographical locations, and species govern ANPP. Aboveground NPP reduces with stand age [15,16] and is generally higher in tropics than in temperate and boreal areas [17,18]. Because ANPP changes globally, regionally, and locally, estimating ANPP of any forests will provide a better understandings of carbon cycling and nutrient returns, which is important for sustainable management of plantations. The aim of this study is to estimate the ANPP of *Acacia hybrid* plantation in Northeast Vietnam.

2. MATERIALS AND METHODS

2.1 Study Site

The study was conducted in Northeast Vietnam at 21°4'9.14"N and 106°48'30.81"E. The site is located in the monsoon climate region with an average temperature of 22.2°C and air humidity of 81% [19]. The site has an annual precipitation of 1,600–2,200 mm and 153 rainy days in a year [19]. The soil at the site is classified as Ferralic Acrisol with a depth of 60-70 cm. At the time of the experiment, the soil had a pH of 3.6, organic matter of 2.6%, Nitrogen of 0.18%, and Phosphorus of 2.1 mg P<sub>2</sub>O<sub>5</sub>/100 g soil [20].

The *A. hybrid* plantation was 21 months old at the start of the experiment in March 2018. A planting density of 1,100 trees/ha (3×3 m) was used for plantation establishment in June 2016. A plot of 300 m<sup>2</sup> size (15×20 m) containing 27 *A. hybrid* trees was established for setting litter traps and measuring the diameter at breast height (DBH). The initial planting included 30 trees in that plot, however for the duration of the experiment it included only 27 trees as three individuals were dead less than 6 months after planting.

2.2 ANPP Estimation

Aboveground Net Primary Production (ANPP) was estimated as ANPP = ΔAGB + LF (ΔAGB is aboveground biomass increment and LF is litterfall).

2.2.1 Estimating aboveground biomass increment

The DBHs of all 27 trees in the plot were measured at three-month intervals in March, June and September 2018, as well as January and March 2019. ΔAGB at a time interval was estimated basing on DBHs measured at times t<sub>i</sub> and t<sub>j</sub>. First AGB (kg) of each stem was estimated as AGB = 0.223·DBH<sup>3.1661</sup> [21], then ΔAGB of each stem was estimated as ΔAGB = AGB<sub>j</sub> - AGB<sub>i</sub>. Where, AGB, and AGB<sub>i</sub> are aboveground biomass at time t<sub>i</sub> and t<sub>j</sub>, respectively. The sum of ΔAGB of all 27 stems was plot ΔAGB, which was converted to the unit of tones per hectare, equaling (ΔAGB/300)×10<sup>3</sup>.

Basal area of each stem was estimated basing on measured DBHs (cm), equaling [3.14*(DBH/100)<sup>2</sup>]/4. Then, sum of basal area of all stems is basal area of the plot (m<sup>2</sup> 300 m<sup>2</sup>).

2.2.2 Aboveground litterfall

The LF (all fallen materials to litter traps including leaves, branches, and productive organs) was estimated based on 12 litter traps of 1 m<sup>2</sup> each distributed randomly in the plot. Litter was
collected at three-month intervals on the same dates of measuring DBHs. The litter was then dried in an oven at 105°C to a constant mass and weighed to obtain the dry mass for each litter trap separately at each time interval.

2.3 Statistical Analysis

Mean litterfall and its spatial variation among 12 litter traps as standard errors were estimated. While mean DBH, basal area, AGB and ΔAGB, and their spatial variation as standard errors were estimated based on all 27 measured trees in the plot. Univariate analysis of variance and post-hoc tests were used with statistical significance ($P < .05$).

3. RESULTS

3.1 Growths and AGB

The DBH of A. hybrid trees increased with plantation ages (Figs. 1 and 2). A 21-month old plantation had an average DBH of 8.03 cm, increasing to 10 cm at 27 months old and to 10.54 cm at 33 months old. The relationship between ages and DBH was best fitted by Logarithmic pattern ($R^2 = 0.94$; Fig. 2). The same patterns of increase with increasing plantation ages were found in basal area and AGB (Figs. 1 and 2), indicating Logarithmic pattern is best fitted for basal area and age relationship, and power pattern is best fitted for AGB and age relationship (Fig. 2). In March 2019, when the plantation was 33 months old, the basal area achieved 0.257 m$^2$ 300 m$^2$, while AGB was 1,086.4 kg 300 m$^2$ (Fig. 1).

3.2 DBH and Basal Area Increment

There was a difference of DBH increment among collected intervals (Fig. 3), indicating its seasonal dependence. The difference was statistically significant ($P = .05$). The lowest DBH increment was found during January-March (winter), increasing to September-January (late summer, winter) and March-June (spring and early summer); the highest DBH increment was found during summer/rainy season (June-September).

The pattern of basal area increment was similar to that of DBH increment (Fig. 3), indicating seasonal dependence ($P = .05$) as the highest one during summer (June-September) and lowest during winter (January-March).

![Fig. 1. Diameter at breast height (DBH), basal area, and aboveground biomass (AGB) of Acacia hybrid plantation. Bars indicate +SE](image1)

![Fig. 2. The best-fitted relationships between stand age and DBH, basal area and aboveground biomass (AGB)](image2)
3.3 Biomass Increment, Litterfall and ANPP

The difference among the collected intervals was statistically significant ($P = .05$), indicating the seasonal-dependence of litterfall (Fig. 4). The highest litterfall (3.38 g m$^{-2}$ day$^{-1}$) was found during September-January (late summer, early winter), reducing to 2.12 g m$^{-2}$ day$^{-1}$ during June-September (summer) and to 1.64 g m$^{-2}$ day$^{-1}$ during January-March (winter), and the lowest litterfall (0.61 g m$^{-2}$ day$^{-1}$) was found during March-June (late spring, early summer).

The pattern of AGB increment among collected intervals was different from that of litterfall (Fig. 4). The difference in AGB increment among the time intervals was also significant ($P = .05$). The highest AGB increment (7.7 g m$^{-2}$ day$^{-1}$) was found during June-September, reducing to March-June (4.6 g m$^{-2}$ day$^{-1}$) and January-March (2.3 g m$^{-2}$ day$^{-1}$), and the difference between those two intervals was not significant.

*Acacia hybrid* plantation in this study had a total ANPP of 26.31 tones ha$^{-1}$ year$^{-1}$. In which, AGB increment was 18.94 ±1.0 tones ha$^{-1}$ year$^{-1}$ (accounting for 72%) and litterfall was 7.37 ±0.6 tones ha$^{-1}$ year$^{-1}$ (accounting for 28%).
4. DISCUSSION

The seasonal dependence of litterfall was observed in an Acacia mangium plantation [3], while a similar pattern was found in the present study for Acacia hybrid plantation (Fig. 4). The duration of June-September belongs to summer in the present study site, leading to the highest AGB increment, but the second-highest litterfall. In this duration, low litterfall indicated numerous leaves on trees to support photosynthesis and promote the highest AGB increment. During the September-January and January-March, trees had the lowest AGB increment because it is winter with low radiation and moisture [19]. To sustain their life, trees must shed leaves, leading to high litterfall during these times. In turn, the high litterfall leads to the low AGB increment. The second highest litterfall during June-September accompanied with the highest AGB increment in the present study could be explained by shedding leaves to have more change for newly leafing to support photosynthesis during summer (June-September).

March-June covers late spring and early summer/growing season in the present study site when trees form new leaves. In addition, high litterfall during September-January indicated high shedding of old leaves. Therefore, litterfall was lowest during March-June (Fig. 4). Growth of A. hybrid is significantly controlled by climate conditions such as temperature and moisture like other Acacias [22], leading to the lowest AGB increment during winter (September-January and January-March) and highest during summer (June-September).

Litterfall and its decomposition are important to contribute to the forest carbon cycle and soil nutrient. High litterfall leads to high organic carbon and nutrients in the soil, improving soil water holding capacity and then promoting the tree's growth. However, heterotrophic respiration decomposes litter in the soil and on the forest floor leading to increased atmospheric carbon, causing global warming and climate changes [23]. Therefore, improving AGB increment and reducing litterfall are necessary to enhance carbon sequestration of A. hybrid plantation.

Comparing ANPP among forest types around the world indicated that ANPP of the present study A. hybrid plantation is higher than that in tropical natural forests in Peru (13.58 tones ha\(^{-1}\) year\(^{-1}\)) [24]; in Amazon (12.88 tones ha\(^{-1}\) year\(^{-1}\)) [25], temperature natural forests in Japan (7.01 tones ha\(^{-1}\) year\(^{-1}\)) [17], temperature plantations in northeastern India (16.1 tones ha\(^{-1}\) year\(^{-1}\)) [14]; in young plantation Japan (17.56 tones ha\(^{-1}\) year\(^{-1}\)) [26] and in boreal forest in central Siberia (1.79 tones ha\(^{-1}\) year\(^{-1}\)) [15]. The differences of ANPP are controlled by forest types, ages, climate conditions, geographical locations and stand ages [15,16]. The A. hybrid plantation in this study had litterfall of 7.37 tones ha\(^{-1}\) year\(^{-1}\). This amount could be soon decomposed to return nutrients to the soil, indicating a significant contribution to the soil nutrient cycle. Therefore, planting Acacia in the present study site, Northeast Vietnam could be recommended on the sites with low fertility. By such high amount of litterfall, plantation will soon improve soil fertility for higher production in the following rotations. Meanwhile, if acacia is planted in medium and rich fertility soil, fertilizing plantation is not required as acacia can support itself through high amount of litterfall.

5. CONCLUSION

Twenty eight percent of ANPP belonged to litterfall in A. hybrid plantation in Northeast Vietnam for one-year duration. Such amount (7.37 tones ha\(^{-1}\) year\(^{-1}\)) is a considerable contribution to soil organic matter and nutrient cycling. Long-term study as a rotation of acacia plantation should be conducted to fully understand how much litterfall could contribute to nutrient cycling. High contribution of litterfall to nutrient cycling indicates availability of nutrients for planted trees. Therefore, fertilizing plantation should be carefully considered to reduce loss of applied fertilizer and increase benefits for plantation owners.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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