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Full Length Research Paper

Aboveground biomass and productivity of nitrogen-fixing tree species in the Philippines

Marilyn S. Combalicer[1], Don Koo Lee[2], Su-Young Woo[4], Pil Sun Park[2], Ki Woong Lee[2], Enrique L. Tolentino[5], Edwin A. Combalicer[5], Yong Kwon Lee[6] and Yeong Dae Park[3]*

[1]College of Forestry, Nueva Vizcaya State University, Bayombong, Nueva Vizcaya, Philippines.
[2]Department of Forest Sciences, College of Agriculture and Life Sciences, Seoul National University, Seoul, Republic of Korea.
[3]Research Institute for Agriculture and Life Sciences, Seoul National University, Seoul, Republic of Korea.
[4]Department of Environmental Horticulture, University of Seoul, Seoul, Republic of Korea.
[5]College of Forestry and Natural Resources, Institute of Renewable Natural Resources, University of the Philippines Los Banos, College, Laguna, Philippines.
[6]International Cooperation Division, Korea Forest Service, Daejon, Republic of Korea.

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Aboveground biomass and productivity traits of two nitrogen-fixing exotic species (*Acacia auriculiformis* A. Cunn. ex Benth. and *Acacia mangium* Willd.) and one nitrogen-fixing native species (*Pterocarpus indicus* Willd.) were compared in this study using 10 and 20-year-old age classes. Parameters measured were stand density, basal area, importance value index, aboveground biomass and carbon, annual litterfall, aboveground net primary productivity (*ANPP*), leaf area index (*LAI*), specific leaf weight (*SLW*), and nitrogen productivity. Results of the study showed that *ANPP* and nitrogen productivity were higher in the 20-year-old *A. auriculiformis* (6.28 tons ha^{-1} yr^{-1} and 267.23 kg kg^{-1} yr^{-1}, respectively) and *A. mangium* (6.43 tons ha^{-1} yr^{-1} and 221.72 kg kg^{-1} yr^{-1}, respectively) stands which were attributed to their higher values of litterfall and aboveground biomass and carbon. Also, *SLW* was much higher in the 10- and 20-year-old *A. auriculiformis* (244 and 245 cm^2g^{-1}, respectively) and 20-year-old *A. mangium* (255 cm^2g^{-1}) than *P. indicus* stands. The density of woody species (>5 cm DBH) was highest in the 20-year-old *A. mangium* stand (1,492 trees ha^{-1}) and lowest in the 10-year-old *P. indicus* stand (592 trees ha^{-1}). *Acacia auriculiformis* and *A. mangium* showed better performance in the field which serves as a basis in recommending them for reforestation in the Philippines. These species are very important in the initial establishment of the plantation and could be considered as priority species to lessen the vast degraded areas in the country.

Key words: Aboveground net primary productivity, exotic species, native species, nitrogen productivity, rehabilitation.

INTRODUCTION

Because of the ecological importance as well as due to rapid and extensive deforestation of tropical forests including Philippines, the restoration and rehabilitation of degraded and secondary forest has become an important issue (Parrotta et al., 1997). Many studies have investigated rates of forest clearing and their respective causes (FAO, 2007; Hansen et al., 2008; UNEP, 1999).

Southeast Asia is the region where forests are under the highest pressure and with highest rate of deforestation (Mayaux et al., 2005). And according to

*****Corresponding author. E-mail: parkyd70@snu.ac.kr.

FAO (2007), Philippines is one of the countries in Southeast Asia with the highest rates of forest loss, which is exceeding 1.5% per year. Forest resources have been decreased tremendously due to many human and natural factors. As of 2003, the remaining total forest cover of the country was around 7 million ha or 23% (FMB, 2003), which could be mainly found in Palawan, Mindanao and the uplands of Luzon.

The traditional approach of the Government in rehabilitating degraded areas is through reforestation with fast growing species, usually exotics for commercial tree plantations (de la Cruz, 1995). These include broadleaved species such as *Acacia mangium*, *A. auriculiformis*, *Eucalyptus* spp., *Gmelina arborea*, *Paraserianthes falcataria*, *Swietenia macrophylla*, *Tectona grandis*, and *Leucaena leucocephala* which dominate the plantations of the Philippines (JOFCA, 1996; Lasco and Pulhin, 2003). These species are commonly used for reforestation due to their rapid growth, tolerance of poor soil condition, and commercial wood purposes. The exact area of rehabilitated uplands is not known, but has been estimated at 600,000 ha (Lasco and Pulhin, 2000). Fast growing tree plantations provide wood for various purposes and play a significant role in rural economy in tropical regions. They are also often considered as the soundest way of rehabilitation in the tropics and have been proposed in the Kyoto protocol as a strategy for mitigating the greenhouse effect (Lemma and Olsson, 2006). As these species have a potential to become dominant because of their growth characteristics, it is very important to identify factors that influence their ability to survive in various conditions.

The Philippines has almost a century of experience in reforestation. The Government, people-oriented forestry programs, and local and foreign-assisted projects were implemented all throughout the country. The major driving forces of forest rehabilitation in the Philippines are the scientific needs in finding practical methods of converting *Imperata cylindrica* grassland areas into forest plantations, promoting environmental stability, political factors, economic considerations due to the eminent symptoms of impending timber crisis in the country, and among others (Chokkalingam et al., 2001; Chokkalingam et al., 2006).

Nitrogen-fixing trees are well recognized for their contribution in restoring degraded areas and in improving the productivity of the land. In the Philippines, either exotic or endemic, these species are being used for reforestation. However, their productivity is not well determined or poorly understood. Productivity of plantations depends strongly on soil nutrient supply and it may be flexible under the influence of management practices and species (Binkley, 1997; Kabzems et al., 2011; Setälä et al., 2000). Almost all the plantations in the country are monocultures, and questions are being raised about the sustainability of their growth and their effects on the site (Khanna, 1997).

The objective of this study was to compare the aboveground biomass and productivity traits in the 10- and 20-yr-old age classes of the exotic species, *Acacia mangium* A. Cunn. ex Benth. and *Acacia auriculiformis* Willd., and native species, *Pterocarpus indicus* Willd.

MATERIALS AND METHODS

Study sites and tree species

The study was conducted in Mt. Makiling Forest Reserve (MFR) and La Mesa Watershed in the Philippines (Figure 1). MFR is located at 14°08'14"N latitude and 121°11'33"E longitudes, which is surrounded by rapidly growing industrial and settlement areas. It has a total land area of 4,244 ha and it is said to be an inactive volcano. It forms part of the municipalities of Los Baños, Bay, and Calamba, all in the province of Laguna, and Sto. Tomas, Batangas. MFR is located in the southeast of Metro Manila, which is about 65 km. The climate is tropical monsoon in character with two pronounced seasons: wet from May to December and dry from January to April. The average annual precipitation is 2,334 mm and the mean monthly temperature ranges from 20.9 to 25.9°C. The dominant soil type of the area is clay loam, which is derived from volcanic tuff with andesite and a basalt base (Luna et al., 1999). The study site is located in Sitio Kay Inglesia on the southwest slope of Mt. Makiling at 500 m asl. Its mean monthly relative humidity ranges from 32.6 to 92.3%. This area had been previously cultivated and perennially burned prior to the 1990s. The last time it was burned extensively was in April 1991. To restore this fire-degraded area, *Acacia mangium* and *A. auriculiformis* were planted accompanied by intensive protection from forest fire.

La Mesa Dam Watershed (14°45'N latitude and 121°05'E longitude) (Figure 1) is the last remaining forest of its size and one of the major sources of water in Metro Manila. It is about 2,700 ha, which is 10 km away from Quezon City. It has two pronounced seasons: dry from January to April and wet from May to December. January is the coolest month while March is the hottest. The watershed has a mean annual rainfall of 2,700 mm and mean monthly temperature of 24.2 to 26.6°C. Its mean monthly relative humidity ranges from 22.2 to 94.1%. The study sites are located *P. indicus* plantations with 113 m asl. Most of the common species planted in the area are *Dracontomelon dao*, *Intsia bijuga*, *Swietenia macrophylla*, *Pterocarpus indicus* and many other native species. Illegal settling, slash and burn activities, timber poaching among others were the causes of the devastation of the watershed area. However, through the initiative of the Bantay Kalikasan of the ABS-CBN Foundation, Inc., rehabilitation and reforestation efforts were boosted thereby making La Mesa Watershed now as a "carbon sink" that absorbs 3% of the total carbon emissions of Metro Manila. Field measurements were carried out in the plantations of *Acacia auriculiformis* (10- and 20-yr-old) and *A. mangium* (20-yr-old) in MFR and *Pterocarpus indicus* (10- and 20-yr-old) in La Mesa Watershed. *Acacia auriculiformis* is a well-known tropical species valuable for forestry especially in Southeast Asia and the Indian sub-continent. This species are rapidly growing with good wood quality and can tolerate a range of climatic and soil condition. Similarly, *Acacia mangium* has the same characteristics and it is well-known for its ability to compete with and suppress weedy species like *Imperata cylindrica* and *Eupatorium*. A*cacia* species, which have substantial nitrogen-fixation ability, have been widely used for afforestation and greening in China and other countries (Peng et al., 2005; Nichols and Carpenter, 2006). *Acacia*, especially *A. auriculiformis* and *A. mangium*, were introduced to degraded tropical and subtropical regions to establish forest communities

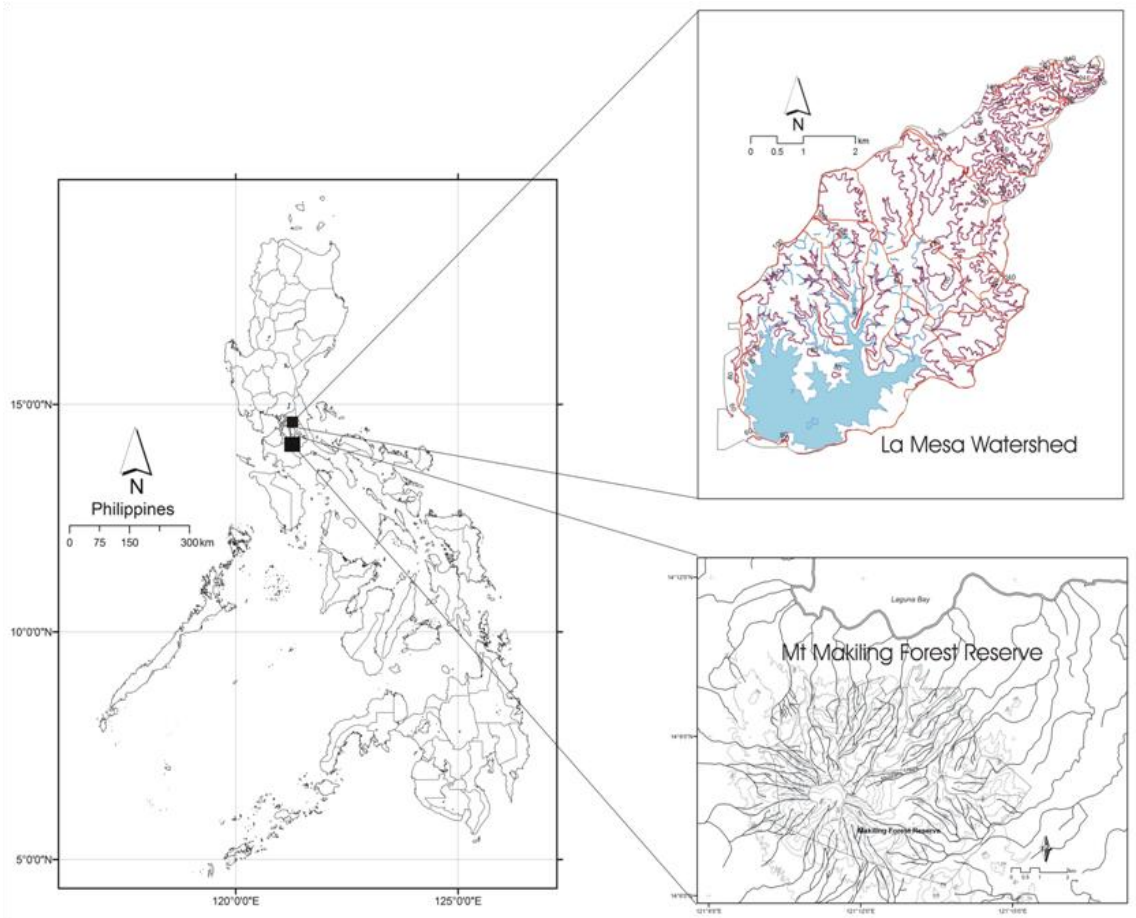

Figure 1. Location of the study sites (Mt. Makiling Forest Reserve and La Mesa Watershed) in the Philippines.

(Norisada et al., 2005; Peng et al., 2005; McNamara et al., 2006). These trees could not only improve soil nutrients, but by shielding against intense radiation and heat loading, they could also facilitate colonization by other plants (Parrotta et al., 1997). *Pterocarpus indicus* is also one of the best-known trees in Southeast Asia and is indigenous in the Philippines. It is known as Narra in the Philippines, the national tree, and favorite timber for the manufacture of fine furniture (Cansanay et al., 2003).

Field layout

In 2003, three sampling plots measuring 20 m × 20 m were established in each of the *A. auriculiformis* and *A. mangium* age class (10 and 20-year-old) stand in Sitio Kay Inglesia, Mt. Makiling, Laguna. Three plots with the same measurement were also established in each of the 10 and 20-year-old stands of *P. indicus* in La Mesa Watershed in 2008. The sites have almost similar amount of rainfall, temperature and relative humidity.

Stand measurements

Stem diameter (DBH) at 1.3 m aboveground of all the trees within each plot (20 × 20 m) was measured using a diameter tape and basal area was calculated as the sum of the individual tree basal areas. Total height of a random sample of trees within each plot was measured using a meter pole at the beginning of the study and after one year. Relative frequency, relative density and relative dominance were obtained to calculate the importance value index (*IVI*) of each species in the *Acacia auriculiformis* (10- and 20-yr-old), *Acacia mangium* (20-yr-old) and *Pterocarpus indicus* (10- and 20-yr-old) stands.

$$Relative\ density\ (RD)\ (\%) = \frac{Number\ of\ individuals\ of\ a\ species}{Total\ number\ of\ individuals} \times 100$$

$$Relative\ frequency\ (RF)\ (\%) = \frac{Frequency\ of\ a\ species}{Frequency\ of\ all\ species} \times 100$$

$$Relative\ coverage\ (RC)(\%) = \frac{Coverage\ of\ a\ species}{Coverage\ of\ all\ species} \times 100$$

$$Importance\ value\ (IV)(\%) = \frac{RD + RF + RC}{3}$$

Aboveground net primary productivity (*ANPP*) was calculated as the sum of litterfall and biomass increment estimated from diameter increments over 6-month periods by biomass allometrics. Stand density was computed in each plot as the number of trees per hectare whereas basal area was computed as follows: $BA = 0.7854 * D^2$, where *BA* is the basal area and *D* is the diameter in meter.

Aboveground biomass and carbon estimation

Tree biomass of *A. auriculiformis, A. mangium* and *P. indicus* was estimated using allometric equation developed by Brown (1997) for tropical moist forest and DBH maximum range: *Y = EXP(-2.134 + 2.530 x LN(D))* where *Y* is the aboveground biomass (kg) and *D* is the DBH (cm).

Within 20 × 20 m plots, all of CWD (≥10 cm) were investigated. The fresh weight and dry weight were also obtained. To measure biomass, the same equation was used and biomass of leaves (about 2 to 3% for heartwood/broadleaf species) was subtracted (Pearson et al., 2005).

The understory/herbaceous vegetation and litters were collected in 2 × 2 m sub–plots. Four sub–plots were established in each of the three plots of *A. auriculiformis* (10 and 20-year-old), *A. mangium* (20-yr-old) and *P. indicus* (10 and 20-year-old) stands. All understory/herbaceous vegetation and litters including fallen branches, leaves and coarse wood debris (CWD: ≤10 cm) were collected and fresh weight was measured in the field. All parts of the samples were mixed uniformly and about 200 g samples were brought in the laboratory for oven drying. The dry weight of samples was measured. Biomass values for litter and understory were calculated using the following formula (Lasco et al., 2005):

$$TODW = \frac{TFW - (TFW * (SFW - SODW)]}{SFW}$$

where, *TODW* is the total oven dry weight; *TFW* is the total fresh weight; *SFW* is the sample fresh weight; and *SODW* is the sample oven-dry weight.

Litterfall

Litterfall was collected monthly for one year (January 2009 to January 2010) for all three species in each plot. Four 0.25 m^2 litter traps made of fine nylon screen were mounted on wooden poles approximately 0.5 m above the ground and distributed randomly in each plot. In the laboratory, the litter was dried at 65°C for approximately 48 h (or until constant weight was obtained) and ground to pass a 1-mm sieve. Samples were sorted in fractions, which included leaves, non-leaves (branches/twigs), and reproductive part (flowers and fruits). Total litter was obtained by adding their weights (Fassnacht and Gower, 1999).

Foliage and soil analysis

Both foliage and fresh litter samples were composited to make up a single sample from each plot. N, P, K, Ca, Mg, Zn, Cu, Mn and Fe were analyzed in the Analytical Services Laboratory of the Soils and Agro-ecosystems Division, College of Agriculture, University of the Philippines Los Banos (UPLB), Laguna, Philippines. Leaf area was measured for the subsequent determination of specific leaf weight (*SLW*). Leaf area index (*LAI*) was estimated optically from nine points within each plot by using hemispherical photography (fish-eye lens) and analyzed using the hemiview software. Nitrogen productivity was determined as the ratio of *ANPP* (on a year basis) to the amount of foliage N.

Soil samples were collected at 0 ± 30 cm depth using soil auger from four random positions in each plot. Samples were put into plastic bags and labeled. The fresh weight of the soils was obtained and were air-dried for 2 to 3 weeks, pulverized and sieved in 2-mm mesh wire. Thereafter, the samples were brought in the Laboratory of Silviculture and Restoration Ecology, Department of Forest Sciences, College of Agriculture and Life Sciences, Seoul National University, Republic of Korea to estimate the organic matter using "loss-on-ignition" method. Soil samples were oven-dried at 105°C before being ignited in an electric muffle furnace at 600°C for 4 h (Konen et al., 2002). The weight of samples before and after ignition was measured. Calculation for the organic matter content (OM) is as follows:

$$OM\ (\%) = \frac{Sample\ weight\ after\ ignition\ (g)}{Sample\ weight\ before\ ignition\ (g)} x\ 100$$

Other soil samples were then brought to the Analytical Services Laboratory of the Soils and Agro-ecosystems Division, College of Agriculture, UPLB, Laguna, Philippines. Soil properties, such as total N, K, P, Ca and Mg as well as pH and CEC were determined.

Statistical analysis

All statistical tests were performed using a statistical software package (SPSS 16.0 program, SPSS Inc., Chicago, Illinois, U.S.A.). Productivity variables were compared using paired t-test. Duncan's multiple range test (DMRT) was used for multiple comparisons. Graphs were plotted using Sigma Plot 2000 software (version 6.1, SPSS Inc., U.S.A.).

RESULTS AND DISCUSSION

Stand characteristics

A total of 4, 11, 9, 7, and 9 species were recorded in the 10-year-old *A. auriculiformis,* the 20-year-old *A. auriculiformis,* the 20-year-old *Acacia mangium,* the 10-year-old *P. indicus* and the 20-yr-old *P. indicus* stands, respectively. The density of woody species (>5 cm DBH) was highest in the 20-year-old *A. mangium* stand (1,492 trees ha^{-1}) and lowest in the 10-yr-old *P. indicus* (592 trees ha^{-1}) stand (Figure 2; Tables 1 to 5). When the 10-yr-old *A. auriculiformis* was compared among the other stands, it was found to be significantly different (P = 0.001) from the 20-year-old *A. auriculiformis* and the 20-year-old *A. mangium*. When the 20-year-old *A. auriculiformis* was compared among other stands, it was found out to be significantly different (P = 0.001) from the 10-year-old and the 20-year-old *P. indicus*. The 20-year-old *A. mangium* was significantly different (P = 0.001) also from the 10-year-old and the 20-year-old *P. indicus*. In addition, the 10-year-old *P. indicus* was significantly different (P = 0.003) from the 20-year-old *P. indicus* age. Stand density can describe how much a site is being used and the intensity of competition between trees for the site's resources (that is, water, light, nutrients, and space) (UOF, 2006) regardless of the age and type of the forest. At higher densities, the growth rates of individual

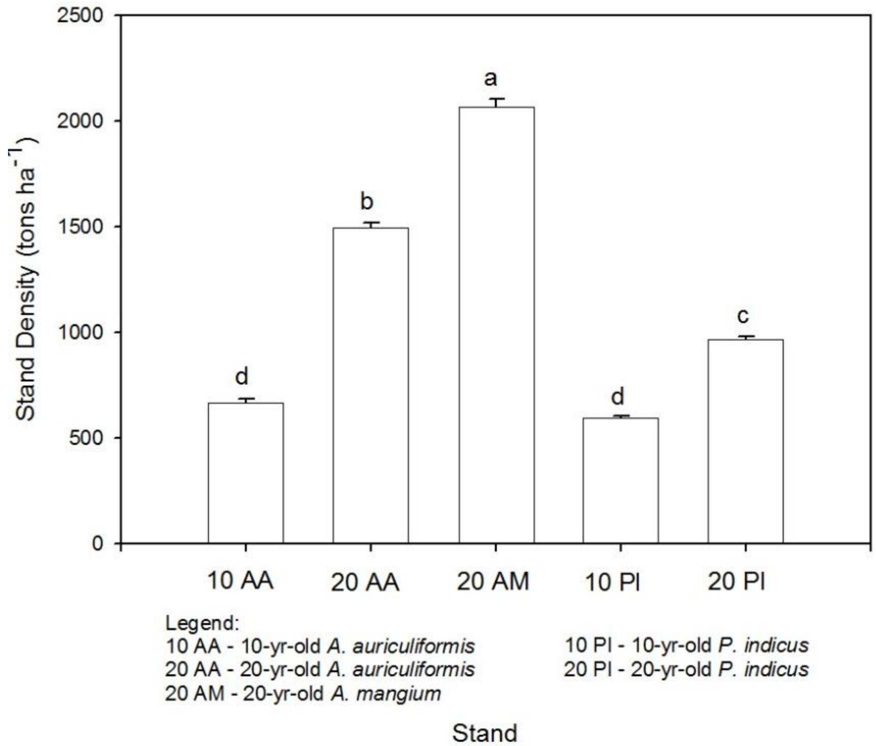

Figure 2. Stand density of species and age classes used in the study. Each bar represents the mean (with standard error). Means followed by the same letter are not significantly different at 5% level by Duncan's Multiple Range Test (DMRT).

trees slow down because there are more trees competing for the site's limited resources.

Basal area, which determines the total cross-sectional area of the trees in a stand at breast height (1.3 m above the ground), was highest in the 20-yr-old *A. mangium* (81.1 m^2 h^{-1}) and was lowest in the 10-yr-old *P. indicus* (35.4 m^2 h^{-1}). In between the two age classes of *A. auriculiformis,* the basal area was higher in the 20-yr-old (69.0 m^2 h^{-1}) compared to the 10-year-old (49.7 m^2 h^{-1}) stand. Similarly, in between the two age classes of *P. indicus,* the basal area was higher in the 20-year-old (52.7 m^2 h^{-1}) stand than the 10-yr-old (35.4 m^2 h^{-1}) stand (Figure 3; Tables 1 to 5). The 10-yr-old *A. auriculiformis* was only significantly different (P = 0.021) from the 20-yr-old *A. mangium* stand while the 20-yr-old *A. auriculiformis* was significantly different (P = 0.052) only from 10-year-old *P. indicus* stand. On the other hand, the 20-year-old *A. mangium* was significantly different from the 10-yr-old *A. auriculiformis* (P = 0.02), the 10-year-old *P. indicus* (P = 0.001) and the 20-year-old *P. indicus* (P = 0.023) stands. Basal area is one of the quantitative measures of stand density along with other quantitative measures including the number of stems per acre and stand volume.

Consequently, it was found out in this study that stand density and basal area increase with stand age. According to Anhold et al. (2006), size-density based indices of relative density such as stand density index are independent of site quality and stand age, and let silviculturists compare levels of growing stock, competitive stress, degree of site occupancy and relative growth among stands, regardless of differences in site quality and age. West (2009) mentioned that stand basal area of forests tends to increase with age as the trees grow. It varies also with the number of trees in the stand.

Importance value index (*IVI*) gives us an idea of the sociological structure of a species in its totality in the community but does not indicate its position separately with regard to other aspects, such as frequency, density and so on (Dash, 2001). In this study, in the 10-year-old *A. auriculiformis* stand, *A. auriculiformis* had the highest *IVI* of 59.2% followed by *Gliricidia sepium* (16.7%), *Leucaena leucocephala* (15.6%) and *Ficus septica* (8.5%) (Table 1). In the 20-year-old *A. auriculiformis* stand, *A. auriculiformis* (48%) also had the highest *IVI* of 48% followed by *Leucaena leucocephala* (8.6%), *Gmelina arborea* (8.4%), *Pterocarpus indicus* (7.1%), *F. septica* (6%), and so on (Table 2). In the 20-year-old *A. mangium* stand, *A. mangium* had the highest *IVI* of 51.6% followed by *F. septica* (9.5%), *Swietenia macrophylla* (9%), *L. leucocephala* (7.1%) and so on (Table 3). In the

Table 1. Stand characteristics of the 10-year-old *Acacia auriculiformis* stand.

Species	Basal area (m^2 ha^{-1})	Stand Density (trees ha^{-1})	DBH		Height		RD (%)	RC (%)	RF (%)	IVI (%)
			Mean ± SE	Max	Mean ± SE	Max				
Acacia auriculiformis	49.3	611	12 ± 0.5	22.1	7.0 ± 0.2	9.5	91.7	42.9	42.9	59.2
Gliricidia sepium	0.2	33	7.4 ± 0.6	8.0	5.6 ± 0.3	6.1	5.0	16.3	28.8	16.7
Leucaena leucocephala	0.1	11	10.2	10.2	6.5	6.5	1.7	31.0	14.2	15.6
Ficus septica	0.1	11	5.7	5.7	4.0	4.0	1.7	9.7	14.2	8.5
Total	**49.7**	**667**					**100.0**	**100.0**	**100.0**	**100.0**

DBH=Diameter at breast height; RD=Relative dominance; RC=Relative cover; RF=Relative frequency; and IVI=Importance value index.

.**Table 2.** Stand characteristics of the 20-year-old *Acacia auriculiformis* stand.

Species	Basal area (m^2 ha^{-1})	Stand Density (trees ha^{-1})	DBH		Height		RD (%)	RC (%)	RF (%)	IVI (%)
			Mean ± SE	Max	Mean ± SE	Max				
Acacia auriculiformis	52.2	808	14.7 ± 0.6	31.8	8.7 ± 0.2	15.4	54.2	79.6	10.3	48.0
Leucaena leucocephala	4.0	167	10.9 ± 0.2	12	8.9 ± 0.5	12.5	11.2	3.6	10.3	8.6
Gmelina arborea	2.4	167	7.5 ± 0.5	14.5	6.7 ± 0.3	9.1	9.5	6.1	10.3	8.4
Pterocarpus indicus	2.4	108	9.0 ± 1.0	16.9	7.2 ± 0.5	10	7.3	3.6	10.3	7.1
Ficus septica	1.3	83	7.6 ± 1.0	15.2	6.4 ± 0.7	11	5.6	2.0	10.3	6.0
Syzygium nitidum	1.1	50	9.2 ± 0.9	12	6.8 ± 0.9	11	3.4	1.6	10.3	5.1
Swietenia macrophylla	0.7	42	8.2 ± 1.1	11.3	7.3 ± 0.9	9.5	2.8	1.1	10.3	4.7
Polyscias nodosa	0.7	25	10.5 ± 1.8	12.3	10.1 ± 1.0	11.5	2.2	0.6	6.9	3.3
Calliandra calothyrsus	0.4	33	7.0 ± 1.0	10	6.4 ± 0.8	8.5	1.7	1.0	10.3	4.4
Artocarpus heterophyllus	0.4	25	8.2 ± 0.8	9	7.0 ± 1.0	8	1.7	0.6	6.9	3.1
Spathodea campanulata	0.1	8	7	7	7	7	0.6	0.1	3.4	1.4
Total	**65.5**	**1,492**					**100.0**	**100.0**	**100.0**	**100.0**

DBH=Diameter at breast height; RD=Relative dominance; RC=Relative cover; RF=Relative frequency; and IVI=Importance value index.

10-year-old *P. indicus* stand, *P. indicus* had the highest *IVI* of 37.2%followed by *Parkia timorniana* (15.1%), *Antidesma cumingii* (14.9%), *L. leucocephala* (12.5%) and so on (Table 4). Lastly, in the 20-year-old *P. indicus* stand, *P. indicus* also had the highest *IVI* (37.6%) followed by *L. leucocephala* (14.8%), *F. nota* (11.5%), *P. timorniana*(9.8%) and so on (Table 5). This means that the species in this study with the highest *IVI*

Table 3. Stand characteristics of the 20-year-old *Acacia mangium* stand.

Species	Basal area (m² ha^{-1})	Stand Density (trees ha^{-1})	DBH		Height		RD (%)	RC (%)	RF (%)	IVI (%)
			Mean ± SE	Max	Mean ± SE	Max				
Acacia mangium	70.0	1133	14.0 ± 0.7	39	8.2 ± 0.2	14	54.8	86.3	13.6	51.6
Ficus septica	2.6	208	7.2 ± 0.2	8.6	5.9 ± 0.2	8	12.5	2.4	13.6	9.5
Swietenia macrophylla	2.1	83	9.3 ± 1.4	16	6.6 ± 0.6	10	10.1	3.2	13.6	9.0
Leucaena leucocephala	1.9	258	5.6 ± 0.1	6.6	5.0 ± 0.2	7	6.0	1.5	13.6	7.1
Pterocarpus indicus	1.7	158	6.6 ± 0.3	8.6	6.6 ± 0.3	9	4.0	2.5	13.6	6.7
Syzygium nitidum	1.3	83	7.9 ± 0.8	13.3	6.3 ± 0.3	7.5	4.0	1.7	13.6	6.4
Calliandra calothyrsus	1.2	125	6.4 ± 0.2	8.6	6.2 ± 0.3	8	7.7	2.1	9.1	6.3
Ficus variegata	0.2	8	9.2	9.2	8.0	8.0	0.4	0.2	4.5	1.7
Ficus nota	0.1	8	6.9	6.9	5.0	5.0	0.4	0.1	4.5	1.7
Total	**81.1**	**2,067**					**100.0**	**100.0**	**100.0**	**100.0**

Legend: DBH=Diameter at breast height; RD=Relative dominance; RC=Relative cover; RF=Relative frequency; and IVI=Importance value index.

Table 4. Stand characteristics of the 10-year-old *Pterocarpus indicus* stand.

Species	Basal area (m² ha^{-1})	Stand Density (trees ha^{-1})	DBH		Height		RD (%)	RC (%)	RF (%)	IVI (%)
			Mean ± SE	Max	Mean ± SE	Max				
Pterocarpus indicus	18.4	483	13.6 ± 0.7	26.5	9.7 ± 1.2	16.2	81.7	6.9	23.0	37.2
Parkia timorniana	12.8	25	26.2 ± 3.4	31.1	20.4 ± 0.1	22.2	4.2	25.7	15.4	15.1
Antidesma cumingii	1.9	8	30.9	30.9	7.2	7.2	1.4	35.7	7.6	14.9
Leucaena leucocephala	1.4	33	33 ± 2.7	27.3	20.9 ± 0.4	14.3	5.6	16.3	15.4	12.5
Buchanania arborescens	0.6	17	16.6 ± 7.3	20.3	14.1 ± 0.4	14.5	2.8	10.4	15.4	9.5
Litsea glutinosa	0.2	17	8.8 ± 1.2	9.9	7.8 ± 0.3	8.1	2.8	2.9	15.4	7.1
Melanolopsis multiglandilosa	0.1	8	7.4	7.4	7.3	7.3	1.4	2.0	7.6	3.7
Total	**35.4**	**592**					**100.0**	**100.0**	**100.0**	**100.0**

DBH=Diameter at breast height; RD=Relative dominance; RC=Relative cover; RF=Relative frequency; and IVI=Importance value index.

were dominant or common in the site indicating the measure of their influence on forest community (Karkee, 2004). Importance value index is a better expression of relative ecological importance of the species than the single absolute measure like frequency, density, and basal cover

Table 5. Stand characteristics of the 20-year-old *Pterocarpus indicus* stand.

Species	Basal area (m^2 ha^{-1})	Stand Density (trees ha^{-1})	DBH		Height		RD (%)	RC (%)	RF (%)	IVI (%)
			Mean ± SE	Max	Mean ± SE	Max				
Pterocarpus indicus	25.4	692	15.6 ± 0.8	34.4	11.2 ± 0.5	19.1	71.6	26.1	15.0	37.6
Leucaena leucocephala	10.8	25	17.2 ± 1.2	18.9	9.5 ± 2.9	14.5	2.6	31.7	10.0	14.8
Ficus nota	10.8	100	9.2 ± 1.1	17.1	6.2 ± 0.7	13.1	10.3	9.2	15.0	11.5
Parkia timorniana	2.4	75	7.8 ± 0.8	12.8	9.8 ± 0.6	13.1	7.8	6.5	15.0	9.8
Ficus septica	1.3	33	8.0 ± 1.1	10.3	6.8 ± 0.9	9.5	3.4	7.0	10.0	6.8
Artocarpus blancoi	1.2	17	5.2 ± 0.1	5.3	6.5 ± 0.4	6.9	1.7	2.9	10.0	5.0
Canthium monstrosum	0.1	8	9.3	9.3	7	7	0.9	9.3	4.9	4.9
Anthocephalus chinensis	0.1	8	6.5	6.5	7.1	7.1	0.9	4.5	4.9	3.4
Macaranga tanarius	0.1	8	5.1	5.1	3	3	0.9	2.8	4.9	2.9
Total	**52.7**	**967**					**100.0**	**100.0**	**100.0**	**100.0**

DBH=Diameter at breast height; RD=Relative dominance; RC=Relative cover; RF=Relative frequency; and IVI=Importance value index.

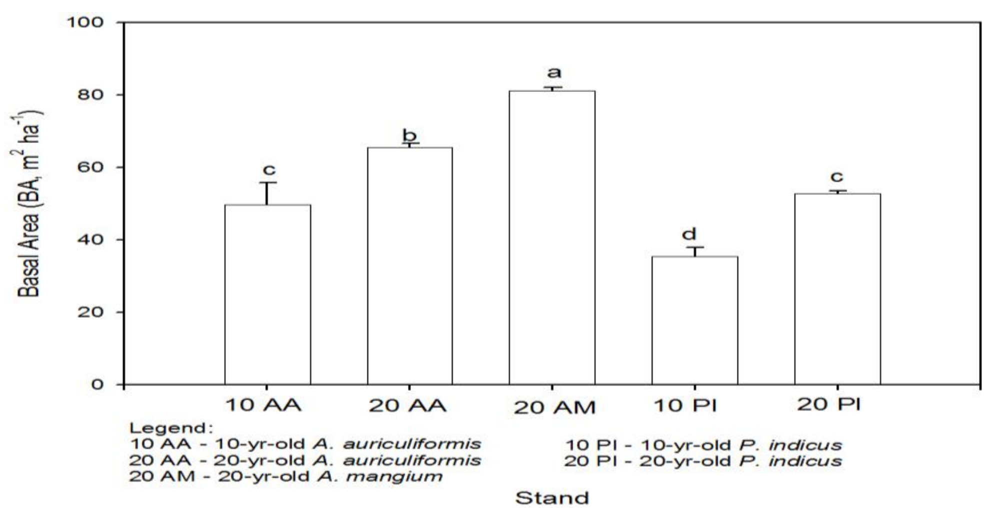

Figure 3. Basal area of species and age classes used in the study. Each bar represents the mean (with standard error). Means followed by the same letter are not significantly different at 5% level by Duncan's Multiple Range Test (DMRT).

Table 6. Aboveground biomass and carbon content of *Acacia auriculiformis*, *Acacia mangium* and *Pterocarpus indicus* stands.

Sites	***Acacia auriculiformis* (10-yr-old)**		***Acacia auriculiformis* (20-yr-old)**		***Acacia mangium* (20-yr-old)**		***Pterocarpus indicus* (10-yr-old)**		***Pterocarpus indicus* (20-yr-old)**	
	Biomass (tons ha^{-1})	**Carbon content (tC ha^{-1})**	**Biomass (tons ha^{-1})**	**Carbon content (tC ha^{-1})**	**Biomass (tons ha^{-1})**	**Carbon content (tC ha^{-1})**	**Biomass (tons ha^{-1})**	**Carbon content (tC ha^{-1})**	**Biomass (tons ha^{-1})**	**Carbon content (tC ha^{-1})**
Trees	64.10 (0.28)	29.50 (0.35)	149.25 (0.90)	68.65 (1.73)	198.84 (1.43)	91.47 (0.33)	88.20 (0.45)	40.60 (1.53)	122.50 (0.55)	56.10 (1.22)
Understory/ Herbaceous vegetation	1.70 (0.11)	0.70 (0.04)	0.72 (0.03)	0.29 (0.01)	1.08 (0.04)	0.43 (0.02)	2.40 (0.02)	1.00 (0.12)	2.00 (0.18)	0.80 (0.09)
Litter layer	5.00 (0.67)	2.10 (0.02)	3.87 (0.07)	1.63 (0.05)	3.90 (0.05)	1.64 (0.05)	1.20 (0.02)	0.50 (0.04)	1.70 (0.06)	0.60 (0.01)
CWD	0.04 (0.01)	0.02 (0.01)	0.07 (0.01)	0.03 (0.01)	0.39 (0.01)	0.15 (0.01)	0.05 (0.01)	0.02 (0.01)	0.06 (0.03)	0.02 (0.01)
Total	**70.84**	**32.34**	**149.25**	**70.60**	**204.21**	**93.69**	**91.80**	**42.10**	**126.30**	**57.50**

Standard errors of the means are given in parentheses.

(Huy, 2004). Values obtained can be applied to other ecological studies, such as the development of species-specific height~diameter regression equations (Djomo et al., 2010), measurement of species niche per resource apportionment, Shannon-Wiener diversity, and dominance-diversity curve among others.

Aboveground biomass and carbon

The total aboveground biomass (*AGB*) was greater in the 20-year-old *A. mangium* stand (204.21 tons ha^{-1}) than *A. auriculiformis* and *P. indicus*. Also, the highest carbon was stored in the 20-year-old *A. mangium* stand (93.69 tons ha^{-1}). In between *A. auriculiformis* stands, the *AGB* and carbon were higher in the 20-year-old stand (149.25 tons ha^{-1} and 70.60 tC ha^{-1}, respectively) than the 10-year-old stand (70.84 tons ha^{-1} and 32.34 tC ha^{-1}, respectively). In between the *P. indicus* stands, the *AGB* and carbon were also higher in the 20-year-old stand (126.30 tons ha^{-1} and 57.50 tC ha^{-1}, respectively) than the 10-yr-old stand (91.80 tons ha^{-1} and 42.10 tC ha^{-1}, respectively) (Table 6).

The *AGB* values of all stands in this study were significantly different (P = 0.001) among each other. The observed *AGB* values in the 20-year-old stands of *A. auriculiformis, A. mangium* and *P. indicus* (149.25 to 204.21 tons ha^{-1}) were comparable with the findings of Brown and Lugo (1992) who reported a value range of 153-221 tons ha^{-1} from Sri Lankan tropical rain forests. These values are also comparable with the result of other studies. For instance, Terakunpisut et al. (2007) reported an *AGB* value of 275 tons ha^{-1} for the tropical rain forests of Thailand. Also, the lower *AGB* values of 170 tons ha^{-1} for the broadleaved forests of tropical America, 260 tons ha^{-1} for tropical Africa, 215 Mg ha^{-1} for tropical Asia and 150 Mg ha^{-1} for total tropics were reported by Brown and Lugo (1984). However, observed values *AGB* values in the 10-yr-old *A. auriculiformis* and *A. mangium* stands (70.84 tons

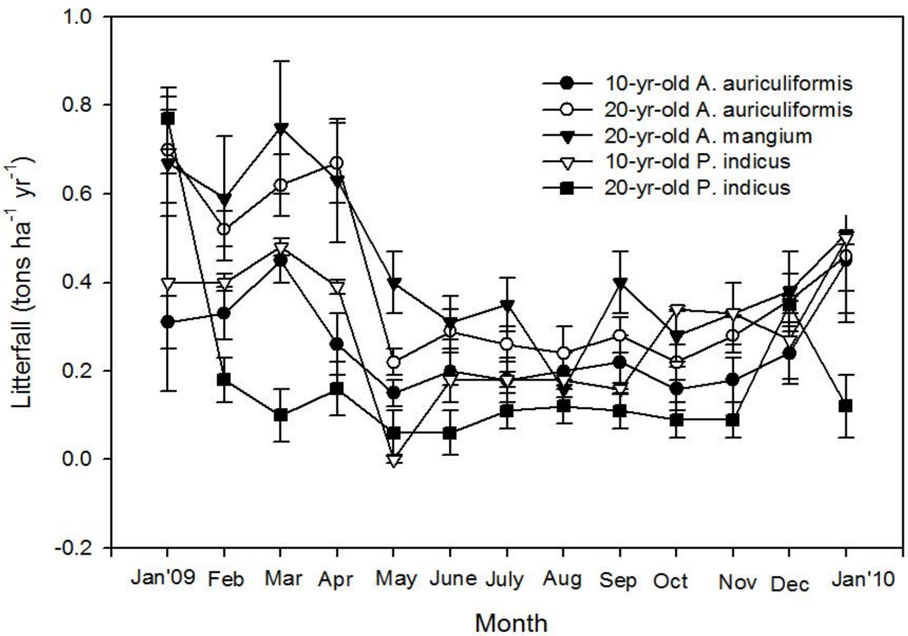

Figure 4. Monthly litterfall of the different stands from January 2009 to January 2010.

ha^{-1} and 91.80 tons ha^{-1}, respectively) are much lower than these. The present value range is less than the *AGB* values of 607.7 tons ha^{-1} and 468 tons ha^{-1} reported for tropical wet evergreen forest and tropical semi-evergreen forest of Western ghats of India by Rai (1981) and Swamy (1989), respectively, as cited by Baishya et al. (2009).

The 10-yr-old *A. auriculiformis* was significantly different (P = 0.001) from all other stands but insignificantly different (P = 0.064) from the 10-year-old *P. indicus* as they are both young stands. The 20-year-old *A. auriculiformis, A. mangium* and *P. indicus* was also significantly different (P = 0.001) from all other stands. The potential of forests to sequester carbon depends on the forest type, age of forest and size class of trees (Terakunpisut et al., 2007). The amount of carbon stored in the three stands of this study (32.34 tC ha^{-1} to 93.69 tC ha^{-1}) is comparable with the disturbed tropical forests of Sri Lanka (77 tC ha^{-1}), but lower than the relatively undisturbed matured tropical rain forest of Malaysia (223 tC ha^{-1}) as reported by Brown and Lugo (1982). Flint and Richards (1996) estimated carbon sequestration in Southeast Asia, including India, Thailand, Cambodia, Malaysia and Indonesia, and reported the value range of 17 tC ha^{-1} in severely degraded tropical dry forest to 350 tC ha^{-1} in the undisturbed matured tropical rain forests.

Analyses have shown that forests with reduced biomass either had their large trees removed by past human disturbance or represent regenerating secondary forests which do not yet have large trees (Baishya et al., 2009). In Mt. Makiling where *A. auriculiformis* and *A. mangium* were planted, the site experienced forest fires in the previous decades. On the otherhand, in La Mesa Watershed where *P. indicus* was planted, the site was previously covered by *I. cylindrica*. The distribution of biomass in large trees, therefore, could be an indicator of the presence or absence of past anthropogenic disturbance (Brown, 1996).

Plantation forests with higher annual productivity were reported to be ideal for carbon storage and sequestration. Thus, creation of new plantation on degraded lands is a better option for carbon storage when these are planted and harvested periodically and used as a long-term source of timber. With the findings of the present study, the *A. auriculiformis*, *A. mangium* and *P. indicus* stands having less *AGB* had the greater potential to accumulate significant quantities of biomass, and thus sequestering more atmospheric C in the future.

Litterfall

Annual litterfall (January 2009 to January 2010) of the study sites ranged from 2.30 to 5.72 tons ha^{-1} yr^{-1}. Monthly litterfall in the study sites are presented in Figure 4. The 10-year-old *A. auriculiformis* stand was significantly different from the 20-year-old *A. auriculiformis* (P = 0.043*),* the 20-year-old *A. mangium (*P = 0.042*)*, and the 10-year-old *P. indicus* (P = 0.050*)* except for the 20-year-old *P. indicus* (P = 0.061). The 20-

year-old *A. auriculiformis* was not significantly different (P = 0.071) from the 20-year-old *A. mangium* but significantly different from the 10-year-old (P = 0.001) and the 20-year-old *P. indicus* (P = 0.050) stands.

The 20-year-old *A. mangium* stand was significantly different (P = 0.010 and P = 0.050, respectively) from the 10 and 20-year-old *P. indicus* stands. The 10-year-old *P. indicus* was significantly different (P = 0.001) from the 20-year-old *P. indicus* stand.

The range of values in this study is comparable with the values reported by Lugo et al. (1978) in the deciduous forest of Guanica, Puerto Rico having value of 2.5 tons ha^{-1} yr^{-1}. Greater litterfall was recorded in the 20-year-old *A. auriculiformis* and the 20-year-old *A. mangium* (5.47 and 5.72 tons ha^{-1} yr^{-1}). Contribution of leaf litter to the total litter was greater when compared to other categories. Contribution of barks/twigs and reproductive part was low.

Litterfall increased with the productivity of the stand (Forrester, 2004). Litterfall pattern in a rainforest ecosystem, as in any other forest ecosystem type (Facelli and Pickett, 1991) is determined by a variety of factors, such as species composition, successional stage in its development and related microclimatic differences. Therefore, it is reasonable to expect variations in the litterfall pattern (production) among the species and age classes as shown in the present study. The mean annual litterfall was greater in the 10-yr-old and the 20-yr-old *A. auriculiformis* and the 20-year-old *A. mangium* stands. This variation in litterfall pattern among the sites could be attributed to species composition. Facelli and Pickett (1991) reported that the species composition are important for litter production within the same climate range. In *A. auriculiformis* stands, *Gliricidia sepium, Leucaena leucocephala, Ficus septica, Gmelina arborea, Pterocarpus indicus, Syzigium nitidum, Swietenia macrophylla, Calliandra calothyrsus*, and *Arthocarpus heterophyllus* contributed greater quantity of litter in addition to the common species (*A. auriculiformis*) to the total litter production. Similarly, in the 20-year-old *A. mangium* stand, *L. leucocephala, F. septica, P. indicus, S. nitidum, S. macrophylla* and *C. calothyrsus* contributed more in addition to common species (*A. mangium*). Therefore, the results suggest that species composition and their contribution towards litter becomes important in overall community or site-litter production, as observed in *A. auriculiformis* and *A. mangium* stands. Differences could be explained by either tree behaviour, mean annual temperature, minimum monthly mean temperature, precipitation and latitude.

Past studies failed to establish cause and effect relationships between such parameters and litterfall in temperate forests and tropical forests (Kumar and Deepu, 1992). In contrast, Stohlgren (1988) suggested that annual litterfall can be better predicted by a function derived from the individual tree basal area and live crown ratio. The outcome of the present study suggests that further scientific research is to be oriented towards understanding the intricacies of variations in litterfall production between years.

Periodicity of litterfall is largely followed by annual cyclesof environmental parameters. This study showed that one major peak of litterfall (0.45 to 0.77 tons ha^{-1} yr^{-1}) occurred during the dry season (January to April) (Figure 4). The seasonal variation in litter production with highest values in the dry months is in agreement with the results of other authors (Kumar and Deepu, 1992). Available studies concerning deciduous plantations clearly showed that the deciduous species yielded maximum litter during the summer period.

Jackson (1978) assumed that, in environments where the temperature variation throughout the year is small and moisture availability is seasonal, dry season leaf fall and wet flushing will occur to avoid seasonal moisture stress. Moore (1980) reported that water stress triggers de novo synthesis of abscissic acid in the foliage of plants which, in turn, can stimulate senescence of leaves and other parts. Besides, the rise in ambient temperatures owing to fires can also spur an accelerated fall during the summer as is reported by Kumar and Deepu (1992) in tropical moist deciduous forests.

Productivity, resource use and foliar nutrients

Figures 5 to 7 show estimate of aboveground net primary productivity (*ANPP*), leaf area index (*LAI*) and specific leaf weight (*SLW*) of *A. auriculiformis, A. mangium* and *P. indicus* stands. *ANPP* ranged from 3.3 to 6.43 tons $ha^{-1}yr^{-1}$. *ANPP* among the species was both higher in the 20-year-old *A. auriculiformis* (6.28 tons ha^{-1} yr^{-1}) and *A. mangium* (6.43 tons ha^{-1} yr^{-1}) which are both fast-growing species located at Mt. Makiling. In *A. auriculiformis* age classes, the 20-year-old stand (6.28 tons ha^{-1} yr^{-1}) was much higher than the10-year-old stand (4.05 tons ha^{-1} yr^{-1}). In between *P. indicus* age classes, the 20-year-old stand (4.99 tons ha^{-1} yr^{-1}) was slightly higher than the 10-year-old stand (3.30 tons ha^{-1} yr^{-1}).

The 10-year-old *A. auriculiformis* stand was significantly different (P = 0.001 and P = 0.010, respectively) from the 20-year-old *A. auriculiformis* and *A. mangium* stands but not significantly different (P = 0.082 and P = 0.071, respectively) from the 10-yr-old and the 20-yr-old *P. indicus* stands. The 20-year-old *A. auriculiformis* stand was not significantly different (P = 0.701) from the 20-year-old *A. mangium* but was significantly different (P = 0.011 and P = 0.050, respectively) from the 10-year-old and the 20-year-old *P. indicus* stands. On the other hand, the 20-year-old *A. mangium* stand was significantly different (P = 0.003) from both the 10-year-old and the 20-year-old *P. indicus* stands. The 10-year-old *P. indicus* was significantly different (P = 0.022) from the 20-year-old *P. indicus* stand. *ANPP* is strongly correlated with

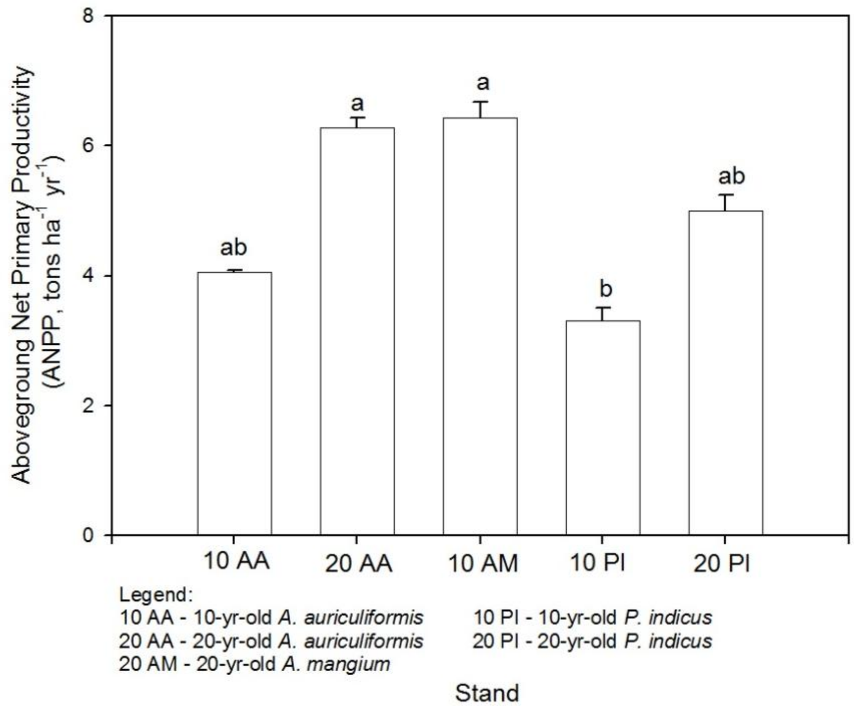

Figure 5. Aboveground net primary productivity (*ANPP*) of *Acacia auriculiformis*, *Acacia mangium* and *Pterocarpus indicus* stands. Each bar represents the mean (with standard error). Means followed by the same letter are not significantly different at 5% level by Duncan's Multiple Range Test (DMRT).

precipitation, temperature and evapotranspiration as (Harcombe et al., 1993). Species composition, vegetation physiognomy, and biomass also change with rainfall and temperature along regional geographic gradients. However, the result of this study is contrary with the studies of Gower et al. (1996) and Gholz et al. (1994) wherein *ANPP* declined with stand age.

Leaf area index (*LAI*) didn't much vary among the stands in this study (Figure 6) and analysis showed that they were not significantly different among each other (P = 0.220). *LAI* is an important structural characteristic of forests because the forest canopy is the site of significant ecosystem processes, such as transpiration, rainfall interception, dry deposition, and photosynthesis (Maass, 1995). As a result, *LAI* has been identified as a key parameter in studying and modeling ecosystem function at local, regional and global scales (Parton et al., 1992). *LAI* varies greatly among ecosystems, ranging from less than 1 m^2 m^{-2} in arid ecosystems, up to 20 in some conifer stands (Kozlowski et al., 1991). It also varies within ecosystems depending on site conditions, particularly water supply and soil fertility. Although *LAI* is well documented for temperate forests, only a few determinations have been made for tropical ecosystems (Murphy and Lugo, 1986). In deciduous, and some evergreen ecosystems, *LAI* varies seasonally, having a maximum during the growing season and a minimum in the dormant season (Maass, 1995).

On the other hand, specific leaf weight (*SLW*) was much higher in fast-growing species, the 10- and the 20-year-old *A. auriculiformis* (244 cm^2g^{-1} and 245 cm^2g^{-1}, respectively) and the 20-year-old *A. mangium* (255 cm^2g^{-1}) stands than *P. indicus* stands, a slow growing species (Figure 8). The 10-year-old *A. auriculiformis* was not significantly different (P = 0.970 and P = 0.521, respectively from the 20-yr-old *A. auriculiformis* and the 20-year-old *A. mangium* stands but significantly different (P = 0.001) from the 10-yr-old and the 20-yr-old *P. indicus* stands. The 20-year-old *A. auriculiformis* was not significantly different (P = 0.613) from the 20-year-old *A. mangium* but was significantly different (P = 0.001) from the 10-year-old and the 20-year-old *P. indicus* stands. The 10-year-old *P. indicus* stand was not significantly different (P = 0.092) from the 20-year-old *P. indicus* stand. In the study conducted by Hodanova (1975), *SLW* was found lowest in the young leaves. This is in contrast with this study because the 10-year-old *A. auriculiformis* and *P. indicus* had higher values than the 20-year-old stands.

Foliage analyses effectively measure macro and micronutrients and indicate the need for changes in

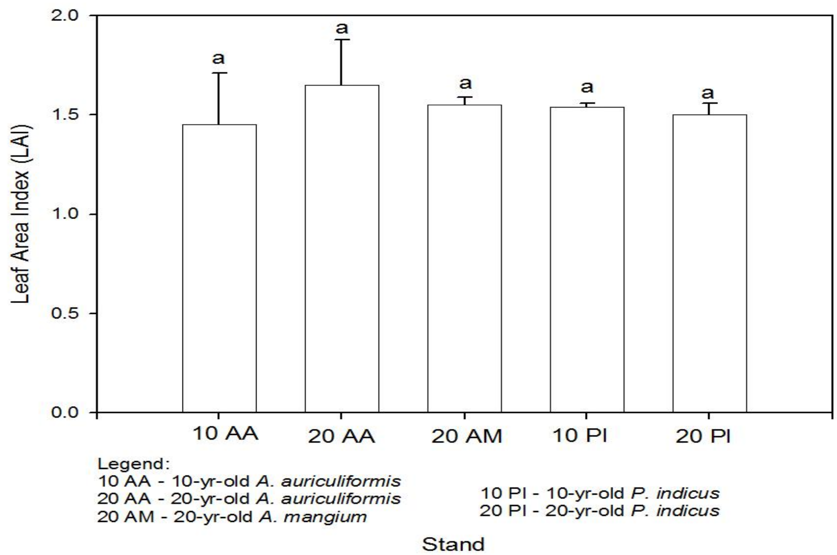

Figure 6. Leaf area index (*LAI*) values of *Acacia auriculiformis*, *Acacia mangium* and *Pterocarpus indicus* stands. Each bar represents the mean (with standard error). Means followed by the same letter are not significantly different at 5% level by Duncan's Multiple Range Test (DMRT).

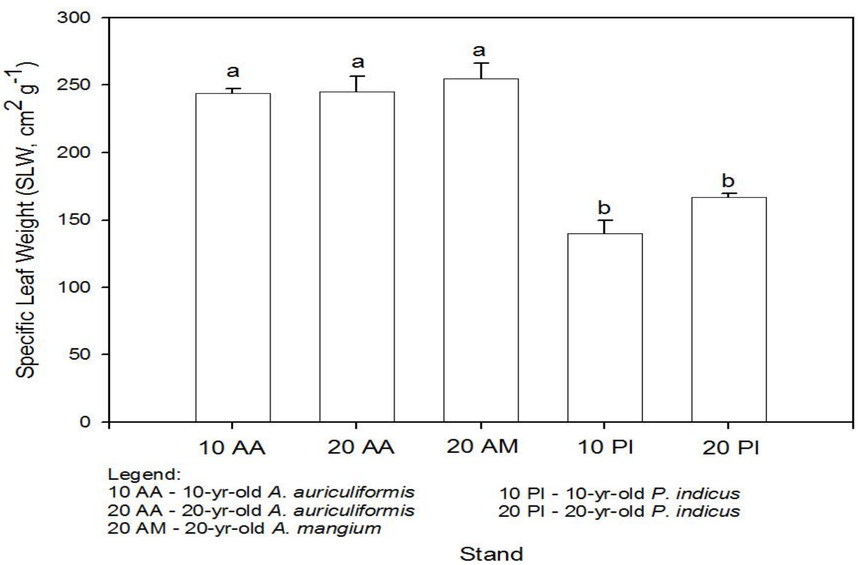

Figure 7. Specific leaf weight (*SLW*) of *Acacia auriculiformis*, *Acacia mangium* and *Pterocarpus indicus* stands. Each bar represents the mean (with standard error). Means followed by the same letter are not significantly different at 5% level by Duncan's Multiple Range Test (DMRT).

fertilizer programs. It integrates all the factors that might influence nutrient availability and uptake and it shows the balance between nutrients. Nutrient levels within the plant are continually changing. N, P and K levels normallydecrease, while calcium (Ca) and Mg increase as the season progresses (Cline, 1991). However in this study, the foliage nutrients did not much vary among the species (P = 0.064) (Table 7). According to Ennos (2010), as trees grow, they take up nutrients and sequester them in their leaves and woody tissues and this reduces their

Table 7. Foliar nutrients and nitrogen productivity (NP) of *Acacia auriculiformis*, *Acacia mangium* and *Pterocarpus indicus* stands

Species/Age Class(yr-old)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Zn (ppm)	Cu (ppm)	Mn (ppm)	Fe (ppm)	Nitrogen productivity (kg $kg^{-1}yr^{-1}$)
					Acacia auriculiformis					
10	3.14 a (0.20)	0.02 c(0.10)	0.24 b(0.10)	2.20 a (0.05)	0.36ab (0.02)	32 b (0.51)	0.8 ab (0.13)	124 c (0.06)	3409 b (0.53)	152.26 b (0.27)
20	2.84ab (0.20)	0.06 ab(0.10)	0.25 ab(0.20)	2.44 a(0.03)	0.32ab (0.02)	44 b (0. 42)	1.1 a (0.17)	208 b (0.04)	332 d (0.48)	267.23 a (0.31)
					Acacia mangium					
20	3.18 a (0.50)	0.05 ab(0.10)	0.40 a(0.10)	1.85ab(0.02)	0.41ab(0.03)	39 b (0.54)	1.3 a (0.12)	272 a (0.11)	1220 c (0.39)	221.72ab 0.29)
					Pterocarpus indicus					
10	2.71 ab (0.40)	0.08 ab(0.20)	0.32 a(0.20)	2.41 a(0.04)	0.59 a(0.05)	61ab (0.26)	0.7 ab (0.35)	276 a (0.09)	7313 a (0.46)	87.53 c (0.36)
20	3.19 a (0.50)	0.16 a(0.10)	0.35 a(0.30)	2.39 a(0.02)	0.65 a(0.06)	86 a (0.21)	0.9 ab (0.23)	233 ab (0.13)	2985bc (0.25)	143.80bc 0.41)

Standard errors of the means are given in parentheses. Means within a column followed by the same letter are not significantly different at 5% level by Duncan's Multiple Range Test (DMRT).

availability in the soil. As a consequence, larger trees would have to divert more of their biomass to their roots to maintain the nutrient supply and they may not get enough to produce new leaves or branches. Nutrientavailability is one of the key factors which control forest plantation growth and which can also be modified by management through processes, such as fertilizer application or fire. The quantities of nutrients required and utilized by forests differ between the species, between their productivity, and the stage of stand development represented by age or stage of maturity (Turner and Lambert, 2008).

The highest nitrogen productivity (increase in plant dry mass per unit plant N per unit time) was shown by the 20-year-old *A. auriculiformis* (267.23 kg kg^{-1} yr^{-1}) followed by the 20-yr-old *A. mangium* (221.72 kg kg^{-1} yr^{-1}). In the study of Gower et al. (1996), they mentioned that *ANPP* commonly reaches a maximum in young forest stands and decreases by 0 to 76% as stands mature due to an altered balance between photosynthetic and respiring tissues, decreasing soil nutrient availability, and increasing stomatal limitation leading to reduced photosynthetic rates. However, in this study, nitrogen productivity increased with stand age. According to Jandle et al. (2007), this increase could be a consequence of the enriching effect of N deposition, rising CO_2 levels in the atmosphere, and changes in forest-management practices. In addition, nitrogen fixing species have a function to enrich N in soil. Previous studies have suggested that introduction of N-fixing species into plantations could enhance both litter quality and quantity (He et al., 1997; Liu, 1999) and increase above and belowground productivity (Liu, 2000).

Soil analysis

In terms of pH and N, all the stands were not significantly different (P = 0.110 and P = 0.092, respectively) among each other while other nutrients were significantly different (P = 0.03) (Table 8). The soil organic matter (SOM), K, Ca, Mg and CEC in the 10-year-old (6.23%, 1.91 cmol(+) kg-1, 10.8 cmol(+) kg^{-1}, 7.1 cmol(+) kg^{-1}

Table 8. Soil characteristics of *Acacia auriculiformis*, *Acacia mangium* and *Pterocarpus indicus* stands in Mt. Makiling Forest Reserve and La Mesa Watershed, Philippines.

Age class(yr-old)	pH	OM (%)	N (%)	P (ppm)	K (cmol(+) kg^{-1})	Ca (cmol(+) kg^{-1})	Mg (cmol(+) kg^{-1})	CEC (cmol(+) kg^{-1})
				Acacia auriculiformis				
10	4.6 a(0.20)	6.23 a(0.10)	0.35(0.06)	0.9(0.55)	1.91 (0.43)	10.8 (2.71)	7.1 (2.40)	38.9(2.54)
20	4.9 a (0.30)	6.25 a(0.10)	0.35(0.08)	0.6 (0.19)	2.53(0.61)	10.7(2.18)	5.2(2.67)	38.3(2.68)
				Acacia mangium				
20	4.6 a(0.10)	5.7 a(0.2)	0.33(0.04)	1.3(0.23)	2.03(0.52)	8.9(2.44)	4.7(2.44)	32.3(2.71)
				Pterocarpus indicus				
10	4.5 a(0.10)	3.12 b(0.50)	0.21(0.02)	2.0(0.32)	0.42(0.10)	6.4 (3.33)	2.2(0.77)	21.1(2.18)
20	4.7 a(0.10)	3.55 b(0.2)	0.25(0.03)	3.1(0.77)	0.35(0.08)	7.9(1.92)	2.8 (0.23)	13.6(0.53)

Standard errors of the means are given in parentheses. Means within a column followed by the same letter are not significantly different at 5% level by Duncan's Multiple Range Test (DMRT).

and 38.9 cmol(+) kg^{-1}, respectively) and the 20-year-old (6.25% and 2.53 cmol(+) kg^{-1}, 10.7 cmol(+) kg^{-1}, 5.2 cmol(+) kg^{-1}, and 38.3 cmol(+) kg^{-1}, respectively) *A. auriculiformis* stands as well as the 20-year-old *A. mangium* stand (5.79%, 2.03 cmol(+) kg^{-1}, 8.9 cmol(+) kg^{-1}, 4.7 cmol(+)/kg, and 32.3 cmol(+) kg^{-1}, respectively) located in the mountain area were higher compared to the 10-year-old and the 20-year-old *P. indicus* stands located in the flat areas. The higher soil nutrients in the mountain areas could be attributed to its quite low soil temperature and elevation.

Conclusion

Grassland and degraded areas in the Philippines are so immense due to many natural and human factors, necessitating proper choice of species for forest rehabilitation. Fast growing and nitrogen fixing trees are deemed important to bring back the abundance of forest in the country. This study revealed the different stand productivity of exotic (*A. auriculiformis* and *A. mangium*) and native (*P. indicus*) nitrogen-fixing species in the Philippines. Based on the results obtained, the 20-yr-old *A. auriculiformis* and *A. mangium* exhibited better performance as they had the highest value in terms of annual litterfall and aboveground biomass and carbon than *P. indicus* stands. Since *A. auriculiformis* and *A. mangium* species are fast-growing and could easily develop their growth and coverage, they had an advantage of gaining more height and DBH over the native species. Also, the specific leaf weight, aboveground net primary productivity (*ANPP*), and nitrogen productivity were higher in *A. auriculiformis* and *A. mangium* species as influenced by their higher leaf area, biomass accumulation and nitrogen inputs. Productivity variables particularly, nitrogen productivity, were almost double in *A. auriculiformis* and *A. mangium* than that of *P. indicus* indicating that these species are good to be planted in areas with harsh or poor condition. Also, the values observed were mostly higher in the later stage (20-yr-old stand) than the early stage (10-yr-old stand) as they have already accumulated greater biomass growth increment.

Therefore, because of the higher productivity of *A. auriculiformis* and *A. mangium* as perceived in this study, these species could be recommended as suitable species to be planted in the grassland and degraded areas of the country. It means that these species could not only survive in various conditions but could also serve as nurse species for other native species that would eventually lead to successful forest succession in the future. The implication of this ecophysiological study is very crucial as it provided a great degree of generalization about the nature of *A. mangium* and *A. auriculiformis* in choosing them for reforestation purposes.

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