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Effects of Mixed Plantation on Growth and Biomass Yield of Two Common Plantation Trees of Bangladesh

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Abstract

An experiment was set to assess the effect of mixed plantings on initial growth and biomass yield of two common plantation tree species of Bangladesh namely *Acacia auriculiformis* (A) and *Gmelina arborea* (G). Study was carried out in the nursery bed of the Seed Research Laboratory and Nursery of Institute of Forestry and Environmental Sciences, Chittagong University (IFESCU), Bangladesh during February to November, 2015. The treatments consisted of two pure planting plots (100% A and 100% G) and five mixed planting plots (50%A: 50%G, 35%A: 65%G, 25%A: 75%G, 65%A: 35%G and 75%A: 25%G) of these two species. In nursery, seedlings were raised in a randomized blocks with four replicates of seven treatment plots. Periodic increments on height (cm), collar diameter (cm) and leaf/phyllode number of the seedlings was taken in every month and continued up to 10 months. The growth and biomass yield of seedlings were measured 10 months after the first seed was emerged. The effects of mixed plantation on growth and biomass were compared to that of seedlings grown in pure plantation. At the age of 10 months it was found that *G. arborea* seedlings were significantly tallest (240.13 cm) when planted with *A. auriculiformis* in a proportion of 25%A: 75%G, whereas *A. auriculiformis* were tallest in the pure 100% A plot, with an average mean height of 135.36 cm. Maximum collar diameter (1.38 cm) was recorded for *G. arborea* in the mixed plots 75%A: 25%G. Fresh and dry weight of shoots and roots of the seedlings were found significantly ($p<0.05$) highest in 50%A: 50%G plot for *G. arborea*. *G. arborea* also showed highest quality index when mixed with *A. auriculiformis* in a proportion of 50:50, with an average value of 8.96. The results revealed a positive correlation between seedling growth and various planting patterns.

Key Words: biomass yield, growth performance, mixed plantation, nitrogen fixation, quality index

Introduction

Bangladesh, the world's largest deltaic region, lying in the north eastern part of South Asia with a geographical coverage of 14.76 m ha, is exceptionally endowed with a large variety of flora (Nishat et al. 2002; Dutta et al. 2014). But, the natural forests of Bangladesh have been facing a serious onslaught that a large portion of it has already been lost during the last four decades due to population pressure and unscientific management (Hossain et al. 2008; Dutta et al. 2014). Besides this, the management of these low yielding forests was very complicated and that's why the main objective was to replace these heterogeneous natural forests by the planting of valuable timber species (Hossain 2008).

In Bangladesh, massive failures of established plantations and land degradation have resulted in continuous depletion of forest resources (Aryal et al. 1999). In addition, intensive harvesting of forest resource decreases the nitrogen,

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organic matter and fertility from the forest floor (Khan et al. 2004; Hossain and Hoque 2013). It is necessary to add chemical fertilizers for maintaining the soil fertility in such areas, which is environmentally vulnerable (Hossain et al. 2001). Planting nitrogen fixing leguminous trees may be an important option to enrich the soil nitrogen status since most of the leguminous species form nodules in their root with symbiotic association of *Rhizobium* and fix atmospheric nitrogen (Chaukiyal et al. 1999). The introduction of nitrogen fixing species (NFS) such as *A. auriculiformis* in fast-growing tree plantations is an alternative option to reduce fertilizer applications. The introduced nitrogen fixing species is thought to provide nitrogen to the stand maintaining soil fertility that would stimulate growth of the non-nitrogen fixing species and wood production at the stand level (Bristow et al. 2006; Sayyad et al. 2006). The use of nitrogen fixing trees affects companion species in mixture through the shedding of nitrogen-rich leaf and root tissues and direct assimilation of atmospheric nitrogen by root nodule bacteria (Kelty 1992). However, mixed-species stands are sometimes less productive than target species in monoculture (Petit and Montagnini 2006; Laclau et al. 2008). On the other hand, a wide variety of nitrogen fixing trees is available for use in plantations, but only few species have received much attention for silviculture and management (Giller and Wilson 1991; Gutteridge and Shelton 1994; Binkley and Giardiana 1997). Mixtures with nitrogen fixing species may impose catalytic effects on soils that are naturally poor in nitrogen or depleted by agricultural use or other human activities (Aryal et al. 1999). Recently nitrogen fixing tree species such as *Acacia auriculiformis*, *Albizia* spp., *Cassia fistula, Dalbergia sissoo* and *Leucaena leucocephala* are planted with non-nitrogen fixing trees in the homegarden and large scale plantation programs of Bangladesh (Alam et al. 2005).

Acacia auriculiformis, Albizia spp., *Eucalyptus camaldulensis, Gmelina arborea, Swietenia macrophylla* etc. are predominant in the plantations and extensively planted along roadsides, railway sides, field borders, marginal lands, homesteads, and in agroforestry systems of Bangladesh (Aryal et al. 1999; Kelty 2006). Presently, *Acacia auriculiformis* is an exotic species extensively planted on barren lands, marginal lands, and on former native forests of Bangladesh. *Gmelina arborea* is a native and priority species in large scale plantation programs of Bangladesh (Hossain and Hoque 2013). Therefore, the present attempt was made with a view to studying the effect of mixed plantings with these two common and widely planted tree species of Bangladesh on growth and biomass yield. Determining the benefits of mixing/nitrogen fixation of *A. auriculiformis* with *G. arborea* was another aim of this study.

Materials and Methods

Experiment site

The experimental design was carried out over a period of ten months from February to November, 2015 in the nursery of Institute of Forestry and Environmental Sciences, Chittagong University (IFESCU), Bangladesh. The nursery site enjoys a tropical monsoon climate characterized by hot, humid summer and cool, dry winter (Mahmood et al. 2005). The experimental site (nursery) lies approximately at the intersection of 91°50’ east longitude and 22°30’ north latitude (Khan et al. 2004). The annual rainfall in the nursery is 2500-3000 mm which mostly takes place between June and September (Gafur et al. 1979). The average monthly mean temperature varied from 21.14°C to 29.75°C (Ahmed 1990). Relative humidity was generally the lowest (64%) in February and highest (95%) in June-September (Mahmood et al. 2005). Geographically the area is formed by hills of low to medium high with slope ranges from gentle to steep and soils of color yellowish red to yellowish brown (Osman et al. 1992; Huda et al. 2006). The hills consist of moderate to strongly acidic soils (Osman et al. 1992) and an average soil pH 5.5 (Badruddin et al. 1989). The soil used in the nursery was moderately coarse to fine textured. It has a grey to olive grey colour, sandy loams sub soil with moderate coarse structure (Aryal et al. 1999).

Preparation of the nursery bed

Seeds of *Acacia auriculformis* and *Gmelina arborea* were collected from the Bangladesh Forest Research Institute (BFRI), Chittagong, Bangladesh in the month of February, 2015. The soils collected from the barren hills of the University Campus was sieved well ($<$3 mm) and then fill up the seed bed. The soil in the bed was dug up to the depth of 30-40 cm. The large pebbles, stones, roots and rubbish were removed and cleared all the grass and weeds. After spading and clearing the soil, the soil was properly rolled and packed.

Experimental plot design

Seedlings were raised in a randomized blocks with four replicates of seven treatment plots. Two pure planting plots of *A. auriculformis* and *G. arborea* along with five mixed planting plots of two species (*Acacia*×*Gmelina*) were established. Two pure planting plots were P_1 (100% A), P_2 (100% G) and five mixed planting plots were N_1 (50%A: 50%G), N_2 (75%A: 25% G), N_3 (25%A: 75%G), N_4 (65%A: 35%G), N_5 (35%A: 65%G). Each plot was 200 cm×60 cm in size with 30 seedlings at a spacing of 20 cm×20 cm (seedling to seedling distance: 20 cm).

Care and maintenance

Three seeds of each species were sown in each point of the experimental bed. When germination completed, single seedling was maintained per point and others were removed carefully so that the seedlings do not get injured. Adequate watering by fine shower and care were taken regularly as per requirement. Removal of weeds, grasses etc. were done as far as possible. Weeding was done in every 10-15 days and continued up to 10 months. Proper care and maintenance were given for one year.

Measurement of Growth Parameters in the Nursery

Measurement of height, collar diameter, leaf/phyllode number and branch number

Seedlings were allowed to grow for ten months from the time of seed sowing. Five representative seedlings from each species were selected from each replication of a treatment for measuring physical parameters. Periodic measurements on height of the seedlings were taken in every month from the ground to the tip of the highest bud. Similarly, collar diameter and leaf/phyllode number were taken along with height. Shoot height was measured from collar region to the tip of seedling at each reading time. Collar diameter was measured at the collar region transitional zone between root and shoot of the seedlings with a vernier caliper. Total number of nodes and branch on the stem of seedlings from each replication was counted and average number was calculated.

Growth data collection in the nursery

Five randomly selected seedlings of each species were uprooted carefully from each mix plot and ten seedlings from each pure plantation plot after 10 months of germination. The uprooted seedlings were washed to clear the root region off all soil particles. The data on seedling morphological characters (shoot length, shoot diameter, branch number, leaf number, tap root length, lateral root length, tap root diameter, and number of lateral roots) were recorded. Fresh weight of the stem, root and leaves were measured after removal of all water from the root portion of the washed seedlings. Stem, root and leaves were kept in open air for 2 weeks in the laboratory to dry the samples. Then the samples were oven dried at 70°C for 72 hours according to Aryal et al. (1999) and after that oven dry weight of shoot, root and leaf of the seedlings was measured.

Measurement of relative yield of A. auriculformis and G. arborea seedlings

Expected relative yield (RY) for *A. auriculformis* and *G. arborea* occurs when plants of these species grow equally well in mixture and monoculture (Harper 1977). Relative yields (RY) of *A. auriculformis* and *G. arborea* were measured using the following formulas:

Relative yield of *A. auriculformis* (RY_A)=

$$\frac{\textit{Yield of A. auriculformis in mixture}}{\textit{Yield of A. auriculformis in monoculture}}$$

Relative yield of *G. arborea* (RY_G)=

$$\frac{\textit{Yield of G.arborea in mixture}}{\textit{Yield of G.arborea in monoculture}}$$

Relative yield total (RYT)$=RY_A+RY_G$

Values of RYT of 1.0 imply that there is competition, >1.0 imply niche differentiation, and <1.0 imply mutual antagonism.

Determination of efficiency of intercropping system/ mixed plantation

The efficiency of inter-cropping system/ mixed plantation can be evaluated by the land equivalent ratio (LER) defined as the total area required under sole or pure plots to produce the equivalent biomass yields obtained under inter-cropping/ mixed plots (Reza et al. 2013).

$$LER = L_A + L_G = (B_A / S_A) + (B_G / S_G)$$

Where, S_A and S_G=Sole biomass of the *A. auriculformis* and *G. arborea*;

B_A and B_G=Biomass of *A. auriculformis* and *G. arborea* in the mixture.

A total of LER value greater than 1.0 indicates advantages from inter-cropping or mixture in terms of the use of environmental resources for plant growth. Values of L_A, and L_G are greater than 0.5 indicates advantage for an individual species in intercropping system over the pure plantation.

Measurement of Quality Index (QI) of A. auriculformis and G. arborea seedlings

The quality index (QI) of *A. auriculformis* and *G. arborea* were measured to quantify seedlings morphological quality. The quality index (QI) as developed by Dickson et al. (1960) to quantify seedlings morphological quality was calculated as follows:

$$QI = \frac{\textit{Seedling dry weight (g)}}{[\textit{Height (cm)/ Diameter (mm)} + \textit{Shoot dry weight (g)/ root dry weight (g)}]}$$

Statistical analysis

The periodic height (cm) increment, lateral root length (cm), shoot length (cm), tap root length (cm), collar diameter (cm), shoot diameter (cm), tap root diameter (cm), leaf number, number of lateral roots were compared among pure and mixed plots of the species. Analysis of variance and tests for means ($p < 0.05$) were run using the means of each variable from each of the three replicate plots. All the data collected were analyzed statistically by using the computer software package SPSS and were subjected to analysis by Duncan's Multiple Range Test (DMRT).

Results

Initial growth performance of A. auriculiformis and G. arborea at the nursery

Increasing trend of height

There was significant difference in monthly height increment for *A. auriculiformis* in mixture with *G. arborea* where highest value of monthly increment for *A. auriculiformis* was recorded in P_1 (15.04 cm) and lowest value was re-

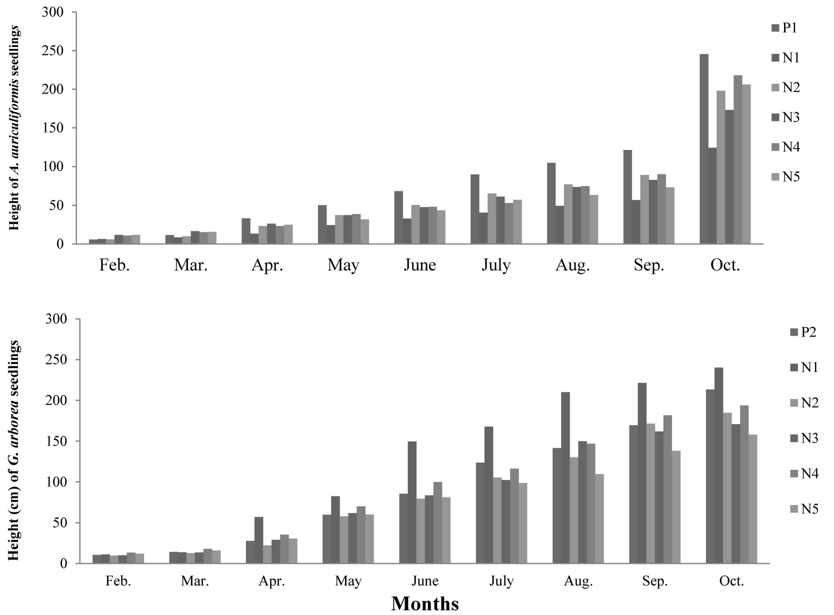

Fig. 1. Periodic height (cm) increment of *A. auriculiformis* and *G. arborea* seedlings in the treatment plots.

corded in N_1 (7.13 cm). Highest value of height was recorded in P_1 (234.36 cm) and lowest value was recorded in N_1 (124.24 cm) for *A. auriculiformis* (Fig. 1).The order of height increment for *A. auriculiformis* was $P_1 > N_2 > N_4 > N_5 > N_3 > N_1$.

The present study revealed that there was significant difference in height increment per month for *G. arborea* in mixed plantation with *A. auriculiformis* and highest value (26.68 cm) of height increment per month was recorded in N_1 plot and lowest value (17.54 cm) in N_5 plot. *G. arborea* showed better growth performance (240.13 cm) in mixed plantation with *A. auriculiformis* than pure plantation (213.40 cm). Seedlings of *G. arborea* were tallest (240.13 cm) in N_1 followed by N_4 (193.80 cm) and shortest in N_5 (157.89 cm) (Fig. 1). The order of height increment for *G. arborea* was $N_1 > P_2 > N_4 > N_2 > N_3 > N_5$.

Increasing trend of collar diameter

Results from periodic measurement of collar diameter of the *A. auriculiformis* seedlings (Fig. 2) showed that, there were significant differences in monthly collar diameter increment for *A. auriculiformis* in the mixture with *G. arborea. A. auriculiformis* showed better growth performance in pure plantation- P_1 (0.117 cm) than mixture with *G. arborea*- N_1 (0.063 cm). Highest value of collar diameter was recorded in N_2 (0.887 cm) and lowest value was recorded in N_1 (0.571 cm) for *A. auriculiformis* in the mixed plantation with *G. arborea*. In the mixed plots, the order of monthly collar diameter increment for *A. auriculiformis* was $P_1 > N_2 > N_4 > N_5 > N_3 > N_1$.

Highest value (1.284 cm) of collar diameter for *G. arborea* was recorded in N_1 plot followed by N_4 (1.276 cm) and lowest value (1.204 cm) in N_2 plot (Fig. 2). The order of monthly collar diameter increment for *G. arborea* was $N_1 > N_4 > N_5 > N_3 > P_2 > N_2$.

Increasing trend of phyllode number of *A. auriculiformis* seedlings

A. auriculiformis showed highest (94) phyllodes in pure than mixed plantation with *G. arborea* (79) (Fig. 3). The order of phyllode (number) increment for *A. auriculiformis* was $P_1 > N_2 > N_3 > N_1 > N_4 > N_5$.

Increasing trend of leaf number of *G. arborea* seedlings

The present study revealed that, there was significant difference in monthly leaf increment for *G. arboreain* the mixed plantations with *A. auriculiformis*. Highest number (87) of leaves after 9 months of seed sown were recorded in N_3 followed by N_4 (79) and lowest number (63) in N_2. *G. arborea* showed highest leaf number (87) in the mixed plantation (N_3) than in pure P_2 (75) plot. The order of leaf (number) increment for *G. arborea* was $N_3 > N_4 > P_2 > N_1 >$

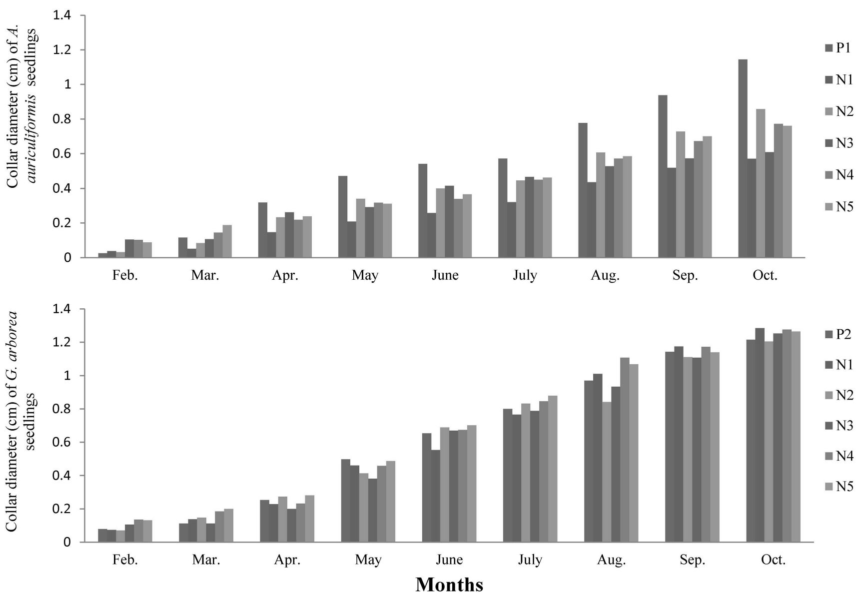

Fig. 2. Periodic collar diameter (cm) increment of *A. auriculiformis* and *G. arborea* seedlings in the treatment plots.

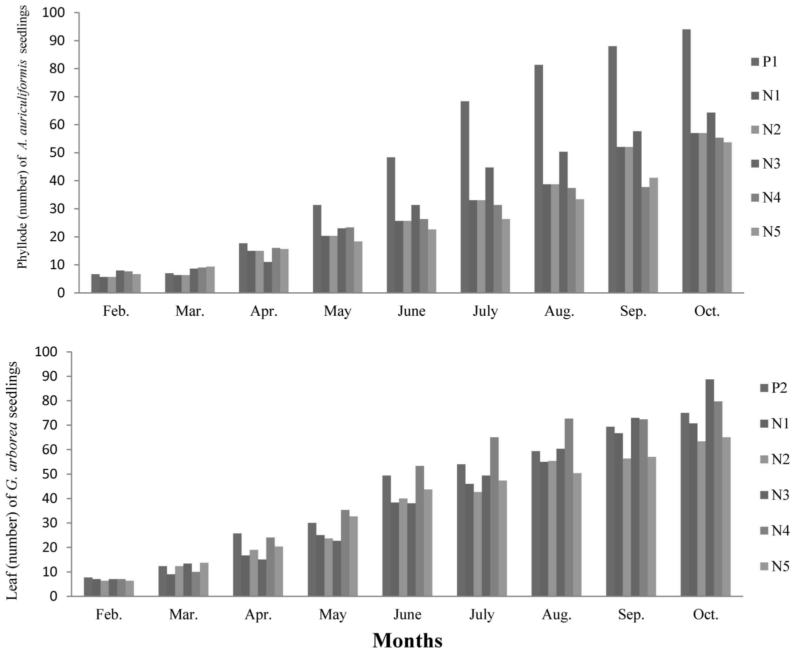

Fig. 3. Periodic increment of phyllode (number) of *A. auriculiformis* and leaf (number) of *G. arborea* seedlings in the treatment plots.

Table 1. Seedling morphological characters (stem height, collar diameter, branch number, leaf number, lateral root number, tap root diameter, tap root length and lateral root length) of *A. auriculiformis* and *G. arborea* in pure and mixed planting plots at 10 months after germination

Treatment		Shoot				Root			
		Stem ht. (cm)	Collar dia. (cm)	Branch number	Leaf number	Lateral root number	Tap root diameter (cm)	Tap root length (cm)	Lateral root length (cm)
A. auriculiformis	P_1	149.53^{de}	1.14^{bc}	8.34^{abc}	98.33^{ab}	21^{abcd}	1.07^{e}*	32.87^{b}	36.8^{cd}
	N_1	68.73^{a}	0.67^{a}	0.34^{a}	67.67^{a}	17^{abc}	0.68^{ab}	17.9^{a}	5.67^{a}
	N_2	103.1^{abc}	0.71^{a}	3^{abc}	89.34^{ab}	12^{ab}	0.53^{a}	18.53^{a}	13.93^{ab}
	N_3	94.97^{ab}	0.76^{a}	0.35^{a}	70.67^{a}	18.68^{abc}	0.63^{ab}	20.4^{ab}	19.89^{abc}
	N_4	105.9^{abcd}	0.88^{ab}	1^{ab}	73^{a}	15^{abc}	0.73^{abc}	23.94^{ab}	16.38^{ab}
	N_5	106.07^{abcd}	0.78^{a}	0.67^{ab}	65^{a}	7.66^{a}	0.67^{ab}	19.7^{a}	10.76^{ab}
G. arborea	P_2	225^{b}*	1.27^{a}	3^{a}	78^{a}	24^{ab}	1.09^{abc}	34.1^{b}	47.88^{b}
	N_1	273.2^{c}	1.35^{a}	0.67^{a}	75.33^{a}	36.34^{b}	0.98^{a}	21.38^{a}	30.93^{a}
	N_2	201.7^{ab}	1.38^{a}	0.67^{a}	69.33^{a}	14.35^{a}	1.276^{c}	29.73^{ab}	35.16^{a}
	N_3	190.93^{a}	1.35^{a}	0.33^{a}	90.33^{b}	21^{ab}	1.22^{bc}	25.75^{a}	37.47^{ab}
	N_4	196.47^{a}	1.37^{a}	0.67^{a}	84.35^{ab}	14.68^{a}	0.94^{a}	18.57^{a}	34.57^{a}
	N_5	179.53^{a}	1.30^{a}	1.33^{a}	69^{a}	12.35^{a}	1.07^{ab}	13.14^{a}	34.68^{a}

*Means followed by the same letter(s) in the same column are not significantly different at $p < 0.05$ (DMRT).

$N_5 > N_2$ (Fig. 3).

Seedling morphological character

Results of variance analysis for morphological characteristics of intercropping *A. auriculiformis* and *G. arborea* seedlings are represented in Table 1.The result of variance analysis for seedling morphological character after 10 months of *A. auriculiformis* revealed that the effect of planting pattern was significant ($p < 0.05$).

After 10 months, significantly ($p < 0.05$) highest mean shoot length (273.3 cm) for *G. arborea* was observed in mixed plot N_1 followed by P_2 (225 cm) (Table 1). *G. arborea* showed maximum shoot length in mixed plantation with *A. auriculiformis* than pure plantation. Maximum collar diameter was found in N_2 (1.38 cm) followed by N_4 (1.37 cm) and N_3 (1.35 cm). *G. arborea* showed better collar diameter (1.27 cm) increment at 10 month in mixed plots than pure plantations. Highest number (90.33) of leaves was found in the N_3 plot followed by N_4 (84.35), and P_2 (78). Highest mean lateral roots (36.34) for *G. arborea* were observed in N_1, followed by P_2 (24) and N_3 (21). Maximum mean tap root length (34.1 cm) was observed in pure P_2 plot and lowest in N_5 (13.14 cm). Maximum mean lateral root length (47.88 cm) for *G. arborea* was found in pure P_2 followed by N_3 (37.47 cm) and N_2 (35.16 cm).

Biomass productivity

The result of variance analysis for dry weight of *A. auriculiformis* and *G. arborea* revealed that the effect of planting pattern was significant ($p < 0.05$). Mean comparison using Duncan multiple range test (DMRT) showed that the highest amount of yield for dry weight obtained in pure plot

Table 2. Biomass productivity of *A. auriculiformis* and *G. arborea* seedlings in pure and mixed planting plots at 10 months after germination

Treatment		Fresh weight (g)				Dry weight (g)			
		Stem	Root	Leaf	Total	Stem	Root	Leaf	Total
A. auriculiformis	P_1	45^{ab}*	20.06^{cd}	38.07^{ab}	103.07^{ab}	23.25^{bcd}	10.06^{cde}	17.48^{ab}	50.76^{bcd}
	N_1	7.06^{a}	6.33^{a}	8.08^{a}	21.47^{a}	4.7^{a}	4.2^{a}	5.17^{a}	14.07^{a}
	N_2	9.58^{a}	9.66^{ab}	21.89^{a}	41.13^{ab}	5.72^{a}	5.28^{abc}	8.54^{a}	19.53^{ab}
	N_3	11.87^{ab}	7.74^{a}	11.93^{a}	31.50^{ab}	6.38^{ab}	4.83^{ab}	6.47^{a}	17.69^{ab}
	N_4	12.47^{ab}	8.42^{a}	12.85^{a}	33.74^{ab}	7.15^{ab}	5.25^{abc}	6.14^{a}	18.55^{ab}
	N_5	9.64^{a}	6.49^{a}	9.80^{a}	25.98^{ab}	5.31^{a}	4.62^{ab}	5.97^{a}	15.9^{a}
G. arborea	P_2	115.37^{ab}*	45.87^{ab}	41.87^{c}	203.15^{ab}	54.47^{a}	24.68^{ab}	14.17^{b}	93.35^{ab}
	N_1	219.43^{b}	80.67^{b}	22.36^{abc}	322.53^{c}	124.73^{b}	39.17^{b}	8.53^{a}	172.42^{b}
	N_2	35.17^{a}	18.37^{a}	10.29^{a}	63.83^{a}	15.67^{a}	8.347^{a}	6.01^{a}	30^{a}
	N_3	54.01^{a}	28.96^{a}	20.93^{abc}	103.92^{ab}	26.47^{a}	14.86^{a}	8.65^{a}	49.98^{a}
	N_4	30.003^{a}	17.92^{a}	12.35^{a}	60.28^{a}	15.89^{a}	10.47^{a}	7.41^{a}	33.77^{a}
	N_5	41.63^{a}	17.55^{a}	15.88^{ab}	75.07^{a}	18.83^{a}	10.11^{a}	7.95^{a}	36.91^{a}

*Means followed by the same letter(s) in the same column are not significantly different at $p < 0.05$ (DMRT).

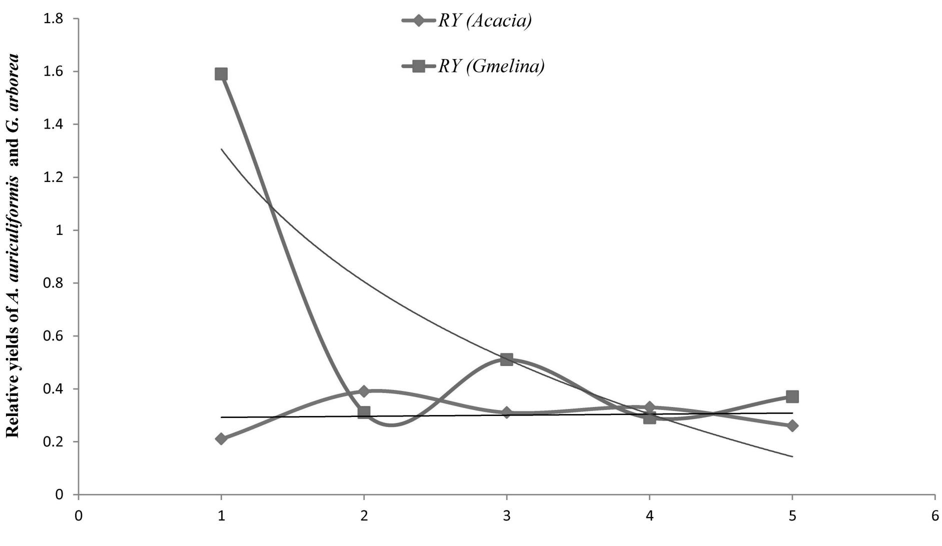

Fig. 4. Distribution of relative yields of two species among five mixed plots.

P_2. Compared to pure plot (50.76 g), the dry masses of stem, root and leaves were also significantly lower in mixed plots (Table 2).

Mean comparison using Duncan multiple range test (DMRT) showed that the highest amount of yield for fresh weight obtained in mixed plot (N_1). At the time of *G. arborea* seedlings harvest, the highest fresh weight (322.53 g) was recorded in N_1 followed by 203.15 g in P_2. Compared with pure plot (203.15 g), the fresh weight of stem, root and leaves were also significantly higher in mixed plots.

Compared to pure plot (93.35 g), the dry masses were also significantly higher (172.42 g) in mixed plot N_1. The dry masses of stems, roots and leaves were also significantly higher in N_1 for *G. arborea* compared to pure P_2. Among the mixed plots, maximum (172.42 g) oven dry weight was found in N_1 followed by N_3 (49.98 g) and N_5 (36.91 g) (Table 2).

Relative Yield (RY)

From the present investigation it was found that RY was highest for *A. auriculiformis* (0.39) in N_2 plot and for *G. arborea* (1.59) in N_1 plot (Fig. 4). Values of RYT ($<$1.0) in N_2, N_3, N_4 and N_5 plots imply mutual antagonism between *A. auriculiformis* and *G. arborea* (Table 3).

Quality Index (QI)

The present study revealed that at ten months after germination, the quality index was highest (8.96) for *G. arborea* seedlings in N_1 plot followed by *A. auriculiformis* (1.66) seedlings in P_1 plot (Table 4).

Table 3. Efficiency of plant mixture represented by the land equivalent ratio (LER)

Mixed Plots	B_A*	L_A**	B_G*	L_G**	LER***	RY_A#	RY_G#	RYT##
N_1	14.07	0.28	30.01	1.84	2.13	0.21	1.59	1.8
N_2	19.54	0.38	49.98	0.32	0.71	0.39	0.31	0.7
N_3	17.69	0.35	33.77	0.53	0.88	0.31	0.51	0.82
N_4	18.55	0.37	36.91	0.36	0.73	0.33	0.29	0.62
N_5	15.90	0.31	103.45	0.39	0.71	0.26	0.37	0.63

Note: *B_A and B_G=Biomass of *A. auriculiformis* and *G. arborea* in the intercrop/ mixture; **L_A and L_G=Advantage for an individual species (*A. auriculiformis* and *G. arborea* respectively) in mixture over the pure plantation; ***LER=Land Equivalent Ratio in the mixed plots; #RY_A and RY_G=Relative yields of *A. auriculiformis* and *G. arborea* in the mixture; ##Relative Yield Total (RYT)=RY_A+RY_G.

Table 4. Quality Index of *A. auriculiformis* and *G. arborea* in pure and mixed plots at ten months after germination

Treatment		Seedling dry weight	Height (cm)	Collar dia. (mm)	Ht. (cm)/ Collar dia. (mm)	Shoot dry weight (g) [S.D.W.]	Root dry weight (g) [R.D.W.]	S.D.W./ R.D.W.	Ht/Coll.dia.+ S.D.W./ R.D.W.	QI
A. auriculiformis	P_1	50.79	149.53	11.4	13.13	40.74	10.07	4.07	30.59	1.66
	N_1	14.06	68.73	6.7	10.26	9.87	4.2	2.34	15.42	0.92
	N_2	19.54	103.1	7.1	14.52	14.26	5.29	2.69	23.06	0.85
	N_3	17.69	94.97	7.6	12.49	12.87	4.83	2.66	18.96	0.93
	N_4	18.55	105.9	8.8	12.04	13.3	5.25	2.53	18.17	1.03
	N_5	15.90	106.07	7.8	13.59	11.28	4.62	2.44	19.56	0.82
G. arborea	P_2	93.36	225	12.67	17.78	68.67	24.68	2.79	20.55	4.54
	N_1	172.42	202.64	12.81	15.83	133.27	39.16	3.41	19.24	8.96
	N_2	30	201.7	13.80	14.62	21.65	8.34	2.59	17.22	1.74
	N_3	49.99	190.93	13.50	14.15	35.12	14.86	2.37	16.51	3.03
	N_4	33.77	196.47	13.70	14.34	23.31	10.46	2.23	16.57	2.04
	N_5	36.91	179.53	13.01	13.81	26.79	10.12	2.64	16.46	2.24

Discussion

In this study, the height of *A. auriculiformis* and *G. arborea* seedlings were measured for ten times. In this respect, given the values presented in Fig. 1, it has been determined according to variance analysis applied that there were statistically significant differences between height increment of these two species ($p<0.05$). According to the results of Duncan Multiple test implemented, it has been found that the height of seedlings in pure plots were lower than the height of seedlings in mixed plots.

In this research, the effects of mixed plantations on growth and biomass of two common plantation tree species (*A. auriculiformis* and *G. arborea*), and the root and stem development of these species were investigated. In this respect, it has been determined that there were significant differences between growth performance of the seedlings ($p<0.05$). Accordingly, it has been found that the growth performance of the non-nitrogen fixing *G. arborea* seedlings exposed to various patterns of mixed plantations with *A. auriculiformis* were much higher than the growth performance of the *G. arborea* seedlings in pure plantations.

The initial growth performance of *A. auriculiformis* and *G. arborea* in the experiment showed that both the species performed better in combinations than in pure plantations. Compared with pure plantation, performance of *G. arborea* was significantly higher when it was planted with *A. auriculiformis* in 50:50 proportions. *G. arborea* also showed best performance in the mixture with *A. auriculiformis* in 75:25 and 25:75 ratios. The better performance of *G. arborea* in mixed plots attributed to greater nutrient availability in the soil as *A. auriculiformis* is nitrogen fixing tree species. In this study, the height and collar diameter of *A. auriculiformis* seedlings at three months after germination were recorded 33.2 cm and 3.59 mm accordingly in pure plot which was higher than Khan et al. (2004). Khan et al. (2004) reported maximum height (22.9 cm) and collar diameter (3.50 mm) for three months old *A. auriculiformis* seedlings in nursery condition.

The present study indicates the possible synergy due to various root architecture between these two species might have benefited *G. arborea* in the mixed plots for moisture absorption and nutrient uptake. This might be the reason for better height increment of *G. arborea* in mixed plots than in pure plots. Similar beneficial effects on height growth on non-nitrogen fixing species in mixture with Acacia spp. have also been reported when non-nitrogen fixing *Eucalyptus sieberi*, *E. botryoides* and *E. sideroxylon* were planted with *Acacia longifolia* in Victoria, Australia (FAO 1992; Aryal et al. 1999).

Nitrogen is the major nutrient required for growth of tree crops and forests contribute nutrients to the soil in the form of litterfall (Aryal et al. 2000). The present study indicates the increment of nitrogen in the soil through plantation of nitrogen fixing tree species. If plant species do not provide any nutrient to the forest soil, it is necessary to input chemical fertilizers in the forest floors for improving forest production. Chemical fertilizers are also considered as means to produce more foods and provide food security for the developing countries though these fertilizers are thought as a source of pollution. High input of fertilizers, insecticides or pesticides has led to serious environmental pollution and threatening the life supporting system of the nature. Poor purchasing capacity, increasing costs of chemical fertilizers and continuous deleterious environmental consequences of such fertilizers and pesticides have drawn attention of environmentalists and foresters to find alternative farming systems or plantations which are viable economically and ecologically as well as environment friendly. Organic farming system (OFM) and plantation of nitrogen fixing species such as *A. auriculiformis* with mixture is one of the most promising such alternatives. The present study also shows the higher rates of nutrient cycling in mixed stands of *A. auriculiformis* with *G. arborea* than in *G. arborea* monocultures which is similar to Forrester et al. (2005). Forrester et al. (2005) showed that nutrient cycling was higher in mixed stands of *Acacia mearnsii* with non-nitrogen fixing *Eucalyptus globulus* than in *E. globulus* monocultures.

The reasons for better initial growth performance of *A. auriculiformis* in mixed plantations than in pure plots may be due to greater intra-specific competition among the seedlings for various resources in pure than in mixed plots. The present results also showed that the quality index of non-nitrogen fixing *G. arborea* (8.96) was highest in the mixed plots with *A. auriculiformis* than in pure plots which are similar to Aryal et al. (1999). Aryal et al. (1999) reported maximum quality index (110.5) for non-nitrogen fixing *Eucalyptus camaldulensis* in the mixed plots with *Albizia procera* than in pure plots.

The key to long term sustained production is maintaining and improving soil fertility, preventing soil degradation or, in case of degraded soil, restoring soil fertility. For these purposes, production technologies based on the use of nitrogen fixing plant species such as *A. auriculiformis* and such other symbiosis are considered viable alternatives. *A. auriculiformis* is extensively planted in plantations all over the country for its short rotation, wider adaptability and faster growth. *G. arborea* is a non–nitrogen fixing species extensively planted in forests, marginal lands, institute campuses, roadsides, railway sites, field borders and homesteads of Bangladesh. From the present investigation, it was evident that the mixed stands possess better effects than the pure stands in improving biomass, which was similar to that of Forrester et al. (2005). A study conducted by Forrester et al. (2005) reported that performance of non-nitrogen fixing *Eucalyptus globulus* was significantly higher when it was planted with *A. mearnsii* in a proportion of 50:50.

The present study indicates that *A. auriculiformis* grows easily in open plantation sites, which is in agreement with the finding of Hossain (2015). Hossain (2015) reported that many slow growing and shade loving demanding tropical trees are synecology is not suitable for growing in the open plantation areas. They suffer from weed competition and often need special micro-climates which do not exist in a plantation environment. In such situations, the phyllode Acacias (*A. auriculiformis*) grow easily on open sites. The present study also suggests that *A. auriculiformis* may be planted in degraded lands with long and medium rotation species such as *Tectona grandis*, *Dipterocarpus turbinatus*, *Shorea robusta* etc. *A. auriculiformis* may also be planted in the large scale afforestation programs with various native tree species.

Conclusion

This study has the characteristic of being a pre-study for determining the effects of pure and mixed plantations of *A. auriculiformis* and *G. arborea* on growth and biomass yield in nursery conditions. In this respect, this research should be enhanced and the effects of mixed plantations and intra-specific competition on the genetic structure of the plant should also be investigated. The present study suggests that *A. auriculiformis* and *G. arborea* planted at 50%A: 50%G or 75%A: 25% G distribution can enhance biomass productivity by improving soil water, soil organic matter and nutrients availability. Mixture of nitrogen fixing *A. auriculiformis* and non-nitrogen fixing *G. arborea* may have reduced intra-specific competition among seedlings and thus promoted the growth and biomass production in mixed plantations than monoculture. However, further research should be carried out with other nitrogen fixing tree species at the field level before going for large scale plantation programs.

References

Ahmed GU. 1990. Survival percentage and growth statistics of some plantation species at the Chittagong University Campus. Chittagong University Studies, Part II: Science 14: 45-50.

Alam MS, Masum KM, Rashid MO. 2005.Tree Species Diversity and Management Practices of Woodlot in the Homegarden of the Offshore Island of Bangladesh. Pakistan J Bio Sci 8: 561-566.

Ali Reza AHM, Barua SP, Huq SMI, Khan ASM, Nishat A. 2002. Bio-ecological zones of Bangladesh. IUCN Bangladesh Country Office, Dhaka, pp 1-141.

Aryal UK, Hossain MK, Koirala B, Mridha MAU, Xu HL, Umemura H. 1999. Effects of pure and mixed planting of *Eucalyptus camaldulensis* Dehnh. and *Albizia procera* (Roxb.) Benth on Growth, Biomass Yield and Soil Fertility. Nature Farming and Sustainable Environment II: 57-62.

Aryal UK, Hossain MK, Mridha MAU, Xu HL. 2000. Nodulation status and nitrogenase activity of some legume tree species in Bangladesh. J Crop Prod 3: 325-335.

Badruddin AZM, Bhuiyan MK, Mustafa M. 1989. Comparative growth study of three fuel-wood species grown in the agricultural marginal lands of Chittagong University Campus. Chittagong University Studies, Part II: Science 13: 137-142.

Binkley D, Giardiana C. 1997. Nitrogen fixation in tropical forest plantations. In: Management of soil nutrients and water in tropical plantation forests (Nambier EKS, Brown AG, eds). ACIAR Monograph No. 43, Canberra, pp 297-337.

Bristow M, Vanclay JK, Brooks LO, Hunt M. 2006. Growth and species interactions of *Eucalyptus pellita* in a mixed and monoculture plantation in the humid tropics of north Queensland. For Ecol Manag 233: 285-294.

Chaukiyal SP, Singh KCH, Pokhriyal TC. 1999. Effects of seasonal variations on nodulation and nitrogen fixing behaviour in some *Acacia* species. Ann For 7: 112-119.

Dickson A, Leaf AL, Hosner JF. 1960. Quality appraisal of white spruce and white pine seedling stock in nurseries. For Chron 36: 10-13.

Dutta S, Hossain MK, Hossain MA, Chowdhury P. 2014. Exotic plants and their usage by local communities in the sitakunda botanical garden and Eco-Park, Chittagong, Bangladesh. For Res 4: 136.

Forrester D, Bauhus J, Cowie A. 2005. Growth and species interactions in mixed plantations of *Eucalyptus globulus* and *Acacia mearnsii*. IUFRO World Series Vol. 15, Vienna, pp 40-42.

Gafur MA, Karim A, Khan MAA. 1979. Physiological study of hills of Chittagong University campus. Chittagong University Studies, Part II, Science 3: 11-28.

Giller KE, Wilson KJ. 1991. Nitrogen fixation in tropical Cropping systems. CAB International, Wallingford, p 313.

Gutteridge RC, Shelton HM. 1994. Forage tree legumes in tropical agriculture. CAB International, Wallingford, pp 389.

Harper JL. 1977. Population biology of plants. Academic Press, London.

Hossain MK, Alam MK, Miah MD. 2008. Forest Restoration and Rehabilitation in Bangladesh. In: Keep Asia Green (Lee DK. ed.). IUFRO World Series Vol. 20-III, Vienna, pp 21-66.

Hossain MK, Hoque ATMR. 2013. Eucalyptus dilemma in Bangladesh. Institute of Forestry and Environmental Sciences, University of Chittagong, Chittagong, pp 148.

Hossain MK. 2008. The contribution and critics of exotic species in the plantation forestry of Bangladesh. In: Exotics in indian forestry (Chauhan SK, Gill SS, Chauhan R, Sharma SC. eds). Agrotech Publishing Academy, Udaipur, 324-335.

Hossain MK. 2015. Silviculture of plantation trees of Bangladesh. Arannayk Foundation, Dhaka, 361 pp.

Hossain MS, Hossain MK, Koirala B. 2001. Growth and nodulation status of seven multipurpose tree legumes grown in hill soils under nursery conditions. J For Env 1: 97-101.

Huda SMS, Uddin MB, Haque MM, Mridha MAU, Bhuiyan MK. 2006. Horizontal distribution of ectomycorrhizal infection in *Dipterocarpus turbinatus* plantations of Bangladesh. J For Res 17: 47-49.

Kelty MJ. 1992. Comparative productivity of monocultures and mixed-species stands. In: The ecology and silviculture of mixed species forests (Kelty MJ, Larson BC, Oliver CD, eds). Kluwer Academic Publishers, Dordrecht, pp 125-141.

Kelty MJ. 2006. The role of species mixtures in plantation forestry. Forest Ecol Manag 233: 195-204.

Khan BM, Hossain MA, Hossain MM, Hossain MK. 2004. Performance of eleven multipurpose tree legume seedlings grown in the hill soils under nursery conditions in Bangladesh. Int J Agri Biol 6: 346-349.

Laclau JP, Bouillet JP, Goncalves JLM, Silva EV, Jourdan C, Cunha MCS, Moreira MR, Saint-Andre L, Maquere V, Nouvellon Y, Ranger J. 2008. Mixed-species plantations of *Acacia mangium* and *Eucalyptus grandis* in Brazil: 1. Growth dynamics and above ground net primary production. Forest Ecol Manag 255: 3905-3917.

Mahmood S, Hoque ATMR, Mohiuddin M. 2005. Nodulation behaviors and biomass productivity of three leguminous plant species at nursery stage in chittagong university soils. Res J Agri Bio Sci 1: 89-93.

Osman KT, Islam MS, Haque SMS. 1992. Performance of some fast growing trees in the University of Chittagong Campus. Indian Forester 118: 858-859.

Petit B, Montagnini F. 2006. Growth in pure and mixed plantations of tree species used in reforesting rural areas of the humid region of Costa Rica, Central America. Forest Eco Manag 233: 338-343.

Reza ZO, Allahdadi I, Mazaheri D, Akbari GA, Jahanzad E, Mirshekari M. 2013. Effect of different planting proportions and nitrogen fertilizer in intercropping forage sorghum and lima bean. African J Agri Res 8: 6488-6498.

Sayyad E, Hosseini SM, Mokhtari J, Mahdavi R, Jalali SG, Akbarinia M, Tabari M. 2006. Comparison of growth, nutrition and soil properties of pure and mixed stands of *Populus deltoides* and *Alnus subcordata*. Silva Fennica 40: 27-35.

Wormald TJ. 1992. Mixed and pure forest plantations in the tropics and subtropics. Food and Agriculture Organization of the United Nations, Rome, pp 152.