Early growth, thinning yield and estimated biomass of standing trees of *Dalbergia latifolia* Roxb. in the eastern Terai, Nepal

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Dalbergia latifolia plot was established at Belbari, Morang District, in the eastern terai of Nepal by Plantations Section of Department of Forest Research and Survey. It was planted on 3rd July 1995 in 0.79 ha at a spacing of 4 m x 2 m. Selection thinning was carried out for 7.5 years old *Dalbergia latifolia*. 70 trees were selected from 129 thinned trees for biomass and volume measurements. In thinning operation, 19.7% (31% of total trees) of total basal area was removed in the plot. The model Ln W or V = a+b* Ln (DBH) where W or V stands for weight or volume of tree components, dbh for diameter at breast height, a and b regression constants, was selected to estimate the biomass of tree components and over bark (ob) stem volume. Before thinning, the density (trees per ha) was 524, whereas the number of trees after thinning was only 363 per ha. The top and dominant heights of 7.5 years old *D. latifolia* were 8.1m 8.7m respectively before thinning and the basal area was 3.71 m^2 per ha with mean basal area of 70.7cm^2 per tree (0.0071 m^2 per tree). The density of green stem wood was found 929 kg per m^3. The highest dry matter content (49%) was found in stem wood and the least in leaf (36.1%). Estimated mean green stem wood of 7.5 years old *D. latifolia* was 26.4 kg per tree (13.8 tons per ha), and 31.5 kg per tree (11.4 tons per ha); estimated mean green branch wood 11.2 kg (5.9 tons per ha), and 13.9 kg (5 tons per ha) and estimated mean green leaf 5.4 kg (2.8 tons per ha) and 6.4 kg (2.3 tons per ha) for the sanding trees before and after thinning. Before thinning, *D. latifolia* had the wood productivity of 2.62 tons per ha per year and 5.01 kg per tree per year whereas it was 0.38 tons per ha per year and 0.72 kg per tree for leaf. The ob stem volume of standing trees before thinning was 8.8 m^3 per hectare. Ob stem volume per tree increased with the increase in diameter. Under bark stem volume and bark volume were found to be 70.1% and 29.9% of the total ob stem volume.

Keywords : *Dalbergia latifolia*, growth, biomass, yield, Nepal

Dalbergia latifolia Roxb., Satisal (Indian rosewood), is found in Nepal from the Terai to 1000m. It is common in *Dalbergia sissoo* forests. Because of its multiple use (Troup 1921), it is highly exploited in the natural forest of Nepal. Very few mature trees are left in such forest. Although, its natural regeneration is found remarkable in some places, reports on large-scale plantations are lacking. However, the author has seen its private scattered plantation in a very small scale. In such situation, it is very important to conserve its gene by establishing its plantation.

The information on growth, planting method and yield from thinning would be valuable for community and private plantations as well. The thinned yield can be used for firewood. This paper attempts to provide information on early growth, thinning yield at 7.5 years and estimated biomass of tree components, aboveground wood and aboveground biomass.

Materials and methods

Dalbergia latifolia was planted on 3rd July 1995 in 0.79 ha at a spacing of 4 m x 2 m. This trial was established by the Plantation Section of Forest Research Division of Department of Forest Research and Survey at Belbari of Morang District in the eastern Terai of Nepal. The site has sub-tropical climate. Its altitude is 155 m msl. It has a flat terrain consisting of silt loam soils with a pH range of 6 to 6.3 in A and B horizons respectively. Percent N ranges from 0.02 to 0.1 and organic carbon % from 0.2 to 2. The recorded

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average maximum and minimum temperatures were 30°C and 18°C respectively. The absolute maximum temperature was 39°C (May 1999) whereas absolute minimum temperature was 4.4 °C (January 1993). The mean annual rainfall was 1737mm (Department of Hydrology and Meteorology 1997). The climatic data are from Tarahara, about 20 km to North-west of the plot. The site had a *Shorea robusta*, sal , forest up to 1987, which was heavily exploited and converted into an open land.

The polypot seedlings were raised in Tarahara nursery. The seeds were acquired from Tree Improvement and Silviculture Component, which were collected from Nijgadh forest, Bara District. Spot cultivation was carried out at 0.5m radius around each plant twice a year for the first three years.

Growth assessment was carried out annually. Selection thinning was adopted for 129 trees (dead, dying, diseased, suppressed, poorly grown, few dominant and co-dominant trees) were selected in the population and marked for thinning. 70 trees were selected from 129 trees for biomass and volume measurements. The samples covered the entire range of dbh in the population. (Annex 4). The thinning operation was carried out in January 2003. The marked trees were cut down with a bow saw at about 10 cm from the ground level. Over bark (ob) and under bark (ub) diameters of each felled tree were taken at the base, middle and top portion of the main stem to calculate ob and ub volumes. Leaves along with small twigs were separated from branches and the stem was cut into 1.5 to 2 m sections. Stem sections, branches, and foliage were weighed separately and recorded. Representative seventeen trees were selected for sub-samples of stem wood, branch wood and leaf. A similar method was applied for branch sub-samples. Similarly, leaf sub-samples were weighed and recorded.. These sub-samples were brought to the laboratory in Kathmandu and stem and branch discs were oven dried at 105°C for 48 hours and leaf for 24 hours. During that period a constant weight of stem, branch and leaf was attained.

To convert fresh weight of tree components to dry weight, sample's percentage dry matter values {(oven-dry weight/ fresh weight) x 100} were used for the general data. With the use of sampled data, among the various models, the model Ln W or V = a+b* Ln (DBH) where W or V stands for weight or volume of tree components, dbh for diameter at breast height, a and b regression constants, was selected to estimate the biomass of tree components (stem, branch and leaf) and over bark (ob) stem volume (Annex 1). The mean annual production was obtained by dividing the total biomass of tree components and above-ground wood by 7.5 years.

In the calculation of ob and ub volumes, Newton's formula was used. Twenty trees were used for the validation of the developed biomass and volume models. Prediction error and ratio of actual to predicted green biomass and ob stem volume were calculated.

Results and Discussion

Density of trees

Before thinning, the density (trees per ha) was 524, only 42% of initial density, 1250 plants per ha. Due to the browsing damage of seedlings, there was high mortality in the first three years of planting. After that period plants attained the heights such that goats could not damage them. At 7.5 years, it was found that majority of trees were in 5-6 cm class to 13-14 cm diameter class. The total density in these diameter classes was 433 trees per ha, 83 % of total density. Interestingly, the density found in 11-12 and 13-14 cm diameter class is satisfactory (Annex 3). After thinning, the scenario is slightly changed, as many trees were thinned in the diameter classes from 3-4 to 9-10 cm (Annex 4). So the density is considerably decreased in these classes as compared to the upper diameter classes i.e. from 10-12 cm to 19-20 cm. The number of trees after thinning was only 363 per ha. Trees left after thinning having larger diameter obviously will get optimum space for rapid growth.

Height Growth

Dalbergia latifolia plantations in Tamil Nadu have attained a mean height of 9m in 10 years, and a height of 11 m in 18 years (Indian Timbers 1973) whereas its plantation at Belbari, Morang had a mean height of 6.1 m in 7.5 years, which was slightly lower than Tamil Nadu plantations. The periodic height increment in 10 and 18 years were 0.9m and 0.6m respectively but the periodic height increment in 7.5 years at Belbari was 0.8m (Table 1), nearly equal to both values. In 1916 in the Saitha coppice coupes, the mean heights in coppice growth of *D. latifolia* were 17 feet (5.2m) and 20.5 feet (6.2m) in 8 (eight) and 10 (ten) years, having periodic annual increments

Table 1: Growth results of *Dalbergia latifolia* in different years

Age (year)	Mean height (m)	Std. error (m)	CV (%)	PAI (m)	CAI (cm)	Mean dbh (cm)	Std. error (m)	CV (%)	PAI (cm)	CAI (cm)
0.5	0.5	0.01	49	-	-	-	-	-	-	-
1.5	0.9	0.03	67	0.6	0.4	-	-	-	-	-
2.5	1.8	0.10	56	0.7	0.9	-	-	-	-	-
4.5	4.1	0.20	49	0.8	1.2*	5	0.2	48	1.1	-
5.5	4.9	0.10	35	0.9	0.8	6.3	0.2	44	1.1	1.3
6.5	5.9	0.10	29	0.9	1.0	8.2	0.2	38	1.3	1.9
7.5	6.1	0.10	33	0.8	0.2	8.8	0.2	46	1.2	0.6

* increment over two years due to lack of data at 2.5 years
PAI – Periodic annual increment
CAI – Current annual increment

of 0.65m and 0.62m respectively (Troup 1921). The results indicated that the height growth of *D. latifolia* at Belbari was faster than the coppice growth in Saitha.

At 5.5 years in Tarahara, *D. sissoo* attained the height 8.7m (range: 2.6-13.8m), standard error being 0.30m and CV 31.73%. The periodic annual height increment during that period was 1.58m (Thapa 1998), nearly two times than the growth rate of *D. latifolia* at Belbari. Mean top height of *D. sissoo* at 5.5 year at Tarahara was 12.8m (12.1-13.8m) and the dominant height during the same period was 12m (12-13.8m) (Thapa 1998) whereas 7.5 years old *D. latifolia* had top height (8.1m) and dominant height (8.7m) before thinning (Table 2).

From the comparison of height growth and top height, it clearly indicates that its height growth was slower than *D. sissoo,* however it is highly valued for furniture wood. The height growth among the trees of *D. latifolia* varied considerably. One of the reason may be due to genetic character of the mother tree, as all seedlings were of uniform size during planting and the same management is applied for all the plants in the plot. Other reason for the variation in growth may be due to the damage of plants by cattle and goats in different times.

Diameter Growth

Diameters of plantations in Tamil Nadu were 8 cm and 15cm in 10 and 18 years respectively (Indian Timbers 1973) whereas its plantation at Belbari, Morang had a mean diameter of 8.8cm in 7.5 years. The periodic annual diameter increment in 10 and 18 years were 0.8cm and 0.83cm respectively but the periodic diameter increment in 7.5 years at Belbari was 1.2cm. (Table 1). So the rate of diameter growth of *D. latifolia* was found higher than the rate of growth of two plantations in Tamil Nadu. It may be due to better site quality and genetic character of mother trees.

In Mysore a girth of 6 feet (58.2 cm diameter, periodic annual increment being 0.73cm) was reached in 80 years. Mean annual girth increment was 0.7 to 1.21 inches (diameter increment ranging from 0.57cm to 0.98cm) (Troup 1921).

The rate of growth in girth in Ankola high forest and Kalinaddi slopes in the North Kanara District, Bombay was 7 inches (diameter: 5.7cm) in both sites at 10 years. As coppice measurement was done in 1916 in the Saitha coppice coupes, the mean girth was 6.4 and 7.7 inches (diameters: 5.2cm and 6.2cm) in 8 and 10 years respectively (Troup 1921). In another study, DBH increment was measured at intervals of 5-9 year in 9 tree increment plots established in 1950 to 1953 in tropical moist deciduous forest and southern tropical semi-evergreen forest in Karnataka, South India. The mean age at reaching 60cm (o. b.) is 238 years (PAI is 0.25cm) (Rai 1978). The annual dbh increment in 0-10 cm and 11-20 cm diameter classes were 0.18 and 0.24cm respectively, which took 51 and 42 years to pass the class (Rai 1978). All of these results indicated that the rate of diameter growth in plantation was faster than the rate of growth in natural conditions. Since the competition for the growth is very high with other species in the natural site whereas such competition is less in the plantations.

At 5.5 years in Tarahara, *D. sissoo* attained the diameter 8.4cm (range: 2.8-15.5 cm), standard error being 0.36cm and CV 38.72% (Thapa 1998). The periodic

annual diameter increment during that period was 1.53cm and diameter of the mean basal area was 9cm (Thapa 1998). The mean diameter of 5.5 years old *D. latifolia* was 6.3 cm and periodic annual increment during that period was 1.1cm (Table1). Comparison with the diameter growth of *D. sissoo* with this species, it is found that the mean diameter was slightly higher than the mean diameter of *D. latifolia*. The difference in rate of diameter growth is quite less than the rate of height growth of these two species. It indicated that height growth was slower in *Dalbergia latifolia* than *D. sissoo*. There is a distinct variation in the diameter growth of *D. latifolia* trees. Its possible reasons are already mentioned in height growth.

Basal Area

The main factors that determine the basal area are size and density of trees. Obviously if there are many trees of large size with low density, the basal area will be higher than many trees of small size with high density. However, it may not be true if there is a large difference in density of trees. The basal (over bark, m^2/ha) area reflects how much the site is used by a particular species or crop of a certain age. The distribution of the number of trees in diameter classes determines higher or lower basal area for that tree species.

In thinning operation, 19.7% (31% of total trees) of total basal area was removed in the plot (Table 2). Basal area of 5.5 years old *D. sissoo* at Tarahara was 8.44 m^2 per hectare and mean basal area was 0.0063m^2 per tree (Thapa 1998). But the basal area of 7.5 years old *D. latifolia* at Belbari was found 3.71 m^2 per ha with mean basal area of 0.0071 m^2 per tree before thinning. The total basal area per unit area was found significantly lower than *D. sissoo* (Table 2). The reason for low basal area per unit area of *D. latifolia* may be due to low density. It is to be noted that the mean basal area of 7.5 years old *D. latifolia* was found higher than 5.5 years old *D. sissoo*, although age of *D. latifolia* is two years more than *D. sissoo*. It clearly indicates the effect of density on the increase or decrease of basal area of the crop. As the density of *D. sissoo* was 1328 stems per ha, whereas its density was only 492 stems per ha.

The basal area of standing trees before thinning was the highest (0.9748 m^2 per ha) in 11-12 cm class followed by 0.7628 m^2 per ha in 9-10 cm class (Annex 3) whereas the basal area of standing trees after thing was found 0.8449 m^2 per ha in 11-12 cm class

Table 2: DBH, heights, over bark stem volume, basal area and stocking of thinned and standing trees of 7.5 years *D. latifolia*

Parameter	Thinned trees	Standing	
		Before thinning	After thinning
Mean dbh (cm)	6.9 (0.27)	8.8 (0.17)	9.7 (0.19)
Diameter of mean basal area (cm) or crop diameter	7.5	9.5	10.3
Mean height (m)	5.1 (0.16)	6.1 (0.09)	6.5 (0.10)
Mean crop height (m)	-	7.1	-
Mean top height (m)	-	8.1	-
Minimum top height (m)	-	7.8	-
Maximum top height (m)	-	8.5	-
Mean dominant height (m)	7.9	8.7	8.9
Std. error of dominant height (m)	0.10	0.07	0.07
Minimum dominant height (m)	7.5	8	8.5
Maximum dominant height (m)	8.5	9.8	9.8
Mean basal area (cm^2)	44.6 (3.4)	70.7 (2.6)	82.5 (3.2)
Periodic annual increment of basal area (m^2/ha/year)	0.10	0.49	0.40
Basal area (m^2 per ha)	0.73	3.71	2.98
Over bark stem volume (m^3 per tree)	0.0187 (0.0020)	0.0167 (0.0019)	0.0217 (0.003)
Over bark stem volume (m^3 per hectare)	3.05	8.8	7.8
Stocking (stems per ha)	154	493	339
Basal area removal (%): 19.7	Removal of trees in first thinning (%): 31.0		

The figures in parenthesis indicate standard errors.

followed by 0.6219 m^2 per ha in 13-14 cm class, different than the basal area of trees before thinning (Annex 5)

Wood Density

From analysis of 70 sample trees, the density of green stem wood was found to be 929 kg per cubic meter. In 2-cm diameter classes, it ranges from 725 in 3-4 cm class to 977 kg per cubic meter in 11-12 cm class. The density increased from 3-4cm class to 11-12 cm class, after that it is decreased (Table 4). It may be due to less number of sample trees in these diameter classes. As there was only one sample tree in 15-16cm class and 3 trees in 13-14 cm class.

Biomass and Volume Study

Dry Matter Content

The highest dry matter content (49%) was found in stem wood and the least in leaf (36.1%). The dry matter content in branch wood was slightly lower than the stem wood. The mean dry matter content of above-ground wood was found to be 48.3%. There is no definite trend in increase or decrease in dry matter content of leaf or woody biomass in different 2-cm diameter classes (Annex 2).

The dry matter contents of stem, branch and above-ground wood of 5.5 years old *Dalbergia sissoo* at Tarahara were 43.9%,44% and 43.9% respectively (Thapa 2000) whereas its dry matter content of stem, branch and above-ground wood of *D. latifolia* were found 49%, 46.1% and 48.3% (Annex 2), slightly higher than *D. sissoo*. The results indicate the moisture content of wood is less in *D. latifolia*., indicating higher biomass of the same green weight of *D. sissoo*. But dry matter content of *Acacia catechu* was 46% for stem wood, 43.8% for branch wood and 45.4% for above-ground wood, almost similar to this species.

The dry matter contents of wood of 3.5 years old *C. siamea* and *E. camaldulensis* at Tarahara were 45.1% and 45.4% respectively (Thapa 2001) , slightly lower than the dry matter content of wood of *D. latifolia* at Belbari.

Stem Wood

The model used for estimation of biomass, R^2 value and prediction error are presented in Annex 1. Prediction error is only 3.9% in estimation of the stem wood, which states the validity of the model . The difference in the actual and predicted stem wood is small (Annex 1). Although, it is essential to test the model for estimation of stem wood in another site. Estimated mean green stem wood of 7.5 years old *D. latifolia* was 26.4 kg per tree (13.8 tons per ha) before thinning, and 31.5 kg per tree (11.4 tons per ha) after thinning, and actual green stem wood 17.3 kg per tree (2.8 tons per ha) of thinned trees (Table 3). The contribution of green stem wood of standing trees before thinning in total above-ground wood was 70%, whereas it was 74% for thinned trees and 69% for trees after thinning (Annex 3, 4, 5), whereas its contribution in total above-ground biomass was 62 %. The contribution of stem wood in total above-ground biomass differed slightly in trees before thinning, after thinning and thinned trees (Table 3). The content of stem in total above-ground wood decreased with the increase in diameter, for instance only 55 % of stem wood was in 19-20 cm diameter class. Before thinning, the highest green stem wood biomass was 3709 kg per ha in 11-12 cm class followed by 2958 kg per ha in 13-14 cm class (Annex 3). Due to few number of trees above the diameter class 13-14 cm, the stem wood was found less. The highest stem wood biomass was recorded in the same diameter class of standing trees before thinning and after thinning (Annex 5).

D. latifolia is quite similar to *Acacia catechu, Acacia auriculiformis* and *Dalbergia sissoo* in stem wood contribution in total above-ground wood. As contribution of stem wood of *A. catechu*, *A. auriculiformis*, and *D. sissoo* was 72.7%, 74.3% and 75.5% respectively. The results indicate that all of these four species lack long clear bole and contain many branches.

Branch wood

Estimation of branch wood gives an idea of fuel wood that can be expected from a tree. Due to large variation in branch wood in similar sized trees, the prediction (13.9%) is higher than stem wood (Annex 1). Estimated mean green branch wood of standing trees of 7.5 years old *D. latifolia* was 11.2 kg (5.9 tons per ha) before thinning, and 13.9 kg (5 tons per ha) after thinning, and actual green stem wood 6.4 kg (1.1 tons per ha) of thinned trees (Table 2). The contribution of green branch wood of standing trees before thinning in total above-ground was 30 % whereas its contribution in total above-ground biomass was 26 % (Table 3). The content of branch

Table 3: Actual green biomass of thinned trees and predicted biomass of standing trees before and after thinning

Parameter	Thinned trees (kg per tree)		Standing trees (kg per tree)				Thinned trees (tons per ha)	Standing trees (tons per ha)	
			Before thinning		After thinning				
	Mean	Std. error	Mean	Std. error	Mean	Std. error		Before thinning	After thinning
Stem wood	17.3 (0.8-76.6)	2.0	26.4 (0.02-156.3)	1.2	31.5 (0.09-156.3)	1.5	2.8 (64%)	13.8 (62%)	11.4 (61%)
Branch wood	6.4 (0.05-56.2)	1.3	11.2 (0.0001-128.1)	0.8	13.9 (0.0016-128.1)	1.04	1.1 (25%)	5.9 (26%)	5.0 (27%)
Leaf	3.0 (0.05-13.4)	0.4	5.4 (0.004-31.3)	0.24	6.4 (0.02-31.3)	0.30	0.5 (11%)	2.8 (12%)	2.3 (12%)
Above-ground wood	23.7 (1.0-132.8)	3.2	37.6 (0.02-284.4)	1.9	45.4 (0.09-284.4)	2.5	3.9 (89%)	19.7 (88%)	16.4 (88%)
Above-ground biomass	26.7 (1.2-135)	3.5	43.0 (0.02-315.7)	2.2	51.8 (0.11-315.7)	2.8	4.4 (100%)	22.5 (100%)	18.7 (100%)

Figures in parenthesis indicate the range of biomass. The percentage figures in parenthesis indicate the percentage of stem wood, branch wood, leaf and above-ground wood in total biomass.

Use the following figures for conversion from green to oven dry biomass

Stem wood: 0.461 Branch wood: 0.490

Above-ground wood: 0.483 Leaf: 0.361

wood in total above-ground wood increased with the increase in diameter, for instance 45% of branch wood in above-ground wood was in 19-20 cm diameter class.

Before thinning, as for stem wood, the estimated highest green branch wood biomass was 1509 kg per ha in 11-12 cm class followed by 1486 kg per ha in 13-14 cm class (Annex 3). Due to few number of trees above the diameter class 13-14 cm, the branch wood was found less. The same trend was found for the trees after thinning (Annex 5).

D. latifolia is quite similar to *Acacia catechu, Acacia auriculiformis* and *Dalbergia sissoo* in branch wood contribution in total above-ground wood. As contribution of branch wood of *A. catechu*, *A. auriculiformis*, and *D. sissoo* was 27.3%, 25.7% and 24.5% respectively (Thapa 2000).

Leaf

There was large variation in leaf content in similar sized trees of this species. The prediction error of the model used for estimation of leaf was found 41.3% (Annex 1), higher than stem and branch wood. The model must be validated before using it for the prediction of leaf biomass. Estimated mean green leaf of 7.5 years old *D. latifolia* was 5.4 kg (2.8 tons

Table 4: Mean volumes (over bark, under bark, m^3), green and oven dry biomass (kg) and density of sampled 7.5 years old *D. latifolia*

DBH class (cm)	Volume (m^3 per tree)			Green biomass (kg per tree)				Oven dry biomass (kg per tree)				Density (kg /m^3)
	over bark	under bark	Bark	Stem	Branch	Leaf	Total wood	Stem	Branch	Leaf	Total wood	
3-4	0.0033	0.0022	0.0011	2.4	0.3	0.5	2.7	1.2	0.1	0.2	1.3	725
5-6	0.0088	0.0059	0.0029	7.3	1.4	1.6	8.7	3.6	0.7	0.6	4.2	824
7-8	0.0152	0.0102	0.0050	13.8	3.6	3.3	17.4	6.8	1.6	1.1	8.4	927
9-10	0.0284	0.0200	0.0084	26.8	5.9	3.6	32.7	13.1	2.7	1.3	15.8	942
11-12	0.0371	0.0263	0.0108	36.8	17.5	8.3	54.2	18.0	8.1	3.0	26.2	977
13-14	0.0554	0.0401	0.0152	53.7	38.3	9.3	92.0	26.3	17.7	3.4	44.4	968
15-16	0.0802	0.0589	0.0231	76.6	56.2	2.2	132.8	37.5	25.9	0.8	64.1	935
All	**0.0187**	**0.0130**	**0.0056**	**17.3**	**6.4**	**3.0**	**23.8**	**8.5**	**3.0**	**1.1**	**11.5**	**929**

Bark percentage: 29.9% Ratio of under bark stem volume to over bark stem volume : 0.701

DBH from 2.6 to 4.5 cm should be in 3 to 4 cm dbh class. Follow the same order for other dbh classes.

Table 5: Productivity of 7.5 years *D. Latifolia*

	Green biomass (tons/ha/year)					Oven dry biomass (tons/ha/year)				
	Stem	Branch	Above-ground wood	Leaf	Above-ground biomass	Stem	Branch	Above-ground wood	Leaf	Above-ground biomass
Before thinning	1.84	0.78	2.62	0.38	3.0	0.85	0.38	1.23	0.14	1.37
After thinning	1.52	0.67	2.19	0.31	2.50	0.70	0.33	1.03	0.11	1.14

per ha) before thinning, and 6.4 kg (2.3 tons per ha) after thinning, and actual green leaf 3 kg (0.5 tons per ha) of thinned trees (Table 3). The contribution of green leaf in total above-ground biomass was 11% before thinning, 12% for thinned trees and trees after thinning.

Before thinning, the highest green leaf biomass was 755 kg per ha in 11-12 cm class followed by 599 kg per ha in 13-14 cm class (Annex 3). After thinning, the highest green leaf biomass was 655 kg per ha in 11-12 cm class followed by 519 kg per ha in 13-14 cm class (Annex 5). Due to few number of trees in the diameter class above the diameter class 13-14 cm, the leaf biomass was found less.

It was found that, quantity of leaf was greatly influenced by the crown size, number and size of branches.

Above-ground wood

Estimated mean above-ground wood of 7.5 years old *D. latifolia* was 37.6 kg (19.7 tons per ha) before thinning, and 45.4 kg (16.4 tons per ha) after thinning, and actual green stem wood 23.7 kg (3.9 tons per ha) of thinned trees (Table 3). The highest green above-ground wood biomass was in 11-12 cm class followed by the second highest in 13-14 cm class (Annex 3) before thinning. The content of stem wood was found less above the diameter class 13-14 cm. It was mainly due to few number of trees in these diameter classes. The same trend was found for the trees after thinning (Annex 5). The contribution of above-ground wood in total above-ground biomass ranged from 88% for the trees before ad after thinning and 89% for thinned trees (Table 3). Non-photosynthetic above-ground biomass contributed a lot as compared to photosynthetic biomass in total above-ground biomass.

At Tarahara, Sunsari District of Nepal, fresh wood of *Cassia siamea* at 3.5, 6.5 and 6.5 years (3-year rotation) was found to be 30.5, 48.5 and 63.8 kg per tree, which was higher in comparison to the wood biomass of *D. latifolia* at Belbari. In the same study, fresh above-ground wood of *Eucalyptus camaldulensis* in three different rotations (3 year rotation) were 45.4, 39.1, and 27.6 kg per tree (Thapa 2001), higher than the wood biomass of *D. latifolia*.. As *C. siamea* and *E. camaldulensis* grow very fast and they are used for fire wood production. But *D. latifolia* is very slow growing species and it is mainly for furniture timber.

Productivity

At Tarahara, productivity of green above-ground wood of 5.5 years old *D. sissoo*, *Acacia auriculiformis*, *Acacia catechu*, and *Eucalyptus camaldulensis* were 10.5, 13, 16.2, and 19.7 tons per ha per year and rate of accumulation of these species were 7.79, 7.35, 13.74, and 15.21 kg per tree per year (Thapa 2000). In this study, productivity of green above-ground wood of *D. latifolia* was 2.62 tons per ha per year and rate of accumulation was 5.0 kg per tree per year ((Table 5 and 6). Productivity of *D. latifolia* per unit area was found considerable less than four species, although rate of accumulation of green matter was found slightly less than *D. sissoo* and *A. auriculiformis*.

Table 6: Rate of accumulation of green and oven dry biomass of 7.5 years *D. Latifolia*

	Green biomass (kg/tree/year)					Oven dry biomass (kg/tree/year)				
	Stem	Branch	Above-ground wood	Leaf	Above-ground biomass	Stem	Branch	Above-ground wood	Leaf	Above-ground biomass
Before thinning	3.52	1.49	5.01	0.72	5.73	1.62	0.73	2.35	0.26	2.61
After thinning	4.20	1.85	6.05	0.85	6.90	1.94	0.91	2.85	0.31	3.16

C. siamea had wood productivity of 11.1, 20.7 and 27.2 tons per hectare per year in three different rotations at 3.5, 6.5 and 9.5 years respectively. *E. camaldulensis* attained 16.6, 16.7, and 11.8 tons per hectare per year in 3-rotations of 3-year period (Thapa 2001). *D. latifolia* had the wood productivity 2.62 tons per ha per year (Table 5). Before thinning, production of green leaf was only 0.38 tons per ha per year and rate of accumulation was 0.72 kg per tree per year. The lower productivity is due to its slow growing nature and low density of trees due to spacing and higher mortality rate.

Estimated volume

The ob stem volume was estimated by using the model given in Annex 1. The prediction error was very low (5.8%), which signifies the validity of the model for estimation of ob stem volume. The ob stem volume of standing trees before thinning was 8.8 m^3 per hectare (Table 3). As expected, ob stem volume per tree increased with the increase in diameter (Table 4). Under bark stem volume was found to be 70.1% of the total ob stem volume. It indicated that the bark volume was 29.9% of the total ob stem volume. The highest ob stem volume (2.3394 m^3) per unit area was found in 13-14 cm class followed by the volume in 15-16 cm class for the trees before thinning (Annex 3). The increase or decrease in volume is directly proportional to the size of trees. As the diameter class having two highest volumes had only 49 and 19 trees per ha. On the contrary, the number of trees per ha was 105 in 9-10 cm class, higher than 11-12 to 13-14 cm classes, but the volume was found less than these diameter classes. The same trend was noted in ob stem volume in the upper diameter classes for the trees after thinning (Annex 5).

Conclusion

Promotion of private, community and government plantations of *Dalbergia latifolia* is necessary for its gene conservation and for the production of high valued furniture timber in the Terai /Inner Terai region of Nepal. As its 7.5-years growth performance at Belbari has proved its success in plantations in the eastern Terai region. Thinning in time is essential to promote diameter growth and keep the plantations in hygienic conditions. The results of thinned yield has shown that it can fulfill demand of fire wood to some extent.

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Annex 1: Selected biomass and volume models

The selected model is Ln W or V = a+b*Ln (DBH), where W stands for green weight of stem, branch and leaf in kg; V stands for over bark volume of stem in cubic centimeter; a and b are regression constants; DBH is the diameter at breast height in cm

Particular	No. of sample trees	a	b	R^2	Standard error	Prediction error (%)	Actual/Predicted green biomass and volume
Stem wood	44	-2.40	2.487	96.9	0.188	-3.9	1.04
Branch wood	45	-6.4376	3.7682	92.5	0.4756	13.9	0.88
Leaf or foliage	44	-3.9153	2.4557	85.4	0.4120	41.9	0.71
Over bark stem volume	47	5.02924	2.29199	96.3	0.1974	5.8	1.06
Divide the volume calculated using the above model by 1000000 to get volume in cubic meter							

Annex 2: Oven dry matter content (conversion factor from green to oven dry) in different diameter classes of 7.5 years *D. latifolia*

DBH class (cm)	Stem wood	Branch wood	Foliage or Leaf	Above-ground wood
3-4	0.560	0.515	0.415	0.530
5-6	-	-	-	-
7-8	0.417	0.502	0.372	0.458
9-10	0.470	0.435	0.353	0.459
11-12	0.499	0.502	0.356	0.500
13-14	0.572	0.370	0.340	0.54
15-16	0.523	0.466	0.413	0.508
All	**0.490**	**0.461**	**0.361**	**0.483**

Annex 3: Density, percentage of trees in total trees, basal area, green wood and leaf biomass, and over bark stem volume in different diameter classes of trees before thinning

DBH class (cm)	No. of trees	Density (trees/ ha)	Percentage of trees in total trees	Basal area (m^2/ha)	Stem (kg/ha)	Branch (kg/ha)	Above-ground wood (kg/ha)	Leaf (kg/ha)	Above-ground biomass (kg/ha)	Stem volume (m^3/ha)
<3	10	13	2	0.0024	3.7 (95)	0.2 (5)	3.9	0.8	4.7	0.00007
3-4	42	53	10	0.0630	142.7 (90)	15.1 (10)	157.8	30.0	187.8	0.00255
5-6	70	89	17	0.2288	622.5 (86)	105.4 (14)	727.9	129.5	857.4	0.03480
7-8	76	96	18	0.4249	1314.7 (81)	311.5 (19)	1626.2	271.2	1897.4	0.16653
9-10	83	105	20	0.7628	2660.6 (76)	861.7 (24)	3522.3	544.6	4066.9	0.72074
11-12	74	94	18	0.9748	3709.3 (71)	1509.2 (29)	5218.5	755.0	5973.5	1.75351
13-14	39	49	9	0.7171	2957.9 (67)	1486.1 (33)	4444	599.0	5043	2.33921
15-16	15	19	4	0.3529	1544.9 (63)	906.2 (37)	2451.1	311.6	2762.7	1.77984
17-18	2	3	0.5	0.0627	293.9 (59)	206.7 (41)	500.6	59.0	559.6	0.52748
19-20	3	4	1	0.1163	574.9 (55)	463.7 (45)	1038.6	115.1	1153.7	1.44386
Total	**414**	**524**	**100**	**3.7057**	**13825 (70)**	**5866 (30)**	**19691**	**2816**	**22507**	**8.76859**

The figures in parenthesis indicate the percentage of stem wood, and branch wood in total above-ground wood.

Annex 4: Density, percentage of trees in total trees, basal area, green wood and leaf biomass, and over bark stem volume in different diameter classes of thinned trees

DBH class (cm)	No. of trees	Density (trees/ ha)	Percentage of trees in total trees	Basal area (m^2/ha)	Stem (kg/ha)	Branch (kg/ha)	Above-ground wood (kg/ha)	Leaf (kg/ha)	Above-ground biomass (kg/ha)	Stem volume (m^3/ha)
3-4	17	22	24	0.0237	52.9 (91)	5.3 (9)	58.2 (100)	11.1	69.3	0.0685
5-6	17	22	24	0.0554	150.4 (86)	25.3 (14)	175.7 (100)	31.3	207	0.1799
7-8	9	11	13	0.0489	150.6 (81)	35.1 (19)	185.7 (100)	31.1	216.8	0.1714
9-10	16	20	23	0.1447	502.5 (76)	160.8 (24)	663.3 (100)	102.9	766.2	0.5448
11-12	7	9	10	0.0904	342.7 (71)	137.8 (29)	480.5 (100)	69.8	550.3	0.3588
13-14	3	4	4	0.0536	219.4 (67)	107.9 (33)	327.3 (100)	44.4	371.7	0.2227
15-16	1	1	1	0.0245	108.2 (63)	65.0 (37)	173.2 (100)	21.8	195	0.1065
Total	70	89	100	0.4412	1526.7 (74)	537.2 (26)	2063.9 (100)	312.4	2376.3	1.6526

Out of 129 trees thinned, 70 trees were assessed for biomass and volume study.

The figures in parenthesis indicate the percentage of stem wood, and branch wood in total above-ground wood.

Annex 5: Density, percentage of trees in total trees, basal area, green wood and leaf biomass, and over bark stem volume in different diameter classes of trees after thinning

DBH class (cm)	No. of trees	Density (trees/ ha)	Percentage of trees in total trees	Basal area (m^2/ha)	Stem (kg/ha)	Branch (kg/ha)	Above-ground wood (kg/ha)	Leaf (kg/ha)	Above-ground biomass (kg/ha)	Stem volume (m^3/ha)
<3	5	6	2	0.0010	1.5 (94)	0.1 (6)	1.6	0.3	1.9	0.00002
3-4	12	15	4	0.0204	47.2 (90)	5.2 (10)	52.4	9.9	62.3	0.00092
5-6	36	46	13	0.1174	319.2 (86)	54.0 (14)	373.2	66.4	439.6	0.01780
7-8	56	71	20	0.3190	991.3 (81)	237.5 (19)	1228.8	204.4	1433.2	0.12884
9-10	61	77	21	0.5677	1985.9 (75)	647.9 (25)	2633.8	406.4	3040.2	0.54711
11-12	64	81	22	0.8449	3216.4 (71)	1310.3 (29)	4526.7	654.7	5181.4	1.52508
13-14	34	43	12	0.6219	2561.9 (67)	1282.6 (33)	3844.5	518.8	4363.3	2.00809
15-16	14	18	5	0.3285	1436.7 (63)	841.2 (37)	2277.9	289.8	2567.7	1.64791
17-18	2	3	1	0.0627	293.9 (59)	206.7 (41)	500.6	59.0	559.6	0.52748
19-20	3	4	1	0.1163	574.9 (55)	463.7 (45)	1038.6	115.1	1153.7	1.44386
Total	287	363	100	2.9998	11429 (69)	5049 (31)	16478	2325	18803	7.84711

The figures in parenthesis indicate the percentage of stem wood, and branch wood in total above-ground wood.