Growth of five fast growing tree species in the terai of eastern Nepal

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In July 1985, a fuelwood species trial was established at Tarahara of Sunsari District in east Nepal for a comparative growth assessment of *Acacia auriculiformis*, *Acacia catechu*, *Dalbergia sissoo*, *Eucalyptus camaldulensis*, *Eucalyptus tereticornis* and *Leucaena leucocephala*. The latter was heavily browsed by deer and rabbits after planting, and excluded from the study. At five and half years, *E. camaldulensis* and *A. catechu* were similar in diameter and height growth. *A. catechu* and *E. camaldulensis* attained the larger dbh (11.3 cm and 10.1 cm respectively) whereas *E. tereticornis* attained the lowest dbh (7.4 cm). The mean height (12.5 m) was the highest in *E. camaldulensis* followed by *A. catechu* (10.9 m) and the lowest (8.2 m) in *E. tereticornis*. Four species except *E. tereticornis* did not differ significantly in basal area. Basal area varied from 12.544 m^2 per hectare for *A. catechu* to 11.468 m^2 per ha for *E. camaldulensis*. The results of this study showed that *A. catechu* which is planted on a very small scale at present as compared to *D. sissoo* and *E. camaldulensis*, can be included in the afforestation programme in the Terai/Bhabar region of Nepal. Similarly, good provenance of *Acacia auriculiformis* can be selected for planting. Despite the controversy over *E. camaldulensis*, it can be used for small scale plantings as a single rows or blocks, particularly in those areas with severe grazing problem. In addition to it, the growth of these species in other parts of Nepal and elsewhere is also discussed in this paper.

Keywords : *Acacia auriculiformis*, *Acacia catechu*, *Dalbergia sissoo*, *Eucalyptus camaldulensis*, *Eucalyptus tereticornis* and *Leucaena leucocephala*, fast growing tree, Nepal.

Terai forests are depleting and deteriorating at an alarming rate. It is well documented in the official Master Plan (1988). These forests are also not scientifically managed. Remaining forests are not in a position to meet the firewood demand of the people. If such trend continues, the situation will be even worse than today. The people who reside far from the forest, use cow dung and crop residues at the cost of the crop productivity. It indicates the deficit of firewood. In such a situation, there is an acute need of establishment of plantations of fast growing firewood tree species.

One of the aims of Forest Research and Survey Centre (formerly Forest Survey and Research Office) is to focus research for recommendation on certain tree species which grow faster and provide wood biomass in a short time in the terai. Such studies have not been done before in the eastern terai. The present study aims to collect information on comparative growth of six fast growing species, viz. *Acacia auriculiformis, Eucalyptus camaldulensis,* (proven in the central Bhabar region of Nepal), *Eucalyptus tereticornis, Dalbergia sissoo, Acacia catechu* and *Leucaena leucocephala* in the terai of east Nepal.

The present paper recommends species for planting to get relatively more firewood in shorter rotations. It also compares the growth results of these species in Nepal and elsewhere.

The experimental site

The experimental site is situated at Tarahara, in Sunsari District at about 150 m above sea level. Its latitude and longitude are 26° 42' N and 87° 16' E respectively. It has a flat terrain consisting of well drained loam to sandy clay loam soil with a pH range of 5 to 6.5 in A and B horizons respectively. The organic matter ranges from low (0.2%) to medium (5%) and nitrogen content low to medium, potassium and phosphorus medium to high.

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The mean daily temperature by year is 23.9° C which annually ranges from 23.4° C to 24.2° C. The mean minimum and maximum temperatures are 17.8 ° C (annual range from 17.1° C to 18.2° C) and 30° C (annual range from 29.7° C to 30.6°C) respectively. The absolute maximum and minimum temperatures are 39.4° C in May 1988 and 3° C in January 1989 respectively (Source: Climatological records of Nepal, Department of Hydrology and Meterology).

The site has a humid sub-tropical type of climate with a summer monsoon with about seven months dry season from November until May. The total annual rainfall varies from 1581 mm to 2820 mm with mean annual total precipitation 2121 mm. More than 90% of total annual rainfall occurs from June to October. The annual total evaporation is an about 1460 mm. Wind speed per day varies from 4.6 to 6.4 km per hour with mean wind speed being 5.8 km per hour. Yearly mean relative humidity at 8:45 is 80.6% (range from 79 to 83%) and at 17:45 is 71% (range from 69 to 74%).

The natural vegetation was of *Shorea robusta* with associates like *Terminalia alata, Syzigium cumuni, Terminalia belerica* and mixtures of many other miscellaneous species.

Establishment of the trial

The vegetation prior to trial plot establishment was in a moderately degraded state with few scattered trees. The open patches were covered with *Eupatorium* spp.

The shrubs and bush were cut and removed in March 1985. The plot was fenced with six strand barbed wire. The planting pits (30 cm x 30 cm x 30 cm) were dug out at a spacing of 2.5 m x 2.5 m.

Trial plot was established in a randomised complete block design with four replicates and six species (Seed source in annex 1) covering 0.73 ha. For each plot individual species comprised of forty-nine plants were arranged as 7 x 7 trees. Observation on only the inner 5 x 5 plants were measured. Replacement was carried out only once within one month of the trial plot set up. Spot cultivation was done at 0.5 m radius around each plant twice in a year for the first three years. *Eupatorium* spp. were cut and burned in the winters of 1989 and 1990. Fire lines were cleared in each winter.

Field data collection

Heights were measured using a Sunnto Clinometer and diameter at breast height (dbh at 1.37 m) with a diameter tape. Trees forked below the breast height were treated as a separate stem. In such cases, heights and diameters were recorded separately.

Results

Diameter growth

More than three and falf percent of the total variability in diameter data was explained by block, 67.83 % by differences between species and 28.56 % due to error (Annex 2). Diameter growth at 5.5 years is presented in Table 1.

Acacia catechu attained the greatest diameter followed by *E. camaldulensis.* The coefficient of variation for mean dbh was the highest in *E. tereticornis* and the lowest in *A. catechu* The lowest diameter growth was in *E. tereticornis* (Table 1).

Acacia catechu and *E. camaldulensis* were similar in diameter growth. *A. catechu* significantly differred in diameter growth with other three species. The better dbh (overbark) growth was attained by *A. catechu* and *E. camaldulensis.*

Diameter distribution

It indicates the extent of variation in the growing stock. It also states the number of stems per unit area in each diameter class and is useful to compare the stocking of various species of the same age grown at the same site under similar management options.

Table 1: Average dbh, dbh range, standard error, coefficient of variation for five species

Species	Mean DBH (cm)	DBH range	Standard error (cm)	Coefficient of variation (%)
Acacia auriculiformis	8.4b	4.0 - 18.5	0.26	32.96
Acacia catechu	11.3a	5.9 - 20.3	0.36	27.26
Dalbergia sissoo	8.4b	2.8 - 15.5	0.36	38.72
Eucalyptus camaldulensis	10.1ab	3.2 - 18.0	0.43	38.14
Eucalyptus tereticornis	7.4b	2.2 - 19.1	0.72	56.86

Means followed by the same letters do not differ significantly $P < 0.05$
Tukey's value for mean dbh (cm) = 2.8

In the 10-15 cm dbh class, *A. catechu* attained the highest number of stems (656 stems per ha i. e. 55.4% of the total stocking) and then by *E. camaldulensis* (496 stems/ha i. e. 38.8% of the total). Stocking was found the highest in *A. auriculiformis*, however about 67% of the total i. e. 1200 stems/ha was in 5-10 cm dbh class (Table 2). Within the 15 to 20 cm dbh class, the highest number of stems (144 stems/ha) was in *E. camaldulensis* followed by *A. catechu* (128 stems/ha).

Height growth and survival

About 70.9%, 4.6% and 24.5% variation in the height data are explained by differences between species, block and error respectively (Annex 2). Five species differed significantly in height growth ($P < 0.05$). *Dalbergia sissoo* and *E. camaldulensis* survived well in comparison to other species. *Acacia catechu* and *Acacia auriculiformis* survived satisfactorily. *E. tereticornis* was found the worst of all.

Eucalyptus camaldulensis and *A. catechu* were at the top rank regarding height growth. These species did not differ significantly in height growth. *A. auriculiformis*, *A. catechu* and *D. sissoo* were similar in height growth (Table 3).

Top and dominant height

Top height (mean of the 100 largest diameter trees per hectare) and dominant height (mean total height of the 100 tallest trees per ha) were computed.

The highest top and dominant heights were attained by *E. camaldulensis*. *A. auriculiformis*, *A. catechu* and *E. tereticornis* differed slightly in dominant heights, however, the variation in top heights was found slightly higher for these species (Table 4).

Basal area

Variation in the basal area due to block was 8.67% whereas 60.50% was by species and 30.83% by error (Annex 2). *A. catechu* had the highest basal area per hectare (Table 5) followed by *E. camaldulensis* and *A. auriculiformis*. Four species except *E. tereticornis* did not differ significantly in basal area. Three species *A. auriculiformis*, *D. sissoo* and *E. tereticornis* did not vary much in mean basal area per tree.

Periodic dbh and height increment

The periodic height increment was the highest in *E. camaldulensis* followed by *A. catechu* and *A. auriculiformis* and the lowest in *E. tereticornis* whereas the periodic dbh increment was the highest

Table 2: Stocking (stems per ha) in 5 cm dbh classes

Species	DBH class (cm)								Stocking
	0 - 5 cm		5 - 10 cm		10 - 15 cm		15 - 20 cm		
	a	b	a	b	a	b	a	b	
*Acacia auriculiformis**	176	9.8	1200	67.0	368	20.5	48	2.7	1792
*Acacia catechu**	0	0	400	33.8	656	55.4	128	10.8	1184
Dalbergia sissoo	224	16.9	640	48.2	432	32.5	32	2.4	1328
Eucalyptus camaldulensis	144	11.2	496	38.8	496	38.8	144	11.2	1280
Eucalyptus tereticornis	208	38.2	240	44.1	64	11.8	32	5.9	544

'a' refers to number of stems per hectare
'b' refers to the percentage of number of stems per hectare in each diameter class.
* refers to tree species with more than one stem, for instance *A. auriculiformis* consisted of 29 trees with 2 stems and 7 with three. *A. catechu* consisted of 10 trees with 2 and 1 tree with 3 stems.

Table 3: Mean height, height range, standard error and coefficient of variation and survival percent

Species	Mean height (m)	Height range (m)	Standard error (m)	Coefficient of variation (%)	Survival (%)
Acacia auriculiformis	9.5b	4-15	0.24	26.42	69
Acacia catechu	10.9ab	5-17.1	0.26	20.65	62
Dalbergia sissoo	8.7b	2.6-13.8	0.30	31.73	83
Eucalyptus camaldulensis	12.5a	4.8-20	0.42	30.26	80
Eucalyptus tereticornis	8.2b	3.3-17.1	.63	44.92	35

Tukey's value = 2.768
Means followed by the same letters do not differ significantly $P < 0.05$

in *A. catechu*

Discussion

Except *E. tereticornis*, the other were found similar in basal area per hectare. It is not necessary that low stocking has a lower basal area than high stocking. The basal (over bark, m^2/ha) area reflects how much the site is utilised by a particular species or crop of a certain age. It is generally used as a density measure, particularly as the standard of success against which other measures of density may be compared. It is also useful tool to compare the stockings of different species of the same age grown at the same site. The distribution of the number of stems in diameter classes determines the higher or lower basal area for tree species. Obviously, total basal area of a certain species would be higher if there are larger number of trees in the upper diameter classes but the stocking is low and *vice-versa*. For instance, the highest stocking was in *A. auriculiformis* (Table 2), however, its total basal area per hectare was found lower than *A. catechu* and *E. camaldulensis* (Table 5). The main reason behind it is due to the lower stocking of *A. auriculiformis* in the upper diameter (10-15 and 15-20 cm) classes than *A. catechu* and *E. camaldulensis*. However, if there is a larger variation in stocking of different species, the above theory may not work. For instance, *E. tereticornis* had the lowest stocking (544 stems per ha) of all the species and the variation in stocking is also very large (Table 2). In this case, the low basal area per ha attained by this species is, obviously, due to the low stocking. The highest figures of basal area per tree attained by *A. catechu* and *E. camaldulensis* clearly reflect the good diameter growth in comparison to other species (Table 1 and Table 5). There is no distinct variation in diameter growth of three species, *D. sissoo*, *A. auriculiformis* and *E. tereticornis*.

The basal areas of *E. camaldulensis* aged 6 years were 7.17 and 7.57 m^2 per ha at Puttalum (8^0N, 80^0E; 2m above sea level; rainfall 1100 mm) and Moneragala (6^0N, 81^0E; 170 m above sea level; rainfall 1588 mm) in Sri Lanka respectively (Ranasinghe and Mayhead 1991).

In terms of basal area (m^2 per ha) of *E. camaldulensis*, Tarahara may fall under fair site (11.6 m^2 per ha for fair site as in Yield Table mentioned in the official Master Plan for the Forestry Sector). However, mean dbh of this species at Tarahara is lower than the mean dbh (11.4 cm) of this species for fair site (between good and poor site) (quoted in Jackson 1994).

At the age of five years in Jabalpur, India the mean basal area of *E. camaldulensis* planted at a spacing of 2 x 2 m was 9.25 m^2 per hectare i. e. 19.4% lower than that of Tarahara (Prasad *et al.* 1984). Mean height of *E. camaldulensis* aged six years was 8.4 m and 8.50 m were at Puttalum and Moneragala Sri Lanka respectively (Ranasinghe and Mayhead 1991)

Table 4: Top and dominant height of five fast growing species

Species	Top height (m)	Minimum top height (m)	Maximum top height (m)	Dominant height (m)	Minimum dominant height (m)	Maximum dominant height (m)
Acacia auriculiformis	12.6	10.6	15.0	14.1	13.2	15.0
Acacia catechu	11.9	11.3	13.5	14.3	13.5	17.1
Dalbergia sissoo	12.8	12.1	13.8	12.0	12.3	13.8
Eucalyptus camaldulensis	17.6	14.4	20.0	18.4	17.7	20.0
Eucalyptus tereticornis	14.2	12.3	17.1	14.2	12.3	17.1

Table 5: Mean basal area per tree, DBH of the mean basal area

Species	Basal area (m^2/ha)	Mean basal area per tree (m^2 per tree)	DBH of the mean basal area (cm)
Acacia auriculiformis	10.96a	0.0061	8.82
Acacia catechu	12.54a	0.0106	11.61
Dalbergia sissoo	8.44ab	0.0063	9.00
Eucalyptus camaldulensis	11.47a	0.0088	10.61
Eucalyptus tereticornis	3.38b	0.0060	8.76

Means followed by the same letters do not differ significantly $P < 0.05$ Tukey's $w = 6.69$

Table 6: Periodic DBH and height increment at 5.5 years

Species	Periodic dbh increment (cm)	Periodic height increment (m)
Acacia auriculiformis	1.53	1.72
Acacia catechu	2.05	1.98
Dalbergia sissoo	1.53	1.58
Eucalyptus camaldulensis	1.83	2.27
Eucalyptus tereticornis	1.34	1.49

which are poorer than Tarahara.

In West Bengal of India (Site characteristic: pH - 5.3 to 5.5, Soil- latrine and shallow and sandy loam on the surface) *E. camaldulensis* (Emu Creek, Petford provenance, Queensland, Australia) was found to be better in height growth (mean height- 6.1 m) than *E. tereticornis* (mean height- 5.1 m) which were planted at a spacing of 2 x 2 m (Banarjee *et al.* 1987). *E. camaldulensis* grew faster than *E. terticornis* at Trisuli (730 m) in Nepal. At the age of six years in this site, the mean dbh of *E. camaldulensis* was found 8.4 cm (Jackson 1987) which is lower than the mean dbh attained by this species at Tarahara. In 'Eucalytpus Species Provenance Trial for Fuelwood Production at Adabhar (Altitude- 250 m; 7 months dry season, average rainfall- 1800 mm, pH- 5.6 and water table -10 to 20 m in Bhabar region of Nepal), dbh growth of *E. tereticornis* (North of Woolgoolga Provenance, Queensland, Australia) was 7.8 cm at the age of 4.5 years, slightly higher than the dbh attained by this species at 5.5 years at Tarahara. In another *E. camaldulensis* Provenance Trial in the same site the highest dbh growth (9 cm) at the age of 4.5 years was found in Petford provenance among its six provenances (Petford, Gibb River, Katherine, Leichardl River, Irvine Bank and Hughenden of Queensland, Australia), however, there was no significant difference ($P < 0.05$) in dbh between these provenances provided full cultivation (removal of weeds and grass by cutting and digging throughout the plot) in year two (Hawkins 1986). The above Petford provenance of *E. camaldulensis* attained mean dbh of 10.1 cm at the age of 5.5 years at Tarahara. This provenance showed better performance in growth at Sagarnath in Nepal also. Among the five *Eucalyptus* species (*E. camaldulensis, E. urophylla*, *E. tereticornis*, *E. brassiana*, and *E. microtheca*) planted at Adabhar at a spacing of 2 x 2 m, the highest dbh (8 cm) was attained by *E. camaldulensis* (Petford Provenance) at three and half years at Adabhar. Full cultivation was carried out for the first 2.5 years. The results were found higher in full cultivation than pit cultivation. It reveals that full cultivation is essential for the higher success and growth of *E. camaldulensis* which is clear from experiments at Adabhar, Sagarnath (Hawkins 1986; White 1986) and comparatively poor results available from Tarahara under pit cultivation. At the age of five years in Jabalpur, India mean dbh and heights were 6.1 cm and 5.8 m respectively (Prasad *et al.* 1984) which results are lower than that of Tarahara (Table 1 and 3).

Average top height of *E. camaldulensis* was 17 m at 8 years whereas top height of *D. sissoo* was 13.3 m at 10 years in India. The average top height of these species were found to be 17.8 and 12.6m (Table 4) at Tarahara at 5.5 years, slightly higher for *E. camaldulensis* and slightly lower for *D. sissoo*. The growth of these species was found better than the results given by Trivedi (1986).

At 6.5 years, the mean dbh of *E. tereticornis* (Morehead River, Australia) in Adabhar (Bhabar region) was found 7 cm, lower than that of Tarahara (Table 1), mean dbh *of E. camaldulensis* (Emu Creek, Petford, Australia) was 7.3 cm (Internal report of Plantations Section). Both results are significantly lower than that of Tarahara.

The provenances from the Petford area (specifically Emu Creek) in Northern Queensland Australia were found the most promising at Adabhar (Bhabar region). At Sagarnath, the Petford and the Wroytham Park (also Queensland) provenances performed well (White 1984). *E. tereticornis* provenances (Morehead River, Palmer River, and Kennedy River) showed good performance, but the priority was given to the Petford provenance of *E. camaldulensis* for plantation establishment due to its superior growth rate and density (Neil 1989).

A study was done in the Pakistan Forest Research Institute Research Garden in January 1984. Irrigation was applied fortnightly but not in the winter months. At 4 years, mean diameter and height of *D. sissoo* were found 8.6 cm and 8.7 m respectively (Sheikh and Haq 1982). These results are higher than the results of Tarahara (Table 2).

The results (mean height and dbh) of *D. sissoo* at 5.5 years at Tarahara are slightly higher than the results of this species for low quality site at Sagarnath (mean height: 7.6 m and mean dbh: 7.4 cm) (Jackson 1994). The slow rate of growth of this species at Tarahara may be due to the effect of *Eupatorium* weeds in the early stage and inferior genetic character and to some extent due to poor condition of the site.

In one provenance trial of *D. sissoo* at Adabhar (Bhabar region of Nepal), the mean dbh growth of Manahari provenance at 3.5 years was 7.5 cm having 2.14 cm periodic dbh increment i. e. about 40% more than that of Tarahara (Table 6). Due to the well drainage condition in the Bhabar region, the growth may have been better than the Tarahara (Terai region). Moreover, the site was hand-dug and ploughed before planting in July 1983. Mustard was sown as an intercrop in October, three months after establishment. In March 1984, the entire trial was hand weeded and subsequently weeded as required (Neil 1989).

In a provenance trial of *D. sissoo* at Tarahara, the mean height and dbh of Kankai Mai provenance

were 8.7 m and 9.2 cm respectively in which mean height was found the same as in this study, but mean dbh was slightly higher in provenance trial (Joshi and Thapa 1997).

The average diameter of *A. auriculiformis* (spacing: 2.5 x 2.5 m) is 8.4 cm at Tarahara which is 9.5 % less than the mean dbh (9.2 cm) of this species (spacing: 2 x 2 m) at 7 years in Tirthahally Range of Shimoga Forest Division (site consisted of grass but no vegetation; rainfall: 2000 mm; soil red loam and moderately fertile) of India (Sugur 1989). In reality, these results available at Tarahara are more or less similar. Since the dbh growth of this species at Tirthahally is 1.5 years more than that of Tarahara.

At five years, mean height and dbh of *A. auriculiformis* (spacing: 2 x 2 m) in Western Ghats of Karnataka, India were 4.5 m and 3.9 cm respectively. The results of this species at 5.5 years at Tarahara are 215 % and 211% more in case of height and dbh than Western Ghats (Kushalapa 1987). It reflects the reasonable growth of this species at Tarahara.

At Chang Pu Branch of Taiwan Forest Research Institute near Chalayi, at 4 years, mean height and dbh of *A. auriculiformis* were found 9.6 m and 8.2 cm respectively (Chang *et al.* 1983). Periodic height (2.4 m) and dbh (2.05 cm) increments are 39.5 % for height and 34 % for dbh more than Tarahara.

In another study in Indonesia, at 4 years, *A. auriculiformis* has been found to grow well in marginal sites reaching 10 m in height with 2.5 m annual increment (Anon. 1983) and 45% more than height increment of Tarahara.

The study was undertaken in plantations of *E. hybrid* and *A. auriculiformis* raised in Singhbhum Afforestation and Dhalbhum Forest Divisions of Bihar, India (site characters: altitude-90 m, mean annual rainfall about 1500 mm; site almost flat and consists of good quality sandy loam soil up to the depth of 1 to 2 m). At 5 years, mean dbh of *A. auriculiformis* was 4.8 cm, with 0.96 cm dbh increment (Pande *et al.* 1987), 79.2 % less than that of Tarahara. It clarifies the need of good site for good growth of this species.

In the early 1980's, trials in the Terai/Bhabar Terai indicated the high potentiality of *A. auriculiformis* below 1000 m. Trial sites (Adabhar and Chitrepani) showed the need of complete cultivation for at least the first two years after plantings, if the seedlings are to survive with good growth (Hawkins 1986). In comparisons with other exotic acacias, *A. auriculiformis* always proved to be the most vigorous, and had the best survival.

Naturally *A. auriculiformis* is widely varied showing its importance and necessity of provenance testing. The present practices of planting *A. auriculiformis* using seed from India need to be left and seed from selected sources in Australia and Papua New Guinea (PNG). would provide good form and growth. Establishment of seed source in India is from a limited genetic base and is much inbred (Neil 1990).

In Jatilihur, West Java the height and diameter growth of *A. auriculiformis* was 12.4 cm and 9.0 cm respectively at the age of four years (Wiersum and Ramlan 1982), which are higher than the height and dbh of these species at 5.5 years at Tarahara. But the growth of this species was found even lower at seven years in Bihar, India (Site: average rainfall -1500 mm, altitude- 900 m; soil- good quality sandy loam soils up to the depth of 1 to 2 m) where the mean dbh and height were only 7 cm and 7.1 m respectively (Wiersum and Ramlan 1982). These variation in growth of this species is mainly governed by the use of superior or inferior genetic material, site used for plantation and management.

In well tended situation, early growth of *A. catechu* is very rapid. Under such situation, the growth of 18-month-old trees (4.7 m in mean height by 5.8 cm in mean diameter) clearly proves the above fact. Height (3.13 m), dbh increment (3.87 cm) which are 52.7% (height) 95.5% (dbh) more than the periodic height and dbh increment of Tarahara (Table 6). It further emphasises that weed free conditions are necessary to improve the growth and survival of this species. At Butwal 34- month-old trees were 5.8 m high with a diameter of 6.5 cm, (Jackson 1994), growth (height and dbh) increment is slightly higher than Tarahara. In Uttar Pradesh of India, a crop height of 11.3 m by 12 cm diameter was reached in 10 years (Indian Timbers 1973). The growth of *A. catechu* aged 5.5 years at Tarahara is almost similar to the growth of *A. catechu* aged 10 years in U. P. However, the age of this species is 4.5 years less at Tarahara than U. P. It depicts the good growth of this species at Tarahara.

The data were collected from 11 sample plots in U. P. of India At 10 years, top height (m) was found in a range of 15.6 to 17.6 m in site quality I (Sharma 1981). The present trend of growth of this species at Tarahara may easily cross the top height attained by this species in U. P. at 10 years in Tarahara. It makes clear the good growth of *A. catechu* at Tarahara.

Four species except *E. tereticornis* survived satisfactorily (Table 3). The main reason of poor survival of *E. tereticornis* is may be due to poor quality of seedlings used for planting. These seedlings could not have competed with *Eupatorium* spp. (Banmara) in the early stage.

The early growth of the species tested at Tarahara may have retarded due to the presence of dense cover of *Eupatorium* spp. which might have created moisture and nutrient deficiency for trees particularly in the dry season.

Many of the earlier trials conducted at Adhabar in the Bhabar Terai failed because of inadequate weeding (Hawkins 1986). Full cultivation of the soil to prevent weed competition is essential for the early growth of development of *eucalyptus* in the Terai, where there is profuse growth of *Eupatorium* species and *Imperata* grass during the monsoon. From the research done in this area, it is found that it is possible to double the growth rates of eucalyptus by intensive weeding as compared with only spot cultivation (Hawkins 1986).

Intercropping is not widely practised in the plantations of terai Districts, however, it would have obvious benefits to minimise the weeding cost and to increase the survival rate and growth of trees in the early stage of planting. So it seems essential to keep weed free conditions for the first three years for these species, particularly for *Eucalyptus* spp., after planting by adopting intercropping as suggested by Hawkins (1986). The results of Tarahara further emphasises the importance of intercropping or complete cultivation.

During the time of trial plot establishment, *E. camaldulensis* had the higher priority in research and in planting programme due to the fast growing nature and good coppicing ability. However, at present stage, controversial aspects of *eucalyptus* include more water use, soil nutrient depletion, undergrowth problem, competition and chemical effects, social and cultural concerns. In such circumstances, *Acacia catechu* can be used as an alternative for large scale planting for fuelwood production due to its remarkable diameter growth in this study. However, it should be noted that the ecological effects of planting *eucalyptus* as single trees, rows of trees or in small woodlots may be very different from those produced by plantations in extensive blocks. Again, they are easy to cultivate, not palatable to grazing animals and are therefore easy to protect. If such situation exists, *E. camaldulensis* cannot be ignored. Furthermore, the present severe problem of *D. sissoo* due to unidentified disease has significantly increased the value of *A. catechu* for planting programme. A. auriculiformis can also be used for planting due to its good value for firewood. The site can be protected from nutrient depletion due to its N_2-fixation character. This species can be used for mixture planting e.g. *A. catechu, D. sissoo.*

Conclusion

The growth of these five species is comparatively lower than in those places where either full cultivation or intercropping after full cultivation is adopted for the first three years. Intercropping is essential to adopt in community, private and large scale government plantations in order to enhance the early growth, to increase the success rate and to reduce the weeding cost. The growth of *Acacia catechu* is found to be similar to *Eucalyptus camaldulensis* under pit cultivation for the first three years. *A. catechu* can fix nitrogen and protect the site from nutrient depletion which may not be the case with *Eucalyptus* species. Again, there are many controversial thoughts on *E. camaldulensis.* Thus, *A. catechu*, which is planted on a very small scale at present as compared to *D. sissoo* and *E. camaldulensis*, need to be included in the afforestation programme in the Terai/Inner Terai of Nepal. The same case as for *A. catechu* can be applied for *A. auriculiformis* also. The priority given for *D. sissoo* plantations as monoculture in the Terai needs to be changed to minimise the risk and the priority should be given to *A. catechu* and mixtures of plantations so as to save plantations from epidemic disease as found in pure plantations of *D. sissoo* in the Terai.

Recommendations

- *E. camaldulensis* cannot be ignored if there is a severe grazing problem. Similarly, it would be better to plant in small woodlots, as a single tree or rows of tree rather than large scale plantation. In such small scale plantations, problems regarding ecological effects, undergrowth are minimal. Petford provenance of *E. camaldulensis* could be selected for planting.

- This trial has opened the door for the inclusion of *A. catechu* and *A. auriculiformis* in addition to *D. sissoo* and *E. camaldulensis* in the plantation programme for fuelwood production in the eastern Terai of Nepal. Since the former two species fix nitrogen which is the benefit to the site to protect from nutrient depletion.

- These fast growing species need to be tested in other parts particularly in the Terai/Inner Terai of Mid-Western and Far-Western Regions of Nepal for their growth performance.

- It is worthless to test fodder species in sites were there are wildlife such as deer, rabbit, monkeys, etc.

- *Acacia auriculiformis is* normally known for its bad stem form and frequently possesses multiple stems. Selection of suitable provenances can increase plantation productivity. There have been reports from many countries of superior growth, and also good form provenances from PNG. So, seed from selected sources in PNG and Australia should be used for plantations, rather than seed from India. The Indian seed source is from a limited genetic base and is much inbred. Furthermore, due to wide variation of *A. auriculiformis* provenance testing is necessary.

- Provenance testing of *A. catechu* is also necessary. Unless conclusive results from provenance testing are available, seed can be collected from Amlekhgunj (used in this study also). If the site for planting is too far from planting site, for seedling production seed can be collected from good quality local stands.

- Research results outside Nepal show that closer spacing is more suitable for fuelwood plantations in case of *A. auriculiformis*. Spacing trial for this and other tested species are essential for firewood production in short rotation.

- In the eastern terai, seeds of D. sissoo from Kankai Mai (Jhapa District) can be used for planting. However, seed must be collected from healthy trees with good form.

- The poor performance of *E. tereticornis* as found in this study indicates towards its further investigation.

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Annex 1: Information on seed sources

Species	Seedlot number	Seed source
Acacia auriculiformis	N952	Dehra Dun, India
Acacia catechu	N988	Amlekhgunj, Bara District, Nepal
Dalbergia sissoo	—	Tarahara, Sunsari District, Nepal
Eucalyptus camaldulensis	N535	Emu Creek, Petford, Australia
Eucalyptus tereticornis	N570	Kennedy River, Queensland, Australia
Leucaena leucocephala	N920	Adabhar, Bara District, Nepal

Notes: The original seed source of *Acacia auriculiformis*, *Dalbergia sissoo* and *Leucaena leucocephala* are not known.

Annex 2: Results of ANOVA test for mean height, mean dbh, and mean basal area

Height

Source	DF	SS	SS (%)	MS	Variance ratio (F)	P- value
Blocks	3	3.416	4.62	1.139	0.76	0.540
Species	4	52.422	70.92	13.106	8.70	0.002
Error	12	18.083	24.46	1.507		
Total	19	73.92	100.00			

DBH

Source	DF	SS	SS (%)	MS	Variance ratio (F)	P- value
Blocks	3	2.340	3.61	0.780	0.51	0.686
Species	4	43.991	67.83	10.980	7.13	0.004
Error	12	18.520	28.56	1.543		
Total	19	64.851	100.00			

Basal area (overbark, m^2 per ha)

Source	DF	SS	SS (%)	MS	Variance ratio (F)	P- value
Blocks	3	31.506	8.67	10.52	1.13	0.378
Species	4	219.699	60.50	54.925	5.89	0.007
Error	12	111.975	30.83	9.331		
Total	19	363.181	100.00			