

## Potential of short rotation woody crops for pulp fiber production from arable lands in India

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### ABSTRACT

Wood fiber is used for the manufacture of various kinds of paper, packaging material, tissues, paperboard etc. The conventional soft woods and hard woods used as raw materials by pulp, paper and cellulose based industries are depleting day by day and the wood imports are draining country's foreign exchange. Short rotation industrial agroforestry plantations with the fast growing tree species are potential sources to fill this gap and to make the nation self reliant in pulpwood supply. Poplar, eucalyptus, leucaena and bamboo are the ideal species that can be grown commercially in private lands for meeting the wood requirements and has the potential to produce a biomass of 18 to 49 t/ha per year. The pulp yield from these species ranges from 40 to 49% of the wood biomass produced. With the expansion of wood markets, high biomass yields and amenability for harvesting in short rotations, short rotation woody crops can be one of the profitable options for fiber production on lands which are not suitable for intensive arable cropping. Some of the important fiber supplying species which are grown under Indian conditions and their agroforestry systems and profitability aspects are discussed in the paper.

**Key words:** Agroforestry, Biomass productivity, *Dendrocalamus*, *Eucalyptus*, *Leucaena leucocephala*, *Populus deltoides*, Rainfed agriculture, Wood fiber

Botanically, fiber is defined as a long narrow tapering cell, dead, rigid and hollow at maturity, with thick cell wall, composed mostly of cellulose and lignin, found mainly in vascular tissue. Commercially, fiber is defined as a long narrow flexible material, which may be of an animal (hair or wool), mineral (asbestos), synthetic (nylon), or plant origin. There are three types of plant fibers used in commerce, and they are made of single cells or group of cells. The first one is the textile fibers, which include those fibers which grow from the surface of seeds (cotton) or fruits (coconut coir), soft or bast fibers which are found in the phloem of dicotyledonous stems (flax, linen, jute, hemp, ramie) and hard or leaf fibers which are found in monocot leaf vascular bundles (sisal, Manila hemp, pineapple). The second category is paper making fibers which are single cells of delignified wood. The third one is of miscellaneous category consisting of brush and broom fibers, plaiting and weaving fibers, filling fibers (kapok, milk weed, cattails), etc.

Wood fibers are usually cellulosic elements that are extracted from trees, straw, bamboo, hemp, etc. When

suspended in water, the wood fibers disperse and become more pliable. This pulp suspension can be laid down on a screen to form a sheet of paper, and this is the primary use of wood pulp. Wood pulp is the most common material used in paper making. The timber resources used to make wood pulp are referred to as pulpwood. Wood pulp comes from softwood trees such as spruce, pine, fir, larch and hemlock, and hardwoods such as eucalyptus, leucaena, aspen and birch. Throughout the world, the annual wood pulp production is to the tune of 176 million tonnes (m t) of which the chemically processed wood pulp is 129 m t (FAOSTAT, 2009). The needed end product (paper, paperboard, tissue, cardboard etc.) determines the kind of species or species blend, that is best suited to provide the desirable sheet characteristics, and also dictates the kind of fiber processing techniques, such as the chemical treatment, heat treatment, mechanical brushing, etc. required to achieve the end product.

### Wood fibers in the Indian scenario

In India, the emphasis on paper as an environment friendly packaging material alongwith various uses, such as the news print, printing paper, value added paper, etc. is leading to a rapid increase in paper consumption. In recent years the growth rate of annual paper production has been growth about 4.1% where as the growth in its consumption has been at 5.1% a year. However, the annual per capita consumption of paper and paperboard in India

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is only 4.5 kg, as compared to 42 kg in China and 55 kg worldwide. It is estimated that India's annual per capita consumption of paper and paper board will increase to about 8 kg by 2010 (Shahid, 2001), and will substantially increase further. Due to the insufficient supply of the raw material from Indian forests, the paper industry to a great extent depends on the imported pulp. The pulp imports were to the tune of 1.38 m t, costing about US \$ 1,049 m (Table 1) during 2007 (FAOSTAT, 2009).

Of the 660 paper mills in India, 26 are wood-based and face challenges with the supply of forest-based raw material. Many pulp mills are finding it difficult to gain access to lands where they can establish plantations, and source wood from natural forests (Puri and Nair, 2004). Of the 6.8 m t of wood producing 1.9 m t pulp annually, nearly 20% of wood is procured from forests through government sources and the remaining 80% comes from private sector through agroforestry systems (Kulkarni, 2008). The National Forest Commission emphasized that since forests alone can not meet the increasing wood demand, agroforestry in private and community lands has to be promoted to bridge the shortfall (Kirpal *et al.*, 2006). Fiber farming on agricultural lands using fast-growing, high-yielding short-rotation woody crops has been proposed as an important opportunity for both the forest and agriculture sectors.

#### **Important fiber tree crops and their management practices**

In India, many fast growing plants, including a large number of annuals and perennials, have been screened for their suitability for pulp and paper making. Some of them are *Populus deltoides* Bartr. (poplar), *Dendrocalamus strictus* Rosch. (Bamboo), *Casuarina equisetifolia* L., *Eucalyptus globulus* Labill., *E. grandis* W. Hill ex Maiden, *E. tereticornis* Sm., *Sesbania aculeata* Willd., *S. aegyptica* L., *Moringa oleifera* Lam., *Prosopis juliflora* (Sw.) DC, *Leucaena leucocephala* (Lam) deWit., *Grevillea robusta* A.Cunn. ex R.Br., *Pinus taeda* L., *Acacia auriculiformis* A.Cunn. ex Benth, *Gmelina arborea* Roxb., *Pinus radiata* D. Don, and *Hibiscus sabdariffa* L. Among these species, eucalyptus, leucaena, poplar and bamboo are the important species that have desirable pulp characteristics (Table 2) and are grown widely for the pulpwood.

These species are well accepted by the farmers and are integrated in the existing land use systems. The area under eucalyptus and leucaena has increased rapidly in some Southern states, particularly in Andhra Pradesh whereas, the poplar is grown in large extent in Western tarai region of Uttar Pradesh and Uttara Khand, in Haryana, Punjab and in the plains of Himachal Pradesh. It is estimated that Prakasam district of Andhra Pradesh alone produces 0.7

**Table 1.** Average annual production, imports quantity (m t) and value (\$ m) of paper and paperboard (2007)

Category	Production	Import	
		Quantity	Value
News print	0.62	0.81	505.0
Printing and writing	1.53	0.42	361.0
Household and sanitary	0.04	0.01	1.7
Other paper and paper board	2.03	0.15	182.0
Total paper and paper board	4.18	1.38	1,049.0

**Table 2.** Pulping properties of eucalyptus, leucaena and bamboo wood

Parameter	Unit	<i>Eucalyptus</i>	<i>Leucaena</i>	Bamboo
Ash	%	0.4-1.46	1.0-1.46	2.0-3.0
Lignin	%	24-25	24-26	26-28
Holocellulose	%	71-72	65-70	69-72
Pentosans	%	14-15	16-17	16-17
Average fiber length	Mm	0.8-1.2	1.0-1.2	2.0-2.2
Fiber wall thickness	µm	0.08		
Average fiber diameter	µ	0.19	16.6	15.02
Unbleached pulp yield	%	45-49	42-49	40-44
Kappa number	-	16-18	25-26	17-22

m t of wood annually on private holdings, which is worth of Rs. 560 m (Saigal and Kashyap, 2002). During the last decade, tree growing as a commercial short rotation coppice has also increasingly become a profitable land use systems with the establishment of a functional industry / farmer relationship, trading of wood in the open market, assured market, high returns from trees and supportive policies of the state government.

#### ***Eucalyptus* sp.**

*Eucalyptus* has a long history in India. It was first planted around 1790 by Tippu Sultan, the Ruler of Mysore, in his palace garden on Nandi Hills near Bangalore. Subsequently in 1843, it was introduced in Nilgiri Hills, Tamil Nadu, and from 1856 onwards, regular plantations of *E. globulus* were raised to meet the demands for firewood (Wilson, 1973). One of the other important reasons for raising large scale eucalyptus plantations is to reclothe the denuded and barren hilly areas by replacing the low value natural forests and to meet the raw material requirements of industrial wood fiber.

Most of the large scale eucalyptus plantations in India were raised during two decades, between 1960-1980 due to the support of the foresters, scientists and workers who favoured the concept that eucalyptus being the suitable species for growing in degraded forests, barren lands and marginal private lands. The favourable characteristics of the eucalyptus species, such as drought and browse resistance, fast growth, fire hardiness, good coppicing,

capability to compete with weeds and adaptability to a wide range of edapho-climatic conditions were mainly responsible for the positive attitude towards this species. During the 70's and early 80's, in addition to the efforts of the forest department to plant eucalypts in suitable sites, the forest development corporations also chose eucalyptus as the main species in their plantation projects.

The success of eucalyptus plantations in government land attracted farmers to this species. Along with the large scale planting of eucalyptus in government lands, the country experienced a large scale eucalyptus planting in farm lands, particularly along the farm bunds, irrigation channels and as block plantations. Gujarat, which initiated social forestry, took the lead in this direction and was followed by Karnataka, Punjab, Haryana, Uttar Pradesh and other states. Further, in Gujarat, Haryana and Punjab, farmers went ahead to raise irrigated plantations, where the concept of high density plantations evolved as a suitable alternative to agricultural crops. Eucalyptus plantations in India increased substantially through various forestry and agroforestry programs. Of the estimated 2.5 m ha of land brought under farm forestry during 1981 to 1988, more than two-thirds were planted with eucalyptus (Saxena, 1992). However, the trees failed to come up to farmers' expectations, both in wood yields and monetary value, which led to indifference on the part of the farmers towards trees in general and eucalyptus in particular. Important reasons for this, and a subsequent decline in the area under plantations were the use of poor quality planting material (mostly through seeds whose genetic make up has suffered a gradual and continuous deterioration over almost 150 years), and poor soil preparation and inadequate weeding, which farmers frequently failed to attend to.

#### Varieties and planting material

About 170 species, varieties and provenances of eucalyptus were tried in India (Bhatia, 1984), the favoured one has been the *E. hybrid*, a form of *E. tereticornis* known as Mysore gum. The important characteristics of *E. hybrid* which contributed to its popularity under Indian conditions are its fast growth, high weed competitiveness especially during early stages, good coppicing, fire hardiness, browse resistance and adaptability to a wide range of edapho-climatic conditions (Kushalappa, 1985). Other species which are grown on large scale plantations are *E. grandis*, *E. citriodora* Hook, *E. globulus* Labill., and *E. camaldulensis* Dehnh. The growing stock and yield in eucalypt plantations vary considerably depending on the site, the edapho-climatic conditions and the applied inputs. The potential productivity is around 5 t of biomass /ha per year but the average yield of forest plantations from seed-

lings is about 2.5 t/ha per year. The average yield from the private plantations is much higher. In Kolar district, Karnataka, the average productivity is around 5 t/ha per year. The yield recorded from forest plantations is still less.

The development of high yielding and disease resistant clones has revolutionized eucalyptus cultivation in many parts of India. Private sector initiatives, such as the Indian Tobacco Company-Paper Boards and Specialty Papers Division Limited (ITC-PSPD), based on the superior phenotype selected a large number of candidate plus trees of eucalyptus from plantations raised by farmers and forest departments (Piarelal, 2008). These candidate plus trees were cloned under controlled environments, field tested and the superior clones were released for large scale cultivation. Majority of the clones are from *E. camaldulensis* and *E. tereticornis* and few of them are the progeny of the crosses from these species. The productivity of these clones under rainfed conditions ranged between 92-128 m<sup>3</sup>/ha in 5 years (Table 3). In certain trials, the productivity of best clones has been more than 10 times the productivity of seedlings in control treatment or the worst performing clone (Piarelal, 2001).

**Table 3.** Performance of eucalyptus clones (volume in m<sup>3</sup>/ha) in Andhra Pradesh

Clone no.	1995 (II year)	1996 (III year)	1997 (IV year)	1998 (V year)
71	33.4	45.6	84.2	128.1
10	19.0	35.7	80.8	111.3
6	15.4	38.1	71.6	109.7
7	18.9	32.8	73.2	106.2
4	19.5	34.1	72.0	105.4
27	18.9	30.2	70.7	92.9
3	26.6	44.9	74.5	92.1

#### Spacing and tree density

During 1970's and the 80's when seedlings were the only available planting material, eucalyptus used to be planted at closer spacing. Often trees were spaced at 1.5 m x 1.5 m, and closer planting of 1 m x 1 m was used. A rotation of 7 to 9 years was recommended for the pulpwood, where as for commercial wood, a rotation of 13 to 14 years was recommended. The current annual increment of *E. tereticornis* seedlings in forest plantations peaks in the fifth year and then drops (Chaturvedi, 1989). The wood density increases with age, and reaches a maximum at 13 to 14 years. Farmers were encouraged to plant eucalyptus at a density of more than 4,000 seedlings/ha, in bund plantations, the distance between trees was about a metre. These growing conditions led to a poor-quality product (Saxena, 1991).

The recently developed clones can be planted at a spacing of 3 m x 2 m and in some of the intensively managed plantations at a spacing of 3 m x 1.5 m. Clonal plantations are generally harvested at 4 years after planting. The coppice growth is allowed to grow and normally 2 shoots are allowed. The subsequent harvests are also made at four year interval and thus 4 harvests can be obtained from a single plant crop of eucalypt.

### Intercropping

As the seedlings used to be planted at closer spacing, no intercrops used to be taken up in the seedling plantations. However, intercropping of annuals in timber trees, which are planted at wider spacing compared with sole tree woodlots offers the advantages of reduced tree establishment costs, income generation during the early growth phase of the trees, efficient use of natural resources, and risk reduction from catastrophic fires (Garrity and Mercado, 1994). Couto and Gomes (1995) reported higher intercrop yield and the existence of complementary interaction in eucalyptus-beans system. One row of intercrop maize between two tree rows did not affect the survival and growth of eucalyptus and reduced the plantation cost by 60% (Couto *et al.*, 1994). However, these studies were taken up during the first one year of tree planting and therefore some of these advantages are offset by the increased competition for above ground and below ground resources as tree canopies and root systems expand over years. Eucalyptus was reported to negatively affect the intercrops when it was grown for wood production (Pratap Narain *et al.*, 1998, Kumar and Nandal, 2004). In India, wheat (*Triticum* sp.), chickpea (*Cicer arietinum* L.), lentil (*Lens esculentum* Moench.) yields were depressed as far as 2 to 12 m from the tree row (Saxena, 1991) when trees were grown on the field boundaries.

The clonal eucalyptus plantations raised for pulpwood in Andhra Pradesh are generally harvested at 4-year intervals. A large number of crops such as chickpea, tobacco, chillies, blackgram and greengram are grown with eucalyptus during the first year of planting. The commonly used 3 m x 2 m spacing (accommodating 1,666 trees/ha) by farmers causes yield reduction in majority of intercrops from the second year onwards. The competition between trees and intercrops may start from early stages if the tree is grown at higher density in short rotations for pulpwood (harvest cycle 4 or 5 years), and the competition could be more intense in later stages. For this reason, much of the acreage under plantations is confined to large-landholders who do not need to intercrop the plantations for the want of income for their livelihoods. Smallholders are not able to take advantage of these systems due to the absence of regular annual income, which is essential to their liveli-

hood. Altering the tree geometry by increased tree row spacing (or alley width), effectively increased the intercrop yield during the entire four year period. Improvement in intercrop yields was observed with the increase in tree row spacing (or alley width), especially with the triple row arrangement, which produced 73% and 66% of the sole crop (cowpea) yields in 2003 and 2004, respectively (Praasad, 2006). Cowpea yields in other wider-row arrangements varied from 50 to 62% of the sole crop yields in the third year and 39 to 59% of the sole crop yields in the fourth year of tree plantation (Table 4).

**Table 4.** Yields of cowpea grown in the post-rainy seasons and fodder grasses in both rainy and post-rainy seasons of 2005 in sole and eucalyptus-based agroforestry systems in Andhra Pradesh

Tree geometry	Grain yield (kg/ha)				Fodder (t/ha) <sup>a</sup> 2005
	2001	2002	2003	2004	
10 × 1.5 m TR	1,062	655	518	387	1.53
11 × 1.0 m PR	965	594	441	342	1.83
7 × 1.5 m PR	926	485	405	229	1.36
6 × 1.0 m	865	408	353	285	1.58
3 × 2.0 m	879	296	121	134	0.88
Sole crop	968	650	706	584	1.94
CD (P=0.05)	NS	118	102	57	0.56

<sup>a</sup>Average yield of three fodder grasses

PR- Paired rows, TR- Triple rows

### Nutrient cycling and management

Eucalyptus responds well to nutrient application. In an experiment at Hosakote (Karnataka), application of N (up to 320 kg), P (up to 30 kg) and K (up to 100 kg) applied three times at 9, 18 and 27 months after planting increased the dry weight of stem by 23% (Hunter, 2001, Table 5). In *E. camaldulensis*, application of fertilizers resulted in increased height and volume index from one to three years of tree age, but the level of response declined with the increase in tree age in sodic soils with water logging (Singh *et al.*, 2005). Among the oil cakes tried, neem cake applied @ 1.0 kg/pit significantly improved tree height and collar diameter over mustard cake and mahua cake in sodic soils (Gupta *et al.*, 2006). One of the allegations levelled against eucalyptus is that it depletes the soil, rendering it unfit for any future productive use. There are several studies on this aspect albeit giving contradictory results. Kushalappa (1985) analysed the nutrient status of a 12 year old *E. tereticornis* plantations near Bangalore and found that the nutrient inputs to the soil through weathering, litter, rainwater, and dead root to be greater than its removal through harvesting. George (1986) noted that the organic matter and exchangeable potassium are to be de-

**Table 5.** Dry weight of eucalyptus (t/ha) as influenced by fertilizer application

Fertiliser rate (kg N-P-K/ha)	<i>E. camaldulensis</i>		<i>E. grandis</i>	
	Wood	Leaf	Wood	Leaf
Control	37.1	5.1	35.1	5.9
80 - 7.5 - 25	40.1	4.9	39.4	7.0
320 - 30 - 100	43.0	5.2	41.8	7.2

pleted in the soil under eucalypt plantation than in wood lands, but no difference was observed in calcium and magnesium. Studies conducted in *E.* hybrid plantations show that substantial amounts of nutrients are added to the soil through litter fall, stem flow, and throughfall (George, 1982). Various nutrients input by way of geochemical cycle, biological nitrogen fixation, irrigation and rain water is expected in tropical areas, which would compensate some level of nutrient loss by wood harvesting. However, the research results indicate the need of nutrient application to maintain the yield, especially in second and subsequent rotations.

#### Biomass productivity

Much of the eucalyptus cultivation is confined to rainfed areas where as areas receiving high rainfall are particularly suitable for it. Likewise, the sandy loam soils with good drainage are particularly suitable for eucalyptus cultivation. The productivity of clonal saplings is usually higher than that of seedlings. Besides that the coppicing ability of eucalyptus makes it suitable for 3-4 harvests continuously without any additional expenditure on planting. The debarked bole wood is the marketable product from eucalyptus grown for pulp production. Under better management the average yield levels of clonal material at the end of 4 years varies from 50 t/ha (rainfed conditions) to 150 t/ha (irrigated conditions). In some of the sites under intensive management, clonal eucalyptus developed from elite trees has produced total fresh biomass up to 135 t/ha in a 4-year rotation. In one of the on farm study, the fresh wood productivity was 88 t/ha per 4 years where as the dry wood productivity was 59 t/ha per 4 years (Prasad, 2006). The relative contribution by different above ground tree parts to the total biomass was: bole-81%, bark-8%, branches-8% and leaves-3%. In general, the productivity of clonal plantations greatly exceeds that of the plantations with native accessions.

#### Subabul

Subabul (*Leucaena leucocephala*), is a leguminous multipurpose tree that thrives well in neutral to alkaline soils where the annual rainfall ranges from 600-1,700 mm. It is a high biomass producing tree and its wood has high

calorific value. The forage is highly palatable, digestive and nutritious. Foliage is very rich in nitrogen and can be used as green leaf manure. Besides the above, leucaena has good coppicing ability and fixes atmospheric nitrogen and can be easily grown in marginal lands with less difficulty. Leucaena wood is generally described as being strong, light in weight, easy to work and able to give attractive finish (Rao, 1984). *L. leucocephala* has porous wood structure, longer fiber than that of other hardwoods, high holocellulose,  $\alpha$ -cellulose and low lignin content with xylan type hemicellulose, making it a suitable raw material in pulp and paper industry (Malik *et al.*, 2004). These qualities make leucaena wood suitable for a wide range of uses, ranging from the traditional small scale farm tools and implements making to the more recent utilization by large scale industries for pulp and energy generation (Pottinger and Huges, 1995).

#### Varieties and planting material

Mullen and Gutteridge (2002) evaluated 116 leucaena accessions from 22 species for their biomass productivity and adaptability to the sub tropical conditions of Australia. The hybrid accessions, 'KX2' (*L. pallida* x *L. leucocephala*) and 'KX3' (*L. diversifolia* x *L. leucocephala*), were the most productive, yielding over 50 kg dry matter (DM) per tree in two years. *L. trichandra* (Zucc.) Urb. and *L. diversifolia* (Schltdl.) Benth. were the most productive non-hybrid accessions, producing yields of 41 and 37 kg dry matter/tree, respectively. Cultivar Tarramba (variety 'K636') was the most productive (26 kg dry matter/tree) of the 26 *L. leucocephala* accessions assessed in the trial, but all these accessions suffered from psyllid (*Heteropsylla cubana* Crawford) attack at this site. In India, interest in leucaena was revived during mid 70's with the introduction of giant arboreal varieties from Hawaii and the Philippines, which were evaluated over various climatic regions and soil types. Kushalappa (1980) observed that the varieties K8 and K28, raised in the drier regions of Karnataka having a rainfall of about 500 mm had very poor growth. Qureshi and Desai (1981) made similar observations for Maharashtra region. The growth of Hawaiian giant and other introduced cultivars were not satisfactory in Punjab and drier parts of Tamil Nadu, respectively (Dutt and Jamwal, 1988). The poor growth of the introduced leucaena cultivars in India could be due to the different edaphic and climatic conditions which are not similar to that in Mexico and Central America, and the lack of effective *Rhizobium* strains and their failure to establish effective symbiotic association with vesicular and arbuscular micorrhiza (Dutt and Jamwal, 1988). However, Hegde (1998) reported a biomass yield of 18 t/ha per year of K8 variety at 6 years after

planting with a spacing of 1 m x 1 m with protective irrigation (Table 6). Maslekar (1984) reported 24.78 and 15.33 t/ha yield, respectively for irrigated and rainfed conditions of a 2.5 year old plantation in Maharashtra. However, some of the varieties like K636 have yielded higher biomass productivity levels in Australia (Mullen and Gutteridge, 2002) and in India (Prasad, 2006). *Leucaena* varieties are commercially propagated through seeds or through seedlings grown from seeds. The seeds are to be treated with either with hot water or acid for breaking the dormancy before sowing.

**Table 6.** Productivity potential of 'K-8' *Leucaena* under protective irrigation

Parameter	Measurement
Basal diameter (cm)	7.80
DBH (cm)	5.80
Collar diameter (cm)	3.60
Total height (m)	11.16
Green weight / tree (kg)	17.90
Main stem (kg)	15.40
Branches (kg)	2.90
Total green biomass yield (t/ha)	161.00

#### Spacing and tree density

*Leucaena* for wood is generally harvested in 3 to 4 years and allowed to re-sprout. Three rotations can be taken up successfully. There are a few studies carried out on the identification of optimum tree density and spacing for wood production in *leucaena*. Spacing is found to have a noticeable effect on diameter growth (Prasad, 2006) and generally trees responded to wider spacing and lower competition with greater individual diameter growth. A planting at a spacing of 1 m x 1 m recorded significantly lower height and diameter at breast height (DBH) where as trees in 3 m x 2 m spacing recorded higher tree height and DBH growth (Table 7). Unlike some of the temperate trees, whose height growth is relatively unaffected by tree density, height in *leucaena* was significantly

influenced by density and affected by competition at higher densities (10,000 trees/ha). Spacing also influenced the biomass partitioning in to stems in *leucaena*. Both the bole biomass production and the partitioning of biomass in to bole increased with the increase in tree density (Table 8). Trees in stand density of 1 m x 1 m partitioned 88% of the total biomass in to the stem where as the stand density of 3 m x 2 m partitioned only 82% in to stem in small sized trees (2.5-5 cm). With increased competition between trees, stems will become more cylindrical and branch size and crown length gets reduced resulting in greater partitioning of biomass to the stem (Nielsen and Gerrard, 1999). *Leucaena* trees in the narrow spacing and higher stand density partitioned slightly more biomass in boles and less in branches and foliage than trees in lower stand densities.

#### Intercropping

Much of the literature on *Leucaena* and arable cropping systems is on alley cropping systems where tree spacing varied from 25 cm x 75 cm to 25 cm x 375 cm (Mittal and Singh, 1989; Rao *et al.*, 1991) permitting intercropping for extended periods. Tree pruning is also practiced in alley cropping system, but not in wood production systems. *Leucaena* in many parts of Andhra Pradesh is generally planted at a spacing of 1.3 m x 1.3 m which does not permit intercropping. Trees are first harvested at 4 years after planting and subsequently at three year intervals, making three harvests in a 10 year rotation. Returns from the plantation can be obtained only after four years from planting, during this period considerable investment has to be made on raising the trees. Since trees are closely spaced, there is no scope for raising intercrops. Facilitating intercropping in *leucaena*-based systems not only provides regular income for the sustenance of farmers before the tree is harvested but also fodder for the livestock. Increasing the row width is one of the alternatives to take up an intercrop during the first season. Increased tree row spacing was also found to increase the intercrop yield

**Table 7.** Tree height in m (A) and diameter at breast height in cm (B) of *Leucaena* planted at different spacings over a 4-year period (2001-2005) in Andhra Pradesh, India

Spacing (m)	July 2002		July 2003		July 2004		July 2005	
	A	B	A	B	A	B	A	B
1.00 x 1.00	3.1	3.2	6.6	4.2	9.7	5.4	12.5	6.1
1.30 x 1.30	3.6	3.0	7.4	5.5	11.3	6.9	14.2	8.4
3.00 x 0.75	3.2	3.6	6.7	4.8	11.8	6.5	14.4	8.0
3.00 x 1.00	3.2	2.7	6.7	4.6	11.3	6.5	14.2	7.7
5.00 x 0.80	2.7	2.6	6.5	5.3	11.9	7.3	14.4	8.7
3.00 x 2.00	3.5	3.0	7.4	6.1	12.0	7.9	14.3	9.3
SEd±	0.3	0.3	0.4	0.4	0.8	0.9	0.4	1.0
CD (P=0.05)	NS	NS	NS	0.9	NS	2.1	0.9	2.3

**Table 8.** Fresh and dry biomass (t/ha) of different parts of leucaena at harvest (51 months) planted in different spacings at Bhadrachalam in Andhra Pradesh, India

Spacing (m)	Marketable bole biomass (bole) Fresh weight (t/ha)	Dry biomass production (t/ha)				
		Bole	Branch	Leaf	Bark	Total
1.0 × 1.00	144.9	81.0	4.9	2.2	4.3	92.4
1.3 × 1.30	124.6	70.6	3.4	1.9	3.2	79.2
3.0 × 0.75	136.6	78.1	3.8	1.5	3.7	87.1
3.0 × 1.00	113.9	65.9	3.0	1.2	2.9	73.0
5.0 × 0.80	117.4	68.6	3.7	2.1	2.7	76.9
3.0 × 2.00	94.8	52.1	2.6	1.4	2.4	58.5
SEd±	10.7	6.3	0.9	0.5	0.6	7.1
CD (P=0.05)	23.8	14.1	2.1	NS	1.4	15.7

till second year but not in the third year due to the expansion of leucaena tree canopy resulting in complete shade to the underneath crop (Table 9). Increasing the inter row distance beyond 3 meters however, was not suitable for enhancing the intercropping yield. The magnitude of crop yield losses in agroforestry systems increased with the age of the trees. The increased competition with age was due to the increased size of the trees and their ability to draw resources at the expense of the arable crops (Pratap Narain *et al.*, 1998). Competition of trees with intercrops is expected particularly significant in rainfed conditions because of the limited amount of stored soil water.

**Table 9.** Post rainy season (*rabi*) cowpea yield in sole and leucaena agroforestry systems during three years (2001, 2002 and 2003) in Andhra Pradesh, India

Treatment	Cowpea yield (g/m <sup>2</sup> )		
	Post rainy season ( <i>rabi</i> ) 2001	Post rainy season ( <i>rabi</i> ) 2002	Post rainy season ( <i>rabi</i> ) 2003
13 × 1.00 m (Four rows)	98.1	62.6	21.5
10 × 1.00 m (Triple rows)	106.0	60.0	15.6
7 × 1.00 m (Paired rows)	96.0	56.0	11.0
5 × 0.80 m	98.6	31.5	8.0
3 × 2.00 m	101.5	23.5	7.6
3 × 1.00 m	98.5	23.0	6.9
3 × 0.75 m	100.2	12.7	8.5
Sole crop (crop without tree)	102.9	85.6	71.6
CD (P=0.05)	NS	13.2	3.1

#### Nutrient cycling and management

Little published information is available on the nutritional requirements of leucaena for wood production systems. The possibility of utilizing leucaena leaves and young growth as source of nitrogen, however has been studied for many African systems. In soils where leucaena is grown for the first time, *Rhizobium* inoculation is helpful in increasing the dry matter accumulation, shoot length

and leaf number (Datta and Das, 1997). The *Rhizobium* bacterium can be isolated from the root nodules of seedlings in nursery or existing trees and can be cultured in the laboratory. The cultured inoculum can be mixed in water and applied to young seedlings few days after transplanting in the main field during the first year. In one of the studies, the tree height, diameter and biomass yield increased linearly (Table 10) with the increase in nitrogen application (Saikia and Sharma, 1994).

#### Biomass productivity

Hegde (1988) reported a biomass productivity of 161 t/ha and dry wood yield of 107 t/ha (both in a 6 year period) with the 'K6' variety of leucaena under four irrigations/year. The mean annual growth increment of some of the leucaena varieties in different locations in India is furnished in Table 11. The mean annual increment of Hawaiian Giant in India ranged from 6.5 to 21.8 m<sup>3</sup>/ha per year against 34.5 to 54.8 m<sup>3</sup>/ha per year in the Philippines, and 29.8 to 57.1 m<sup>3</sup>/ha per year in Hawaii (Dutt and Jamwal, 1988). Agarwal *et al.* (1985) reported a mean yield of 66.83 t/ha per year under irrigated conditions and 14.13 t in rainfed conditions in a 3.5 year old plantation. In on-farm trials conducted in Andhra Pradesh, the fresh biomass productivity of 'K-636' leucaena was about 149 t/ha and the dry biomass productivity was about 92 t/ha in a 4 year period (Prasad, 2006). Biomass contributed by different tree parts to the total was: bole>branch>bark>leaf. Mishra *et al.* (1995) reported an annual yield 23 to 43 t/ha per year for *L. leucocephala* in Uttar Pradesh, India. Experiments conducted by Saikia and Sharma (1994) revealed that plant growth and yield parameters were affected by planting density, where maximum dry matter production (160 t/ha) was obtained in the closest spacing and the minimum biomass yield (45 t/ha) was obtained in the widest spacing. The biomass productivity in the subsequent rotations is expected to be high as 2-3 shoots are allowed to grow in the second rotation. Allowing more

**Table 10.** Plant growth and biomass yield of leucaena at the age of 4 and 5 years under various doses of nitrogen

Nitrogen dose (kg/ha)	Plant height (m)		Diameter (cm)		Dry biomass yield (t/ha)	
	4 year	5 year	4 year	5 year	4 year	5 year
No	6.140	6.850	8.050	8.433	36.743	57.470
N <sub>20</sub>	6.523	6.905	8.238	8.616	40.890	60.250
N <sub>40</sub>	6.773	6.965	8.450	8.650	49.556	61.750
N <sub>60</sub>	6.876	7.253	8.519	8.866	55.400	62.816
N <sub>80</sub>	6.943	7.383	8.680	9.066	58.253	64.270
N <sub>100</sub>	7.123	7.390	8.886	9.300	59.650	64.900
N <sub>120</sub>	7.233	7.475	9.160	9.466	61.316	65.600
SEm ±	0.024	0.018	0.038	0.069	0.084	0.064
CD (P=0.05)	0.054	0.039	0.083	0.151	0.183	0.140

**Table 11.** Growth of Leucaena varieties in different locations of India

Location	Variety	Age (years)	Density (trees/ha)	Mean annual increment (m <sup>3</sup> /ha per year)
Dehradun	K8	3.0	2,500	7.1
		3.0	2,500	4.0
Jhansi	Hawaiian Giant	4.0	1,000	6.5
		4.0	5,000	21.8
Jammu	K8	4.0	10,000	14.6
		2.0	2,500	7.7
		2.0	10,000	31.7
		3.0	2,500	15.3
		3.0	10,000	41.4
		4.0	2,500	17.3
Urulikanchan	K8	4.0	10,000	44.7
		3.5	10,000	96.0

shoots (4-6 shoots) could be an advantage if fuel wood production is the main objective and would be of a disadvantage for pole or log production.

### Economics

The financial evaluation of eucalyptus and leucaena with and without cowpea crop is presented in Table 12. Cost of cultivation, gross and net returns were higher in eucalyptus and cowpea agroforestry system followed

leucaena and cowpea system, sole eucalyptus system, sole leucaena and sole cowpea in the decreasing order. Returns from the tree systems were substantially higher in comparison to only arable cropping system. Returns were higher in eucalyptus based agroforestry by 3 times in comparison to cowpea (Table 12). Financial indicators such as the net present value and benefit cost ratio were also higher with tree systems in comparison to the annual crops. Though, the tree cultivation required additional expenditure which was mainly due to the cost of the planting material, its transportation to the field, pitting and planting, however, the high returns have compensated these costs. Intercropping in the initial years allows better cash flow during early growth periods when revenue from trees is not forthcoming.

### Poplar

Poplar is the most widely grown cash tree crop in North and North Western parts of India mostly on irrigated and fertile lands. This is a preferred tree because of its fast growth and multi purpose wood and the ready availability of market for its wood. Poplar wood is well suited for the manufacture of veneer, matches, fibre-board, light packaging, paper pulp etc. Much of the wood produced is being used by the plywood industry and only a part is available for paper production. They, with straight and cylindrical bole, moderate conical crowns, mostly deciduous

**Table 12.** Benefit : cost ratio (B:C) and net present value (NPV) (Rs./ha) of net income at different discount rates for two tree systems in Andhra Pradesh, India

Agroforestry systems	Discount rate					
	6%		12%		18%	
	NPV	B:C	NPV	B:C	NPV	B:C
Eucalyptus + cowpea	62,074	2.1	44,237	1.9	31,584	1.7
Leucaena + cowpea	56,730	2.3	41,228	2.1	30,195	1.9
Sole eucalyptus	54,808	2.3	36,905	2.0	24,292	1.7
Sole leucaena	44,903	2.3	29,838	2.0	19,240	1.7
Sole cowpea	24,374	1.9	21,859	1.9	19,750	2.0

during winter months, combine well with intercropping of agricultural crops. They have gained tremendous importance in meeting the demand for wood products so much so that 80% of the plywood production in North India depends on poplar wood. The Udham Singh Nagar district alone produces 0.2-0.28 m t of farm grown wood annually which is valued at Rs. 650 m (Saigal and Kashyap, 2002). The widespread adoption of poplar agroforestry and other tree-based systems has created a substantial improvement in the water productivity in Northern plains and added significantly to the farmer-livelihood and economic security (Zomer *et al.*, 2007). Poplar clones were first introduced in the *Tarai* belt of Uttar Pradesh in 1959 and outstanding success has been obtained in this region which lies between latitude of 29° and 30°N. It is estimated that around one m ha of agricultural land is under poplar cultivation in one or other form of agroforestry. Poplars prefer good aerated soil. However there are reports that they can grow on alkaline to moderately acidic soils.

#### Varieties and planting material

Poplars have been used as avenue trees in Kashmir since Mughal era, but it was only in 1976, they were considered as possible agroforestry crop. An attempt at introducing exotic Poplars in Himalayas was made in 1950, with cuttings imported from USA and UK but that failed. Another attempt was made with European clones in 1965 when clones of *Populus deltoides* were planted over 2 ha in *Tarai* area of Nainital district. By 1975, two exotic clones 'G-3' and 'G-48' of Australian origin were planted commercially in a significant area. Both these clones produced a biomass of 49 t/ha in 10 years in a degraded alluvial soil in North India, where the clone 'D121' did not perform well (Singh, 1998). All three clones had a polynomial growth pattern of net production over 5-10 years with a peak at 8-9 years. Clones, 'G-48', 'S<sub>7</sub>C<sub>1</sub>', 'S<sub>7</sub>C<sub>8</sub>' and 'S<sub>7</sub>C<sub>20</sub>' performed significantly better in height growth than 'G3' at Punjab. The Stoneville clones from the USA had better growth performance than the clones from Australia and Italy. The clone San-Martino produced higher diameter growth, clones 'S<sub>7</sub>C<sub>1</sub>', 'S<sub>7</sub>C<sub>20</sub>' height, and clone 'S<sub>7</sub>C<sub>8</sub>' both the diameter and height (Sidhu, 1996). The promising clones in central-plain region and semi-arid region were '421-2', '82-26-5' and 'L-62/84', and 'RD-01', '26-N', 'S<sub>7</sub>C<sub>20</sub>', 'ST-124', '38-N' and '40-N', respectively. 'RD-01', '421-2', 'S<sub>7</sub>C<sub>20</sub>' and 'ST-124' registered significantly higher fiber length (Dhillon *et al.*, 2008). A nursery trial of thirty poplar clones, mainly of *P. deltoides* with a few of *P. nigra* L., *P. yunnanensis* Dode, *P. euramericana* Guinier and *P. ciliate* Wall. Ex Royle, planted as cuttings, was carried out at the Poplar Re-

search Nursery of the Forest Research Institute at Dehra Dun, Uttar Pradesh. Among the tested clones, *P. deltoides* clones such as '3294' showed superior growth performance (Table 13) than others (Chauhan and Dhiman, 2003).

#### Spacing and tree density

For transplanting poplars in the field in Northern India, January and February months are the best period because later transplanting results in heavy mortality. The recommended spacing is 5 m x 4 m, i.e. 500 plants/ha. Jha *et al.* (1991) reported significant effect of spacings on diameter growth but not on height growth in exotic clone 'S<sub>7</sub>C<sub>1</sub>' of *P. deltoides*. Rectangular planting geometry lengthwise facing North-South were better than ones facing East-West and square ones. A 5 m x 3 m planting distance was most suited for 10-year rotations for block planting and for intercropping. A closer spacing of 2 m x 2 m, 3 m x 2 m and 4 m x 2 m can be adopted for short rotation systems. Mishra *et al.* (1996) reported that the 5 m x 5 m and 5 m x 3.75 m spacing gave greater tree height, DBH, mean annual increment (MAI) and basal area of individual trees than other spacings at 6.5 year after planting (Table 14). Tree survival was also significantly greater at the 5 m x 5 m spacing. The total volume of wood under bark was greatest at the 5 m x 1.25 m and 5 m x 1 m spacings (Mishra *et al.*, 1996). On agricultural field bunds, poplar is generally planted at 3 to 4 m spacing.

#### Intercropping

Intercropping in poplar provides additional returns from the intercrops and benefits the trees by the additional inputs applied to the inter-crop including the weed control. The narrow canopy of poplar trees and the tree attribute of shedding the leaves during the winter reduce the tree and intercrop competition substantially. Several crops and varieties have been tested for their intercropping suitability and yield performance under poplar cultivation and found that crop-poplar intercropping especially if poplars are planted on bunds can be taken up without any significant yield reduction in crops (Chandra, 2001). Poplar growing has been successfully integrated with agricultural crops and several agroforestry models, which are ecologically and economically viable, are available. Field crops such as wheat, sugarcane, sunflower, mustard, oat, maize, barley, lettuce, beet root, pineapple, yams, pulses, including essential oil yielding annuals *viz.* tagetes, etc. are grown extensively with poplar either in irrigated as well as in rainfed conditions (Sharma and Dadhwal, 1996). Pineapple, beet root, yam and lettuce have shown promise of cultivation as an inter crop with poplars. Lettuce, beet root registered yields as high as 27.5 t/ha and 15 t/ha,

respectively. Among the essential oil yielding crops, patchouli and marigold hold promise (Chandra, 2001). However, when grown under marginal lands without irrigation, their growth rates and biomass accumulation is quite low. In irrigated poplar-based agro-ecosystem, light is the major limiting factor causing reduction in grain yield particularly in the rainy season and in late planted *rabi* crops. On an average, a reduction in grain yield of wheat was 20% under 1-year-old poplar plantation, which increased to 54% in a 4-year-old plantation (Chauhan *et al.*, 2009). Therefore, the selection of suitable varieties which can tolerate shade is important for optimizing yields in poplar systems. Adoption of 'PBW 502' wheat under poplar plantation would substantially improve the overall productivity of the system without any additional input cost (Gill *et al.*, 2009).

#### Nutrient cycling and management

Poplars responded well to nutrient application. A significant response has been noted for nitrogen (160 kg/ha) and phosphorus (100 kg/ha) fertilizers (Mishra and Tewari, 1999). Nitrogenous, potassic and phosphatic fertilizers as well as micronutrients applied to the intercrops will also be utilized by the trees in agroforestry system. Phosphatic and potassic fertilizers to trees are recom-

mended to be applied as basal dose before sowing of the intercrops. Nitrogen fertilizers should be applied in 2-3 splits during active growth period during April to September. Fertilizer should never be placed near the stem of the plants as these can result in girdling of young trees and even kill them. Application of fertilizers must be followed by light irrigation (Piarelal, 1991) where ever possible.

#### Biomass productivity

Poplars produce large quantity of wood in a short period and can attain 90 cm girth and a mean annual increment of 20 m<sup>3</sup>/ha at 8 years of rotation. On an average, poplar growth ranges from 15 to 25 m<sup>3</sup> of wood under bark/ha per year on well chosen sites on a 8 to 12 year rotation. On-farm poplar productivity has been recorded to be 20 to 35 times more than in the natural forests in India (Chandra, 2001).

#### Economics

The net present value and benefit cost ratio analysis indicates the poplar agroforestry system to be financially viable at the discounting rates of 15 and 12% over an eight-year rotation (Table 15) and more profitable than many of the other cropping patterns prevalent in the *terai* region of Uttar Pradesh (Jain and Singh, 2000). The inter-

**Table 13.** Growth attributes in different clones of poplar at Dehra Dun, Uttar Pradesh

Poplar clone	3 years			4 years		
	Height (m)	DBH (cm)	Average crown diameter (m)	Height (m)	DBH (cm)	Average crown diameter (m)
'PD3294'	9.11	9.48	3.4	13.13	13.58	3.8
'PD G3'	10.23	10.34	3.4	14.27	14.34	3.8
'PD G48'	10.83	10.54	4.1	14.94	14.60	4.7
'PD 1/56'	10.39	10.34	3.1	14.45	14.44	3.4
SEm±.	0.32	0.32	0.11	0.30	0.18	0.08
CD (P=0.05)	0.70	0.70	0.25	0.64	0.39	0.18

**Table 14.** Effect of tree spacing and density on survival and growth of Poplar

Tree spacing (m)	Tree height (m)	Diameter at breast height (DBH) (cm)	Mean Annual Increment in DBH (cm)	Basal area /tree (m <sup>2</sup> )	Total wood volume under bark (m <sup>3</sup> /ha)
5 × 5.00	17.30	22.37	3.73	3.97	89.75
5 × 3.75	16.83	21.60	3.59	3.67	95.11
5 × 2.50	16.47	18.61	3.10	2.72	103.17
5 × 1.25	14.43	17.76	2.96	2.51	166.78
5 × 1.00	14.07	16.62	2.44	1.69	125.15
10 × 3.75 (paired rows)	16.33	21.07	3.51	3.49	88.39
10 × 2.50 (paired rows)	15.67	16.78	2.79	2.22	62.11
10 × 1.00	14.00	19.72	3.29	3.07	109.27
SEm±.	0.51	0.79	0.13	0.25	11.24
CD (P=0.05)	1.55	2.40	0.39	0.77	34.10

**Table 15.** Discounted costs and returns (at 12%) in Rs / ha with and without intercropping in poplar

Year	With out intercropping		With intercropping	
	Discounted cost	Discounted returns	Discounted cost	Discounted returns
1	12,562		17,295	13,641
2	8,406		11,674	12,667
3	7,944		12,953	11,371
4	6,924		9,388	5,484
5	6,435		8,619	4,896
6	6,107		7,896	4,371
7	9,249	1,11,103	10,989	1,15,133
Total	57,627	1,11,103	78,814	1,67,563

nal rate of returns (IRR) of agroforestry in an eight-year period was unprofitable at the discounting rates higher than 24 and 14%, respectively. The system is profitable with a seven year rotation (Chaturvedi, 1992). In the plantation of six and seven years, the net income/ha per annum from agroforestry was higher than even that from paddy-wheat rotation, but less than from sugarcane and vegetable based crop rotations. The benefit-cost ratio of poplar agroforestry was either close to, or higher than those of many other cropping patterns of *terai* region of western Uttar Pradesh (Singh and Jhajaria, 2001).

### Bamboo

Bamboo is the world's fastest growing plant. Bamboo has specific advantages over other tree crops interms of low gestation period, fast growth, recurring annual income, diversified uses and easier marketability. Bamboo based forestry, agroforestry systems and homestead plantations have a vast scope to utilize the unutilized spaces in and around the homesteads, fields and field boundaries. The species of *Melocanna baccifera* (Roxb.) Kurz and *Dendrocalamus longispathus* Kurz species have wide-spread uses, viz., young shoots as vegetables, chutney, curry, mature culms for construction of houses, fencing, flooring roofing, drinking water channel or pipe, fuelwood, 'Tabashir' or 'Banslochan' of bamboo (water accumulated in the hollow internodes) as cooling tonic to cure asthma, cough and a source of organic calcium, and the outermost green portion of culms to stop bleeding from wound or cut etc. Nearly half of the bamboo produce is now used in pulp and paper industries. *D. barbatus* Hsuch et D.Z. Li has good potential as a raw material for medium strength wood pulps. The use of bamboo as industrial raw material is leading to their over exploitation and a steady decline in their natural stands.

### Varieties and planting material

Bamboos are one of the few important crop plants that

have never been subjected to either selection or breeding on any scale worthy note. This is partly due to the relative difficulties in obtaining material for breeding owing to the unusual flowering habits of most bamboos. The peculiar flowering behavior in bamboos makes genetic improvement by hybridization very difficult. The conventional method of improvement is by selection and some of the important characteristics for selection are faster growth, higher rates of culm production, culm diameter, thickness of culm wall and diameter of lumen and fiber length, etc.

Efforts were made to enhance the productivity of bamboo using improved planting material raised either through clonal methods or through tissue culture. Several bamboo species were tried and some of the promising were *Dendrocalamus strictus* and *Bambusa bambos* L. The results were quite encouraging in the states of Gujarat and Rajasthan where the survival percentage ranged from 68 to 100% for both the species (Srivastava *et al.*, 2008). In Himachal Pradesh, six species of bamboo - *Dendrocalamus strictus*, *D. hamiltonii* Nees, *D. parshii*, *Bambusa bambos*, *Arundinaria falcata* Nees, *A. spathiflora* Trin. are found to be widely distributed and these species holds a potential for their introduction at larger scale in the vast wastelands of the state (Bhardwaj and Mishra, 2003).

### Spacing and density

From a study conducted, on two bamboo species *Melocanna baccifera* and *Dendrocalamus longispathus* in Mizoram, the maximum average height growth, number of leaves and culm emergence was observed under the 3 m × 3 m spacing (Table 16) while the minimum height growth was observed in 2 m × 2 m spacing (Jha and Lalnunmawia, 2003). The growth attributes of *Bambusa tulda* Roxb. and *B. balcooa* Roxb. species except the number of internodes were statistically at par between closer spacing (10 × 10 m) and wider (12 m × 12 m) spacing (Banerjee *et al.*, 2009).

**Table 16.** Plant height (cm), number of leaves and number of culms of *Dendrocalamus longispathus* up to 24 months after planting

Treatment	Mean height	No. of leaves	No. of culms
2 x 2 m fertilized plot*	140.68	65.55	1.015
2 x 2 m control plot	127.31	62.25	0.705
3 x 3 m fertilized plot*	142.50	72.01	1.035
3 x 3 m control plot	118.27	61.33	0.705
SEm±	5.31	6.78	0.084
CD (P=0.05)	16.92	21.58	0.268

\*(60-40 g/plant urea-SSP in 3 splits at 90 days interval)

### Intercropping

Interspaces between bamboo rows can be effectively utilised for intercropping with ginger (*Zingiber officinale* Rose), turmeric (*Curcuma longa* L.), large cardamom (*Amomum subulatum* Roxb.) and dinanath grass (*Pennisetum pedicellatum* Trin.) up to a lateral distance of 11-15 m from the bamboo row where shading can be expected for a part of the day. Rice, finger millet, soybean, setaria (*Setaria sphacelata* Schum.) and stylo (*Stylosanthes* spp.) are suitable crops beyond this distance. Light availability in bamboo varied from 84 to 95% to a distance of 11 m and was less than 44% near the bamboo row. Turmeric, ginger and dinanath grass produced higher yields near bamboo rows (1-2 m), and their yields decreased with greater light transmittance away from the rows (Ali *et al.*, 2006). However, relatively greater yields were observed at 12-m distance from the bamboo rows. Therefore the cultivation of only shade-loving crops such as turmeric, ginger and dinanath grass are recommended under bamboo clumps (Table 17). Pigeon pea intercropped in 2 m × 2 m and in 3 m × 3 m spacing in the bamboo plantation resulted in net annual return of Rs. 7,900 and Rs. 13,300/ha respectively. The yield of intercrops, such as rice (var. Annada), groundnut (var. JL 24), pigeon pea (var. UPAS 120), cowpea (var. Pusa barsati), lady's finger (var. Parbhani kranti), bottle gourd (var. Summer prolific round), turmeric (var. Sugandham), colocasia (var. Satamukhi) and elephant foot yam (*Amorphophallus paeoniifolius* Blume. Ex Decne.) (var. Kovvur) was higher in wider spacing (12 m × 12 m) as compared to closer spacing (10 m × 10 m) in *Bambusa tulda* and *B. balcooa* based agroforestry systems in red and laterite soils of West Bengal (Banerjee *et al.*, 2009). The growth, yield and land equivalent ratios assessed for pigeon pea, soybean, turmeric and ginger intercropped with *Bambusa bambos*, in Tamil Nadu showed that yield advantage of 20% and 10% has been found in case of pigeonpea and soybean, respectively, in intercropping situation compared to pure stand (Shanmughavel *et al.*, 2001).

### Nutrient cycling and management

Application of N and P has a significant influence on

the growth of bamboo species. Application of urea @ 60 g/plant and superphosphate @ 40 g/plant in three split doses at intervals of three months recorded higher height growth, average number of leaves, and maximum culm emergence in *Melocanna baccifera* and *Dendrocalamus longispatus*, in 3 m × 3 m spacing (Totey *et al.*, 1989). A complete harvest of *Bambusa bambos* at 6 years age removed 2,341 kg/ha of nitrogen, 22 kg/ha of phosphorus, 2,653 kg/ha of potassium, 1,211 kg/ha of calcium and 1,356 kg/ha of magnesium (Shanmughavel and Francis, 2001). Therefore, any fertilizer application schedule should consider the nutrient removal by bamboo.

### Biomass productivity

A 7-year-old *Dendrocalamus strictus* based agroforestry system at Parbhani, Maharashtra, during 2000-2001 produced a biomass of 17.87 kg bamboo/tree having a canopy area of 20.11 m<sup>2</sup>. The annual biomass production in bamboo agroforestry system was 7,150 kg/ha per year. (Patil *et al.*, 2004). Aboveground biomass of thorny bamboo (*Bambusa bambos*) clumps averaged 2,417 kg/ clump with an average accumulation of 241.7 t/ha in the homegardens of Thrissur, Kerala (Kumar *et al.*, 2005). The productivity of *Bambusa bambos* showed that the total biomass increased with age, from 2.2 t/ha in the first year to 297.8 t/ha in the sixth year (Shanmughavel *et al.*, 2001)

### Economics

The net present value, benefit cost ratio and internal rate of return of bamboo based agroforestry systems were Rs.72,550, 2.93 and 47.85, respectively at 10% discounted rate in Orissa. Data collected from 25 farmers randomly from 14 villages in Akola district, revealed that net returns after 15 years were Rs. 54,075 /ha (Rs. 3,605/ha/year) in *Dendrocalamus strictus*. On average, the cost of bamboo establishment was Rs. 7,603/ha. If the bamboo stand is worked out for a period of 15 years, the total cost would be Rs. 53,925 where as the net returns after compounding at the rate of 12% would be Rs. 63,242. The benefit cost (B-C) ratio in this case was 2.01 and the IRR was 27.33% (Marawar *et al.*, 1998). Values of NPV

**Table 17.** Relative intercrop yield as affected by lateral distance from bamboo culms

Crop	Distance from bamboo rows (m)								Max yield (t/ha)	CV (%)
	1-3	3-5	5-7	7-9	9-11	11-13	13-15	15-17		
Turmeric	100.0	84.4	77.4	62.8	56.2	44.8	39.4	38.2	7.82	32.80
Ginger	82.4	100.0	98.4	86.2	71.5	58.4	51.2	42.8	8.85	26.45
Rice	18.5	36.8	55.4	64.8	85.9	92.8	100.0	100.0	8.94	22.82
Fingermillet	28.4	36.8	32.8	39.7	58.4	86.9	98.2	100.0	1.68	42.54
Dinanath grass*	89.5	100.0	85.4	62.8	48.5	52.4	42.3	40.5	12.45	34.52

\**Pennisetum pedicellatum*

and IRR for bamboo agroforestry systems were higher in lower value lands as the loss of agricultural income from them was low, and a bamboo agroforestry system is considered efficient for such lands. On higher value land the wider spacings were more economically attractive, but on the highest value lands the enterprise was not a viable option because the IRR was <14% (Dey *et al.*, 2007).

There is a need to increase the tree fiber production not only to meet the growing domestic requirements but also to exploit the export opportunities. Poplar, eucalyptus, leucaena and bamboo are the ideal tree species capable of producing high quantities of wood fibre in a short period. The sole or intercropping systems of these systems are profitable alternatives for crop diversification over annual crops. These agroforestry systems also increases the employment opportunities at the village level. For example, the poplar cultivation generates a total of 710 mandays of employment/ha for works like ploughing, planting operations, irrigation, leader training, pruning, harvesting, ploughing, irrigation, application of fertilizers and pesticides, weeding, etc. and if we consider operations related to raising seedlings and processing of wood; the employment opportunities would be still higher. Besides, pruning of poplar produces a substantial amount of fuelwood, which reduces livestock dung consumption for fuel purposes and makes it available for field application as a source of nutrients for field application. Leucaena leaves are a good source of nutritious fodder and its leaves being rich in nutrients, when added to soil improves the fertility. These trees can be grown with the annual crops and agroforestry systems provide greater productivity and profitability, which can address some of the food security concerns. Tree systems are less risky under rainfed conditions where crop failures are common due to extremes in climatic variability. These tree species can also be grown profitably in sloppy and degraded lands where intensive arable cropping can not be practiced.

#### **Future research thrusts and policy issues**

- Evaluating alternative crops and materials including the perennial grasses and crop residues as a source of fiber.
- Development of techniques for faster multiplication of quality planting material.
- Development of site specific management practices for enhancing the tree and intercrop productivity. Enhancement of intercrop productivity can be explored by way of manipulating tree geometry and density, tree canopy management, selection of suitable shade tolerant crops and varieties.
- Quantification of nutrient uptake and cycling in these

systems, identification of nutrient requirements and fertilizer management strategies.

- Identification of practices which can enhance decomposition of large quantities of biomass produced from these systems. Identification of microbial inoculants capable of decomposing cellulosic substances particularly in case of eucalyptus.
- In depth investigation on the effect of various management practices on the fiber quality parameters.
- Development of technologies for rapid tree establishment and biomass productivity especially in degraded lands which are not suitable for arable crop cultivation.
- Quantification of carbon and climate change mitigation potential of fiber tree based systems.

Policy issues are important in sustaining the acreage under tree based systems for fiber production. One of the important reasons for the spread of these systems is the ready market for the wood in the form of paper/pulp industry. Guarantees from the wood based industries regarding the purchase of their produce at pre-announced prices or the prevailing prices in the market (which ever are higher) is encouraging farmers to invest in agroforestry, particularly in areas where the wood market is weak and unorganized. However in recent times the wood prices have come down drastically, as a result of which these systems became less profitable and even loss making. The government has to intervene and assure minimum support prices for wood as that of other crops. Timely and adequate supply of credit to meet the initial plantation costs, assured supply of quality planting material suitable for varied situations and extension support services can further contribute to the expansion of fiber tree farming.

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