PRODUCTIVITY ENHANCEMENT IN FORESTRY PLANTATIONS

A Handbook

Indian Council of Forestry Research & Education

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A HANDBOOK

INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION
P.O. New Forest, Dehradun - 248 006

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Foreword

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ICFRE with its Headquarters at Dehradun is an apex body in the national forestry research system that promotes and undertakes need based forestry research and extension. The Council that came into being in 1986 has a pan India presence with its 9 Regional Research Institutes and 5 Centers in different bio-geographical regions of the country. Since then research in different fields of forestry has been a major focus of ICFRE.

There is an earnest need of publication for its research to the stakeholders in a simple and lucid manner, to improve the visibility and relevance of ICFRE. Therefore, it was decided that the information available on the technologies, processes, protocols and practices developed by ICFRE has to be updated and may be published in the form of operational manuals/user manuals. It was also expressed that the manuals should be a comprehensive national level document depicting extent of knowledge in applicable form.

Accordingly, 18 Scientists of ICFRE were nominated as National Subject Matter Coordinators (NSMCs) to carry out the task on the specified subject. These NSMCs were assigned the task to select and nominate nodal officers from other Institutes of ICFRE as well as other organizations if necessary, collect and collate the information on the subject from various sources in coordination with the nodal officers of ICFRE institutes.

This User Manual on "Enhancing Productivity in Forestry Plantations" is a compilation of all the latest information generated by various institutions specializing on different tree species in the country. It provides information on availability of new varieties, methods of cultivation, industry linkages and contact details of species specialists and industries for further information on planting and marketing. It is hoped that this User Manual will be widely used by managers of forest departments, forest corporations, wood-based industries and farmers to successfully raise tree plantations and realize enhanced wood production.

Further, the manual has got good number of new initiatives to facilitate research through innovation. I hope that the manual will provide useful information to the diverse stakeholders and prove to be helpful literature for planning future tree improvement programmes.

Dr. Suresh Gairola

Preface

Despite its rapid economic progress during the last three decades, India has largely safeguarded its forest wealth through various legislations and policies aimed at balancing growth with nature conservation. The Green Revolution in agricultural sector which achieved food sufficiency through increased productivity helped in stopping diversion of forest land for agriculture. The commercial extraction of timber and other wood products from natural forests has been gradually reduced through adopting progressive policies and now completely banned through legal restrictions. The thrust given to raising plantations outside forest areas, farm forestry and agroforestry has helped in meeting the increasing demand for timber and wood for various industrial uses. A liberal import policy has been adopted to make timber accessible and affordable to a large number of people particularly for house construction and furniture making. But recent international developments in the areas of timber import and climate change mitigation compel a review of the current situation and adapt the policies to suit the current and emerging needs. The huge import bill of around Rs. 45,000 crores is a great concern and its reduction will not only save foreign exchange but help in increasing livelihood opportunities in rural areas through tree cultivation, harvest and processing. In the context of climate change, timber is regarded as the best way to lock carbon and treat forests and tree plantations as carbon sinks. India has to meet the Nationally Determined Contributions (NDC) of 2.5 to 3 billion tonnes of additional carbon sinks by 2030. Out of this NDC, 1.92 billion tonnes will be met from natural forests and the rest from Trees outside the Forest (ToF).

Considering the international commitments and the necessity to meet the domestic demand of 153 million m^3 of timber and wood by the year 2020, it is essential that the productivity of forestry plantations are enhanced both in terms of quantity of wood and its quality as well. Since a large portion of ToF is with the smallholding farmers as farm forestry and agroforestry plantations, any increase in productivity will lead to higher farm income and ensure economic stability to the farmers. A partnership between the growers (forest department, farmer), research institutions and the wood-based industries will have to be forged to complement each others' strength and achieve the goal of maximizing productivity.

The Indian Council of Forestry Research and Education (ICFRE), the apex body of providing research solutions to various challenges in the forestry sector has been taking concerted efforts to evolve new varieties and modern cultivation techniques to increase productivity in forestry plantations. The various tree improvement programmes undertaken for over three decades have been making a difference in the way many tree species are grown in the country. ICFRE is now prioritizing the dissemination of the new products and techniques to all stakeholders so that they help in enhancing productivity and thereby contributing to meet the national requirements discussed above. This User Manual on Enhancing Productivity in Forestry Plantations is a compilation of all the latest information generated by various institutions specializing on different tree species and geographic area in the country. It provides information on availability of new varieties, methods of cultivation, industry linkages and contact details of species specialists and industries for further information on planting and marketing. It is hoped that this User Manual is widely used by managers of forest departments, forest corporations, wood-based industries and farmers to successfully raise tree plantations and realize enhanced wood production.

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INTRODUCTION

1.1 ENHANCING PRODUCTIVITY IN FORESTRY PLANTATIONS

INTRODUCTION

India is a wood deficient country and a major importer of timber. However, the shortfall in meeting the demand for wood actually reflects the country's economic progress and its efforts to balance it with forest conservation. Since natural forests in the country are not subjected to commercial extraction of timber and other wood products following the National Forest Policy, 1988 and subsequent legal restrictions, the production could not keep pace with the demand. Rapid economic growth during the three decades after the adoption of the 1988 forest policy has resulted in sharp increase in the demand for timber, plywood and pulpwood. The major responses to meet the demand were to establish plantations both within and outside forest areas and to import from other countries. Currently wood demand for the paper and plywood industries are almost entirely met from plantations of short-rotation trees raised both within and outside forest lands. But a major part of timber demand is still met through import and India is among the largest importer of timber in the world (ITTO 2017) with an annual import bill of around 45,000 crores. In the past such huge expenditure on imports was considered as cost of conserving our natural forests but it is now felt that the indigenous production has to be increased not only for saving foreign exchange but to increase livelihood opportunities associated with tree cultivation and to create more carbon sinks for fighting climate change.

INDIA'S PLANTATIONS AND THEIR PRODUCTIVITY

India's plantations are extensive and meet the requirement of several products and services. They also address livelihood needs of millions of farmers of smallholding and landless agricultural labour force. In particular, India ranks first in the extent of plantation area for Eucalypts (3 million ha), Teak (2.6 million ha) and Casuarina (0.8 million ha) and another 1-2 million ha of plantations of other tree species. The major stakeholders of these plantations are forest departments, wood-based industries and farmers. Despite the large estates of plantations of different species, the wood production is insufficient mainly due to low productivity of these plantations. In fact productivity of Indian plantations is among the lowest in the world. The average productivity of Teak plantations is 3-5 m^3 ha^{-1} $year^{-1}$ whereas the world average is much higher than that. Similarly the average rotation period of 40-50 year is substantially more than international average of 15-25 years (Kollert and Walotek, 2017). Considering the vast areas under plantations, even a small increment in productivity will result in substantial benefits in terms of economic gain to growers, increased raw material availability and reduction in imports (Table 1).

Table 1. *Value of additional wood produced through every 1% increase in productivity of plantations*

Species	Rotation Age (years)	Value of Additional Wood (Rs.)
Teak	50	250,000
Eucalyptus	5	5000
Casuarina	4	6000

Plantation productivity has been steadily increased throughout the world for different tree species through application of tree improvement techniques benefitting all stakeholders involved. Tree improvement includes developing genetically improved planting material through selection and breeding and growing them by adopting the most suitable silvicultural practices. Systematic breeding programmes have been implemented for many species with well defined objectives over a period of time to develop seed and clonal accessions capable of increasing wood production and quality in plantations.

These breeding programmes usually have three well-defined populations namely base, breeding and propagation populations. The genetic gain obtained through breeding is transferred to plantations through seeds collected from seed orchards and vegetatively propagated clones. A seed orchard is a collection of selected clones or families established in one physical location and then managed to produce genetically improved seed for operational forestation (White *et al.* 2007). They are the most common and cost-effective means of making available a stable supply of genetically improved seed (Varghese *et al.* 2000).

But in the Indian context, transfer of genetic gain through seeds has not been successful so far. Early attempts to produce genetically improved seeds of high value species like teak met with problems since the biology of these species especially the reproductive behaviour is poorly understood. In cases where seed orchards were successfully established, the logistics involved in intensively maintaining the orchards, timely collection of seeds and their storage and distribution posed challenges to expand the area of plantations raised with seed orchard seeds. As a result only a small part of plantations at present is developed using seeds collected from seed orchards (Table 2). In contrast, the advent of clonal forestry during the early nineties significantly increased productivity of Eucalyptus plantations in India. Since then clonal plantations have gained much popularity and demand for new clones and large number of clonally propagated plants have resulted in many innovations in clonal forestry. Currently extensive plantations of Acacia, Casuarina, Eucalyptus and Poplars are raised using clones.

Table 2. *Current extent of plantation and seed orchards of different tree species and gains realized them*

Species	Annual Planting Area (000 Ha)	Seed Orchard Area (Ha)	Realized Genetic Gain (%)*	Current Proportion of Plantations from Orchard Seed (%)	Current Proportion of Clonal Plantations (%)
Teak	40	1648	10-68	>5	>5
Eucalypts	300	43	17	5-10	40-50
Casuarina	100	18	21	5-10	20-30
Australian Acacias	10	15	15	>5	>5

**in terms of volume compared with unimproved seed source*

DEVELOPING HIGH PRODUCTIVE CLONES

Clone development involves the following four stages:

(i) Selection of Candidate Clones
(ii) Clonal Testing
(iii) On-site Yield Trials
(iv) Mass Multiplication and Deployment

Selection Candidate Clones

Candidate clones are those phenotypes that are selected based on one or more desired traits for screening through clonal testing. In order to increase the probability of selecting outstanding clones it is necessary to initially include a fairly large number of candidate clones for testing. But testing of large number of entries increases cost of testing and also poses many logistic problems like identifying a suitable area for testing, production of required number of clonal plants and handling the data for analysis. Balancing the number of clones to be tested and increasing the probability of obtaining superior clones can be achieved by careful selection of candidate clones. It is always more rewarding to select candidates with some level of known pedigree, like an outstanding provenance or family in an existing trial than randomly selecting the best trees in plantations. Selecting entries from areas with soil and climatic conditions similar to that of target areas will also help in identifying most adaptable clones. Prior testing of end use characters like wood properties will also help in short-listing clones ranking above-average for further testing.

Clonal Testing

Clonal testing is ideally conducted in two stages. The first stage is known as 'clonal elimination trial' which involves testing of a large number of clones with a limited number of trees per each clone. At half-rotation age, the best 10 to 20% of the clones are promoted to the next stage of testing called 'clonal proving trials'. In such advance testing, large plot sizes (36 or 49 tree plots) are used for each clone to simulate plantation conditions. These plots are usually retained till the full rotation age but clones can still be ranked with confidence at half-rotation age. Usually an outstanding commercial clone and the best seed source available are included in the clonal proving trials as control entries to quantify the superiority of the newly selected clones and to justify the investments made in clonal testing and selection.

Clonal testing is generally conducted in multi locations (3 or more locations) to select site-specific clones and to determine the extent of genotype x environment interaction. This information will be highly useful to make decisions on moving clones to new areas where testing has not been conducted. It is essential to conduct the clonal tests in contrasting areas representing the plantation environment for the species. It is also necessary to adopt cultivation practices similar to those practiced in routine plantations. However, special care has to be taken to ensure a high level of survival (90% and above) which will retain uniform spacing within the trial plot and to make accurate ranking of clones. Adequate and clear record-keeping is crucial for conducting the testing till its logical conclusion especially if personnel involved are liable for transfer.

On-site Yield Trials

Clonal tests are essentially field experiments conducted by technical personnel with special care. But the clones selected through such testing should replicate the same superior performance in the actual plantation areas like a farmer's field or the planting area of a forest plantation corporation. Yield trials are raised by adopting the same practices followed by the farmer or the planting organization in order to make a realistic assessment of the superiority of the new varieties. The most popular clone/seed source which is widely cultivated is included in the trial as benchmark. The trees in yield trials are generally retained up to the normal rotation period and sample plots are harvested to determine the additional wood production realized compared to the benchmark accession. The economic value of the additional wood produced is used for calculating the net profit obtained by using the new clone and to justify the cost of clonal plants and the investments made in the breeding programme. Further the on-site yield trials serve as demonstration plots for creating awareness on the need for using the most suitable clones and provide a platform for farmer-farmer interactions and experience sharing.

CLONAL RELEASE PROCESS FOR FORESTRY SPECIES

New varieties of agricultural and horticultural crops are released for large scale cultivation through a well-defined process of evaluation and approval under the ICAR-State Agricultural Universities System. In forestry release of designated varieties was not common due to absence of such mechanism for testing and approval. The Indian Council of Forestry Research and Education (ICFRE) developed guidelines for testing and release of varieties and clones of forestry tree species during 2008 and was duly approved by the Ministry of Environment and Forests, Government of India. The guidelines may be referred at ICFRE's website www.icfre.org.

The testing and release process is carried out by the following three committees:

(i) Implementation Team – Field evaluation of clonal/varietal test plots and submitting a report on the short listed accessions to the Variety Testing Committee.

(ii) Variety Testing Committees (Regional and All-India) – Scrutinizes the report of Implementation Team and recommends the most outstanding variety/clone for release to the Variety Releasing Committee.

(iii) Variety Releasing Committee – Scrutinizes the recommendations of the Testing Committees and makes final approval for release of the varieties.

The first two Committees work within each of the regional Institutes of ICFRE spread across the country serving for their jurisdictional States. The Variety Releasing Committee (VRC) is headed by the Director General of Forests and Special Secretary, Ministry of Environment, Forests and Climate Change, Government of India and has representation from ICFRE, State Forest Department, Universities and NGOs. The details of new clones approved for release by the VRC since 2010 are provided in Table 3.

Table 3. *Details of clones of different tree species released through ICFRE's Variety Releasing Committee during 2010-17.*

S. No.	Species	No. of Clones Released	Name of Clones	Year of Release	Characteristic Features
1	*Casuarina equisetifolia*	4	IFGTB-CE1, IFGTB-CE2 IFGTB-CE3 & IFGTB-CE4	2010	Fast growth and straight stems
2	*Eucalyptus camaldulensis*	4	IFGTB-EC1, IFGTB-EC2, IFGTB-EC3 & IFGTB-EC4	2010	Fast growth
3	*Dalbergia sissoo*	1	FRI-DS-014	2011	Fast growth and tolerance to *Fusarium solani* causing dieback
4	*Eucalyptus* hybrid *(Eucalyptus camaldulensis x E. tereticornis)*	1	FRI-EH-001	2011	Fast growth
5	*Casuarina equisetifolia*	3	IFGTB-CE5, IFGTB-CE6 & IFGTB-CE7	2014	Adaptability to sodic soils
6	*Casuarina junghuhniana*	2	IFGTB-CJ9 & IFGTB-CJ10	2014	Fast growth, straight stem, drought tolerance
7	*Casuarina junghuhniana*	5	IFGTB-WBC-1 to IFGTB-WBC-2, IFGTB- WBC-3, IFGTB- WBC-4 & IFGTB- WBC-5	2014	Suitability to windbreak agroforestry
8	*Eucalyptus camaldulensis*	7	IFGTB-EC5, IFGTB-EC6, IFGTB-EC7, IFGTB-EC8, IFGTB-EC9, IFGTB-EC10 & IFGTB-EC11	2014	Fast growth, tolerance to gall infestation
9	Casuarina hybrid *(C. equisetifolia x C. junghuhniana)*	5	IFGTB-CH1, IFGTB-CH2, IFGTB-CH3, IFGTB-CH4 & IFGTB-CH5	2017	Fast growth, straight stem, drought tolerance
10	*Melia dubia* Cav. (Syn. *Melia composita* Benth.)	10	Bahumukhi, Kshitiz, Megha, Versha, Sharad, Kartik, Dev, Ritu, Amar, Shashi	2017	Fast growth
11	*Eucalyptus tereticornis*	3	SAHAJ, RIJU & CHAURAS	2017	Fast growth
12	*Rauvolfia serpentina,* a perennial shrub	2	TFRI-RS-1 & TFRI-RS-2	2017	Higher root yield and reserpine content

REGISTRATION OF NEW VARIETIES

Protection of the intellectual property for the new clones is taken care of by the Protection of Plant Varieties and Farmers Rights Authority (PPVFRA) under the Protection of Plant Varieties and Farmers Rights Act, 2001. Currently the registration process is open for more than 150 crops including forestry species (e.g. *Casuarina* and *Eucalyptus*). Registration of a tree variety with the Authority confers the breeder or the organization that developed the variety the legal ownership of it for a period of 18 years. Any commercial propagation and supply of such registered varieties can only be carried out with the consent of the legal owner of the variety. The process of registration intends to protect the rights of both the breeder and the farmer and also ensures the authentic transfer of new varieties for large scale cultivation.

Registration of a plant variety is undertaken through a procedure called DUS (Distinctiveness, Uniformity and Stability) Testing. Distinctiveness refers to the presence of one or more unique morphological character(s) in the new variety not present in all existing and known varieties. Uniformity is occurrence of such character(s) in all individuals of the variety and Stability means that the character(s) do not change across seasons and locations. Any variety that passes through the DUS testing is registered by plant registry of the Authority and a registration certificate is provided to the applicant/breeder. At present the registration process is underway for six varieties of Casuarina and one variety of Eucalyptus. Development of DUS testing procedure is being undertaken for other important forestry crops like Ailanthus, Bamboo, Deodar, Melia, Poplar, Red Sanders, Sandal and Teak. Further information may be obtained from the website of PPVFRA (www.plantvariety.gov.in).

COMMERCIALIZATION OF NEW CLONES

Research Institutions and Universities which are involved in varietal development do not possess the necessary infrastructure and human resources to make available the planting material of new varieties to a large number of tree growers spread across the country. It is essential that partnerships are established with industries, nursery operators and other frontline organizations for reaching a large number of stakeholders for cultivating the newly developed variety.

Non-Exclusive Licensing of Clones

The newly developed clones of *Casuarina* and *Eucalyptus* have been transferred to paper industries and private nursery operators in different parts of the country for mass multiplication and commercial supply to farmers. A non-exclusive license is granted to each organization against the payment of a one-time license fee. Details of plants supplied by ICFRE and its licensees and the area of plantations established with these plants are given in Table 4.

Table 4. *Extent of mass multiplication of Casuarina and Eucalyptus clones and the extent of plantations raised.*

Year	Clonal Plants Produced and Supplied (in lakhs)				Area Planted (Ha)
	Paper Industries	Private Nurseries	ICFRE	Total	
2014	30.0	10.0	0.32	40.3	1677
2015	75.0	20.5	0.82	96.3	4127
2016	110.5	19.0	1.35	130.9	5704
2017	100.5	36.5	2.41	139.4	5989
2018	181.0	100.0	2.69	283.7	10965
Total	497.0	186.0	7.60	690.6	26,462

- Popularizing the Clones among the Farmers

  On-farm demonstration cum yield trials are established in the lands of farmers and forest development corporations to create awareness on the gains that can be realized through planting the new clones. The superior growth, stem

form and drought tolerance characters have made the clones popular among the farmers and professionals of industries and forest development corporations. Harvesting of plantations raised with the new clones has revealed that a minimum of 20 tonnes of pulpwood can be additionally produced in a rotation period of 4 years for Casuarina and 6 years of Eucalyptus. At the prevailing rate of Rs.4,000/- per tonne of pulpwood, the farmers are likely to get around Rs.80,000/- additional income when they harvest the plantations. Such outstanding performance of the new varieties and potential to increase farm income have convinced the paper industries and private nurseries to obtain non-exclusive licenses for large scale multiplication of new clones and supplying to farmers in different parts of the country. Currently around 20 nurseries belonging to paper industries/private nursery operators are propagating these clones in the States of Andhra Pradesh, Karnataka and Tamil Nadu. The cultivation of these varieties in more than 26,000 ha since 2014 in varied agro-climatic conditions has firmly made their presence felt among all stakeholders of plantation industry and have become benchmarks for any future introduction high-yielding varieties.

SOCIETAL BENEFITS FROM PLANTING OF NEW CLONES

Enhancement of Productivity

India is among the countries having the largest area under plantations in the world. Even a small increase in the productivity of these plantations will result in substantial benefits to the farmers as increased farm income and to the industry through securing wood raw material availability. Farmers through adopting intensive cultural practices have brought down the rotation period from 4 years to 2.5-3 years in Casuarina and from 6 years to 4-5 years in Eucalyptus. The new varieties have also helped in expanding the area of cultivation in areas considered not suitable so far due to their desirable properties like drought and pest tolerance and adaptability to grow in high PH sites like sodic sites.

Additional Economic Returns

During the last five years around 6.9 crores of plants supplied to farmers to raise 26,462 ha of plantations of Eucalyptus and Casuarina. The estimated extent of Casuarina plantations harvested till 2018 was 3730 ha and the average yield in these plantations was 140 tonnes per ha in 4 year rotation under irrigated conditions. The additional wood produced against the benchmark clone was 20 tonnes per ha (around 15%). Farmers earned an additional income of Rs.29.78 crores (at the rate of Rs.4000/- per tonne of pulpwood) through the increased wood production by the clones. Similarly during the last five years 3750 ha of Eucalyptus plantations are estimated to have been harvested yielding an additional farm income of around Rs. 30 crores to farmers due to increased wood production.

Environmental Benefits

Apart from the above mentioned direct benefits, the new varieties also provide several environmental services like reclamation of salt-affected and waterlogged areas, protecting agricultural crops and human habitations through windbreaks and shelterbelts. They are also useful to improve the productivity of niche crops like Sandal through synergistic effect. Casuarina, being a nitrogen-fixing tree, also improves the overall soil fertility through biological nitrogen fixation and decomposition and recycling of litter fall.

USER MANUAL

This Manual presents detailed information on the available new varieties and cultivation methods for 13 widely planted tree species. All those involved in developing plantations of any of these species will readily get information on where to source the superior planting material and the modern cultivation techniques. In particular field managers of State forest departments and forest development corporations, wood-based industries, tree farmers and researchers involved in tree improvement programmes will find this Manual useful in their plantation development and research activities.Those species for which specific industrial need exists, the details of industries are also given. Contact details for procuring

planting material (seeds, seedlings and clones), specialists for different species who can provide the latest information on a particular species are provided at the end of each chapter.

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EXTENSIVELY PLANTED SPECIES

2.1 NEW VARIETIES AND CULTIVATION METHODS FOR CASUARINA TO ENHANCE PRODUCTIVITY

INTRODUCTION

Casuarina is an important multipurpose species grown extensively throughout the tropics providing many products of economic importance and environmental services. Casuarina cultivation in India has high socio-economic value as it is closely connected with livelihood opportunities of smallholding farmers and landless agricultural labour. *Casuarina equisetifolia* which was first introduced in India in Karwar, Karnataka during 1868 itself was to fulfil increasing need for fuel wood, preventing sand movement in the coast and to enhance aesthetics through beach and avenue planting. Since then this versatile tree has had a remarkable journey of nearly 150 years evolving into a dependable crop for wood production, environmental services and livelihood improvement.

EXTENT OF PLANTATIONS

India is the largest casuarina-growing country in the world with an estimated half a million hectares of plantations mainly concentrated in the States of Andhra Pradesh, Odisha, Tamil Nadu, Telangana and Union Territory of Puducherry in the east coast. It is also cultivated to a lesser extent in the States of Karnataka, Maharashtra, Gujarat and West Bengal. It is one of the five most extensively planted tree crops in the country and is harvested in short rotations of two to five years.

MAJOR USES AND SERVICES

The principal uses of the wood include pulpwood, poles and fuelwood. It is also preferred for environmental services like shelterbelts, wind breaks and reclamation of mined areas. Casuarina is a nitrogen-fixing tree through symbiotic relationship with the actinomycete bacteria called Frankia. This ability helps the tree to establish well even in nutrient-deficient sites and also to maintain nutrient balance in high density plantations. The market demand for casuarina wood has steadily increased over years mainly due to expansion of production capacity of paper industries.

CULTIVATION PRACTICES

Traditionally casuarina is considered to be a tree of coastal areas. It was originally introduced in the coastal region and its cultivations area expanded in the coastal areas as wood-producing plantations as well as shelterbelts between the sea and human habitations for protection from cyclones and to prevent formation and movement of sand dunes. Over a period of time and with increasing demand for pulpwood for papermaking, people started cultivating casuarina in areas away from the coast (inland) as well. It is common to find casuarina plantations and agricultural crops like paddy are grown alongside each other in South India (Fig. 1). Apart from the traditional sandy soils it is cultivated in all types of soils including clayey soils with short duration of water-logging. Only in soils extremely saline or alkaline, it fails to establish altogether or put up poor growth. Generally casuarina needs irrigation support at least during the first year for good survival and growth.

Fig 1. *Casuarina growing along with paddy in coastal Tamil Nadu*

Casuarina farmers normally adopt a narrow spacing of 1x1 m with a stocking of around 10,000 trees per ha. Such a high density planting is preferred mainly due to the highly variable growth among the trees originating from unimproved sources. Bare-rooted seedlings produced in local nurseries are planted in the well-ploughed fields during the rainy season. Under irrigated conditions, an intercrop is grown during the first three to four months after planting when there is sufficient light penetration in the plantation due to small size of the trees. Intercropping also helps in managing weeds. Pruning of side branches is carried out twice at one and two-years after planting. Fertilizers are also applied during this period. The usual rotation period is 4 to 5 years under irrigation and 6-7 years if grown as a rainfed crop.

CURRENT PRODUCTIVITY

The average yield from a 4-year old plantation raised with unimproved bare-root seedlings is 100 tonnes of pulpwood per hectare (25 tonnes per ha per year). This yield is obtained from the original stocking of about 10,000 trees planted at a spacing of 1 m. The average yield per tree is only 10 kg which is far below the potential of the land and the species. The main reason for this low yield is the tree-to-tree variation found in such high-density plantations. More than a 10-fold difference in wood production is observed between the smallest and the largest tree. Further the proportion of small trees is far greater than that of big-sized trees which produce a major portion of merchantable wood. Till recently clonal plantations of casuarina has been practiced in a limited area by planting only one clone commonly referred as 'Marakkanam clone' or CJ-1. This clone yielded around 125 tonnes of pulpwood per ha in a rotation period of four years under irrigated conditions (31 tonnes per ha per year).

NEW VARIETIES RELEASED

There are two species of *Casuarina* available for cultivation in India. *Casuarina equisetifolia* is under cultivation for over a century and is generally regarded as a coastal species. Plantations are mainly raised through seedlings grown from seeds. Genetically improved seed varieties produced from specially maintained seed orchards are supplied by the Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore.

The other species of *Casuarina* currently under cultivation is *C. junghuhniana* introduced by IFGTB about 20 years ago from Indonesia. It is generally faster growing and more drought and disease tolerant than *C. equisetifolia.* This species is also more wind-resistant than *C. equisetifolia* (Fig. 2). The bark of *C. junghuhniana* is thicker and rougher than that of *C. equisetifolia* providing protection from moisture stress. IFGTB has been implementing systematic breeding programmes for the two *Casuarina* species and established multilocation clonal tests as part of these programmes (Fig. 3). Clones were assessed periodically for fast growth, stem straightness, incidence of pest and disease attack, wind-hardiness, drought tolerance and ability to grow in sodic soils and the best performance across different test locations were shortlisted for public release. IFGTB has so far released 19 high-yielding clones of Casuarina with different superior characters. The following six clones which showed the highest potential for commercialization are registered with the Protection of Plant Varieties and Farmers' Rights Authority (PPVFRA), Government of India to secure the intellectual property right under the provisions of Protection of Plant Varieties and Farmers' Rights Act, 2001.

Fig 2. *Better wind-resistance of Casuarina junghuhniana (left) compared to C. equisetifolia (right) after affected by cyclone.*

Casuarina junghuhniana Clone

- IFGTB-CJ-9 (PPVFRA No. REG/2015/1658)

Casuarina Hybrid Clones

- IFGTB-CH-1 (PPVFRA No. REG/2017/1564)
- IFGTB-CH-2 (PPVFRA No. REG/2017/1565)
- IFGTB-CH-3 (PPVFRA No. REG/2017/1566)
- IFGTB-CH-4 (PPVFRA No. REG/2017/1567)
- IFGTB-CH-5 (PPVFRA No. REG/2017/1568)

The new clones on an average yield 20 tonnes more pulp wood per hectare than the currently cultivated clone (CJ-1) in a rotation period of four years (5 tonnes per ha per year). At the prevailing price of pulpwood (Rs. 4000 per metric tonne), a farmer gets an additional income of around Rs. 80,000/- per hectare in a rotation period 4 years (Rs. 20,000/- per ha per year). These clones also increase the availability of pulpwood raw material to paper industries with 1 to 2 percent more pulp yield than the benchmark clone.

These clones are popularized among farmers through establishing on-farm demonstration plots in locations where casuarina is a major crop (Fig. 4 & 5). Farmer visits are arranged to these plots through various training and awareness programmes to facilitate farmer-farmer interaction on the cultivation of new high-yielding clones. In order to make these clones easily accessible to farmers in different parts of the country, licenses have been issued to paper industries and private nurseries for commercial propagation and supply. The details of such licensees are provided at the end of this chapter.

Fig 3. *Fast growth and straight stems by IFGTB clone CJ-9 (left) compared to the check clone CJ-1 (right) in a clonal test plot.*

Fig 4. *A highly productive plantation of clone CJ-9 in a farmer's land under partial irrigation (age: 3 years)*

Fig 5. *Superior growth and stem straightness in Casuarina hybrid clone IFGTB-CH-1 (right) compared benchmark clone IFGTB-CJ-9 (left) (age: 1.5 years).*

Apart from fast growth, five clones of *C. junghuhniana* were also released by IFGTB for planting as a windbreak around agricultural crops. A windbreak is a narrow row of trees planted in fields bordering a farm plot. Windbreaks on field boundaries effectively control injuries to the tender crops from sand blasting and hot air. It reduces the velocity of the wind by 20-46% and soil erosion by 76%. Downburst is a recurrent annual phenomenon in certain areas to annual crops, especially the banana plantations and farmers incur heavy loss worth crores of Rupees. To address this problem, windbreak agroforestry system was introduced with improved clonal varieties having ideal ideotype suitable to reduce wind speed and at the same time remain productive and amenable to annual crops.

Five superior clones of *Casuarina junghuhniana* viz., IFGTB-CJ-WB-1, IFGTB-CJ-WB-2, IFGTB-CJ-WB-3, IFGTB-CJ-WB-4 and IFGTB-CJ-WB-5 were released for cultivation under windbreak agroforestry system. On an average, 20 MT of wood from four year old Windbreaks can be harvested from one ha area. Presently, the level of acceptance for this system has increased with introduction of the new clones. During 2018-19, around 44,000 plants of these clones have been planted as windbreaks (Fig. 6). They yield about 40% increase in wood production compared to the currently 'Marakkanam clone' (CJ-1). Farmers get an additional income of Rs. 16,250 per ha per year when compared to the benchmark clone. In addition, the released clones possess ideal ideotypic traits that suit as windbreak. These clones show high level of branch persistence with 40 to 46 thick and horizontal branches from the bottom of the tree.

Fig 6. *Casuarina clones planted under windbreak agroforestry system with banana.*

IMPROVED CULTIVATION PRACTICES

The major change that happened in the method of Casuarina cultivation in recent years is reduction in the number of trees grown per unit area. Traditionally about 4000 trees are planted in an acre (roughly 10000 stems per hectare). Such a high density cropping was adopted mainly due to the large tree-to-tree variation in growth and the practice of selling the standing crop as a whole to traders. With the development of clones possessing uniform growth and opportunities to sell the wood on the basis of weight has removed the need to grow a large number of trees. The widely practiced spacing in clonal plantations is 1.5 m (roughly 5 feet) between trees which works out to be approximately 2.25 m^2 per tree. At this spacing about 1750 trees can be planted in an acre and around 4500 trees per ha. If the plantations are intended to be harvested at the age of 3 years or less, the spacing can be 4 x 4 feet. With 10% additional plants for casualty replacement, nearly 2000 plants are needed per acre of plantation. Some farmers use a slightly modified spacing of 2 x 1.25 or 2 x 1.5 m spacing to facilitate mechanized weeding and ploughing between rows (Fig. 7). The wide spacing between rows also facilitates cultivating an intercrop during the first six months (Fig. 8).

Fig 7. *Casuarina planted at a wide specing of 3 x 1.5 m to facilitate ploughing and cultivation of agri crops between rows.*

Farmers tend to apply more fertilizer than what is necessary with the hope that high dose of fertilizer

Fig 8. *Inter-cropping of moongdal with Casuarina*

will increase wood production. But adding chemical fertilizers beyond the level that can be absorbed by the trees remain in the soil and affect soil fertility in the long term. Casuarina trees receive their nitrogen requirement through the help of nitrogen-fixing bacteria called Frankia living in the root nodules. Hence they do not need a large amount of nitrogen fertilizer. Adding phosphorous fertilizer (10 g per plant) and organic fertilizers like farm yard manure or vermicompost as a basal dose helps the nitrogen-fixing bacteria to synthesize more nitrogen for the tree.

Casuarina trees respond well to fertilizer application especially when cultivated under irrigated conditions. Timely application of specific nutrients as fertilizers has been found to significantly increase wood production. Casuarina is cultivated in a range of soil types in various agro-climatic conditions. Specific recommendation of fertilizer application can only be made based on the results obtained from a soil test. However an attempt is made here to provide a generalized recommendation to suit the areas where casuarina is widely cultivated. Modifications may have to be made to this general recommendation if soil test results are available for the given planting area. Two options of fertilizer application is given in Tables 1 and 2. The first option recommends a water-soluble fertilizer, Mono Ammonium Phosphate (MAP) which can be applied in liquid form directly to individual trees so than its uptake in enhanced and prevents excess fertilizer remaining in the soil. The recommended schedule of fertilizer application is given in Table 1. In places where MAP is not available the commonly available fertilizers of nitrogen, phosphorous and potash may be applied in granular form as per the schedule provided in Table 2.

Table 1. *Schedule for application of water-soluble fertilizer for Casuarina*

Fertilizer and Method of Application	Age of Trees (months)	Quantity of Fertilizer * (kg per acre)
Water-soluble mono-ammonium	1	5
phosphate (MAP)	6	8
*The prescribed quantity of fertilizer	12	10
should be dissolved in 200 litres of	18	12
water and applied 100 ml to each plant	24	18

Table 2. *Schedule for application of granular fertilizer for Casuarina*

Fertilizer	Fertilizer Amount (kg per acre) at Different Ages (Months)						Total
	Basal Dose	3	6	12	18	24	
Urea	0	5	7	9	11	13	45
Super phosphate	18	9	9	9	9	9	63
Muriate of potash	0	6	6	10	10	10	42
Total	18	20	22	28	30	32	150
Per plant (g)*	10	11.5	12.5	16	17	18	

**@1750 plants per acre (spacing: 5 x 5 feet). Mix well with 1 kg neem cake and 50 ml neem oil and apply*

The liquid fertilizer may be applied in a small hole made near the plant after watering the plants. Any fertigation beyond second year may not be effective because there will be severe competition for light and space among the trees. It is recommended to apply only the optimum amount of fertilizer to reduce the expenditure and also to prevent accumulation of chemicals in the soil.

Fig 9. *Mechanical weeding in a young Casuarina plantation using a power tiller*

Manual weeding at least four times during the first year is necessary for the uniform establishment of plants. Intercropping during the first six months also help in weed management. Where labour is scarce for manual weedings, farmers adopt wider spacing between rows and take up mechanical weeding through power tillers or mini tractors (Fig. 9). Weed control through application of chemical weedicides should be avoided for long term maintenance of soil fertility. Weeding is usually not necessary beyond the first year during which time the canopy of trees closes-in and suppresses weed growth.

Pruning of side branches up to one-third height of the tree is needed at the age of 6, 12 and 18 months. Pruning improves the growth and straightness of the main stem. It will also promote penetration of air and light inside the plantation helping in improving the overall hygiene and health of the plantation.

MARKETING AND PRICING OF WOOD

The major consumers of Casuarina wood are paper industries and pole market. Paper industries buy wood directly from the farmers as well as through contractors. Traders also buy wood from farmers, categorize according to purpose and sell to end users. It is recommended that tree growers conduct a market survey before deciding on selling their product. Information on current prices can be obtained through directly contacting field officers of paper industries located close by. The portal maintained by the Tamil Nadu Agriculture University also periodically posts the current prices of different tree crops. The average price of debarked casuarina wood during March 2019 is Rs. 5000/- per tonne which includes harvest and transport costs.

Fig 10. *Casuarina stem affected by the insect, bark-eating caterpillar*

PEST PROBLEMS AND CONTROL MEASURES

The common insect problem in Casuarina is attack by the bark-eating caterpillar, *Indarbela quadrinotata*. The larvae dig up deep tunnels in the main stem especially at the points from where the branches arise (Fig. 10). They remain inside the tunnel during day time and emerge out in the night to feed on the bark. Although trees generally survive the attack, the afflicted trees are prone to breaking at the point of infestation during heavy wind. Insect attack also reduces the pole value of the tree.

The stem borer attack generally occurs during the summer months and can be controlled by spraying of Monocrotophos (1.25 ml/litre) at 0.5% over the feeding area or by injecting 0.5% (1 ml/litre) Dichlorvose into the

Fig 11. *Casuarina stem affected by the blister bark disease showing black spores*

bore holes and sealing with mud. It is recommended that pesticide-based control of the insect is undertaken only when more than 20% of trees in the plantation show insect attack. Biological control by application of *Beauvaria bassiana* will be an eco-friendly option. Commercial formulations (e.g., Biocure) are available in the market. Strains specific to the borer of casuarina are available with the IFGTB and these can be mass produced and supplied on demand, if required.

The major disease problem in *Casuarina equisetifolia* is the blister bark disease caused by the fungus *Trichosporium vesiculosum*. So far *Casuarina junghuhniana* trees have not been affected by this disease. Once the disease occurs it is very difficult to save the tree through control measures. Clonal plantations are highly vulnerable to the disease since they have low genetic diversity which leads to large scale mortality. Affected trees show symptoms of yellowing and drying of leaves followed by development of 'blisters' on main stem. At advanced stages these blisters burst open releasing black spores (Fig. 11). The disease is more prevalent in dry areas and usually occurs in plantations older than 4 years. Pruning can increase the chance of incidence by exposing the cut surface to infection. After each pruning, the cut ends have to be treated with Bordeaux paste, to avoid fungal infection. If the disease is noticed in adjacent plantations, drenching of the root zone and spraying with Dithane M-45 or Bavistin (0.1%) is recommended as a preventive measure. If any infection is noticed, the infected tree may be removed and burnt outside the plantation.

In clayey soils, trees may die due to of root/collar rot caused by fungal pathogen during the first year after planting. The affected trees show yellowing of leaves followed by drying up of the entire tree (Fig. 12). The affected tree and also the trees surrounding it may be treated with 250 ml of PhytolonTM (Copper Oxy Chloride 1.5 g per litre). The fungicide may be drenched at the collar zone so as to completely wet the collar and the root zone below. This disease can also be cured through biocontrol method of application of Trichoderma culture. The affected plants are applied around 20 ml of culture by pouring the solution at the root zone. The culture can also be applied as a preventive measure to those plants surrounding the affected plants at 10 ml per plant.

Fig 12. *Young tee of Casuarina showing drying due to collar rot disease*

CURRENT RESEARCH FOCUS

The area under cultivation of high-yielding clones of casuarina has to be expanded to benefit a large number of farmers. They have to be tested and/or demonstrated in new areas having potential for casuarina cultivation. To address this need, the All-India Coordinated Research Project on casuarina is aimed at introducing the new clones in the States of Haryana, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Odisha and Telangana apart from Andhra Pradesh and Tamil Nadu where they are extensively cultivated. Six ICFRE institutes will collaborate in this project to identify end-use and site-specific clones and seed material of Casuarina.

CONTACT DETAILS

Licensing of High-Yielding Clones for Commercial Propagation and Supply:

Director
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Technical Advice

- Dr. A. Nicodemus, Scientist F, Institute of Forest Genetics and Tree Breeding, PB 1061, R.S. Puram, Coimbatore 641 002, Tamil Nadu; Phone: +91-422-2484194; Email: nico@icfre.org.
- Dr. C. Buvaneswaran, Scientist F, Institute of Forest Genetics and Tree Breeding, PB 1061, R.S. Puram, Coimbatore 641 002, Tamil Nadu; Phone: +91-422-2484198; Email: buvanesc@icfre.org.
- Shri A. Mayavel, Scientist C, Institute of Forest Genetics and Tree Breeding, PB 1061, R.S. Puram, Coimbatore 641 002, Tamil Nadu; Phone: +91-422-2484162; Email: mayavela@icfre.org.

Supply of Seeds

- Dr. R. Anandalakshmi, Scientist F, Institute of Forest Genetics and Tree Breeding, PB 1061, R.S. Puram, Coimbatore 641 002, Tamil Nadu; Phone: +91-422-2484166; 2484172; Email: anandalakshmir@icfre.org.

Supply of Clonal Planting Material

- Smt. K. Shanthi, Chief Technical Officer, Institute of Forest Genetics and Tree Breeding, PB 1061, R.S. Puram, Coimbatore 641 002, Tamil Nadu; Phone: +91-9488450674; Email: shanthik@icfre.org.

Licensed nurseries for supplying clones released by IFGTB

S. No.	Name and Address of the Licensee	Contact Number
1	International Papers – APPM Limited Rajahmundry – 533105, East Godavari Dist. Andhra Pradesh	8498094339
2	Tamil Nadu Newsprint and Papers Limited Kagithapuram 639 136, Karur District, Tamil Nadu	9442591419
3	T. Umamaheshwar Rao 254/A MLA Colony, Road No. 12, Banjara Hills, Hyderabad 500 034 Nursery location: Kollegal, Karnataka	9704847636
4	Dr. S. Makesh Near Sandhaipettai Muneeswar Temple, Mithravayal village, Karaikudi Taluk, Sivaganga District, Tamil Nadu, PIN 630 108	9943901055
5	P. Sakthivel Santhi Clonal Nursery, Kullanchavadi Main Road Vegakollai Post, Panruti Taluk, Cuddalore District, Tamil Nadu	9159705868
6	S. Senthilkumar Sangeetha Hitech Nursery, 62/7 Poothurai Road, Chinna Pattanur village, T.C. Kootroad, Vanur Taluk, Villupuram District Tamil Nadu, PIN 605 111	9843500990
7	Seshsayee Paper and Boards Limited, Pallipalayam, Namakkal District, Erode 638 007, Tamil Nadu	9443214628

2.2 NEW VARIETIES AND CULTIVATION METHODS FOR EUCALYPTUS TO ENHANCE PRODUCTIVITY

INTRODUCTION

Eucalyptus belongs to the family Myrtaceae. The species can withstand extreme temperatures and rainfall. It is a best-suited tree species for the areas which receive rainfall from 250 to 600 mm but at the same time it can also grow well in high rainfall areas which receive as high as 1250 mm and some as little as 150 mm. The altitudinal range is 30- 600 m. This species occurs on a variety of soil types from red or black soils to sandy alluvial soils. It can also grow well in salt affected areas, except calcareous soils.

EXTENT OF PLANTATIONS

It is a tree species planted worldwide. It is a common plant for dry as well as wet areas. India is one of the largest planters of Eucalyptus in the world with around 4 million hectares of planted area (Iglesias *et al.*, 2009). Annually about 1.5 lakh hectare is planted mainly with clonally propagated plants. This species grows under a wide range of climatic conditions from warm to hot, sub-humid to semi-arid. The climatic adaptability and superior growth rate makes Eucalyptus a major species among the pulpwood species grown in India.

MAJOR USES AND SERVICES

Wood is used mainly for poles, posts, fire wood, charcoal and paper pulp. It is also used for hardboard and particle board. Logs may be sawn for construction timber, furniture and packing cases, although quality is sometimes poor. It is widely planted for shade, shelter and amenity purposes and as a source of nectar for honey production. Unfavorable characteristics of the wood such as shrinkage on drying, collapse, spiral grain and starch in the sapwood due to growth stress in the plantation (Jacob, 1981) can be ameliorated by post-harvest procedures (Qadri, 1983). Correctly handled, the wood is useful for specialty furniture, construction timber, pulpwood, round wood and fuel wood (Poynton, 1979). Preservation treatment is necessary for durability in the ground (White, 1988).

Eucalyptus leaves are source of traditional herbal medicines. The essential oil found in the leaves is a powerful antiseptic and is used all over the world for relieving coughs and colds, sore throats and other infections (Chevallier, 1996). The oil can be used externally, applied to cuts, skin infections etc. It can also be inhaled for treating blocked nasal passages; it can be gargled for sore throat and can also be taken internally for a wide range of complaints (Grieve, 1984).

SEED AND NURSERY TECHNIQUES

Generally flowering is initiated along with rainy season. Flowering intensity is variable and unpredictable from year to year. Maturation time is about 3- 4 months. *E. camaldulensis* takes three years from planting for the production of the first seed crop. Eucalyptus species have a mixed-mating breeding system with preferential out crossing. Although they are commonly self-compatible, self-pollination generally results in a reduction in capsule production, seed yield and seedling vigour.

Maturing fruit will turn from green to brownish-red with prominent ridges on the top when the fruits ripe. It produces heavy seed crop every 2-3 years (Walsh and Entwisle, 1996). Generally after maturation capsules do not open immediately. Capsule opening is a slow process which takes 2-3 months period when present in the tree. However, once they are collected from the tree, seeds dehisce on shade drying in 2-3 days. Seed can be distinguished from chaff as the seeds are bigger and yellow-brown in colour while chaff will be small and elongated. Seeds weigh approximately 700 seeds per

gram. They can be stored for more than 10 years if they are placed in hermetic containers at a temperature of 3 to 5 °C and a moisture content of 5.5 to 10 percent. Seeds stored at 25 °C had a germination rate of 91% after 5 years, and 87% after 10 years (Gunn, 2001). Germination is epigeal. Normally, the seeds show high germination percentage (more than 90 %) without any pretreatment. Rapid and complete germination is achieved under moist, warm (32 °C) conditions in the presence of light. Seeds are eaten by ants hence need to be protected.

For all Eucalyptus, the texture of the medium of germination must be fine. A fertile mixture of soil with sand in a proportion of 1:1 may be used. Seed should be sown under shade on a free-draining and sterilized medium and covered very sparingly with inert material (e.g. sand). Seeds must be sown deep enough to prevent uncovering when watered, but they must not be too embedded. The germination period for this method ranges from 4 to 5 days. Smoke treatment has been found to improve germination (Ralph, 2003). The seedlings are lifted from the mother bed when they are 5 to 7 cm in height and transplanted in poly bags or root trainers. Alternatively, seeds can also be planted directly into bags when the germination is good.

Shade cover is needed after transplanting for about six weeks. Growth is fast under tropical conditions and plants could reach plantable size (30 cm tall) in four to five months. Seedlings require periodic watering in the first stages of development. Common mistakes in propagation are over-watering and associated disease problems, over-shading and allowing the germinants to become too large for easy transplanting leading to malformed tap roots or root curling in the pots. To prevent damping off, cupric fungicides should be applied. About 1-2 lakhs seedlings can be obtained from one kg of seed in nurseries.

CULTIVATION PRACTICES

Selection of the correct planting material for a particular planting site is of paramount importance. There is variation in growth of clones across locations. A few clones are suitable for deep soil and few others are suitable for saline and gravelly soils. Hence choice of clone for a particular locality is the first and foremost issue for the success of a planting programme. Weeding and burning of underbrush are recommended before planting. The ability of the species to compete with weeds is poor. In high rainfall areas, frequent weeding (2-3 times) is required until closure of canopy (2-3 years). Inadequate weed control may lead to complete failure of the planting.

Spacing and cropping systems are very variable, pulpwood plantations are made with a spacing of 3x2 m (1667 stems per ha). Wider spacing of 4x2 m (1250 stems per ha) or 4x4 m (625 stems per ha) are recommended for plywood. For energy plantations, a spacing of 2x2m is recommended. In India, Eucalyptus is managed through clear-felling system followed by coppice rotation for two times. After three rotations, the below ground biomass is taken out and replanted with seedlings.

Coppice-with-standards is recommended to supply a range of wood products. A thinning of 700 stems per ha at half rotation age provided posts, poles and fuel wood, leaving the better trees to grow-on to 10 years for products like plywood and sawn timber. Rotation lengths vary depending on the end use. For pulpwood depending on the soil fertility and availability of water, the rotation can fixed from 5 to 6 years for small-sized pulpwood. Under wide spacing, trees are also grown for timber for various endues at a rotation of 8-10 years.

Application of 100g of NP or NPK (3:2:1) fertilizer to each tree at the time of planting to assist establishment of growth is common. Crown die-back during dry-season as a result of boron deficiency is prevalent and must be corrected. A dosage of 10-20 g of borax per tree depending on soil type is applied.

E. camaldulensis is usually grown on a short rotation and clear felled at an age that maximizes production of logs of optimum size for a particular end use. This is usually small-diameter material suitable for pulpwood, mining timber or fuel wood. The species coppices well for three times. The season of felling affects coppice regeneration. Felling during the dry season delays sprouting and increases the risk of the stump mortality. Felling by saw gives a cleanly-cut stump with

minimum bark damage. Reduction of the number of coppice shoots on stool is a very important and time consuming operation in coppice management.

AGROFORESTRY PRACTICES

E. camaldulensis in plantation has a relatively narrow crown and pendulous leaves which allow light to the forest floor. This permits weed growth initially up to two years but can be turned to advantage with intercrops. A wide range of crops like groundnut, chilly, onion, leguminous plants, etc can be grown. A spacing of 5 m x 2 m is recommended for intercropping for one year under normal planting spacing and three years under wide spacing of 5 m x 2 m. Paired row method of planting with 5m species between row and 1m between plants is also practiced. Wider spacing between rows facilities mechanical cultivation for weed control as well.

CURRENT PRODUCTIVITY

Very high productivity is possible under favorable conditions: growth of 70 m^3 ha^{-1} yr^1 of wood in a four-year-old plantation at 3 m x 2 m spacing on a fertile, well-watered site has been recorded (Zohar, 1989). Clonal forestry has emerged as a new revolutionary technology to substantially enhance the productivity of Eucalyptus from 20 m^3 ha^{-1} yr^{-1} to 25m^3 ha^{-1} yr^{-1}. In Tamil Nadu, about 15-20 t/ha at a rotation of 7 years was realized through seed raised plantations during early 1990's. Introduction of clones increased the yield up to 45 t/ha in six years rotation. Through site-clone matching, a yield of 100-150 t/ha is achieved depending on the fertility level of the soil.

NEW VARIETIES RELEASED

Introduction of Clonal Technology increased the cultivation area of Eucalyptus due to its superiority in uniformity and higher productivity. Although many clones have been introduced after careful hybridization and or selection, at present there are less than half a dozen clones only planted widely across the country. These clones are being multiplied by paper industries, private nurseries and Forest Corporations for the past three decades, used for their planting programmes and sold to farmers. None of the clones could thrive when there was an outbreak of *Leptocybe invasa* (Gall insect) during 2008 in southern states that moved to northern states during 2010.There is an urgent need to increase the clonal diversity in the country to have higher productivity in adverse environments, edaphic conditions and resistance to pest and disease.

Eucalyptus camaldulensis clones

As a part of the long-term breeding program, a large germplasm received from Australia was screened and about 80 clones were selected and tested in multilocation clonal trials and four *Eucalyptus camaldulensis* clones viz., IFGTB-EC-1, IFGTB-EC-2, IFGTB-EC-3 and IFGTB-EC-4 were released for cultivation in Tamil Nadu and Andhra Pradesh for higher productivity during 2010. The clonal plants were given to Forest Development Corporations of Tamil Nadu and Andhra Pradesh, paper mills in southern states and private nurseries for unrestricted multiplication and supply to farmers. Among these clones, IFGTB-EC-4 expressed consistent superiority in its growth. The productivity of bench mark clones were 20 m^3 ha^{-1} yr^{-1} and the same is 25 m^3 ha^{-1} yr^{-1} in ICFRE-EC-4 in an irrigated farmland in a six year rotation period. Considering the growth superiority and the rooting potential, IFGTB-EC-4 is multiplied in large scale by Tamil Nadu Newsprint and Papers Limited (TNPL), Seshasayee Paper and Boards

Fig 1. *IFGTB-EC-4 planted by TAFCORN at Pudukottai, Tamil Nadu (age: 4 years)*

Table 1. *Production of IFGTB-EC-4 by various planting agencies (in lakhs)*

Year	TN Newsprint and Papers	Seshasayee Paper & Boards	JK Papers	TAFCORN	Others	IFGTB	Total
2014	10.0	1.0		1.0	2.0		14.0
2015	15.0	2.0	4.0	1.0	2.0		24.0
2016	18.0	2.0	12.0	1.0	6.5	0.5	40.0
2017	21.0	2.0	15.0	2.0	6.5	0.2	46.7
2018	23.0	2.0	25.0	2.0	10.0		62.0
					Total		186.7

Limited (SPB), JK Paper Mills and Tamil Nadu Forest Plantation Corporation Limited (TAFCORN) and planted widely by farmers. At present, annually about 6 million clonal plants of IFGTB-EC-4 is multiplied, planted in an area of 3100 ha and each farmer is benefitted with Rs.50,000 per ha.

Hybrid Clone (*Eucalyptus camaldulensis x E. tereticornis*)

Hybrids between *Eucalyptus camaldulensis* and *E. tereticornis* were established in a field trial during 1972-73 at Dehradun. Few selected F_1 hybrid clones were observed to be three fold superior over their parental control and double to Mysore gum (Mysore hybrid) in mean standing volume. Subsequently these clones were tested for their superiority in multiple locations and FRI-EH-001 was released for commercial cultivation during 2011. The single tree volume was observed to be 0.1188 m^3 which was superior to other commercial clones being planted. Although, this clone has all the potential to be cultivated in the farmlands, the overall preference for Eucalyptus has come down in the target areas and hence the superiority of the clone need to be once again demonstrated in the form of demo plantations.

Insect Resistant Clones of *E. camaldulensis*

Considering the outbreak of *Leptocybe invasa* in 2008, further screening was carried out in 18 sites covering Tamil Nadu, Karnataka and Andhra Pradesh. Seven clones viz., IFGTB-EC-5, IFGTB-EC-6, IFGTB-EC-7, IFGTB-EC-8, IFGTB-EC-9, IFGTB-EC-10 and IFGTB-EC-11 were released during 2014 for higher productivity and resistance to gall infestation, which was studied in the hotspot areas of the outbreak during the period between 2008 and 2010. All the clones were multiplied and supplied to farmers. Demo plantations along with commonly planted clones of the AP Forest Development Corporation and TAFCORN have been established in their estates for comparison. The growth of IFGTB-EC-6 and IFGTB-EC-9 was comparable to that of the commercial clones viz., C226, C271, C274 and C3 planted by the corporation. IFGTB-EC-11 grows well in irrigated farmlands. IFGTB-EC-6 has provisional IP protection from PPV&FR Authority and is commercially licensed to TNPL for mass multiplication and sale to farmers.

Eucalyptus tereticornis Clones

It order to enhance the genetic base of *Eucalyptus tereticornis*, new germplasm from 13 native provenances, comprising 91 single tree collections from Australia was imported by FRI during 2002, from CSIRO, Australia. The provenance trials were conducted and 16 clones were selected and tested in three locations, one each in Haryana, Uttar Pradesh and Uttarakhand. Potentially there were three clones viz., Sahaj, Chauras and Riju superior in productivity when compared to other commercially cultivated bench mark clones viz., Clone SPM-7, ITC413, Clone SPM-9, Clone 316-P, Clone 2070, Clone SPM-2, Clone 316 and Clone 288. Sahaj, Chauras and Riju have been observed to have high productivity of 23.0, 20.6 and 14.7 $m^3\ ha^{-1}\ yr^{-1}$ which was 75%, 50% and 10% respectively more than commonly planted commercial clones. Hence, these three clones were released during 2017 for commercial cultivation in Northern states. Two of these selected clones were derived from Burdekin River, Queensland, Australia, and one is a unique collection from the FRI Estate. In this way, depleting diversity levels of Indian eucalypts could well be enriched to substantial level by infusing such newer clones.

Considering the superiority of these clones the germplasm is being shared with Punjab Forest Department, Haryana Forest Department and Star Paper Mills, Saharanpur and being considered for mass multiplication under non-exclusive licensing. Presently about 225 ha area is planted with these clones.

INSECT AND DISEASE PROBLEMS AND CONTROL MEASURES

In the nursery, Eucalyptus seedlings are susceptible to diverse fungi causing damping-off, collar rot and leaf diseases. Attention to nursery hygiene and care not to over-water are preferable to chemical controls. Insects (e.g. termites and aphids) and rodents may be troublesome, and both physical and chemical control measures may be needed. Termites affect planted seedlings and young trees and must be chemically controlled.

Eucalyptus is severely attacked by an invasive gall insect *(Leptocybe invasa)* which lead to formation of gall like structure in the midrib and petiole and young stem. The problem is severe in young seedlings and coppice shoots.

Leaf and root diseases are common where the species is planted off-site or where inappropriate provenances are used. Stem cankers and leaf diseases proliferate where rainfall and humidity are much higher than normally encountered in the natural habitat. For example, in humid regions it is defoliated by fungi including *Cylindrocladium* species during the wet season (Sharma and Mohanan, 1991).

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2.3 HIGH-YIELDING AND DISEASE RESISTANT SHISHAM TO INCREASE PRODUCTIVITY

INTRODUCTION

Dalbergia sissoo Roxb. (Fabaceae; Papilionoideae) is native to the sub-Himalayan tract from Afghanistan through Pakistan to India and Nepal either as pure or in mixture with species like *Acacia catechu* (Champion and Seth, 1968). It occurs in highly varying environmental and soil conditions within its large natural distribution range. It is a popular multipurpose species extensively cultivated in many tropical countries both within and outside the area of its natural occurrence.

MAJOR USES

The main use of the tree is its highly durable timber considered among the finest for cabinet, furniture and veneer. In India, *D. sissoo* is commonly called as 'Shisham' and its timber is highly affordable to people and hence liberally used for a range of purposes. Shisham wood is normally golden brown to dark brown in colour with medium coarse texture and fairly straight to somewhat interlocked grains (Rao and Purkayastha 1972). Although the wood is hard with a high density of 785 kg m^{-3} at 12 % moisture content, it is easy to work and finish (Limaye and Seaman 1933; Sekhar and Bhatia 1957) and possesses moderate shrinkage (Tewari 1994). Apart from the finest furniture, exquisite carvings and in-lay works are also made using Shisham wood providing livelihood to a large number of artisans and workers in wood-processing units. Shisham is the most widely cultivated timber species in northern India apart from Teak and contributes significantly towards reducing the timber imports.

The leaves and young pods with high levels of crude protein and dry matter digestibility are used as fodder (Joker 2002). Due to its leaf flushing in early summer, it is an important source of fodder when other tree species are in their deciduous phase. Its nitrogen-fixing ability in association with *Rhizobium* makes it adaptable to sites with nutrient deficiency. Its fast growth makes it a highly preferred species for planting along canals, road and rail sides, farm bunds and as shade trees. *D. sissoo* has excellent coppicing ability and stumps often produce masses of shoots. Root suckers sprout up from lateral roots when exposed or cut making it suitable for erosion control.

SHISHAM DECLINE

In the recent years Shisham has been facing severe decline due to vascular wilt and root rot disease throughout its natural distribution range. Although large scale mortality in Shisham was reported in both naturally distributed and planted trees for the last three decades, it has taken epidemic proportions during the past decade. The extent of mortality was around 25% two decades ago and now up to 70% of trees found dying (Shukla 2002; Shukla and Harsh 2010). It was estimated that around 400,000 matured trees were lost in India till 2010 causing a loss of USD 150 million (Shukla and Harsh 2010). Huge losses were also reported in Pakistan and Nepal (Shakya and Lakhey 2006; Javaid, 2008).

Fusarium solani (Mart.) Appel. & Wr. f. subsp. *dalbergiae* was identified by Bakshi and Singh (1954) as causal agent of vascular wilt disease in Shisham. The first report of Shisham mortality was by Baghchee (1945) followed by Bakshi (1954) in plantations raised in Dehra Dun and Saharanpur districts of Uttar Pradesh (now in Uttarakhand State). The symptoms include yellowing of leaves followed by drying and dropping making the branches bare showing typical dieback symptoms. Eventually the entire tree dries up in a span of four to six months. The trees of all ages are affected, and bark of infected trees cracks at places to form typical bands. These cracks later convert into cankers, and black pitch oozes out continuously. The roots, when exposed, appear dark brown in colour, withering and emit foul smell. The symptoms of root rot and associated dieback disease are more specialized than that of vascular wilt which includes gradual thinning of leaves and crown, drying up of branches to give a stag-head like appearance and finally drying up of entire top portion of

the tree (Fig. 1). *Ganoderma lucidum* is the major fungal pathogen with root rot and dieback disease of Shisham being more prevalent in drier areas of Haryana and Punjab States (Bakshi 1976; Bakshi *et al.* 1976; Harsh 2012). Other pathogens which are attributed to dieback of Shisham include *Fusarium oxysporum, Lasiodiplodia theobromae, Phellinus gilvus* and *Phytophthora cinamomi* (Harsh 2012). Various control measures attempted slowed down the spread of the disease but had limited effect on already affected trees.

Fig 1. *Different stages of die-back of Shisham*

INITIATIVES FOR RESTORATION

The Forest Research Institute, Dehra Dun has been undertaking genetic improvement of Shisham since 1990 to improve the growth, stem form and disease resistance properties. Shisham has a number of desirable traits but its stem form is generally poor (Bangarwa *et al*. 1990) and the forked bole reduces timber quantity and quality. However, large variation exists for this trait providing scope for selecting populations/individuals with a high level of axis persistence and stem straightness. Multilocation clonal tests were conducted with 36 phenotypic selections from the States of Haryana, Punjab, Uttarakhand and Uttar Pradesh in India and Nepal. As an interim output from the clonal testing programme, clone FRI-DS-014 possessing fast growth, excellent bole form and tolerance to *Fusarium solani* was released for commercial scale cultivation (Table 1; Fig. 2). Selection and release of more clones is in progress. The productivity of the clone was estimated to be 12 m^3 per hectare per year compared to 5-7 m^3 per hectare per year realized from plantations raised with unimproved seed sources. The new planting materials are expected to play an important role in increasing productivity of Shisham plantations and benefit those whose livelihoods are dependent on availability of its timber.


Fig 2. *Superior growth and tree form of Shisham clone FRI-DS-014*

Table 1. *Survival, growth and stem form characters of Dalbergia sissoo clone FRI-DS-014*

Character	3 years	6 years	Superiority (%) over Check Accession (6 years)
Survival (%)	100	98.66	89.52
Height (m)	3.32	5.69	8.16
Clear bole height (m)	1.43	2.52	10.87
DBH (cm)	3.3	6.83	2.04
Stem straightness	2.93	2.45	36.87
Branching behaviour	2.72	2.69	37.24

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2.4 GENETIC RESOURCES AND CULTIVATION PRACTICES TO INCREASE PRODUCTIVITY OF TEAK

INTRODUCTION

Teak (*Tectona grandis*) is the most important timber tree belonging to the family Lamiaceae. It is native to South and South East Asia particularly India, Thailand, Myanmar and Laos. Teak is also naturalized and cultivated in many South and Central American and African countries. It is also introduced into Sri Lanka, Malaysia, Bangladesh, Pakistan, Indonesia, Zambia, Tanzania, Uganda, Ivory Coast, Ghana, Togo, Nigeria, West Indies, Honduras, and Panama. In India, it is naturally distributed mainly in the Central and Peninsular region and teak forests are found in Madhya Pradesh, Maharashtra, Tamil Nadu, Karnataka and Kerala besides Gujarat and Odisha.

UTILIZATION OF TEAK

Teak is versatile type of wood and has the physical properties of high strength, flexibility during woodworking, high resistance to rot and weather elements and low shrinkage ratio. The wood is used for ship and boat building, wood flooring, wood paneling, carving, furniture, veneer, windows frames and indoor and outdoor structural beams. The teak wood has been used for decking, deck houses, rails, bulwarks, hatches, weather doors and planking. Varieties of teak have versatile utilization based on grains and colour of the wood. The large teak trees from Western Ghats region are used for structural needs like ship and boat building, construction and bridge building. Teak grown in Central India is known for colour, texture and grains and preferred for making furniture and aesthetic articles. Teak wood from Godavari valley has ornamental figuring and used for making furniture and cabinet.

VARIETIES OF TEAK

Traditionally foresters, timber traders and wood workers recognized different varieties of teak based on the wood properties Table 1.

Table 1. *Varieties of teak recognized in India.*

S.No.	Teak Types	Growth Habit	Grain	Colour	Price
1	Adilabad teak	Fast	Attractive grains	Rose	High price
2	Central province teak	Slow	Close wavy	Deeper	High price
3	Dandeli teak	Slow	Close grained	Darker	High
4	Godhavari teak	Fast	Attractive grains	Rose	Moderate
5	Konni teak	Slow	Close	Darker	High
6	Myanmar (Burma) teak	Slow	Close	Darker	High
7	Nilambur teak	Fast	Straight	Golden yellowish	High
8	South and Central American teak	Fast	-	Light	Low
9	West African teak	fast	Wavy	Black steaks	Low

TEAK CULTIVATION

Growth Requirements

- Soil

  Teak grows well in alluvial soils, fairly moist, warm, tropical climate with pH ranging from 6.5 to 7.5. Teak showed poor growth and form on dry sandy soil, shallow or hard pan soil, acidic, laterite, black cotton and waterlogged soils. It fails to grow in the soil with pH below 6.5.

- Climate

  Teak plant prefers humid, moist, warm tropical climate. It is a light demanding species and requires relatively high intensity light. It is grown from an altitude of 1200 MSL with 800-2500 mm rainfall regime and also grown in very moist areas with the annual rainfall of over 3,500 mm. It can withstand extremes of temperature (13-44 °C), but more profuse growth observed between 13-27 °C. Teak also grows in dry areas of Tamil Nadu, Rajasthan, Madhya Pradesh, Andhra Pradesh and Maharashtra.

Seed Propagation

The time of seed collection in teak is normally between November and January. In spite of profuse flowering, teak is known for very poor fruit set due to various factors. The size of the fruits also varies with the population and 1100 to 2800 fruits weighed in one kg of fruits. Forty year old teak trees can produce 3-4 kg of fruits. Teak fruits contain four locules, generally filled with 1-2 seeds. Teak seeds can be stored up to 2 years at 12% moisture level in proper storage condition. Storage at 0-3 °C can maintain viability up to 5 years.

Seed germination in teak is greatly affected due to dormancy and pre treatment of seeds by alternate wetting and drying for a week will improves germination. The seeds must be kept in gunny bag and in running water for 12 hours and subsequently the seeds are sundried for 12 hours. This procedure has to be repeated for a period of one week. The germination also affected by the size of seeds and always bigger size seeds have better germination than the smaller size seeds. Higher germination percentages of 30 to 50% were recorded in moist teak whereas lower levels were recorded in 5 to 10%.

Nursery Management

The seeds are sown in the raised nursery beds with the size of 10 x 1 x 30 m prepared with mixing of sand, soil and manure. The bed should be fully exposed in the open sun light. Seeds were sown in nursery beds at 1 to 1.5 cm depth. The nursery beds have to be watered regularly and covered with coconut leaf or paddy straw. Seeds germination starts 15 days after sowing and continues up to 50 days. For preparation of stumps seedlings can be maintained for 8-10 months or transferred to poly bags 60 days after sowing.

Preparation of Stumps

The teak stumps are prepared by cutting one year old healthy seedlings uprooted from the nursery. In the seedlings 15-20 cm root portion and 2.5 cm shoot portion with more than one cm thickness are used for preparation of stumps. The quality teak stumps are produced from the seeds collected from identified best seed sources such as seed production areas and seedling/clonal seed orchards as well as vigorous culling of inferior ones in the nursery which ensures enhanced yield of teak in plantations.

Establishing Plantations

Establishment of a teak plantation is a long-term activity and hence it needs proper planning. Well drained land with moderate slope (5%) should be selected for establishment of teak plantation. Generally planting should be done before onset of monsoon, In South India, planting is done during June – July or October to November subject to the monsoon rainfall and water availability. Rectangular or line planting system can be followed for establishing teak

plantation. The spacing of teak plantations depends upon soil type, soil depth and climatic conditions. The land should be ploughed thoroughly with tractor drawn rotavator twice. Aligning and staking should be done for digging of pits. Pits of 60x60x60 cm size are dug out in a spacing of 2x2m (or) 3x3 m and 2 m intervals are maintained in case of bund planting. The pits are dug out a month prior to planting and kept open for at least a month for disinfestation by solar radiation. The pits can be drenched with 0.15% Carbendazim and 0.2% of Chloropyriphos 4 – 5 lit/pit. Pits are filled with dugout earth and remaining half of the pits can be filled with farm yard manure 2 kg, Neem cake 500g, Calcium sulphate 100g and Trichoderma 25g. Watering is done to allow the soils to settle down. Well-developed cuttings or one year old teak stumps or 150 days old poly bag seedlings should be used for planting in the centre of the pits. The teak plants should be irrigated immediately after planting.

Agroforestry

Teak is one of the most important and preferred tree species largely planted by the farmers in different planting systems such as block planting, bund planting and paired row system of planting along with different agriculture and horticulture crops. It is planted in different models, combinations as well-as in different placements. The popular agroforestry models practiced in India are given in Table 2.

Table 2. *Agroforestry models involving teak as the major tree crop*

S.No.	Name of Agroforestry Systems	Details of Systems
1	Agri- silvicultural model	Teak + casuarinas with agricultural crops: maize, cotton, turmeric, tomato and chilly
2	Agri-silvi-horticulture model	Teak + coconut with agricultural crops plantain, turmeric, vegetables, maize and cotton Teak + maize, cotton, turmeric, tomato + Guava, or Annona
3	Horti –Silvicultural model	Teak + coconut
4	Silvipasture model	Teak and Casuarina as tree components and Napier and Guinea as pasture components

Nutrient Management

Though teak grows well in fertile soil, its productivity and wood quality can be enhanced by adequate supply of nutrients. The balanced nutrition is essential for the young trees up to the age of 10 years for better growth and optimum wood production. Application of fertilizers varies with soil type and planting density. Calcium is very much essential for better growth and development. Fertilizer should be applied in ring basin formed 1.5 m away from main trunk.

Year	Fertilizer (g)	Organic Manures (kg)	Dolomite (g)
I	50 (15:15:15)	1	50
II	100 (15:15:15)	2	50
III	150 (15:15:15)	3	100
IV	200 (15:15:15)	4	100

Application of water soluble fertilizer through drip irrigation system will improves availability of nutrients and their uptakes, application is restricted to wetted area where root activity is most intensive, loss of nutrients by leaching is minimized, soil compacting is prevented, weed population is reduced and labour and fertilizer cost is minimized.

Weed Management

Weed management is an important operation in teak plantation development. Rainfall and regular irrigation will encourage weed growth in teak plantation, that will compete with trees for water, light and soil nutrients. In addition, weeds can also act as host for pest and disease which is seriously damaging growth and development of teak plantations. Mulching with black polythene sheet or organic mulches such as sawdust, banana trash, paddy husk, sugarcane trash etc. may be used for soil moisture conservation and weed control. Mulching will save 20-25 % water requirement and control 20 % weed populations. Manual weeding may be carried out 3 times in the first year, 2 times in second year and subsequently one time in every year. Application of post emergence herbicide Glyphosate will help in managing the weed population.

Pruning

Pruning is the removal of unwanted dead and diseased branches which will help to increase clear bole height and reduce knots on the main stem. It will support diversion of food material to the growth and development of main stem and canopy. Teak pruning commences in the third year after planting, branches and twigs from the lower half of the tree should be completely removed. Pruning more than 50% shoots can affect the growth and development of teak trees. Pruning should be completed in early rainy season and avoid pruning during rainy season. Branches should be removed during early growth stages. If pruning is delayed, removal of large shoots will result in knot defects in the wood and also make trees vulnerable for pest and disease infestation. Immediately after pruning the cut ends are treated with the 2% copper oxychloride paste.

Thinning

The teak plantations are initially raised in close spacing and early thinning is needed for reducing competition for light, water and nutrients. The complete removal of stressed, unhealthy and slow-growing trees will support better growth and formation of good stem form in the remaining trees. The trees harvested during thinning can be sold for midterm income generation. Any thinned teak trees more than 10 cm diameter can be used for scaffolding in construction and also used as fire wood. Thinning of teak plantation is depending on the spacing, soil quality and rainfall. Generally under good growing condition and close spacing, two mechanical and three silvicultural thinnings are being practiced by different forest departments and forest development corporations. The interval of thinning cycle is at age 5, 10, 15, 20, and 30 years after planting for 60 year rotation in Kerala and at ages 5, 8, 16, and 20 for 40 year rotation in Maharashtra are being practiced. After final thinning 150 to 170 trees per hectare are to be maintained.

TREE IMPROVEMENT IN TEAK

Teak has wide natural variation and it is due to genetic makeup of stands and distribution in different climatic and edaphic conditions. Kedharnath and Mathews (1962) have first formulated a programme for the genetic improvement of teak in India and following this teak improvement activities gained importance in all the teak growing States. During the past four decades considerable progress has been made on selection of plus trees, understanding provenance variation, establishment of clonal seed orchards and seed production areas to enhance productivity in teak.

Provenance Variation

Teak is distributed over a wide range of climatic and geographic conditions and based on distribution there are three main populations such as Indian Peninsular, Burmese-Thai-Laos and the insular populations have been identified. Provenance variation in growth rate, stem form, seed morphology germination and wood quality have been observed in teak. In India teak wood has shown a wide variation in the colour, texture and grains, quality of the timber and this variation due to genetic, climatic and edaphic conditions of the teak stands. Teak grown in Western Ghats region attains bigger sizes due to high rainfall and it is preferred for structural needs like ship and boat construction.

On the other hand, teak grown in Central Indian region is known for colour, texture and grains preferred for furniture and other aesthetic needs. Teak grown in Seoni, Kanker and parts of Bastar in Madhya Pradesh has golden yellow timber colour with the heartwood blending into the sapwood. Teak wood of Godavari valley regions in Andhra Pradesh is highly priced for furniture and cabinet making for its ornamental figuring. Teak timber of Chandrapur (Maharashtra) is well known in Indian market for its colour and texture.

International Provenance Trial

DANIDA Forest Seed Centre (DFSC) has established a series of international provenance trials with 75 provenances and 48 field trials in early 1970s. Keiding *et al.* (1986) evaluated the trials in 21 sites. The general evaluation at different ages showed:

- Indonesia provenances have good survival, health, fast growth, but rough in respect of branch size, epicomic branching and buttressing.
- Kerala provenances have good appearance, stem quality and branch size.
- Thailand provenances have slow growing tendency and produce good clear bole, stem form but relatively have high epicormic shoots.

In India, the International provenance trial was established at Maredumilli in Andhra Pradesh with 11 provenances during 1973.The evaluation of the trial after 26 years indicated no significant difference on survival rate, growth, GBH, straightness and roundness of stem and health characteristics (Rao *et al.*, 2001). Genetic analysis showed low heritability in height and GBH and moderate to high heritability for straightness and roundness of stem.

Seed Production Area (SPA)

Seed production areas (SPA) are established by converting the best natural stand or plantation by removing the inferior trees, and allowing to remain only good trees to produce quality seeds for raising plantations (Fig.1). It functions as an interim measure till the seed orchards produce seed. About 5000 ha of SPAs of teak are established in different teak growing states in India (Mandal *et al.*, 1997).

Fig 1. *A seed production area of teak in Kerala*

Fig 2. *A candiddte plus wec of teak in Kerala*

Selection of Plus Trees

Selection of outstanding trees called plus trees from natural populations and plantations is the first step in tree breeding programme. Plus trees of teak are selected based on check tree method, and selected tree must be distinctly superior to the average of the stand. Emmanuel and Bagchi (1984) identified different phenotypic characters for selection of plus trees of teak (Table 3; Fig. 2). Selection of plus trees is expensive and time-consuming, but indispensable for improvement of teak.

Table 3. *Desirable characters in a plus tree of teak.*

S.No	Characters	Specifications
1	Age	More than 30 years
2	Growth	Vigorous, healthy and showing superiority in height and diameter when compared with the surrounding trees.
3.	Stem Form	i) Straight stem. ii) Stem cylindrical, circular without excessive taper. iii) Absence of spiral grain, if present not to exceed 5 degrees. iv) Free from pronounced buttress or fluting.
4.	Crown and branching	i) Narrow to intermediate in width. ii) Not suppressed either from the top or from the sides at any time. iii) Light and spreading branches which are either flat or moderately ascending. iv) Good natural pruning. Less epicormic branches. v) Dense mass of healthy foliage.
5	Tolerance to Pest and disease	Free from leaf skeletoniser and leaf defoliator
6	Flowering and fruiting	Moderate to good flowering and fruiting

In India 700 plus trees of teak have been selected in different teak growing States till 1980 (Kedharnath,1984), and fresh selections are being made by Forest Departments and different Research Institutes.

Vegetative Propagation

Teak productivity can be increased by establishing plantation from genetically improved planting stock. The clonal seed orchards (CSO) are the main focus on genetic improvement of teak to produce quality seeds for the planting programme. However, most of the CSO showed very low seed production and the plantations are raised through seeds of unselected seed source.

Vegetative propagation plays an important role in teak tree improvement programme and it has many advantages like multiplication of desired genotypes for establishing clonal seed orchards, breeding populations and plantations to enhance wood productivity. Capturing of full genetic potential, preservation of elite genetic resources and avoiding the problem of low flowering are the main advantages of clonal propagations. Various methods of vegetative propagation like grafting, rooting of cuttings and micro propagation have been reported in teak to produce quality planting stock.

- Grafting

  Rawat and Kedharnath (1968) standardized the budding and grafting technique for teak which has been used for establishing large scale clonal seed orchards in India. The success of grafting, varied with the season, age of buds and rootstocks and under favourable nursery environment 80-95 % of success was reported.

- Rooting Branch Cuttings

  Rooting of mature branch cuttings was generally used for establishing clonal seed orchards and conservation of elite genetic resources. The teak trees shed their leaves in the months of November and December and new sprouts will emerge during March to April. Trees accumulate nutrients and metabolites in the shoots before onset of leaf fall and which are subsequently utilized for emergence of new sprouts. Palanisamy *et al.*, (1998) reported that formation of new sprouts leads to increase in the endogenous presence of root forming substances in the shoots which results in rooting of branch cuttings. Branch cuttings of size 15 to 20 cm length and 1 to 2 cm thickness are collected from superior teak trees in the month of April to June. After removing the leaves, the cuttings were treated with auxins (1000 to 2000 ppm) at the basal end (1 to 2 cm) for 1 to 12 h. After auxin treatment the top end of the cuttings were sealed with paraffin wax to avoid any water loss and planted it in mist chamber or polytunnel with intermittent misting and maintained at 80 to 90% relative humidity and

temperature around 30 to 32 °C for rooting. Rooting occured 45 to 60 days after planting, and it showed very moderate rooting (Palanisamy *et al.*, 1995). Rooting of branch cuttings is not suitable for mass multiplication and planting programme because rooting is season specific and it also takes longer time for rooting.

- Rooting Coppice Shoots

Palanisamy and Subramanian (2001) developed a cost effective clonal multiplication technique for large scale multiplication of superior teak trees through coppice shoots. The coppice shoots emerge after felling of selected tree and the shoots are physiologically juvenile in nature. Porpagules raised from rooting of coppice shoots are suitable for establishing large scale clonal plantations. The procedures involved in coppice shoot propagation are selection of superior teak trees in plantations or natural populations, felling of the selected tree, maintenance and collection of coppice shoots, rooting of coppice shoots in mist chamber or polytunnel and hardening of the propagules for raising plantation. The superior trees of teak were selected from the plantations and felled at 20 to 30 cm above the ground level. Coppice shoots emerged 2 to 3 weeks after felling.

Coppice shoot cuttings with 15 to 20 cm in length and1.0 to 1.5 cm in diameter are collected from selected trees and planted in polythene bags containing coarse sand and kept in polytunnel or mist chamber under intermittent misting with 80 to 90% humidity. New sprouts emerged from the planted coppice shoots within a week and these sprouts (4 to 6 cm length and 0.2 to 0.3 cm diameter) were collected and treated with 2000 ppm IBA, and then planted in root trainers (150 cc) filled with composted coir fibre as rooting media and kept in polytunnels or mist chamber at 80 to 90% relative humidity are maintained for rooting. Rooting initiates within 15 to 20 days after planting. About 60 to 90% rooting was observed throughout the year. This is the most suitable method for mass multiplication of plus trees of teak.

Fig 3. *Tissue culture of teak clones (above) and hardening of rooted clonal plants (below)*

- Micro propagation

Tissue culture is an important tool for large scale multiplication of desired genotypes. Micropropagation of teak has been developed and it is commercially practiced in Thailand and Malaysia (Goh *et al.*, 2005). In India, Institute of Forest Genetics and Tree Breeding, Coimbatore has developed a tissue culture protocol for large scale multiplication of selected teak genetic resources (Fig. 3). Field testing of tissue culture raised teak clones is under progress and early results showed the superior performance of clones in farm forestry plantations. The tissue culture teak seedlings are available for commercial sale from IFGTB to the stakeholders.

Clonal Seed Orchard (CSO)

The CSOs are established with the bud grafts of selected plus trees to produce seeds (Fig. 4). Grafted seed orchards will initiate flowering and fruiting 3-4 years after establishment but the orchards may require 15 years for reaching its full potential. The clonal seed orchards (CSO) are established from 1960 onwards to supply genetically superior seeds for plantation programme. About 1000 ha of CSO has been established in India in different teak growing states. The major constraints in CSO are poor flowering, asynchrony in flowering, low fruit and seed set. Indira (2005) stated that asynchronization of flowering, rain fall, spacing and site factors affect fruit production in seed orchards. Nagarajan *et al.*, (1996a) reported that clones of one region when moved to another region, flowering and

Fig 4. *Evaluation of fruit production in a Teak CSO.*

fruiting were significantly affected. It is suggested that a CSO should have plus trees from the same provenance or ecotype with as many trees as possible to avoid non-overlapping of flowering and to maintain a broad genetic base (Kedhannath, 1984; Subramanian *et al.*, 1994).

Seedling Seed Orchards (SSO)

A seedling seed orchard is a plantation of seedlings of selected trees which takes a longer time to produce seeds than CSO but it has the advantage of having a broader genetic base than the latter. Seeds are collected from 100+ plus trees from different locations and established as progeny trial with family identity or bulked seeds. The progeny trial will be subjected to two thinning at the age of 10 and 15 years. After evaluation and ranking, first thinning will be done 10 years after planting by removing the inferior trees and retaining only the best trees. At the age of 15, second thinning will be done and the progeny trial converted into seedling seed orchard by maintaining only superior trees for seed production.

Clonal Forestry

Low seed production generally encountered in teak has necessitated to take up teak plantations raised with fast-growing clones with high timber quality. Clonal forestry is gradually increasing in aggressive teak cultivating countries like Indonesia, Latin American and African counties. Apart from increasing the plantation productivity through uniform and vigorous growth of site-specific clones, clonal forestry ensures timely availability of high quality planting stock and removes uncertainties associated with low seed production. Tissue culture plants raised under asceptic conditions also facilitate hassle-free worldwide distribution of teak clones (Monteuuis and Goh, 2017).

IFGTB has selected vigorous individuals from progeny of clones from CSOs and CPTs selected from plantations. These superior individuals were designated as candidate clones and clonally propagated through tissue culture of shoots followed by ex vitro rooting. Four clones (MHAL (2), SBL and TNT) were planted in a row plot design Panampally Research Station, Kerala during 2000 along with seedlings (unimproved) as control. Growth parameters (height and girth) were recorded once in two years. At the end of 18 years, wood core samples were sampled to assess the heartwood formation.

The average of 25 trees per clone in terms of height and girth is presented in Table 4. The initial height of the clones versus seedlings remained on par, but with increased age, the clones put in more height. At the end of 18 years, all

Table 4. *Growth parameters of the tissue culture plants of Teak.*

Growth Parameters	Clone	2 yrs	5 yrs	10 yrs	15 yrs	18 yrs
Height (m)	MHAL	1.4	5.5	10.0	12.3	17.3
	SBL	1.2	4.7	9.0	11.3	16.9
	TNT	1.3	4.7	9.0	11.4	16.7
	Seedling	1.2	4.8	9.5	10.7	15.2
GBH (cm)	MHAL	15.5	32.2	52.7	55.6	59.0
	SBL	14.8	25.6	45.3	46.5	53.9
	TNT	13.0	23.3	47.3	51.0	52.9
	Seedling	13.0	21.0	25.0	31.0	33.0

the three clones recorded 10 to 13 per cent increase over seedlings with respect to height. The girth showed clear signs of difference from the fifth year onwards. Clones tend to put in more girth than the seedlings. The increment over seedlings was 60 to 75 per cent. The variation within seedlings could be attributed to the low average girth recorded in seedlings (Yasodha and Warrier, 2019).

ROTATION PERIOD AND PRODUCTIVITY

The rotation period of teak plantations in India differs according to the site conditions, environmental factors and management. In Madhya Pradesh teak plantations have 80 years rotation, 50 to 60 years in Kerala and 40 years in Maharashtra. Canal bank plantations in Tamil Nadu have 40 year rotations. The Mean Annual Increment of the Nilambur teak plantations in Kerala ranges from 0.97 to 5.64 m^3 $ha^{-1}year^{-1}$, and the average productivity is 2.85 m^3 $ha^{-1}year^{-1}$ in a 53 years rotation period (Subramanian *et al.*, 2000). Recent studies conducted on teak growing in farmlands with irrigation, fertilizer application and management revealed the possibility of reducing the rotation period to 25 years with increase in productivity. Teak timber and pole are classified in various states depending upon their utilization. In Kerala following four classes of timber and five classes of teak poles are recognized. Timber of quality class-I, free from all defects is considered for export quality whereas timber below 3 m is considered a short log.

Fig 5. *Row planting of IFGTB teak clones in Tamil Nadu (left) and Chattisgarh (right).*

PEST AND DISEASES

A wide range of pest and diseases affect the growth and development of teak plantations and cause a significant loss to the farmers. It reduces the quality of wood as well as market price. It is attacked by 30 species of insect pests belonging to three orders and 15 genera. The important pest and diseases which seriously affect growth and development of teak plantations are given in Table 5 and 6.

Table 5. *Symptoms and management of insect pests of Teak.*

S. No.	Common Name	Entomological Name	Symptoms	Management
1	Teak defoliator	*Hyblaea puera*	Leaves defoliation Entire leaf is eaten leaving midrib	Clip badly affected leaves with larva; spraying of Neem Seed Kernel Extract (NSKE) 5%; setting up of light trap to trap adult moths.
2	Teak skeletonizer	*Eutectona machaeralis*	Larva causes damage through skeletonization of leaves; severe damage result in browning of leaves	Establishing of mixed plantations; clip severely affected leaves; spraying of Neem Seed Kernel Extract (NSKE) 5%; spraying of Quinalphos @ 2 ml/lit.
3		*Phassus signifier*	It is a large caterpillar that feeds on teak saplings. They make a tunnel in the central pith and emerge at night to feed on the bark under a cover of mat of frass, silk and wood dust. Such feeding causes a canker fprmation at which point the stem may break.	Application of 0.2% Quinalphos at the site of infection after removing the frass is highly effective.
4.		*Hypsipyla robusta*	The caterpillars destroy the apical shoot causing the tree to form many side branches and frequently a deformed trunk. It mainly attacks trees in high light areas severely affecting young plantations particularly those with a single species.	Application of 0.5% Quinalphos at the site of infection after removing the frass is highly effective.

Table 6. *Symptoms and management of diseases of Teak.*

S. No.	Name of the Disease	Causative Organism	Symptoms	Management
1	Leaf blight	*Rhizoctonia solani*	Infected plants show water soaked grayish brown patches and enlarge rapidly and cover a large part or the entire lamina. The infected leaves dry up and are eventually shed	Immediate removal of infected plants helps to prevent the disease spread. Application of Dithane M-45 (0.1%) is found effective in controlling disease.
2	Leaf rust	*Olivea tectonae*	Common in nursery and young plantations. Infected leaves are almost plastered with yellowish brown. Upper leaf surface presents a grey appearance due to the formation of fleek. Infected leaves fall off prematurely resulting in retardation of plant growth	Isolation of infected plants. Burning of dead seedlings. Spraying of Sulphur based fungicide
3	Powdery mildew	*Phyllactinia coryleais Uncinula tectonae*	Fungus forms white powdery coating on the under surface of leaves. Conidia are air-borne which are produced abundantly and cause fresh infection. The metabolic changes in plants take place which lead to drying of infected leaves.	Sulphur dust is highly effective in controlling powdery mildew in two year old seedlings followed by Baycor, Mortesan and Calixin
4	Bacterial Wilt	*Pseudomonas solanacearum*	Attacks 6-month to 2 year old seedlings and cause complete mortality	Avoid waterlogging and create good drainage facilities and avoid root injury during weeding and transplanting.

CHALLENGES IN CULTIVATION OF TEAK

Teak growing farmers are faced several challenges for cultivation of teak in the farm land:

- Non-availability of quality seeds from seed production areas (SPAs).
- Conversion of Teak plantations into SPAs towards to meeting the future seeds requirement.
- Non-availability of fast-growing tested clones with high productivity.
- Lack of awareness on precision silviculture techniques for cultivation in farm lands.
- Lack of awareness on integrated pest and disease management strategies for management of pest and diseases.
- Fluctuation of market prize and fixing minimum support prize for farm grown teak trees.
- Non availability of credit system tree insurance scheme and subsidised inputs.

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2.5 PRACTICES FOR ENHANCING PRODUCTIVITY IN BAMBOOS

INTRODUCTION

Bamboos are associated with mankind since time immemorial. They are regarded as a renewable forest resource because of their capability of regeneration after harvest without the need for replanting. Worldwide there are more than 1250 species of bamboo belonging to 75 genera, which are unevenly distributed in various parts of the humid tropical, sub-tropical and temperate regions of the earth. India is very rich in bamboo diversity and 136 (125 indigenous and 11 exotic) species are reported under 23 genera. However all the species are not economically important. National Bamboo Mission has selected the following 10 species viz. *Bambusa tulda, B. bambos, B. balcooa, B. cacharensis, B. polymorpha, B. nutans, Dendrocalamus asper, D. hamiltonii, Thyrostachys oliveri, Melocanna baccifera* as commercially important ones.

MAJOR USES

Special characteristics and versatility in use has made bamboos one of the most sought after group of plants. Till date more than 1500 uses of bamboos are documented. It is used in pulp and paper industries, as wood substitute, building and construction, households and crafts, cottage industries, as food, in packing industry and as a source of material for handicraft, agricultural implements and carts, toys, musical instruments, fences, animal fodders etc. Shoots of some species are also used as vegetable and also for making pickles. Bamboo plywood is also in high demand for their beautiful look. Production of bio-ethanol from bamboo is one of the newest entries in this list.

AREAS/SOIL TYPES SUITABLE FOR CULTIVATION

Bamboos are mainly distributed in tropical, subtropical zones and tropical monsoon region. Tropical Asia is the major centre of bamboo diversity with as many as 45 genera and 750 species. In India, bamboos are found in all the states except Kashmir. It grows from sea level to 4000 m elevation, from very high rainfall areas to the areas of scanty rainfall in Rajasthan. According to FSI report (2017), the total bamboo bearing area of the country is estimated to be 15.69 million hectare. Madhya Pradesh has maximum bamboo area (1.8 m ha) followed by Maharashtra (1.6 m ha), Arunachal Pradesh (1.5 m ha) and Odisha (1.2 m ha). Bamboo grows in almost all types of soil. However for cultivation, well drained, well aerated soil rich in organic matter is required.

AVAILABILITY OF GENETICALLY IMPROVED PLANTING MATERIAL

During 1997 bamboo improvement programme was started at Rain Forest Research Institute (RFRI), Jorhat, Assam with the objective of enhancing productivity by selecting superior genotypes of economically important bamboo species. RFRI has extensively surveyed bamboo growing areas of North-east India and assembled 497 Candidate Plus Clumps (CPC) of 10 economically important species till date (Table 1).

Currently, survey and selection in 15 commercially important species viz., *Bambusa bambos, B.balcooa, B. tulda, B. nutans, B. pallida, B. vulgaris, B. cacharensis B. polymorpha, Dendrocalamus hamiltonii, D.longispathus, D. giganteus, Melocanna baccifera, Schizostachyum dullooa ,S.Pergracile and Thrysostachys oliveri,* is under progress.

Table 1. *Year-wise selection of Bamboo CPCs of 10 species by RFRI, Jorhat*

Sl. No.	Species	1998-99	2007	2017 onwards	Total
1	*Bambusa tulda*	37	43	72	152
2	*B. balcooa*	39	31	35	105
3	*B. nutans*	14	31	32	77
4	*B. pallida*	23	10	21	54
5	*B. bamboos*	22			22
6	*Dendrocalamus gigantious*			06	06
7	*D. hamiltonii*	18	26	15	59
8	*Melocanna baccifera*			10	10
9	*Schizostachym dulloa*			05	05
10	*Thyrostqchys oliveri*			07	07
				Total	497

Quality planting materials are raised vegetatively from the selected genotypes through macro and micro proliferation technique at RFRI. This QPM may be obtained from RFRI @ 30/- per planting material. A rhizome bank of selected Germplasm has also been established at RFRI from which rhizomes may also be obtained. Further, the Institute has identified 16 superior genotypes in terms of high yield from the species, *Bambusa tulda, B. nutans, B. balcooa* and *Dendrocalums hamiltonii*. These genotypes may be obtained from RFRI through non- exclusive licence agreement by any public or private nursery/tissue culture lab for commercial propagation and supply.

PROPAGATION METHODS FOR BAMBOO

Bamboos can be propagated both sexually as well as vegetatively. Propagation through seeds is the easiest and cheapest method. However, most of the bamboo species do not flower annually. Unavailability of seeds due to erratic nature of flowering is the major hurdle in propagation through seeds. Whenever seeds are available they can be germinated in nursery beds. To screen sound seeds, dipping of seeds are done in water and the floated seeds are discarded. Bamboo seeds are sown in nursery beds in the mixture of soil, sand and FYM in the proportion of 1:1:1. Germination starts within 7 to 10 days of seeds sowing. Seedlings are pricked out at four leaf stage and transplanted into polybags or nursery beds. Planting in the field is done as soon as the rainy season starts.

Propagation Through Rhizome

Propagation through seeds does not ensure genetic uniformity of the offsprings which is not desirable for large scale commercial plantation. Because of the hurdles associated with seeds, preferred method of propagation is through vegetative means. Traditionally Bamboos are propagated through rhizome. Sections of rhizomes containing buds is separated during the months of March to May or before emergence of new shoots from healthy, 1.5 – 2 year old culm. This rhizome should be planted in pits size of 50 X 50X 50 cm with mixing of 100 g Urea, 100 g SSP, 50 g MoP and 5 kg FYM with soil. The upper portion of rhizome is sealed with polythene /wax or paint to check water loss from the rhizome and is then treated in 0.1% Bavistin solution before planting in the pits (Fig. 1). The buds present in rhizome neck develop into new culms during the monsoon period.

Fig 1. *Propagation through rhizome*

Although it is a traditional and successful practice, but propagation of bamboo through rhizome has some limitation. Very few rhizomes can be extracted from a mother clump, hence it is not suitable when the objective is to develop large plantations.

Propagation through Culm Cuttings

A Culm Cutting without rhizomes, but with buds when planted horizontally in nursery beds gives a high rate of propagation in bamboo. Three main factors affecting propagation through culm cutting are:

(a) Season

(b) Age of culms

(c) Growth regulators.

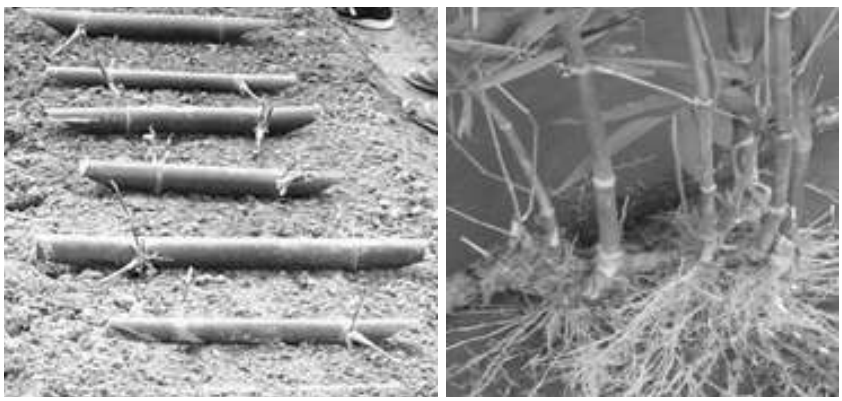

Fig 2. *Propagation through culm cuttings: Two noded culm cutting kept in nursery bed (left) and regeneration from culm cutting (right)*

Culms of age 1.5 – 2 years are collected from superior clumps by cutting just above the first node in the months of March and April. The branches are trimmed without damaging the auxiliary buds. Two-noded cuttings are prepared leaving 5-7 cm on either side of nodes (Fig. 2). Two holes are then drilled in the centre of internodes and 200ml hormonal solution (200 ppm IBA) is poured onto the culm cavity. Lastly, the hole is closed by wrapping polythene strip. In case of solid bamboo, the cuttings are dipped in hormonal solution for 24 hours. Bavistin (0.1%)is applied at the cut ends before placing in the nursery beds.

Propagation through Branch Cuttings

In thick walled bamboo species like *Bambusa balcooa, Dendrocalamus hamiltonii* and *D. asper,* primary branches with rhizomatous swelling is the ideal planting material. The branch cuttings can be extracted without damaging the mother clump. Branches are collected from 1.5 – 2 year old culms in the months of March and April. Preparation is done with two-noded branch cuttings along with rhizomatous swelling at their base and aerial root. Cuttings are quickly transported to prevent drying. The cuttings are then dipped in 200 ppm IBA solution for 24 hours to facilitate root formation. Before planting, the upper cut portion is sealed with wax and the lower portion is treated with 0.1% Bavistin solution. Cuttings are planted vertically in raised beds, 15-20 cm apart or in polybags size of 7 x 9 cm keeping rhizomatous swelling and one node in the rooting media. The planting media used is soil, sand and FYM in the ration of 1:1:1. Regular misting and shade is required for 15 days. After 10-15 days of planting, sprouting takes place and root development occurs in 45-60 days and also, new shoot development takes place. Once roots and shoots are developed, the cutting is ready for field plantation.

Macro Proliferation

Macro Proliferation Technique involves regular separation of rhizome in such a way that each rhizome containing buds on it with some roots and a single shoot portion at 4-6 months intervals. The saplings of 4-6 months age usually produce 4-6 shoots and that stage is suitable for Macro proliferation. At this stage individual rhizomes are separated from the clump of neck region of rhizome. Upon separation, each individual propagule is chopped at upper portion of shoot leaving two nodes. The cut end of the shoot is sealed with wax and root portion is treated with 0.1% Bavistin solution before planting in polybags or nursery beds. Regular misting and shade is required for initial stage. This method can be used throughout the year. Macro proliferated seedlings will again develop multiple culms within 4-6 months. Therefore, every year, seedling can be multiplied at the same rate and a big portion of them may be planted

while keeping a stock for further macro proliferation. But same seedling multiplication should not be continued for very long time.

Tissue Culture

For large scale propagation in bamboo, micro propagation is the most efficient technique. Bamboo tissue culture protocols are available for all the commercially important bamboo species. RFRI has optimised its own workable protocol in four commercially important bamboo species viz. *B. tulda, B. balcooa, B. nutans and D. hamiltonii*. Forced axillary branching technique of micro propagation is followed for in vitro regeneration of bamboo. Single nodal cuttings (2-3 cm) from lateral branches of selected mother clumps are used as explants for regeneration under *in vitro* condition. Once enough multiple shoots are developed, rooting is induced. Rooted propagules are hardened as per existing protocol.

MODERN CULTIVATION PRACTICES

Considering the high demand of bamboo in local and in modern applications, it is necessary to enhance area under bamboo plantation with clone of selected species and quality planting material. Intensive silvicultural practices can only improve the yields from the plantation and ensure regular supply of raw materials.

Raising Plantations

- Site Selection

  Generally bamboo grows well in sandy loam to loamy clay type of soil, prefers usually well –drained soils for its luxuriant growth. It prefers neutral to marginally acidic soil. In temperature ranging from 8.8 ^{0}C to 36 ^{0}C and annual rainfall of 1270-4050 mm, most of the bamboos thrive well. Bamboo generally grows from mean sea level to 4000 m.

- Field Preparation

  Depending on ground cover of the plantation site, selection of suitable clearing method is used for ground preparation. For raising commercial plantation, area is cleared and ploughing is necessary for preventing woody growth and grass.

- Protection

  The bamboo plantation needs protection from domestic cattle and wild animals. Plantation site is fenced to prevent grazing animals during the establishment period. Trench also can be made along the periphery of the plantation to prevent entry of animals.

- Selection of Species

  Choice of species for cultivation is mainly based on location, climatic and edaphic conditions of the planting site. Commercial uses, market preference and availability of planting materials also are preferred for plantation. Plantation is done with at least 2-3 different species at the same site.

- Spacing for Plantation

  Closely cultivated clumps create congestion and there will be less workable space. Different bamboo species require different spacing based on their clump size, growth patterns and objective of plantation. Medium size bamboo species particularly *Bambusa* spp. need 5 x 5 to 7 x 7 meters spacing. But for larger clump forming bamboos like *Dendrocalamus giganteus* require 10 x 10 meters spacing or 100 plants per hectare. The spacing also depends on the purpose of the plantation. If the purpose of the plantation is only for shoot harvesting or soil stabilization or control of erosion then spacing can be reduced to 3 X 3 meters or 1100 plants per hectare.

- Pit Digging

  The pits are dug at the prescribed spacing well before the planting season. The soil is dug out and is kept for weathering for sometime and refilled. Pit size may vary according to the planting materials. For the planting of offsets/ rhizomes, pit size should be a minimum of 50 cubic cm and for seedlings/ sapling or rooted cuttings it may be of 30 cubic cm. Large size pits provide more working space for easy establishment and rhizome growth than small pits.

- Planting Methods

  The time of planting is the most important factor for the success of the plantation. The propagules are collected before emergence of new shoot or in the later part of February to first part of May. Plantation of bamboo is carried out before the beginning of the rainy season, up to the start of the monsoon. Casualties are replaced in the same year of planting and again in the beginning of next year rainy season. A few days before planting, 5 kg of FYM/ vermicompost is mixed with Urea -100 g, SSP-100 g and MoP- 50 g to the dugout soil. Rhizomes/ seedlings is planted vertically keeping the rhizome and root portion below the ground level and compacting the area around the plant.

Management Practices

Depending on the type of rhizome growth, the bamboos may be clump forming or non-clump forming. The establishment period of bamboo varies depending on the propagules used. In case of rhizome/offsets, the establishment period is 3-5 years and for seedling is 5-7 years. For ensuring high productivity of bamboo regular clump, regular management is required. This can be done through following practices:

- Weeding

  Weeding is done at least twice a year for initial 2 years after rain and end of the wet season.

- Soil Loosening

  Soil loosening around the clumps for 1-2 times every year is important to maintain a good soil structure. These practices improve the growth of shoots and the root system.

- Mulching

  Mulching is an important silvicultural practice. It reduces loss of moisture due to evaporation from the planting pits. Mulching improves soil texture and enhances the nutrient value of the soil by biodegradation of mulch.

- Soil Mounding

  Rhizome emerges at an upwardly inclined angle. During this period of growth, exposure to sunlight may stop rhizome development. Therefore, mounding or heaping fresh soil around the clump every year before the new culm emergence is done.

- Pruning

  Pruning is practiced only in those species, which produce thorny/ thick branches in species like *Bambusa bambos, Bambusa balcooa, Dendrocalamus hamiltonii*. Pruning of these branches reduce clump congestion and helps in keeping the clump in working condition. Pruning is started in the second year after planting and all the branches up to 1.5 m height is pruned, leaving one node on the branch stalk.

- Thinning / Improvement Cutting

  Thinning is started in the third year after planting and carried out every year before the rains. All malformed and damaged culms are removed. Culms causing congestion are cut to make the remaining culms equally spaced.

- Manuring and Fertilizer Application
- The result of several experiments conducted in South and South East Asia have shown that the productivity increases when yearly manuring and fertilization is done. Three things are to be taken into consideration while fertilizing the clumps.

- Method of application
- Kind and dosage of fertilizer
- Fertilization time

- Harvesting and Harvesting Schedule

  When the clumps are established and they attain the productive stage, proper harvesting technique and schedule is followed in order to ensure continuous production for long time. Mainly bamboos are harvested for two purpose-(i) bamboo shoots (ii) bamboo culms. For commercial purposes harvesting of bamboo can begin from the third year of establishing a plantation. The felling is not done during May to October. The felling must complete before emergence of new shoots. Following points are taken care on harvesting–age of the felling of culms be 3 years old and above.

  - The cut is made above the first prominent node (about 15 cm from the ground level) with a sharp instrument.
  - Tending operation is done along with felling by cutting malformed, dead, diseased or otherwise useless culms, stumps and climbers
  - No clump is considered harvestable unless it contains more than eight mature culms.
  - In a mature clump, culms of current season and eight culms of previous year are retained.
  - Under no circumstances the felling is done between May and October.
  - Selective harvesting is preferably done every year.
  - The congested culms are removed leaving only the current year culms where congestion has already set in.

  In congested clumps a special technique is applied for felling. The same techniques are also followed in natural forest where such management practice is not followed earlier. These are:

  - Perpendicular Tunnel Method: In this method, two tunnels are made in right angles so as to divide the clump into four quadrants.
  - Horse Shoe Method: In this method, clump is converted into a horseshoe shape by thinning the inner culms.

DURATION OF CULTIVATION AND EXPECTED YIELD

The establishment period and production stage of bamboo plantation varies depending upon the propagaules used. In case of clumps raised from rhizome, full sized harvestable bamboo culms can be obtained from third year of establishment. In a case where plantation is raised from Macro or Micro propagated planting material, merchantable culm size attain usually 5 to 6 years in properly managed plantation.

Advantage of plantation raised from seeds is that harvesting can be continued till the next flower which usually ranges from 35-60 years. Through productivity in plantation raised from vegetatively propagated material of superior genotypes will be more but duration of plantation depends on the history/origin of mother clumps used for propagation.

One hectare plantation accommodates 400 clumps when planted at a spacing of 5 x 5 m. From a properly managed 5-6 year old plantation, approximately 8 poles can be obtained from one clump every year. Thus, from 1 ha plantation 3200 numbers of poles can be harvested.

AVENUES FOR MARKETING

There is a high demand of bamboo in local as well as different industrial uses. The major use of bamboo includes construction, cottage industry and paper industry. Regarding marketing of bamboos in Assam, there is no well

developed organized marketing channel. The growers and the middlemen are mainly involved in the supply of bamboos across Northeast. The commercially important bamboos are sold in local markets and are mostly used for traditional applications. One of the major users of bamboos is pulp and paper industry. But due to some reasons, the market of this industry has collapsed in Assam and is no more in working process. In Northeast, bamboo based cottage industries are coming up which procure a good number of bamboos. NRL has set up an industry for production of bio-ethanol from bamboos which in turn requires huge amount of bamboos for the purpose. Many bamboo composite centres have come out in recent times in Northeast India which consume large amount of bamboos. It can be concluded that the use as well as the market value of bamboos will rise significantly considering the above scenario in the near future.

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3

SPECIES WITH FAST EXPANDING PLANTATIONS

3.1 NEW VARIETIES AND CULTIVATION METHODS OF GMELINA

INTRODUCTION

Gmelina arborea is a multipurpose tree belonging to the family Lamiaceae. It is naturally found in both dry and moist deciduous forests and has a great potential for establishing as large scale plantations in the tropics. It is indigenous to India and also found naturally distributed in Pakistan, Bangladesh, Myanmar and parts of Sri Lanka, Thailand, Laos, Cambodia, Vietnam, China, and Yunnan. In India, it has a wide distribution occurring in several States such as Uttar Pradesh, Punjab, West Bengal, Assam, Andhra Pradesh, Odisha, Tamil Nadu, Kerala, Karnataka, Maharashtra Gujarat and Madhya Pradesh. It is also found in the eastern sub-Himalayan tract, Indo-Gangetic plains, Aravalli hills, Western peninsula and the Western Himalayas. The species occurs naturally in latitudes ranging from 5 to 30 ^{0} N and longitudes 70 to 110 ^{0} E with an altitudinal range of 50 to 1300 m.

Gmelina is a moderate to large deciduous tree with a straight trunk bearing numerous branches. The species usually attains a maximum height of 25 m with a clear bole at 6-9 m and a GBH of about 1.5 to 2 m. It is a preferred species by farmers, forest departments, ayurvedic industries and other stakeholders due to the versatile utility, rapid growth and high economic returns. It is grown extensively in north eastern India and certain parts of South India.

MAJOR USES

Gmelina wood is used for particle board, matches, packing cases, general carpentry and joinery, furniture components and other household fixtures. It is also used for pulpwood production due to a high kraft pulp yield and low chlorine requirement. Gmelina is an ideal species for carving musical instruments and boat decking. The round timbers are used for posts, house timbers and poles while rotary cut veneers are utilized for plywood. The leaves and fruits are used as fodder. Root is an important ingredient of “Dasamula”, an Ayurvedic medicinal preparation. It promotes digestion and improves memory. Roots are useful for curing fever, heart diseases, nervous disorder, dyspepsia, haemorrhoids, piles and burning sensation. The root decoctions are used in folk remedies to cure abdominal tumors. Bark extract is used for controlling fever and dyspepsia.

CULTIVATION PRACTICES

Gmelina is grown in a variety of soil types, climatic conditions and cultivation regimes in different parts of the country. A general description of soil, climatic and other factors suitable for Gmelina cultivation is given below:

Soil

Gmelina grows well in moist, fertile and well-drained soils. It prefers fairly moist, calcareous soils and alluvial soils with pH ranging from 5.5 to 8. It shows poor growth and form in dry sandy soil, shallow or hard pan soil, acidic and waterlogged soils. Similarly, it cannot grow in heavy clay soils. The soil depth and drainage are crucial factors responsible for growth and development of the species.

Climate

It grows at an elevation of 0-1200 m MSL and comes up very well in humid climate with an optimum temperature ranging from 20-38 ^{o}C. The annual rainfall requirement is 750-4500 mm. It grows very well in the high sunshine with low shade areas.

Land Preparation

Plough the field 2 to 4 times at a depth of 50-60 cm with tractor drawn disc plough or victory plough in order to make the soil into a fine tilth.

Planting

The seedlings/cuttings should be planted in a pit with dimensions holding 45x45x45 cm with a basal application of 5 kg of FYM and 70 g of NPK complex fertilizer plus 10 g of Borax. 120 days old seedlings/cuttings are used for planting. The seedlings are planted with the spacing of 3x3 to 5x5 m. In case of pulp wood and bio energy plantations, 2x2 m spacing is being practiced and bund planting 2 m between the plants are to be maintained.

Irrigation

Gmelina is a fast growing tree species that requires regular irrigation for better growth and development. Irrigation is to be done at weekly interval. Irrigating Gmelina plantation through drip irrigation system will reduce water requirement and also control growth of weeds.

Weeding

Gmelina is a light demanding species and its growth and development is reduced sharply under poor light conditions. Intensive weeding is hence very essential, during one to three years of age. Regular weeding should also be carried out at six month interval.

Pruning

Pruning is an important practice in the cultivation of *G. arborea* in farmland. Pruning decides the growth, clear bole and intercropping ability. Removal of side branches, dead and insect affected shoots should be done in every six months. Regular removal of epicormic shoots is mandatory for better growth and development. Always pruining ratio are to be maintained in 1: 3.

Thinning

It is an important practice to enhance the production of sawn logs. In case of closely planted plantations, the first thinning of alternate rows is to be done at the age of 4-5 years after planting and the thinned woods are used for pulp production. Second thinning should be done at the age of 8-9 years after planting to avoid competition between the trees and to maximize the growth. Thinned wood are used for making plywood and softwood timber products.

AGRO FORESTRY SYSTEM

Growing of *G. arborea* in agroforestry model is commercially practiced in several parts of India. Some of the popular agroforestry models practiced in the State of Tamil Nadu are:

Gmelina + Groundnut

Gmelina + Water melon

Gmelina + Pulses

Gmelina + Maize

Gmelina + Banana

Multi-tier cropping system also has been followed in Pudukkottai district of Tamil Nadu involving Coconut + Gmelina + Banana + Pepper (Pepper trained on the Gmelina trees). Table 1 shows the different combinations of agri, horti and pasture crops grown with Gmelina under agroforestry system.

Table 1. *Combinations of agri, horti and pasture crops grown with Gmelina under different agroforestry systems in Tamil Nadu.*

S. No	Cropping System	Spacing (m)	Agricultural Crop
1	Agri Silviculture Agri Silviculture	4 x 4 4 x 4	Sugar cane Maize Groundnut
2	Horti Silviculture	4 x 4,10 x 10	Oil palm Coconut
3	Multi-tier	2 x 2, 5 x 5, 10 x 10	Banana Coconut Pepper
4	Silvi pasture	4 x 4	Cumbu, Napier

Gmelina Plantations (2 years old)

Agri Silviculture (Gmelina + Cumbu)

Silvipasture (Gmelina + Cumbu napier)

Agri Silviculture (Gmelina + Sugarcane)

Horti Silviculture (Gmelina+Pepper)

Multi-tier cropping system (Gmelina+ Banana+ Pepper +Coconut)

Horti Silviculture (Gmelina + Coconut)

CURRENT PRODUCTIVITY

The growth of Gmelina trees is remarkably fast and on a good site they can reach 20 m height in 5 years. The form of the tree is fairly good, with 6-9 m clear bole. The average yield of Gmelina is approximately 21 m^3/ha/yr and in poor sites a lower value is found (7 m^3/ha/yr). The maximum of 50 m^3/ha/yr on clay loams has been reported (Ladrach, 2003; Akachuku, 1981; Duke, 1983; Hossain, 1999).

Under good management regime each tree yields about 1.5 to 2 tons of wood under a 12 years rotation. The total yield per hectare is around 250 – 300 tonnes / ha. The price of Gmelina wood ranges from Rs.8,000 to 12,000 per tonne in local market based on size of the tree, location of plantations and the time of harvest.

INCREASING PRODUCTIVITY THROUGH TREE IMPROVEMENT

Despite its large scale cultivation and demand for timber of Gmelina, tree improvement efforts are only in their early stages. Clonal tests and seed orchards have been established in southern and north eastern region but high-yielding clones and genetically improved seeds have not been deployed in commercial planting. In such a situation it is necessary to raise seedlings of high quality through adopting efficient seed collection and nursery practices.

Seed Collection, Processing and Nursery Techniques

- Collection of Fruits

  It is recommended to avoid collecting seeds from isolated trees which is likely to have poor seed filling. Seeds should be collected from sources with similar ecological conditions matching the planting location, including altitude, climate, and soil type. The best stage of fruit collection is when it is in greenish yellow or yellow in colour. As all fruits do not mature at the same time, they should be collected at regular intervals. Cleaning of shrubs and weeds from the forest floor or seed orchards is recommended to ease seed collection. Production of fruits varies with age of stands, ecological and stand conditions. The number of seeds per kg range from 1750 to 2500. Fresh seeds can be stored in bags in a cool dry place for about 3 months without losing much viability. Fresh seeds generally show a high germination rate of 95% (Anandalakshmi *et.al.*, 2016).

- Processing and Handling

  Transport of fruits to the processing site should be in open baskets or nets, not in plastic bags. In order to avoid fermentation, fruits should be brought to the cleaning area within 24 hours. This is especially important for fully ripen (yellow and brown) fruits. All possible care should be taken to avoid damage of fruits, since fermentation is more likely to start among the damaged fruits. At the processing site, the fruits should be sorted into those that are ready for immediate processing (yellow and brown colour) and green and green-yellow fruits, which will benefit from after-ripening. After-ripening is done in shade by spreading the fruits in a 10-15 cm thick layer until they have turned yellow.

  Depulping of small quantities of fruits can be done manually by mashing the fruits until the pulp is removed from the stone, and rinsing with water. A depulper is used if the quantity of fruits is large. Soaking the fruits in water for 24 hours before depulping will fasten the process. After depulping, the fruits are spread out on a wire-mesh tray and rinsed with water to remove juice and pulp. Normally traces of pulp will remain on the stones after depulping and further cleaning or polishing of the stones is required. This can be done either manually by rubbing the stones with sand and water or mechanically. Finally the stones are washed and dried well in the sun.

- Seed Storage

  Fruits which have been dried down to a moisture content of 5-8% and kept below this moisture content in cold storage (15 ° C), can be stored for almost a year without reduction in viability. If seeds will be sown within a year from processing, sun drying and storage in airtight containers is sufficient. Rodents may cause severe losses in stored stones and storing in metal containers prevents such losses.

- Dormancy and Pre-Treatment

  The seeds have no dormancy, and no pretreatment is required. Soaking of the seed in cold water for 24-48 hours before sowing is recommended.

- Sowing of Seeds

  Seeds are either sown directly in root trainers or in raised beds measuring 0.6 m in height and 1 m in width and in convenient length. The bed should be filled with sand up to a height of 0.5 m. Floating seeds should be discarded because they might be aborted, or non-viable, or both. The seeds are closely placed in rows at a depth of 1 to 2 cm and spacing between rows is 5 cm. The beds need to be to be watered twice a day.

  Seeds are sowed in loosened soil and covered thinly (0.5 to 1.0 cm) with soil. Germination occurs 7 to 21 days after sowing. The optimal temperature for germination is about 30 ° C and it should be noted that low temperature reduces germination. The seed bed should be exposed to sunlight with partial shade and full shade will reduce germination percentage. After germination, the seedlings can be transplanted to containers.

Selection and Testing of CPTs

Tree improvement programme of *G. arborea* was initiated during early 1990s. Fast-growing clonal accessions and seeds from clonal seed orchards is available in Rain Forest Research Institute, Jorhat. Institute of Forest Genetics and Tree Breeding has carried out intensive survey in natural forests and farmers plantations of Tamil Nadu, Kerala and Andhra Pradesh. 120 CPTs were selected based on growth superiority, clear bole length, pest and disease resistance.

Seeds were collected from the selected CPTs and progeny trials were established at Salem and Thuvarankurichi with 44 open pollinated families planted in randomized block design with a spacing of 4 x 4 m. Morphometric parameters were recorded for evaluating the growth performance of progeny. Standardized silvicultural techniques were also established for commercial cultivation of Gmelina in farmlands. The outstanding progenies were shortlisted for clonal multiplication. The quality seeds of selected genetic resources are available for sale in IFGTB, Coimbatore.

Clonal Propagation

Clonal propagation facilitates both production of planting material throughout the year and also increasing plantation productivity through multiplication of high-yielding clones. The best method of vegetative propagation in Gmelina is rooting of coppice shoot cuttings. Coppice shoot production is induced by felling the selected trees at a around 30 cm from ground level. Juvenile coppice shoots emerge 20-30 days after felling and 60 days old shoots with 15–20 cm length and 1.0–1.5 cm diameter are used for rooting. Cuttings are prepared by excising the leaves and treating with 1% aqueous Bavistin (2-methoxycarbamoyl benzimidazole) for 3 min. The top end of the cutting is sealed with paraffin wax to avoid moisture loss and bottom end treated with 2000 ppm of IBA. The cuttings are planted in 40 cc root trainers containing vermiculite as rooting substrate and placed inside a polytunnel (size :70 × 90 × 60, relative humidity: 80–90% and temperature: 30 ± 2 °C) under intermittent misting. The polytunnels were placed in a 70% shade house. New sprouts emerge from the coppice cuttings within a week and rooting occurs 30 days after planting. Rooted cuttings are transplanted into polythene bags containing red soil, sand, farmyard manure (2:1:1) and hardened in a shade house for 30 days before exposing to full sunlight. The clonal plants are ready for field planting 60 days after shifting to open sunlight.

Clonal propagation through mini cuttings: Mini hedges of Gmelina are established with rooted cuttings by planting them at a spacing of 30 × 30 cm in the mother bed chamber in a polyhouse. The top of hedges are pruned to promote axiliary shoot production. Generally cuttings with 3 – 6 axiliary shoots are used for the production of planting material.

IMPORTANT INSECT-PESTS AND DISEASES

Nursery

The major pests are Gamari weevil (*Alcides ludificator*) and Gamari leaf minor. The diseases that affect *G. arborea* are (*Fusarium* sp), root rot (*Sclerotium* sp), collar rot (*Sclerotium* sp) and Nodal necrosis (*Sclerotium* sp). Maintenance of prophylactic measures and application of systemic insecticide/fungicide in the nursery will manage the pest and disease infestation.

Plantation

Eupterote undata, Calopepla leayana (leaf defoliator), Beetles (*Periopterra maculipennis*) and White fly (*Aleuropapillatus gmelinae*) are the pests infesting the plantation. The diseases like leaf spot (*Glomerella cingulata*), Stem canker (*Griphosphaevia gmelina*), Stem griddle (*Phomesis gemelinae*), Pink disease (*Erythriciumsal monicolor*), Stem gall (*Agrobacterium tumifaciens*). Root disease (*Psedophaeolus baudoni*) and Heart rot (*Trametes straminia*). Wood borer (*Sahyadrasus malabaricus*) and ambrosia beetles are the stem insects. Introducing predators, parasitoids and bio control agent to manage the pest and disease are the biological means of pest control. Chemical control involves application of systemic insecticides and fungicide.

CURRENT RESEARCH FOCUS

The main trust of current tree improvement research in Gmelina is to develop and release high-yieling clones so that prospective growers of this multipurpose species are provided with site- and end use specific planting material. IFGTB has established collaborative clonal trail of Gmelina arborea at Forest Research Centre, Lingamalai, Tiruchirappalli, Suthamalli, Ariyalur and Veeranatham, Cuddalore. About 25 clones of Gmelina were planted in Randomized Block Design at a spacing of 5 x5 m in 3 replications and seedlings used as control. The clonal trials are being evaluated towards to release of high yielding clones for commercial cultivation.

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3.2 NEW VARIETIES AND CULTIVATION TECHNIQUES TO INCREASE PRODUCTIVITY OF LEUCAENA

INTRODUCTION

The genus Leucaena has around 30 species native to the tropics of Central and South America and Mexico. Around five million hectares of Leucaena plantations are available worldwide apart from those grown as patches and individuals in a range of landscapes. Considering its fast growth, regeneration potential, highly nutritive fodder and biological nitrogen fixing ability, its cultivation is regarded as the most productive and sustainable forage system in the tropics. The most significant introduction of Leucaena (*Leucaena leucocephala*) in India occurred during the late 1970s to meet the country's acute demand for fodder and fuel wood. It spread rapidly initially but did not become a major plantation crop until the turn of last century. The main reasons for this were the reluctance of farmers to use its fodder due to toxicity and other issues, difficulties in growing them into trees without expensive fencing since it is grazed by animals and the poor quality poles it produced. Its high natural regeneration through seed dispersal and ability to invade local vegetation was also a serious concern for its promotion. However, the importance of Leucaena as a pulpwood was realized by the paper industries in the country at the beginning of this century which again encouraged farmers to take up plantations. Currently it has a high socio-economic importance in terms of livelihood for smallholding farmers, industrial wood production and environmental amelioration.

EXTENT OF PLANTATIONS

The current extent of Leucaena plantations is estimated to be around 150,000 ha mostly in the coastal Andhra Pradesh and parts of Gujarat, Karnataka and Maharashtra. It is grown in small woodlots and individual trees throughout the country.

MAJOR USES

Leucaena is preferred by farmers for its many favourable attributes like wide adaptability, fast growth (rotation age 2 years onwards), nitrogen-fixing ability, coppicing ability, drought tolerance and stable market from paper industries. Paper industries prefer this species as pulpwood due to high pulp yield and various superior papermaking properties. Currently Leucaena wood meets approximately 10% of the pulpwood demand in the country (Fig. 1). The other uses of Leucaena are fuel wood, fodder and amelioration of mined areas.

CULTIVATION PRACTICES AND PRODUCTIVITY

The most concentrated plantations of Leucaena are located in the coastal districts of Andhra Pradesh where farmers take up intensive cultivation practices to fasten the growth and reduce the gestation period. Leucaena puts up the best growth in sandy and black cotton soils although it is adapted to other soil types as well. It responds well to irrigation and fertilizer application but can also be cultivated under rain-fed conditions.

Fig 1. *Leucaena wood transported to paper industry through railways.*

Nursery

Leucaena leucocephala produces abundant seed and has a high germination capacity

making nursery establishment one of the easiest among the woody species. Seeds are soaked in water overnight and dibbled in polybags or root trainers filled with standard potting media. Seeds are treated with Rhizobium culture before dibbling to enhance root nodule formation. Seeds germinate within a week and are grown under 50% shade for about a month and then transferred to open sunlight for hardening. Three month old seedlings are ideal for raising plantations.

Plantation Establishment

Since Leucaena is a fast-growing species farmers prefer to have high-density plantations. Trees are planted at a narrow spacing of 1 x 1 m or 3 x 3 feet to accommodate 10,000 or more trees per ha (Fig. 2). Seedlings are planted in holes made with a crowbar in well-ploughed soil during the rainy season (ideal time in the east coast is between October and December). A basal dose of 5-10 g superphosphate is added to each plant to enhance nodulation and increase survival and early growth.

Fig 2. *A young plantation of Leucaena.*

Varieties for Planting

As mentioned earlier, the main purpose of introducing Leucaena in India was fodder production. The varieties originally introduced had a bushy tree form with a short clear bole meant for a large crown formation and thereby higher fodder production. The new varieties developed by the University of Hawaii, USA have been found more suitable for wood production. The most popular varieties are K8 (“Hawaiian Giant”) and K636 (“Tarramba”). Since *L. Leucocephala* is a self-compatible species, seeds collected even from isolated trees possessed the same characters of the variety and also retained the vigour. Most of the seed used for raising plantations come from the existing plantations of Leucaena.

Plantation Management

Leucaena plantations can be grown both with irrigation and without it. Since the spacing between the trees is narrow, weed control may be necessary only for the first six months after planting after which the canopy closes-in to prevent any further weed growth. Leucaena is a nitrogen-fixing tree and there is no need to apply nitrogenous fertilizer but small doses of phosphorous fertilizer facilitates higher rate of biological nitrogen fixation by the bacteria and helps in faster growth of trees. Pruning of side branches is undertaken between first and the second years after planting to promote the growth of the main stem and to maintain a hygiene environment within the plantation.

Rotation Period and Yield

Leucaena is generally cultivated under 3 to 5 year rotations depending on the soil type, moisture availability, intensity of cultivation practices and prevailing market prices. Farmers even find harvesting irrigated plantations raised in fertile soils lucrative when the wood price is high. On an average 100 tonnes of pulpwood is obtained from a hectare. Leucaena has high coppice regeneration potential and the cut trees usually produce 3 or more vigorously growing stems which make the yield better in the second harvest than the first one. Farmers generally uproot the stumps after three harvests and replant the field.

TREE IMPROVEMENT

Although Leucaena was originally introduced to meet the fodder demand, currently the crop is mostly used as pulpwood for paper making. It is regarded as a highly suitable wood for papermaking with a pulp yield of 49.5% coupled with kappa

number of 20.7 (Umesh Kanna *et al*, 2011) With the acute raw material shortage faced by the paper industry there is a renewed interest in the cultivation and genetic improvement of Leucaena in India. In the past, efforts on domesticating Leucaena outside its natural range were towards increasing fodder production and quality and psyllid resistance (Hughes, 1998). The University of Hawaii, USA which has the largest collection of *Leucaena germplasm* has released a few accessions suitable for wood production. Some of them are also low seed producing and tolerant to psyllid attack (Brewbaker, 2013). The tree improvement of Leucaena in India should be aimed at increasing the pulpwood production and quality and reducing the fecundity to control its unintended proliferation.

Although many notable introductions of germplasm from native locations occurred in the past, no systematic tree improvement programme has been undertaken for wood production. During the last 40 years, the genetic base of the *Leucaena* germplasm has severely eroded resulting in low productivity of plantations and vulnerability to pest attack. The large area under cultivation, industrial demand and short economic and reproductive rotations are encouraging factors to undertake a long-term genetic improvement programme in Leucaena. Any genetic gain realized through such improvement will benefit both farmers and industries and also secure the germplasm from the threat of pests and changing climate.

Seed Source Evaluation

IFGTB conducted seed source evaluation trials to identify the best source for the current planting requirement and to select individuals for use as clones after tests or as accessions for seed production in orchards. Twenty nine seed sources were collected from the College of Tropical Agriculture and Human Resources, University of Hawaii, USA and different organizations located in five States of India. Three field tests were established at Neyveli (coastal), Dharapuram (inland, riverine) and Forest Campus, Coimbatore (inland) during 2014.

Although the collection of germplasm tested in the study is not exhaustive, highly significant levels of variation was observed for growth, form and wood properties at three years' age. The best performing seedlot in all locations produced at least 70% more volume of wood than the site mean. If we assume the site mean is an indication of the current level of productivity in Leucaena plantations, a simple seed source matching can substantially increase the wood production in farm forestry plantations. The consistent superior growth of improved varieties from Hawaii like K636 and KX36 suggests that they should be deployed in commercial plantations for immediate improvement in plantation productivity (Fig. 3). Seed Orchards for Leucaena should necessarily include these sources for enhanced genetic gain. Seed sources from different parts of India showed a large variation in growth and many were found to be inferior in growth and other characters. Any long-term genetic improvement programme should draw from the large gene pool assembled from native populations notably by University of Hawaii, USA and Oxford Forestry Institute, UK (Hughes, 1998; Brewbaker, 1995, 2013).

Fig 3. *Variation in growth, tree form and seed production among Leucaena seed sources. Trees on the left are K636 from Hawaii with erect stem form and low fecundity.*

The testing of Leucaena accessions in different locations indicated a large across-site variation for various characters particularly for clear bole height, stem verticality and stem form. The clear bole height was highly reduced in the coastal site (Neyveli) compared to other two sites. The ratio of clear bole to total height for Dharapuram and

Fig 4. *Variation in tree form in Leucaena: straight boles with large clear bole height in a riverine site (left) and short clear bole and stems with bends in coastal site (right)*

Forest Campus trials was 0.81 and 0.66 respectively whereas it was only 0.38 in Neyveli (Fig. 4). It is necessary to investigate the relationship between soil properties and early forking across different provenances and clones in Leucaena.

The wood density and moisture content values obtained for the selected trees compare favourably with values reported as suitable for pulpwood production. The bark thickness observed indicates a bark content of less than 5%. The moisture content around 45% coupled with the density value of 0.61 g cc-3 indicate higher recovery of pulpwood from the trees benefitting both farmers and industries. More detailed studies are required to understand the pattern of variation existing Leucaena for wood properties and to determine the relationship between wood properties and non-destructive assessments like pilodyn penetration.

Fig 5. *A CPT of Leucaena with vigorous growth, long clear bole and straight stem.*

Apart from variation among different seedlots for growth, stem form and pilodyn characters, there was also a large variation between individual trees within a seedlot. In order to capture this variation through clonal propagation, 30 outstanding individuals were selected based on growth and stem form traits. The mean of selected trees were 26% higher for height, 44% for diameter, 125% for volume index and 15% for stem straightness. The CPTs selected were found to originate from different seed sources in different locations indicating the presence of strong G x E interactions for growth and form traits. As mentioned earlier the clear bole height and straightness of stem were markedly different in riverine and coastal trials. The clonal trials involving the CPTs will be established in multilocations with adequate replications to undertake a detailed study on G x E interactions for growth and form traits of Leucaena.

Vegetative Propagation of CPTs

The selected trees were pollarded at a height of 1.5 m from ground level (Fig. 6) to induce juvenile shoot production. All selected CPTs produced juvenile shoots and one-month old shoot cuttings were used for rooting. At this age, the stem started becoming brown and lenticels were formed. The cuttings were 20 cm in height, treated with the rooting hormone IBA at 2000 ppm and kept in root trainers filled with decomposed coir pith. The root trainers were placed in polytunnels to induce rooting. Root initiation occurred after 10 days and roots emerged out of root trainers after one

Fig 6. *A pollarded CPT of Leucaena with vigorous coppice shoot growth.*

Fig 7. *Rooted cuttings of CPT of Leucaena.*

month. Rooted cuttings were hardened in 50% shade for a month and then transferred to open sunlight. The overall rooting was around 40% (Fig. 7). The cuttings produced so far were used to establish a Vegetative Multiplication Garden (VMG) to produce sufficient number of cuttings to undertake multilocation clonal testing in future.

PEST PROBLEMS

The psyllid*, Heteropsylla cubana,* is native to Cuba and is found only on Leucaena species and hybrids. They affect the plants by sucking the sap of young leaves, buds and flowers. The sugary excretions of psyllids are used by a fungus to colonize and this gives a sooty appearance to the plant. They are reported to cause an average yield reduction of 28%, ranging from 8% to 49%, with losses as high as 75% in conditions ideal for infestation.

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3.3 NEW VARIETIES AND CULTIVATION METHODS FOR MELIA TO ENHANCE PRODUCTIVITY

INTRODUCTION

Melia dubia is fast-growing and possesses strong potential as a reforestation and agroforestry species. It occurs naturally in the deciduous forests throughout the country. Traditionally the tree is grown as individuals or a small patch along farm bunds, homesteads and avenues. In the recent years, the impressive performance of trees grown in such environments triggered interest in raising them in block plantations. Raising plantations is more active in the Peninsular and Northern States and the current extent of plantations is estimated to be around 50,000 ha.

MAJOR USES

The principal use of Melia wood is for plywood manufacturing. Large sized trees are used as timber. In the recent years paper mills are also using young trees as pulpwood. Its utility in match industry is also being explored.

CULTIVATION PRACTICES

Growth Requirements

Melia dubia grows well in temperature range of 30-45 °C at an altitude of 650 – 1800 m. The species requires a mean annual rainfall of 750 – 2500 mm. It grows in well drained red, red loam and black loam soils with pH ranging from 5.5 to 7.0 and depth 50-150 cm, requires moderate soil fertility and can come up in soils with salinity of < 4 dS/m.

Silvicultural Characteristics

The tree is a heavy light demander, requiring full overhead light for development. Young plants are easily browsed, and hence care should be taken during the first year of planting. It is an excellent coppicer, coppicing profusely from large stumps, however, younger stems or stumps of one to two year old trees yield only a few coppice shoots. It produces root suckers freely. Six month old seedlings are suitable for raising plantations.

Soil quality, source of seedlings and spacing affect plantations. Seedlings obtained from natural populations show better growth than the seedlings from unknown seed sources. Clones show uniform and fast growth.At the end of seven years, clonal plantations with a spacing of 8 x 8 m recorded an average GBH of 100 cm while a seedling plantation of the same spacing showed about 60cm. The clean bole height was greater for clonal plantations than seedling-raised plantations, especially in closer spacing.

Spacing

The species performs best in wide spacing of 5 x 5 m in staggered rows, though lesser spacings of 4 x 4 and 3 x 3 are also adopted. Planting should be done prior to the rains. Pit size of 0.6 m^3 is essential. Irrigation is essential during the first two years, devoid of which the species does not survive even in good sites. Application of farm yard manure, twice a year during the first two years hastens growth.

Agroforestry

It is advisable to undertake regular intercropping with banana or sugarcane during the first two years followed by turmeric, groundnut or papaya once the canopy closes (Fig. 1). This is to facilitate regular watering and fertilizer application to the soil which enhances the growth of the tree crop without affecting the yield of the intercrop. It is also

Fig 1. *Melia in agroforestry system with wheat (left) and banana + turmeric (right)*

planted as inter crop among coconut trees. Groundnut, Blackgram and Greengram grow well as intercrop under *Melia dubia*. It also performs well as a bund plant for Casuarina, banana, drumstick and sugarcane plantations and Mango orchards. The species can form a three tier agroforestry system with tomato/turmeric. It is also grown as a shade tree in coffee and tea plantations.

CURRENT PRODUCTIVITY

Based on information from private plywood industries, the economics is worked out. Logs of Melia with Girth 60 cm and above can be used for core veneer. Such logs are saleable at a rate of Rs. 8500/- per tonne for ply industry. The match industry also takes log with 40 cm girth at Rs. 6500/- per tonne.

Spacing	8 x 8 m
Total trees planted (Block)	50/ acre
Total expenditure for plantation (includes cost of material, establishment, weeding, manuring, watering) upto maturity	1,00,000/-
Average height of the plantation after 10 years	7.84 m
Average girth of the plantation after 10 years	96 cm
Market value of timber (current price)	Rs. 600/- per cuft (logs with Ht >8.5 m and GBH 115 cm fetch higher prices)
Average value per tree	600 x 15 = 9000/-
Current value of the plantation*	9000 x 45 = 4,05,500/-
Net profit	3,05,500/-

** Cost of land not included. #Only clear bole is taken into account. Lops and tops are not accounted for.*

This performance of the species can be expected only under good maintenance and controlled irrigation upto atleast six years. Unattended plantations with weed growth, poor soil conditions, water logging, etc., do not produce logs of the desired size. If bund planting is taken up in a single row about 60 trees can be planted at six feet spacing which will fetch an income of about Rs. 4 lakhs in the sixth year, as trees planted along bunds have been recorded to put on girth faster than the block planted material. If the plantation is maintained for 30 years, the logs fetch higher prices (Rs. 750/- per cft) as the utility value of the wood is increased. The logs can be used for face veneer and the process is more akin to splitting for which larger sized logs are required.

NEW VARIETIES AND THEIR PRODUCTIVITY

Since Melia improvement is in its early stages, there are no benchmark accessions available for comparison with the new varieties released. The productivity of plantations raised with unimproved seed sources ranges from 10 to 12.50 m^3 ha^{-1} yr^{-1}. The average productivity of the released varieties has been estimated to be 34.57 m^3 ha^{-1} yr^{-1} ranging from 23.19 to 55.83 m^3 ha^{-1} yr^{-1}. The wood production by the new varieties in terms of weight is given in Table 1. These figures indicate that the productivity of Melia plantations could be increased up to 173.58 %. These varieties were also found to be generally doing well under drought conditions and saline soils (Fig. 2-5).

Fig 2. *An evaluation trial of Melia established by FRI, Deharadun*

Fig 3. *A Melia plantation established with a high-yielding clone released by FRI, Dehradun*

Table 1. *Productivity of clones of Melia dubia presently available in the market*

Clone	Growth and Wood Yield at 5 years		
	Height (m)	Girth (cm)	Yield (MT per ha)
GK-10	15.60	90.00	275.75
FCRI – MD1	16.68	51.00	182.16
FCRI – MD2	16.44	60.60	254.14
FRI/MD/235 SHARAD	14.33	80.79	223.32
FRI/MD/349 SHASHI	16.18	76.55	161.64
FRI/MD/032 BAHUMUKHI	123.3	73.26	159.16
FRI/MD/232 VARSHA	12.16	71.18	148.44
FRI/MD/241 KARTIK	15.21	72.00	134.84
FRI/MD/075 KSHITIZ	12.33	66.98	133.72
FRI/MD/262 AMAR	16.19	66.98	124.4
FRI/MD/231 MEGHA	12.17	60.07	106.92
FRI/MD/256 DEV	13.67	54.01	97.44
FRI/MD/261 RITU	9.67	62.58	92.76

Fig 4. *Plantations of Melia clone GKD-10, Tamil Nadu*

Fig 5. *Plantations of Melia clone FCRI-MD-01, Tamil Nadu*

INSECT AND DISEASE PROBLEMS AND CONTROL MEASURES

M. dubia is reported to be free from insect and disease incidence in north India. However, when it is grown under irrigated farmland conditions, it was observed that many insects and diseases cause damage to the tree. A brief description of major pest incidences and their control measures are given below:

Insect Attack

- Red Spider Mite

  The mite occurs in groups beneath the leaves and feed on the epidermal tissues. Chlorosis can be easily located on the adaxial side in infested seedlings. Low to medium level infestation was found during June to July and November to December. Application of Derrimax 0.3 ml/lit of water can control the mites.

- *Ascortis selenaria* - Defoliator

  A polyphagous defoliator attacks Melia seedlings during the rainy season June to July and November to December. The main host is *Prosopis juliflora*. It also occurs in *Peltoforum ferrugenium, Santalum album, Delonix regia* etc. At low infestation level, handpicking of caterpillars can be done to manage the pest. Adults are usually attracted to light and therefore light traps can be installed for a week after the first showers. At high infestation level Methyl parathion (2 ml/lit) can control the pest.

- *Ferrisia virgata*- Mealy bug

  Occasional incidence of mealy bugs was noticed at low levels in seedlings. Period of occurrence is March- April. Application of Neem oil, tobacco extract directed towards the underside of the leaves can control the scales. Spraying of foliage with Dimethoate 0.05 to 0.075 % water clipping and destroying severely affected branches and or fish oil rosin liquid at 2% conc. with neem oil controls the pest.

- Leaf Miners

  Leaf miners also damage the leaves in nursery seedlings. Very low level incidence was observed in seedlings.

- Fruit Infesting Beetles

  Fruit pulp of fallen fruits is eaten by beetles. Seeds during storage were also found to be attacked by unidentified beetles.

- *Parlatoria* sp.

  Occasional incidence of mealy bugs was noticed at low levels in seedlings. This scale attacks the young plants all above ground parts of the trees particularly the bark of the stem and leaves. Severity of this pest leads to drying up of the plants. Occurrence is observed in Feb – April. During severe infestation 0.065% dimethoate or 0.05% methyl dematon can be sprayed.

- *Empoasca* sp.

  Occasional incidence was noticed at low levels in seedlings. Occurrence is observed in Feb – April. The nymphs emerge from the egg shell is enclosed in a membrane which ruptures immediately after emergence is nymphs are more or less transparent. They rest closely pressed to the surface of leaves and suck the sap of the leaves. The adult leaf hopper feeds on green shoots. The nymphs and adults suck the sap of the leaves and tender shoots in the nurseries and in young plantations resulting in chlorosis or discoloration of leaves. Mechanical control could be achieved by using light trap or sticky traps for the nymphs. Adults can be collected and destroyed. Good control can be achieved by spraying 0.1 % Dimethoate or 0.15% DDVP.

- Thrips

  Minute, black thrips infest young shoot tips resulting in the disfiguration of leaves when they expand or drying during severe infestation levels. Feeding by adults and young ones in group results in curling of young leaves during Feb – May. Spraying of 0.2 % Dimethoate will bring down the pest population levels.

Diseases

The following are the major disease incidences observed in Melia particularly in the nursery stage:

Name	Age of Attack	Symptoms	Causative Organisms	Control Measures
Leaf blight	6-12 Months	White flies followed by necrosis at tip of the leaves	*Helminthosporium* sp. and *Alternaria* sp.	Application of Indofil M-45 or Blitox or Sulphur based fungicides.
		Necrosis at tip of the leaves	*Colletotrichum* sp.	0.1% of Carbendazim 50% (Add 0.1 g of Carbendazim 50% in 100 ml water)
Root rot	6 Months	Wilting of leaves followed by plant death	*Fusarium* sp.	Application of bio-control agents *Trichoderma viride* and *Pseudomonas fluorescens* to the infected trees and also other uninfected trees as prophylactic measures to prevent the spread of the disease pathogen.

CURRENT RESEARCH FOCUS

Reports state that large-scale planting is hampered by poor seed (< 10 %) germination, despite producing abundant quantities of fruits. A study was conducted to understand reasons for poor germination in this species. Fruits collected from isolated trees, plantations and natural populations were observed for their physical characteristics. Seed filling was observed in depulped fruits and viability of seeds tested. Fruits collected from single trees were one seeded or unfilled while fruits collected from natural populations had all locules filled. Fruits from plantations raised from a single seed source showed poor filling, while plantations raised from different seed sources showed better filling. Germination and

seedling fitness showed a similar trend with seeds from natural populations having as high as 75 percent germination as against the reported ten percent in literature. Seedling survival and vigour were also greater for seeds from plantations. This clearly indicates a strong tendency for outcrossing in the species, though it is also clear that there is a considerable potential for selfing. Hence care should be taken to collect fruits from natural stands/plantations as selfing and limited mobility of pollen in single trees would result in reducing variation within the species resulting in a reduction in quality and quantity of the planting stock leading to plantations with low productivity.

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3.4 PRACTICES FOR ENHANCING PRODUCTIVITY OF *SANTALUM ALBUM* L. (EAST INDIAN SANDALWOOD)

INTRODUCTION

Sandalwood (*Santalum album* L.) commonly known as East Indian Sandalwood is historically interwoven with Indian culture and heritage. Sandalwood is a hemi root parasite tree species and requires a host plant for survival and growth. Sandalwood is believed to be indigenous to peninsular India though naturalized plantations are available in many parts of India including Assam in North east.

MAJOR USES

Sandalwood trees are source of highly prized and fragrant heartwood. The essential oil is commercially known as "East Indian sandalwood oil" which is one of the oldest perfumery materials. Heartwood yields fragrant sandalwood oil. The oil is an excellent fixative and base for other high grade perfumes. It is also an antipyretic, antiseptic, antiscabietic, diuretic and used as cure for bronchitis, diseases of urinary tract and migraine in indigenous medicine system. The wood paste is an ointment to dissipate heat and used as beauty aid. The wood is used in carving and handicrafts and incense stick making and is also used for religious rituals in Buddhism, Hinduism and Islam .

AREAS / SOIL TYPES SUITABLE FOR CULTIVATION

In India, *Santalum album* is distributed all over the country and more than 90% of the area is in the States of Karnataka and Tamil Nadu covering 8300 sq.km. In Karnataka, it grows naturally in the southern as well as Western parts over an area of 5000 sq.km. In Tamil Nadu, it is distributed over an area of 4000 sq.km and dense populations exist in North Arcot (Javadis and Yelagari hills) and Chitteri hills. In Kerala pure natural sandalwood forest can be seen in a 15 sq km patch in Marayoor Sandalwood reserve where close to 62,000 mature trees have been enumerated. The other States where sandal trees are found are Andhra Pradesh, Maharashtra, Madhya Pradesh, Odisha, Rajasthan, Uttar Pradesh, Bihar, Assam and Manipur. The tree flourishes well from sea level up to 1800 m altitude in different types of soils like sandy, clay red soils, laterite loam and even in black cotton soils. Trees growing on stony or gravelly soils are known to have higher scented wood. It flourishes well in moderate rainfall of 600 to 1600 mm in cool climate with long periods of dry weather, but adapts well to different climatic conditions excepting water logged or very cold places. It grows well in early stages under partial shade but at the middle and later stages shows intolerance to heavy overhead shade.

AVAILABILITY OF GENETICALLY IMPROVED VARIETIES/PLANTING MATERIAL

Quality planting material (QPM) of sandalwood currently available is through seeds only. However, there is no authentic source for seeds or planting material except Institute of Wood Science and Technology (IWST), Bengaluru, Karnataka Soaps and Detergents Limited (KSDL) and Marayoor Forest Division, Kerala Forest Department (KFD). IWST Bangalore collects seeds from its own germplasm bank in campus and in Gottipura Field Station, Hoskote. KSDL also does the same. Kerala Forest Dept collects seeds from its Sandalwood reserve forest spread over 15 sq km and having around 62,000 recorded sandalwood trees through local communities in a participatory approach. A limited quantity of seeds is also procured by IWST and made available to stakeholders/farmers at a price of around Rs. 1000 per kg. (see website htpp://www.iwst.icfre.gov.in). Micropropagated plants of sandalwood is currently not available anywhere in the Indian market scenario though efforts are underway in IWST to standardize the full tissue culture protocol. QPM of sandalwood plants through seed origin are available at KSDL nurseries in Shimoga and Mysore @ Rs. 15/plant and in IWST limited quantities are available @Rs. 30/plant as per 2017-18 rates. The Karnataka Forest Department through its nurseries in Srinivasapura, Kolar district also makes effort to produce large quantities of QPM of sandalwood seedlings through seed.

MODERN CULTIVATION PRACTICES

Fig 1. *Raising QPM of sandalwood through seeds*

IWST has standardized nursery practices to raise quality seedlings of sandalwood. Seed collection, handling, storage and germination methods have been standardized in IWST after a series of nursery experiments. Freshly collected sandal fruits from IWST seed collection areas are depulped and dried in shade. Seeds are soaked for 16 hrs in Gibberellic acid (500 ppm) before sowing in germination beds with a dimension of 1x10 m composed of fine river sand with underlying gravel layer. Seedlings at 2-3 leaf stage are pricked and transplanted in 270 cc root trainers containing potting media consisting sand: soil: compost in the ratio 35:15:50 with *Mimosa pudica* or *Cajanaus cajan* as primary host. Media is supplemented with NPK + micronutrients as foliar spray at 15 days periodic intervals. As prophylactic measure Dithane M-45 (0.25%) and Ekalux (0.02%) are sprayed at monthly intervals. Healthy plantable seedlings having a height of 30-50 cm and collar diameter of 3.0 mm turning brown at the base, referred to as quality planting stock is ready in 6 months time (Fig. 1). The production cost per seedling works out to around Rs. 20/- excluding supervisory cost and capital investment cost on infrastructure.

With the Karnataka Forest (Amendment) Act 2001 of substitution of Section 83, which recognizes the right of occupant or land holder to be legally entitled to the sandal tree in his land, there has been a marked demand from private entrepreneurs and farmers for raising private plantations. High demand of sandal wood and remunerative prices of sandal heartwood have motivated private individuals to take up sandal cultivation on farmlands even though protection issues are still to be addressed. Farmers have shown preference for horticultural species like Indian goose berry (amla), grafted mango, pomegranate, citrus, sapota, guava, ber, instead of conventional host trees with an objective of obtaining intermediate returns during the long gestation of sandal.

Based on data available from IWST sandalwood agroforestry demonstration plots in 2008, the economics of sandalwood agroforestry practices were worked out. In sandal agroforestry a spacing of 6x3 m with amla at the same spacing in between sandal in quincuxial design of planting appears to be promising. This spacing also ensures cultivation of agricultural crops like horse gram or field bean or low spreading legume fodder during the initial years. Currently 5 x4m spacing appears to be more favored by farmers with host plant planted 2.5m distance within the sandalwood row between two sandalwood plants separated at 5m distance and 4m between the sandalwood rows to promote intercultivation of annual crops like horse gram, pulses etc. This spacing also ensures cultivation of agricultural crops like horse gram or field bean or low spreading legume fodder during the initial years. The cost of raising sandal based agroforestry plantations may be marginally higher than raising sandal block plantations due to additional intercultural operations. However this may be more than offset by periodic additional returns from horticultural crops. Sandal plants are expected to establish and perform well in intercropping since periodic intercultural operations can improve soil physio-chemical properties. However there is a paucity of data on sandal growth and related heartwood formation in sandalwood under actual agroforestry situations. To accommodate more plants per ha, a spacing of 4x4 m with a long term host like *Casuarina equisetifolia* in the center also at the same spacing in quincuxial design of planting appears to be popular.

The total cost of cultivation over the 15 year period works out to Rs. 19.87 lacs/ha and the total benefits around Rs. 143 lakhs/ha. Of the total cost nearly 30% works out to be protection costs. The revenue from sandal tree extraction and processing in 15th year works out to Rs 25,000/tree (sapwood, heart wood and mixed wood including). In the 20th year Rs. 31,400/ tree was estimated when the heartwood out turn from a 15 year old tree was estimated at 3kg/tree and 4

Fig 2. *Sandalwood based agroforestry model with Pomegranate as secondary host at 5x4 m espacement.*

kg/tree in 2008 which were entirely based on projections. (IWST, 2008). However recent estimates in 2017 have put the figure at 15-20kg heartwood/tree. An assessment of viability of different sandal based agroforestry models viz, sandal monoculture plantations and sandal intercropped with another perennial *Emblica officinalis* Gaertn. (amla) and an annual *Macrotyloma uniflorum* (Lam.) Verdc. (horse gram) using indicators like Net Present Value (NPV), Benefit Cost (B/C) ratio, Internal Rate of Return (IRR), Equivalent Annual Income (EAI) at different discount rates for two different rotation periods (15 and 20 years) to determine a financially optimal model showed that all the options were financially viable.

However, for the farmer who prefer regular cash flow, the sandalwood + horticultural species as long term secondary host + annual crops in a 15 year rotation is recommended. In recent times farmers have preferred to have spacing of 5 x4 m with the long term secondary hosts like amla, pomegranate, citrus etc (Fig. 2). In between two sandalwood trees at a distance of 2.5m on either side within the same row and leaving 4 m distance between the sandalwood rows for intercultivation and intercultural operations. Long term secondary hosts like *Casuarina equisetifolia* and *Melia dubia* at the same placement are also being tried out by farmers.

PEST AND DISEASES

Spike disease is one of the important diseases of sandal. This disease is caused by mycoplasma-like organisms (MLO). It can occur at any stage of development of the tree. As the disease progresses, the new leaves become smaller, narrower or more pointed and fewer in number with each successive year until the new shoots give an appearance of fine spike. At the advance stage of disease the internodal distance on twigs becomes small, haustorial connection between the host and sandal breaks and the plant dies in about 2 to 3 years. Spread of disease is sporadic and the disease is transmitted in nature by insect vectors. It has been found that other insect vectors in addition to *Nephotettix virescens* may also be responsible for transmission of disease. So far no permanent remedial measures have been prescribed for control of spike disease. Stem borers *Zeuzera coffease* Nietn (red borer) *Indarbela quardinotata* Walker (bark-feeding caterpillar) and *Aristobia octofasiculata* Aurivillius (heartwood borer) are some of the pests causing considerable damage to living trees.

DURATION OF CULTIVATION AND EXPECTED YIELD

The duration or rotation that can be recommended for sandalwood is highly variable and largely dependent on edapho-climatic factors and genetic factors (origin of seed/planting material). In natural forests the growth is slow and a MAI of one cm/year is reported. Under cultivated conditions and MAI of around 5cm/year has been noticed till the heart wood initiation in the tree which normally happens around 7-8 years age after which there is a decline in MAI. Hence the rotation can vary between 15 to 20 years. For the farmer who prefer regular cash flow, the sandalwood + horticultural crop as secondary host + annual crops at least in initial 6 years in a 15 year rotation is recommended. At around 15 years, an

average heart wood yield in the range of 15-20 kg/tree may be expected from the stem and roots plus some mixed wood and sapwood.

AVENUES FOR MARKETING

Currently Government subsidiaries like Karnataka State Handicrafts Development Corporation (KSHDC) and Karnataka Soaps and Detergents Ltd (KSDL) and State Forest Departments are authorized to procure and deal with sandalwood from private cultivators. However, the high retail price of sandalwood has not translated into matching remunerative profits for farmers when sandalwood grown in farmlands is sold to Government agencies. In 2017, the average procurement price of sandalwood from farmers by KSDL was Rs. 6400/kg of heartwood and a 15 year old tree is estimated to yield at least 15kg heartwood under cultivated conditions. Thus there appears to be a huge gap between procurement price of sandalwood by govt agencies and retail price sold by them through their outlets which is a disincentive for sandalwood farmers. Despite this anomaly, there is an increasing demand for sandalwood seedlings over the past decade. National Medicinal Plant Board through its subsidiary State Medicinal Boards has initiated various schemes to promote sandal cultivation. The demand of sandalwood seedlings in Kolar district of Karnataka alone is estimated to be 5 lakhs annually.

Fig 3. *Grading sandalwood billets in Marayoor depot, Kerala Forest Dept*

FARMERS' EXPERIENCE/SUCCESS STORIES

Though there is a paucity of authentic data on sandalwood cultivation across India, currently it is estimated that more than 20,000 ha of sandalwood plantations is available under various age groups. In Karnataka alone more than 3000 ha and in Gujarat > 10,000 ha is under sandalwood based cultivation practices. Most of these plantations are around 8-10 years old and there are few reports of mature plantations being harvested. There has been still fewer reports regarding growth and yield of heartwood in sandalwood under cultivated conditions. Recently in 2017, KSDL had procured around 75 mature sandalwood trees (18 years age) having a gbh ranging from 60 to 75cm from a farmland in Nelamangala 40 km from Bengaluru. On an average the trees yielded 15kg heartwood and around 6 kg mixed wood and were valued at Rs. 22,000 /tree. KSDL valued the trees after fixing a rate of Rs. 6400/kg heartwood, Rs. 2000/kg mixed wood, Rs. 80/kg of sapwood and Rs. 30/kg bark and chips (KSDL, pers. comm.).

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4

EMERGING SPECIES

4.1 TREE IMPROVEMENT OF *AILANTHUS* SPECIES FOR INCREASING PRODUCTIVITY

INTRODUCTION

Among the 10 species of the genus *Ailanthus* (Family: Simaroubaceae), *A. excelsa* and *A. triphysa* are the commercially important species. *Ailanthus excelsa* (Roxb.) Pierre is popularly known as the Tree of Heaven and also as *Madala* (Sanskrit), *Maharukh* (Hindi), *Arduso* (Gujarati) and *Thee maram* (Tamil). It is commonly found in farm bunds, along railway tracks, roadsides and in foothills (Fig.1). It is cultivated as pure plantations in Tamil Nadu for wood production and in Rajasthan and Gujarat for fodder production. Although *A. excelsa* is grown throughout the country except in the Himalayan region, information on the extent of plantations is not available due to its scattered occurrence. The tree is known to grow for 50 years and more attaining large dimensions but commercial wood production is achieved from the sixth year onwards.

Fig 1. *Ailanthus excelsa tree*

A. triphysa (Dennst.) Alston (syn. *A. malabarica* DC.) naturally grows in the evergreen forests up to 1500 m in the Western Ghats region and Andaman islands. It was initially grown as mixed plantation along with Teak, Bombax and Evodia but later raised as pure plantations due to its commercial demand. In Kerala, there are about 2500 ha of mixed plantations and 533 ha of pure plantations. It is an important component of the homesteads of Kerala which is a major source of matchwood.

MAJOR USES

The wood of *A. triphysa* is the most preferred wood for match splints followed by *A. excelsa*. Leaves of *A. excelsa* are used as fodder particularly in arid regions of Gujarat and Rajasthan. It also yields an inferior type of Hog gum. Ailanthus trees are also planted as ornamental and avenue trees in parks, roadsides, gardens and other areas.

TREE IMPROVEMENT

Tree improvement of *Ailanthus* species is in the early stages. As in any other tree species, the need for tree improvement is felt only when the supply heavily falls short of the demand. Traditionally the need for matchwood has been met through supplies from *A. triphysa* grown in forest plantations and homesteads. When this supply started dwindling the industry adapted its manufacturing techniques to make use of the less preferred wood of *A. excelsa*. But currently even *A. excelsa* wood is not available to meet the huge demand and the industry is mainly depending on import of poplar wood from Europe. Thus there is a clear case for investing in tree improvement of Ailanthus to increase plantation productivity leading to meeting industrial demand for wood and reducing dependence on imports. Tree improvement activities for *A. excelsa* started in the ICFRE institutes viz., Arid Forest Research Institute (AFRI), Jodhpur and Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore nearly a decade ago. Tree improvement of *A. triphysa* has been recently initiated in Kerala Agricultural University (KAU), Thrissur.

Provenance-Progeny Testing

A multilocation provenance-progeny testing involving around 80 accessions has been conducted by IFGTB in different agro-climatic zones of Andhra Pradesh and Tamil Nadu. These accessions were drawn from the States of Andhra Pradesh, Karnataka, Rajasthan, Gujarat and Tamil Nadu forming a broad genetic base for continuous genetic improvement. Significant differences were found among the provenance-families for growth, stem form and wood properties. Leaves of these accessions were also subjected to analysis of fodder value and found significant differences among them for moisture, crude protein, crude fibre content and presence and anti-nutrient factors (Sumathi *et al.* 2017). These trials are around 10 years old and selection of CPTs has been made based on growth, stem form and branching habits. Since flowering has not commenced in most of the trees in the trial, thinning of the plots to convert them into seed orchards has been deferred. Meanwhile efforts are made to vegetatively propagate the CPTs and subject them to multilocation clonal testing.

Fig 2. *A provenance-progeny trial of Ailanthus excelsa at Salem, Tamil Nadu*

Fig 3. *A progeny trial of Ailanthus triphysa at Thrissur, Kerala*

The Kerala Agricultural University has established a progeny trial of *A. triphysa* with 20 open-pollinated family accessions of CPTs selected in Kerala (Fig. 3). The trial established in 2016 was assessed for early growth, tree form and wood properties to understand the variation between the families. Families showed significant variation for growth (growth, collar diameter and volume), stem straightness, branching habit, wood density and fibre traits. The results showed that there is good scope to undertake both forward (selection of outstanding individuals in the family trial) and backward (selecting the CPTs based on the progeny performance to establish seed orchards) selections to increase productivity of *A. triphysa*.

Ailanthus trees show different sexual systems. Trees may be monoecious or dioecious. Female flowers may have stamens, but these do not contain pollen (Nooteboom, 1962). As per literature, flowers might also be bisexual, but empirical data on the occurrence and proportion of flower types in different populations are scanty. Tomar *et al* (2014) reported that female trees showing better productivity than male trees in terms of height and diameter growth. Nooteboom (1962) and Hu (1979) never observed bisexual flowers. Possibly, some authors address female flowers with sterile stamens as bisexual or 'hermaphrodite'. Further, male inflorescences are larger and produce more flowers than those on a female plant (Hu, 1979). Till date no information is available on the ratio of male and female trees available in nature. Because of these biological features, the seed orchards need to be established carefully when there are no morphological, biochemical or molecular markers available to distinguish the sex of the tree.

Vegetative Propagation

- Rooting of Stem Cuttings

  Vegetative propagation of this species is difficult and many challenges are faced at different stages of vegetative propagation like low percent of rooting of cuttings. Percentage of rooting has been reported from a mere 5.3 to 38 in *A. excelsa* and 65 in *A. triphysa* (Sharma and Tomar, 2003; Mamata and Rao, 2014, Bachpai *et al.* 2014). Large variation in rooting behaviour was observed among different CPTs selected for vegetative propagation. Even those cuttings that successfully rooted in the mist chamber/polytunnel struggled to develop into plantable saplings while hardening. They either grew very slowly or gradually dried up despite the best care given in the nursery. Several factors are attributed to such poor performance of rooted cuttings like poor root-shoot development, presence of gum ducts or unsuitable potting mixture.

- Grafting

  Grafting techniques were developed for *A. excelsa* at AFRI as an alternative vegetative propagation method (Tomar *et al*. 2004). Grafting helps in selective propagation of female and male trees for gender-identified clonal testing and for specific deployment in seed orchards. Out of two methods of grafting viz. wedge and patch grafting, wedge grafting yielded better results. This was the first report on successful grafting in Ardu though the success rate was very poor (only 10%) and it was not viable for large scale production of clonal plants through this method.

  In the light of above review ,it is clear that there is a great need to develop more effective clonal propagation technique for *Ailanthus* species .The successful clonal forestry practiced for Casuarina ,Eucalyptus ,Poplar and Teak is mainly due to the availability of cost effective and highly successful method of vegetative propagation . Similar methods have to be developed through intensive research in Ailanthus so that its productivity could be improved through clonal forestry or production of genetically improved seeds from clonal seed orchards .

Clonal Testing

Female plants in case of Ailanthus excelsa were found to be more vigorous than the male plants in all growth parameters of above ground ,which can be useful for Agroforestry planning and also help in the improvement of the economy for the farmers .The 3 .I2 Irrigation treatment was best fitted for both types of trees and the differences between female and male trees were also maximum on all growth parameters

Assessment of growth and biomass viz .plant height ,collar diameter ,crown size ,stem height ,fresh weight of stem , fresh weight of branches ,fresh weight of leaves ,number of branches ,fresh weight of root ,number of primary root , length of primary root ,number of secondary root ,number of tertiary root ,between male and female trees were done . The observations show that female trees are superior to male trees in all the characteristics except length of primary root .Length of primary root of male trees was found to be longer than that of female trees .Maximum difference was seen within fresh weight of leaves and number of branches ,in which females are 70 97% and 68 97% superior to males ,respectively .Least difference was seen within number of primary roots ,where the value comes out to be only 13 3% in favour of female trees .While male trees were superior to female only in length of the primary root by the proportion of 1 5% which was statistically insignificant .

The rotation of *A excelsa* is considered as 30 years ,but it was found to grow up to 50 years or more .Leaf fodder from one tree is available for at least 30 years .It is estimated that an average tree gives about 1 ,2 and >4 quintal green leaf fodder per year when it attains the age of 5 ,10 and >20 years respectively (*et al* 2011).In addition to the leaf fodder the wood of the tree also has good value in the fuel ,matches and wood packing industries .Through grafting we get 25% increment in the stem height which can yield a good amount of wood per tree to the farmer .This can also increase the total profit of the farmer after compensating the total cost of plantation through grafting .Cost of raising grafted plants is four times higher than through seeds but gender of plant cannot be guaranteed through seeds .

Field trial shows an increment of around 60% through grafting female plants over male plants in leaf fodder yield at five year age. Female plants also exhibit higher growth in fuel wood and timber. Calculations form demonstration trial indicates that the initial higher cost of raising plantations of grafted female plants is recovered within five years through fodder only. Thereafter plantation starts yielding profits up to 20 years. After every 5th year onwards, leaf fodder is just double from the previous year. I1 irrigation schedule was the best for all above ground parameters of growth. In I1 treatment 45 litre water was given to each tree at interval of 20 days in summer (March to June) season and 45 days during winter (October to February) season.

INSECT AND DISEASE PROBLEMS AND CONTROL MEASURES

Pest incidence was found to be one of the major hindrances to the growth of the species. Bioassay using *Bacillus thuringiensis* (Bt) was found to be effective against both the lepidopteran defoliators, *Eligma narcissus* (Cram.) and *Atteva fabriciella* Swederus. In case of *E. narcissus*, median lethal dose (LD50) was achieved with 10 % concentration of Bt whereas in *A. fabriciella*, 2.5% Bt concentration was found to be effective. Neem oil showed a clear antifeedant activity against *E. narcissus*, the feeding rate was reduced to 3.58 % in 2 % neem oil treated leaves as compared to 30.91 % in control. Scoring of pest incidence was found to be non significant among the progenies, all the progenies affected moderately by both *E. narcissus* and *A. fabriciella*.

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4.2 NEW VARIETIES AND CULTIVATION PRACTICES FOR *NEOLAMARCKIA CADAMBA* TO ENHANCE PRODUCTIVITY

INTRODUCTION

Neolamarckia cadamba (=*Anthocephalous cadamba*) is an evergreen tropical tree belonging to the family Rubiaceae and native to South and Southeast Asia. It has scented orange flowers in dense globe-shaped clusters. The tree is grown as an ornamental plant and for timber, paper making, pencil, matches and plywood industries. Cadamba features in Indian religions and mythologies and literature extensively records its medicinal value. The major constituents of the plant are triterpenes, triterpenoid glycosides, flavanoids, saponins, indole alkaloids; cadambine, cadamine, isocadambine, isodihydrocadambine. Wood-based industries are exploring utilizing kadam for manufacturing paper, pencil, matchstick and plywood.

NATURAL DISTRIBUTION AND EXTENT OF PLANTATIONS

It has a worldwide natural distribution in Australia, Bangladesh, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Nepal, Papua New Guinea, Thailand, Sri Lanka and Vietnam. It occurs throughout southern central and north east India and Andaman Islands.

Private pencil industries has raised 170 acres of cadamba plantation in Narasipuram and Devarayapuram in Coimbatore district, Tamil Nadu. In Assam they are raised as an agroforestry plantation by planting the seedlings in the bund. Other than that, IFGTB has extended the cadamba plantations in Tamil Nadu and Kerala as demo trial, progeny trials and clonal trial. Although individual trees are planted widely in homesteads, community lands, parks and avenues, farmer are yet to benefit from this tree through large scale block plantations.

MAJOR USES

Pencil, plywood, matches and pulpwood industries, high medicinal value of all parts of the plant, ornamental, fodder for livestock, edible value for fruit, bark, leaves, root etc, and for hair oil, fragrance scent, attar, soap, face cream, shampoo, wine, green tea etc.

TREE IMPROVEMENT

Considering the potential of *N. cadamba* for meeting the demand for industrial wood through cultivation of indigenous tree speices, IFGTB has initiated long-term tree improvement programme for this species during 2010-11. Extensive surveys were carried out and CPTs were selected based on superiority in growth, stem form, branching habit and wood properties. The selected trees were vegetatively propagated and also raised their progeny through open-pollinated seeds. Multlocation trials and demo plots have been established in different agroclimatic conditions in Tamil Nadu.

Demo Trials established by IFGTB in Tamil Nadu

- Namakkal (farmer field)
- Kenipet, Villupuram District (farmer field)
- Kollathoor, Salem District (farmer field)
- Tindivanam, Villupuram District (KVK- TNAU field)

Proegeny/Clonal Trials established by IFGTB

- Gudalur Research Station, Maraimalainagar, Chennai (including a clonal trial)
- Neyveli Research Station, Villupuram District
- Thuvarankurichi Research Station, Tiruchirapalli District

Establishment of more clonal trials is underway to select the most outstanding and stable accessions for public release.

CULTIVATION PRACTICES

Spacing: 2 x 2m for pulp wood purpose and 3m X 3m or 4mx3m / 4 x 4m for plywood/match/pencil wood.

Planting Method

Digging of pits should be minimum of size 45 x 45 x 45 cm with required spacing and manuring of about 3-5 kg of FYM or vermicompost per pit. Digging can be carried out either by manual or by machine

Post-Planting Operations

After planting, soil work has been done. Watering should be done weekly two times. To maintain the cadamba field, weeding has to be carried out once in a month during summer period and at fortnight interval during rainy season. Pesticides are used to control *Cossus cadambae* stem borer insect attack. Pruning of side branches is important after 6 months of planting to diminish the branch growth and pruning should be done without causing damage to main stem to prevent the above mentioned borer attack.

Rotation Period

For pulp wood purpose we can fell the tree after 3-4 years (up to 5 cm at commercial height) and for pencil, matches plywood industries the tree can be felled after 6 years i.e, if it attains more than 13 inches girth (up to 13 inch girth at commercial height) .

Current Productivity

Prior to introduce and cultivate in farmers field, economics on cultivation of cadamba biomass estimation of 3-8 years old trees were studied, at eight years, average weight comes around 225-275 kg/tree.Market survey was also done ,it fetches around Rs. 7000/- tone if the log is around more than 23 inches it fetches around Rs. 350-400/- cubic feet(>10000 per tones).

Rotation (years)	Number of trees/ ha	Mean yield per tree (kg)	Wood yield (tonne per ha)	Sale price per tonne (Rs.)	Income per ha (Rs.)	Cost incurred per ha (Rs.)	B/C Ratio
8	500	225	112	7000	7,84,000	1,28,050	2.06

PEST PROBLEMS

Cossus cadambae is an insect borer which infests the whole cadamba plant. To control this problem, insecticides carbaryl, acephate, fenvalerate and permethrin has to be sprayed to the young plants.

CURRENT RESEARCH FOCUS

Currently multilocation clonal trials are raised to select and release of high yielding clones. Efforts are taken to popularize cadamba among the farmers, industries as an alternate tree crop for pulp and paper, plywood/match wood. The possibility of developing bio products from cadamba like Cadamba Wine, Chutney, Sambar, Cosmetics from fruits and Green tea, Shampoo, Attar, Bath soap from leaves is also being explored.

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4.3 PLUS TREE SELECTION AND ESTABLISHMENT OF SEED PRODUCTION AREAS FOR INCREASING PRODUCTIVITY OF *CEDRUS DEODARA*

INTRODUCTION

Deodar *(Cedrus deodara)* is a high value timber species of the Western Himalayas. Although it has a restricted natural distribution and limited areas with plantations, the majestic deodar forests are regarded as a natural heritage and calls for improved plantation technology to increase production for highly acclaimed deodar timber. Deodar along with *Pinus roxburghii , Pinus wallichiana, Picea smithiana, Abies pindrow* and *Quercus* species occurs naturally in the hilly terrain of Western Himalayas on the ridges forming vegetational bands. *Cedrus deodara* is found growing right from Afghanistan to Garhwal up to the Valley of Dhauli River below the Niti pass at elevation ranging from 1200 m to 3050 m (Tiwari, 1994), but has not been worked upon to exploit the variability in tree improvement programme. The altitudinal range of deodar is usually higher on the southern than on the northern slopes and the tree grows best and reaches its largest dimensions in cool situations on northern aspect. The great majority of best deodar forests are found where the rainfall varies from 1000 to 1800 mm mainly from July to September with snow from December to March. However, the pure forests are especially typical of the inner dry valleys. At higher elevations it occurs only on sunny areas but generally found on all the important geological formations and attains best growth on deep, fairly porous, fertile soil and cool situations.

MAJOR USES

Deodar wood is valued for high priced timber and was formerly extensively used for building railway sleepers and other purposes for which durability is required. The wood of deodar possesses diaphoretic, diuretic and carminative properties and is useful in fevers, piles, and pulmonary and urinary disorders.

SEED REQUIREMENT FOR CURRENT PLANTING PROGRAMMES

Plantations of deodar are regularly raised by the State Forest Departments (SFD) of Himachal Pradesh and Jammu and Kashmir every year in various divisions. (1,504 ha area was planted under deodar by HP SFD during 2011-12 of the total 13,296 ha covered under plantations including coniferous and broad leaved species). They need large quantities of high quality seed which will ensure high survival, fast growth and desirable timber quality in the plantations. However, lack of designated seed sources like seed production area (SPA) and seed orchards, the planting agencies are compelled to use seed sources with no proven identity and the resultant plantations do not show increased productivity as envisaged. Hence, to make these plantations establish successfully, and to increase their productivity, quality seed is a pre-requisite. To meet the demands of the SFDs, the Himalayan Forest Research Institute (HFRI), Shimla has identified 50 ha of seed stands for their conversion into SPAs.

Taking into consideration the geographical distribution, wide utility and the ever-increasing demand of this species, it is imperative to screen/identify the best stands and make use of the genetic variation that exists amongst them for increased productivity through selection. The knowledge of genetic variability and association among seed traits is considered to provide considerable help in the genetic improvement of the species by making available reliable information on the nature, extent and direction of selection. HFRI has taken the initiative to survey the areas of deodar forests and make final selection of seed stands after sample plot analysis to convert these stands into SPAs after removing the inferior ones from the stand.

Based on results of previous studies and vast experiences of field staff it has come to known that deodar produces a good seed crop once in four years. The number of cones per tree and the number of seeds per cone varies from tree to tree but it has been estimated that on an average one kilogram of seed contains about 7900 (range: 7000 to 9000). In

other words, 60-70 cones from 5-7 trees produce one-kg seed. Though, the number of cones per tree and number of seeds per cone vary considerably but on an average 20 (15-35) cones per tree and 130 (120-145) seeds per cone respectively are obtained. For an ideal SPA, the number of trees to be retained as seed bearers varies between 100-120 trees per hectare. Since, both dioecious and monoecious trees are found in deodar, marking of male and female trees should be done carefully. Given the statistics of seed above, the seed requirement of the state forest department of Himachal Pradesh for deodar is 25-30 quintal per annum, and the occurrence of good seed years, a minimum of 125 ha of SPAs need to be established.

ESTABLISHMENT OF SEED PRODUCTION AREAS

In the state of Himachal Pradesh and Jammu and Kashmir the state forest departments have shortlisted and marked seed stands of deodar. These stands were marked as potential areas for seed production; however, without taking up the exercise of removing inferior trees from the stand, the very objective of getting quality seed in principle could not be achieved.

HFRI, Shimla in its endeavour to work for the enhancement of productivity carried out survey and selection of seed stands of *Cedrus deodara* both in the state of Himachal Pradesh and Jammu & Kashmir and shortlisted 1610 ha of potential seed stands (Table 1) based on sample plot studies wherein trees were evaluated both for quantitative and qualitative traits.

Extensive surveys of the deodar forest areas including those identified by SFD to shortlist potential sites for converting into SPAs were carried out. First short listing was done on the basis of ocular observation of these areas.These observations were supplemented in the field with Sample Plot Studies. The sample plots were laid out with an objective to finally select superior stands with the help of statistical analysis to eliminate any bias in the selection procedure.

Table 1. *Details of seed stands identified for conversion into seed production areas in the States of Himachal Pradesh and Jammu and Kashmir*

Location	Division	Area (ha)
Himachal Pradesh		
Narkanda	Kotgarh	130
Chatri	Chamba	62
Nagar	Kullu	86
Surkhigala	Dalhousie	65
Cheog	Theog	295
Deha	Chopal	140
Chopal	Chopal	210
Nichar	Kinnaur	78
RF Khani	Churah	108
Gahan	Rampur	65
Nankhadi	Rampur	55
Dudlu	Kullu	60
Kalatop	Dalhousie	70
Bajrundi	Kullu	45
Jammu and Kashmir		
Patnitop	Udhampur	48
Shira/Dhuna	Udhampur	138
Total		1610

Assessment of Trees in Seed Stands

Fig 1. *A seed stand of deodar shortlisted for conversion into SPA*

To finally demarcate the SPAs, rigorous sample plot studies with a sampling intensity of 5% were carried out. The sample plots of the size 0.2 ha were laid out in different parts of the selected stands and trees were enumerated both for quantitative as well as qualitative traits using SCORE method. In a sample plot the quantitative traits included for study were height, diameter at breast height and clear bole whereas, health, straightness and roundness of bole and branch size were taken as qualitative traits. Quantitative traits of total height and clear bole length were assigned score of 18 each, diameter at breast height (dbh) of 36, and qualitative traits were given scores of 5, 9, 5, 9 respectively. The score for quantitative characters was computed as % superiority of individual tree over the mean of the sample and the average score of the stands were computed. The stands with maximum average score were finally selected. As a result of these studies Cheog Forest R11 C-VI (25.00 ha), Nankhari C112 (15.00 ha) were finally selected for their conversion into SPAs of the species for the state of H.P. Similar exercise were also carried out in the state of Jammu and Kashmir in collaboration with State Forest Research Institute, Janipur, Jammu and potential areas were selected in Udhampur and Bhadarwah Forest Divisions and Neeru forest (10 ha) in Bhadarwah Forest Division was enumerated for removal of inferior trees and allowing the best one to recombine and produce quality seed. These finally selected seed stands were enumerated with marking of trees for retention and culling were submitted to concerned SFDs to execute culling.

SELECTION OF PLUS TREES AND PROGENY TESTING

Since the quality seed production sources like SPAs are established to supply good quality healthy seeds continuously for future afforestation programmes, their selection, establishment and management need to be given high importance. Seed orchards, the ultimate source of good quality genetically tested seeds, takes a long time for its establishment, particularly for long rotation species like deodar. For establishing seed orchards, good quality seed from various phenotypically superior trees is required. It is here that the necessity and importance of selecting Candidate Plus Trees (CPT) from the distribution zone of the species becomes important. Besides providing seed for raising seed orchards, the seed from CPTs could also be used for raising good quality plantations till such time high quality seed is available from the seed orchards. HFRI selected 77 CPTs of *Cedrus deodara* both in the States of HP and J&K, though all the areas in the state of J&K could not be covered for security reasons. The site details of these CPTs were also provided to the concerned forest divisions for collection of seed for use in their plantation programmes.

Fig 2. *A plus tree of deodar*

Sex Expression in Deodar

Conifer species are known to have good seed year once in three to four years with deodar as no exception, hence every effort is made to

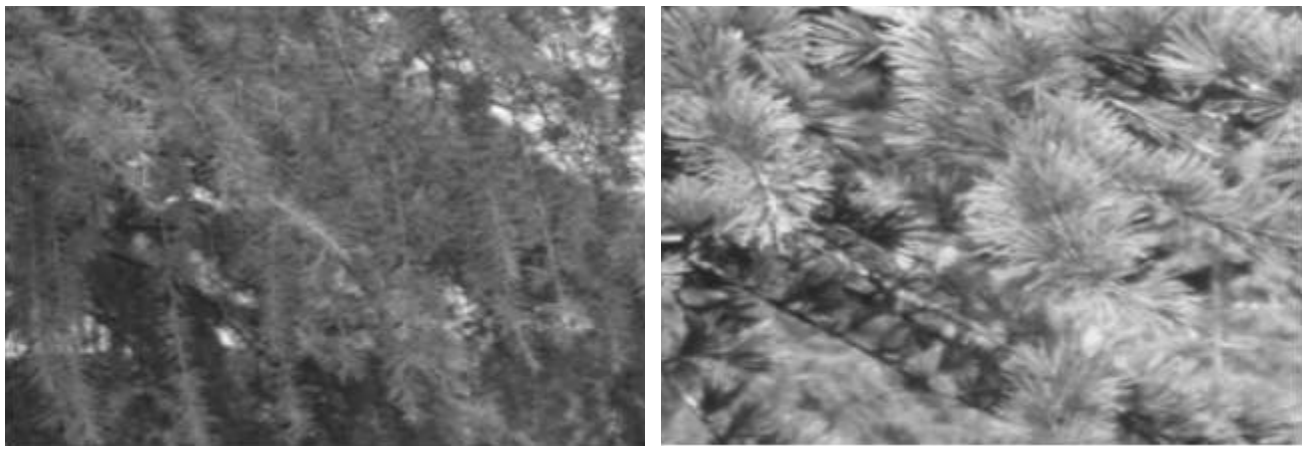

Fig 3. *DUS character for Deodar: drooping (left) and erect (right) needle type*

collect seed during good seed years and store and preserve it. Though deodar has been described as predominantly monoecious in nature with dioecious trees also available, however, the survey of deodar population over the years has shown the species to be both monoecious and dioecious. Hence, the collection of seed from selected trees can vary considerably. Since, the selected trees are located in interiors of the forest areas and seed collection from large dimension trees is cumbersome every effort needs to be made to maintain the identity of each seed lot and use the seed collected from such superior genotypes in afforestation programmes to realize the gains of productivity enhancement.

Towards Developing Genetically Improved Planting Material

The species has not been worked upon to produce genetically improved variety. HFRI has undertaken studies to standardize the vegetative propagation technique by attempting grafting in deodar so as to conserve the selected superior genotypes and eventually establish Clonal Seed Orchard of the species. Though various grafting methods were attempted, the standardization of grafting could not be made. The grafts were found to survive only for 8 to 10 months and thereafter slowly wither away.

DUS DESCRIPTORS

HFRI has formulated DUS guidelines for *Cedrus deodara* and *Pinus roxburghii* based on morphometric traits. During formulation of DUS guidelines and defining descriptors for *Cedrus deodara* it was established the species is both monoecious and dioecious, with unpredictable change in the reproductive behavior (Sharma and Bhondge, 2016) and also some of the trees remain in vegetative state. This makes selection of trees retained for seed production in SPAs or CPTs to be non-static and is a grey area to work upon. The information on DUS descriptors can be made use of by the state forest departments in their afforestation programme by selecting populations and individuals within populations for desired traits and collecting seed from selected individuals to raise future plantations.

PROPAGATION METHODS AND MODERN CULTIVATION PRACTICES

Cedrus deodara is a long gestation species (~ 150 years) with pure forests of high origin in its distribution zone in the north western Himalayan states. As the species experiences good seed year in three to four years, raising nurseries with quality seed with intercultural operations of pricking requiring two years of nursery tending before field planting takes place. With no standardized vegetative propagation technique in place raising QPM through seed is the only method, though the

institute has also worked upon raising QPM in root trainers to reduce the nursery gestation period of the species by six months (Fig. 4).

Though some of the progressive farmers have shown interest in planting deodar on their farmlands but it is the state forest departments who are the ultimate end users of the species as it takes many generations of human life before a good deodar tree reaches its harvestable age. Hence, the stakeholders need to make concerted efforts to make use of the efforts made by the research organizations in establishment of SPAs, selection of CPTs and collect seed from these identified sources to raise quality planting stock for use in their afforestation prgrammes and realise the gains of increased productivity.

Fig 4. *A nursery of Deodar*

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4.4 CULTIVATION METHODS FOR RED SANDERS TO ENHANCE PRODUCTIVITY

INTRODUCTION

Red sanders *(Pterocarpus santalinus)* is an economically important tree species, highly valued for its heartwood and medicinal properties. It is endemic to India and naturally distributed in the southern parts of Eastern Ghats (Fig. 1 and 1a). Till date, the demand for Red sanders wood is met from natural forests, with very few plantations under private ownership (Fig. 2). Long gestation period and the unfavorable policies governing Red sanders cultivation and trade were the main reasons for its unpopularity among tree farmers. However, the continued international demand, high wood price and the gap in demand and supply, have spurred interest among tree farmers. With an imminent change in policy scenario governing all aspects of Red sanders cultivation and trade, Red sanders cultivation is going to be a profitable venture, especially for large holding farmers, who are willing to invest and wait long term. This guide is prepared based on research carried out at various institutes under Indian Council of Forestry Research and Education (ICFRE) and the pool of knowledge that is available in the public domain. The guidelines provided here will help the prospective farmers in choosing the right area and right cultivation practices for maximizing yield from Red sanders plantations.

Fig 1. *A natural population of Red Sanders*

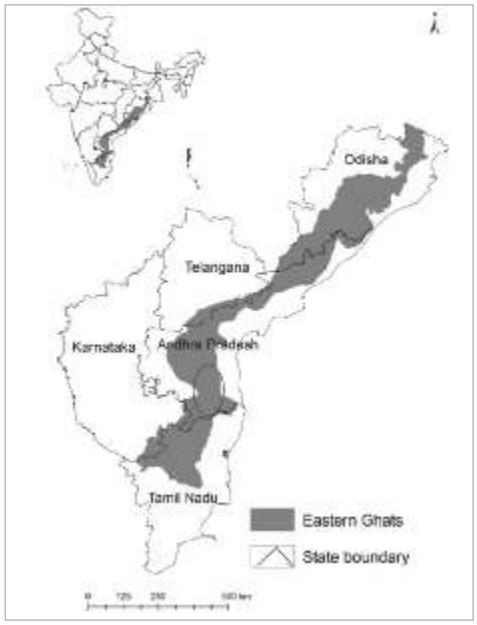

Fig 1a. *Map showing natural range of Red sanders ( ) in the Eastern Ghats*

Fig 2. *A plantation of Red Sanders*

MAJOR USES

Santalins extracted from wood is used as an organic dye in textile, food and pharmaceutical industry. The wood is put to numerous other uses starting from high value furniture, toy making to musical instruments. Wood extracts are used in Ayurvedic preparations to treat ailments like diabetes and skin diseases. The wood has high demand in international markets, with wavy grained wood (WG) having more value than straight grained (SG) wood type due to its superior acoustic qualities.

CULTIVATION PRACTICES

Soil: Red sanders grows well on soils that have their origin from gneiss, quartzite, shale and lateritic rocks. Lateritic loam is considered best for its growth and development. In nature, the species is found growing on dry, hilly and often rocky grounds. Highly fertile agriculture lands must be avoided. On fertile lands Red sanders put on good diameter and height growth, however, the heartwood formation gets delayed (Fig. 3 & 4).

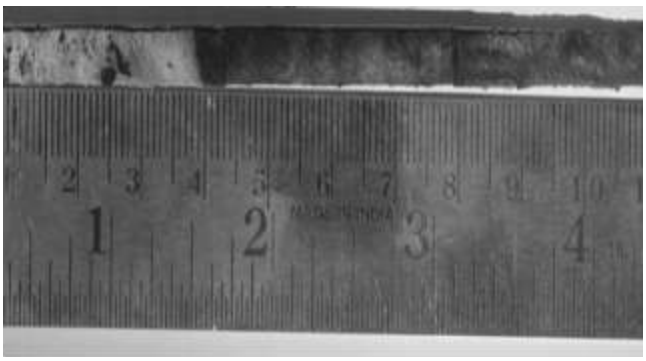

Fig 3. *Increment core showing heartwood formation (18 year old tree growing on lateritic soils)*

Fig 4. *Increment core showing poor heartwood formation (18 year old tree growing on fertile agriculture soils)*

Rainfall

Red sanders, basically, is a species of dry deciduous forests and suited to semi-arid tropical climate. Natural ranges of this species receive about 700 mm to 1200 mm per annum in a bimodal pattern. A minimum of 700 mm rainfall is needed for Red sanders, preferably distributed throughout the year. It should not be cultivated in areas receiving high amount of rainfall.

Temperature

The natural ranges of Red sanders experience a dry hot climate with mean annual temperature ranging from 26-28°C and maximum temperature reaching as high as 48 °C.

Nursery Development

Red sanders pod (fruit), containing one or two seeds, is hard and bony. The pods contain a large amount of phenolic compounds that inhibit germination. Pretreatment with water flushes away phenolic compounds and softens the pods. Soaking in tap water for six days with daily change of water has been found to be the optimum pretreatment for Red sanders.

Pods are sown vertically with stalk side up, in primary beds containing river sand (Fig.5). Daily watering and overhead shade is provisioned for the primary beds. Germination is epigeous and starts within 8 to 10 days of sowing. Seedlings develop a long and tapering primary root with few fibrous lateral roots. Seedlings are pricked out when the primary roots attain a length of about 12 - 15 cm (5-6 inches) and planted in long polybags (Fig.6).In nursery, shoot

Fig 5. *Primary bed with vertically sown pods; Radicle and cotyledons emerging out of pod (inset)*

Fig 6. *Transplanting of seedlings to polybags*

growth is poor compared to root system. Seedlings have to be tended for a period of 1 to 2 years in nursery for making them field worthy.

CURRENT PRODUCTIVITY

Recent studies have shown that the growth and predicted yield of Red sanders timber from plantations are much higher compared to the natural forests. However, there is wide (within plantation i.e. plant to plant and between plantations) variation in heart wood content, wood density, colour of heart wood and heart wood extractives. The wood quality parameters (wood density, colour of heart wood and heart wood extractives) of plantation-grown wood are slightly on the lower side compared to wood from natural forests. Wood from plantations growing on dry and degraded lands have shown better quality parameters compared to wood from plantations growing on rich soils with high amount of rainfall.

Red sanders, basically, is a long rotation (gestation) species and is not suitable for small holding farmers looking for quick returns. The initiation of heart wood formation, which is the main economic product of Red sanders, starts at the age of around 20 years. At 30 years age, the tree puts up an average diameter at breast height (dbh) of 20 cm. Considering an average heart wood content of 30% and an average wood density of 0.865, a single tree is expected to yield an average of 59 kg heart wood. The expected yield per hectare will be around 16.2 metric tonnes (considering 275 stems at 30 years age).

At 40 years age, the tree puts up an average dbh of 35 cm. Considering an average heart wood content of 35% and an average wood density of 0.865, a single tree is expected to yield an average of 190 kg heart wood. The expected yield per hectare will be around 38.0 metric tonnes (considering 200 stems at 40 years age).

The domestic consumption of Red sanders wood by the local Ayurvedic industry and toy making handicraft industry is very less compared to the international demand, mostly from China and to a certain extent from Japan. As a result, the pricing of Red sanders wood is mostly dependent on international demand as well as the quality of wood. The heart wood is usually converted into logs of 75 cm in length and graded into three grades as A, B and C with criteria like presence or absence of wavy grain, soundness, presence or absence of any defects etc. The average sale price, during 2017, was Rs. 27.8 lakhs per metric tonne. As Red sanders is a highly restricted tree species, there are several state, national and international legislations governing its felling (cutting of trees), transport, domestic trade and exports. Forest department is the only marketing agency in the country at present. All activities starting from felling to sale of wood is done through permits from the respective state forest departments.

SOURCING QUALITY PLANTING MATERIAL (QPM)

Since tree improvement work has just been initiated for Red Sanders, there are no specific varieties / clones available for a given planting site. High quality planting material is still raised with seeds collected from natural forests and a few plantations available under private ownership (Fig. 7). It is recommended to procure seeds and seedlings from authentic sources like State Forest Departments and Forest Research Institutions. The Andhra Pradesh Forest Department is the only authentic source of Red sanders seeds. Seeds may be procured by contacting State Silviculturist whose address is provided at the end of this chapter.

Fig 7. *Seed collection from phenotypically superior plus tree (left); Quality planting stock (right)*

IMPROVED CULTIVATION PRACTICES

Red sanders is a strong light demander and requires adequate spacing for its optimum growth. However, large spacing at the time of planting leads to stem forking and multiple branching from a very low level. An initial spacing of 3x3m (1111 plants/ha) is recommended for clean bole formation and which is, also, amenable to mechanized weeding. A close spacing of 3m between plants is recommended for row plantings along boundary. Red sanders is an excellent tree species for Silvi-pastoral systems owing to its deep root system, small crown, palatable leaves, nitrogen fixing and deciduous nature.

The planting area is prepared with a tractor to remove any previous growths including rootstocks. Large sized pits (45x45x45 cm) are dug up at the aforesaid spacing to accommodate tall seedlings (Fig. 8). Depending on the nutrient

Fig 8. *Field planting of Red Sanders; tall sized seedling and soil fortified with chemical fertilizers (left) and Planting of tall seedling after removing the polybag (right)*

status of the plantation area, the dug up soil is fortified with chemical fertilizers and organic manures containing macronutrients (Nitrogen, Phosphorous and Potassium). Red sanders is also amenable for stump planting in crowbar holes. Seedlings are prepared for field planting by de-topping the main stem, about 2.5 cm above the collar region, two months before the planting schedule. This is done to promote coppicing. A single coppice shoot is retained and allowed to take the place of main stem. Seedlings prepared like this establish in field very quickly and show good shoot growth. Planting is normally done at the beginning of rainy season.

Fig 9. *Pruning in Red sanders plantations*

Weeding

Weeding of plantation, at least once a year, during the initial three years helps the plants establish quickly free of any competition. The recommended spacing of 3x3 m is amenable to mechanized weeding with a tractor.

Pruning

Red sanders saplings develop forking and multiple branching from low height unless side branches are pruned annually. Pruning of side branches up to one-third height of saplings is recommended during initial years of establishment (Fig. 9). Pruning operations are taken up during lean period (December-January) when plant growth and development is least affected.

Thinning

The initial close spacing at the time of planting and subsequent annual prunings help in clear bole (stem) formation. However, horizontal growth (increase in diameter) requires more photosynthetic activity, as well as more space. Thinning creates the much needed space for crown development and increase in photosynthetic area. Owing to the wide plant to plant growth variation in seed originated plantations, selective thinning is recommended. Poor performers, diseased/moribund trees are thinned first, subsequently other trees are removed as per requirement of the good performers. First thinning should be carried out around the age of 10 years. The number of plants retained should be around 275 at 30 years age.

Fig 10. *Leaf blight disease in Red sanders nursery.*

INSECT AND DISEASE PROBLEMS AND CONTROL MEASURES:

Two diseases viz., (i) leaf spot disease caused by *Cylindrocladium scoparium*, (ii) leaf blight disease caused by *Sclerotium rolfsii* (Fig. 10), have been reported from Red sanders nurseries. These diseases reduce photosynthetic area and severely affect the growth of seedlings in nursery. Control measures for these diseases include *viz.*, (a) Incorporation of *Trichoderma viride* into the potting mixture (One part *Trichoderma* added to 10 parts soil); (b) Foliar spray of Carbendazim (Trade name - Bavistin) or any other sulphur based pesticides (@ 0.2% i.e. 2gm in 1 litre water) at 15 days interval.

Mechanical damage to tree stem during ploughing or due to any other cause leads to fungal attack and, degeneration of

Fig 11. *Fungal attack leading to degeneration of bark and conducting tissues*

bark and conducting tissues (Fig. 11). Wood decaying fungus *Ganoderma lucidum* (Fig.12) have been found to infect adult trees in plantations. Cultural measures like pruning the affected branches and sealing the cut ends with Neem oil or Bordeaux paste or with any water repellant paint controls further spread of this disease in plantations. Dieback (tree dries up/dies top downwards) of Red sanders trees have been observed both in natural forests and plantations, the exact cause of which is not known (Fig. 13).

Fig 12. *A Red sanders tree infected with wood decaying fungus Ganoderma lucidum*

Fig 13. *Dieback in Red sanders*

CURRENT RESEARCH FOCUS

Looking at the economic importance and conservation significance of Red sanders, Indian Council of Forestry Research and Education is about to launch an All India Coordinated Research Project on 'Conservation and productivity improvement of Red sanders'. This coordinated initiative involving seven national research institutions will take up nine research components starting from plus tree selections, development of techniques/molecular resources to improved products. The project is expected to create improved resource base (seed orchards, germplasm banks, molecular resources), improved techniques (clonal propagation, heart wood evaluation, genetic diversity & structure evaluation, wood forensics) and improved products (quality planting material, biofertilizers) for increasing area under Red sanders cultivation.

CONSERVATION STATUS AND FUTURE CULTIVATION PROSPECTS

International Union for Conservation of Nature (IUCN) specifies criteria, assesses, declares and updates threatened species across the world. It has a five main measurable set of criteria for classification of threatened species. Red sanders was added to its list during 1998 as EN B1 + 2de (Ver. 2.3 1998), based on recommendations of CAMP workshop on medicinal plants, held during January 1997. Recently, during February 2018 it has been down listed as 'Near Threatened' (Ver. 3.1 2018).

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) restricts international trade in threatened species and their products by listing them in Appendix I, II or III. Red sanders is added to Appendix II, which puts restrictions on international trade of its wood and wood products from natural forests. CITES restrictions are not applicable to trade of Red sanders wood sourced from plantations. However, Directorate General of Foreign Trade (DGFT) Ministry of Commerce & Industry, Government of India (GOI), had imposed a blanket ban,till recently, on export of Red sanders from India in any form and from any source.

Recently, during February 2019, DGFT has revised the earlier prohibited policy for 'Red sanders wood in log form and roots, exclusively of cultivation origin obtained from private land (including Pattaland)' to 'restricted' category, which permits exports under license subject to conditions/ documentations like (i) Application of export license to be submitted along with certificate of origin from PCCF of concerned state, (ii) Certificate of current position from a verification authority nominated by PCCF of concerned state, (iii) Issue of export license subject to conditions such as MEP, quantity ceiling requirements under CITES, etc., (iv) Issue of export license subject to an yearly quota fixed by MoEF&CC upon recommendations from CITES Management Authority.

The present day policy governing cultivation of Red sanders, its felling, transport, possession, trade, conversion of wood to various end products and its sale, are yet to be farmer and industry friendly. The farmers have to go through complex procedures for obtaining permissions for felling, transit and trade of Red sanders wood. Recognizing the importance of trees outside forest (TOF) in conserving Red sanders as well as meeting market demands partially by farm grown wood, National Biodiversity Authority (NBA) undertook a comprehensive study recently on various issues pertaining to conservation and sustainable utilization of Red sanders. Following the study, NBA has recommended for liberalization of domestic trade in plantation grown Red sanders timber and exemption of plantation sourced timber for export under foreign trade policy (FTP). Also, it has recommended for simplifying and decentralizing procedures for various permissions pertaining to Red sanders cultivation, felling, transit and its trade. The future prospects are looking a lot better for farmers and industries who are keen in cultivating Red sanders.

CONTACT DETAILS

Technical Advice

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- Dr. Maheshwar T. Hegde, Scientist F, Arid Forest Research Institute, New Pali Road, Jodhpur-342 005, Rajasthan; Phone: +91-291- 2729162; Email: hegdem@icfre.org
- Sri M. Maria Dominic Savio, Scientist E, Institute of Forest Genetics and Tree Breeding, P.B. No. 1061, P.O. R.S. Puram, Coimbatore-641002, Tamilnadu; Phone: +91-422-2484143; Email: dominic@icfre.org

Supply of Seedlings

- State Silviculturist, Biotechnology Research Centre (BIOTRIM), Akkramalli Post, Tirupati-517 507, Andhra Pradesh

GMELINA

Gmelina plantations (2 years old)

Agrisilviculture (Gmelina + Sugarcane)

Silvipasture (Gmelina + Cumbu napier)

Agrisilviculture (Gmelina + Cumbu)

GMELINA

Hortisilviculture (Gmelina + Pepper)

Multi-tier cropping system (Gmelina + Banana + Pepper + Coconut)

Horti Silviculture (Gmelina + Coconut)

CASUARINA

Casuarina planted at a wide specing of 3 x 1.5 m to facilitate ploughing and cultivation of agri crops between

Inter-cropping of moongdal with Casuarina

Mechanical weeding in a young Casuarina plantation using a power tiller

CASUARINA

Casuarina stem affected by the insect, bark-eating caterpillar

Casuarina stem affected by the blister bark disease showing

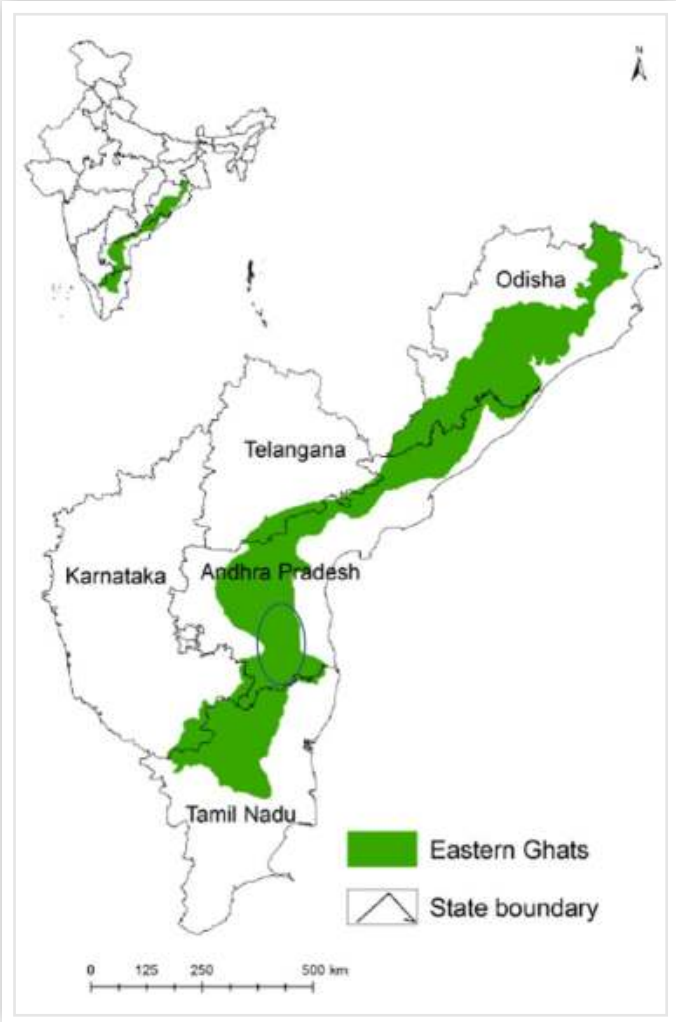
Young tree of Casuarina showing drying due to collar rot disease

RED SANDERS

A natural population of Red Sanders

Increment core showing heartwood formation
(18 year old tree growing onlateritic soils)

Increment core showing poor heartwood formation
(18 year old tree growing on fertile agriculture soils)



Map showing natural range of Red sanders
(marked as circle) in the Eastern Ghats

A plantation of Red Sanders

RED SANDERS

Primary bed with vertically sown pods

Transplanting of seedlings to polybags

Seed collection from phenotypically superior plus tree

Quality planting stock

RED SANDERS

Field planting of Red Sanders; tall sized seedling and soil fortified with chemical fertilizers

Planting of tall seedling after removing the polybag

Pruning in Red sanders plantations

Leaf blight disease in Red sanders nursery

RED SANDERS

Fungal attack leading to degeneration of bark and conducting tissues

Dieback in Red Sanders

A Red sanders tree infected with wood decaying fungus *Ganoderma lucidum*

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