



Teak in India: Status, Prospects and Perspectives

R. P. S. Katwal

Teak is a celebrated timber of the tropics and India is one of the major teak growing and utilizing countries in the world. Domestication through plantations for one and a half centuries has made teak the most widely planted and researched tropical hardwood species. Significant developments have taken place in standardizing plantation techniques, perfecting harvesting and post-harvest utilization methods and tree improvement. In spite of these efforts, teak resources of the world need immediate attention for their sustainable management. The ecological and economic aspects of raising teak in monoculture have to be considered for long-term management of supply of timber and the soils in which they are grown. Whilst bottlenecks in tree improvement and seed production have to be removed through increased basic research, the potential of frontier areas like biotechnology must also be used for rapid improvement of this plantation species.

Keywords : Teak, sustainable management, improvement, productivity, conservation.

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Ups and Downs of Teak Forest Management in Indonesia

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In Indonesia, teak was introduced during the fourteenth century, especially in Java, where it spread quickly in central and eastern parts. The Dutch colonial rule extensively extracted the timber, leading to degradation of teak forests in the country. They eventually introduced modern methods to manage the teak forests, which are also in use at present. There are State teak forests and Community teak forests in Java, apart from teak grown outside the island. The State teak forests, extending to about 600,000 ha are managed by the government enterprise called *Perum Perhutani* and the teak areas outside Java are looked after by the local government. Community forests containing teak are in private lands, which are more widespread due to improved demand and price. The timber from government sector is either sold directly or by auctioning, and in general, they fetch more price than that of the private sector due to improved quality.

Since 1998, there is decline in the standing stock of teak forests in the country mainly due to illegal and widespread logging consequent to the political crisis. However, these non-productive areas are being rehabilitated since 2002. Improved planting stocks are used for the purpose, and for that, clonal seed orchards are established. Intensive silvicultural practices, including fertilization, are adopted to increase the productivity. Also, community-based forest management programmes are implemented. Improved environmental protection measures to improve the ecosystem and the biodiversity are also part of the management of teak forests in the country. Ecoglobal certification, even though introduced, could not be contained for many forest districts and only one fourth of the districts are maintaining it at present.

Keywords: Plantations, Java, State and Community teak forests, improved management.

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Current Status of Teak in Thailand

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Natural teak forests in Thailand decreased from 2,324,300 ha in 1954 to about 150,000 ha in 2000, mostly due to the demand for agricultural land and constructional wood by the increasing human population. Plantations could hardly keep pace with deforestation. Up to 2000, both private and public sectors in Thailand could establish only 836,000 ha of teak plantations, as reported by FAO. Thailand, therefore, has to import natural teak wood from overseas, especially from Myanmar, Lao P.D.R. and Indonesia, on an average of about 2 billion Baht annually. However, small logs from teak plantations can be used for furniture, carving, general construction, household utensils, toys, etc. domestic consumption as well as for export. Recently, the Forest Industry Organization of Thailand achieved 2 FSC certificates for its teak plantations and is still trying to get additional certificates to manage teak plantations sustainably. Information on teak improvement, research and development programmes in the country is discussed in the paper, pointing out the constraints in teak plantation establishment.

Keywords: Teak plantations, Thailand, research and development

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Growing Teak in Malaysia

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There is an enduring global demand for teak wood because of its outstanding appearance and durability. Yet, supply of the timber is diminishing and there is an increasing reliance on plantation timber to fill the gap. Growth rates of teak are modest, generally averaging less than $10\text{m}^3 \text{ha}^{-1} \text{yr}^{-1}$, except where exaggerated claims are made about the potential performance of plantations. This discourages significant investments in plantation development and research and development to support the activity. However, if systematic research efforts are put into the improvement of the species, better yield and improved quality timber is achievable, as in the case of many other plantation species around the world.

While, there has been a lot of interest generated by private sector investors in Malaysia to go into forest plantations, there is a need to find out if at all any genuine efforts have been made by these investors to pursue their efforts to success. The other major area of concern is that, if the interest is genuine and if the investors are moving into such plantation programmes, is there sufficiently good quality planting material of teak available at reasonable price for such ventures? The paper, therefore, attempts to look at the state of teak plantations in Malaysia and the research and other efforts that have been carried out till date, to support establishment of teak plantations in the country.

Keywords: Demand and supply, Malaysia, teak, private plantations

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Development of Teak Plantations in Ghana: Propagation, Processing, Utilization and Marketing

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The development of teak (*Tectona grandis* L.f.) plantations in Ghana is traced back to 1875. Since then, teak was grown as the most popular plantation species in the Country covering more than 50per cent of the total plantation forests, estimated to be about 150,000 hectares. The success of teak plantations in Ghana is dependent upon factors like ease of cultivation, fast growth, fire resistance, tolerance to wide range of soils and rainfall and superior wood quality.

Artificial regeneration of teak in Ghana is by direct sowing, bag planting and stump planting. Beds of about 1.2 m width are used for seed broadcasting and the germinated seeds are potted in a mixture of sand and compost. The seedlings are transplanted at a spacing of 1.8m x 1.8m in savanna forests or at 2m x 2m in other forest zones. Thereafter, they are managed by singling, pruning and thinning until maturity, at about 30 years. Thinnings from 10 to 15-year-old plantations are used mainly as transmission poles, after pressure treatment with CCA preservative. Mature stems of over 20 years of age are processed into sawn timber which is exported to India at a price of 460 USD per m³. Limited finished products like furniture and paneling and flooring materials are manufactured by local craftsmen for domestic uses. Demand for teak poles, sawn timber and finished products by far exceeds supply, making establishment of teak plantations a very viable venture.

Past and present research in agroforestry, progeny testing and assessment of variations in quality and properties, which span over a period of 30 years, have been concluded. It is hoped that a new collaborative research programme, with four other partner countries, funded by the European Community, will improve the quality and productivity of future teak plantations in Ghana and the West African sub-region.

Keywords: Teak plantations, Ghana, artificial regeneration, utilization, research.

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Teak in Brazil: Overview of Plantations, Know-how, Expertise and Market

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The paper describes the actual situation of teak plantations in Brazil, the technologies used in order to improve their productivity and local market development for first and second thinnings of teakwood. The advanced expertise in reforestation (mainly in pines and eucalypt forests), and the availability of fertile soil and manpower will make Brazil an important player in the teakwood market.

A Brazilian and Dutch capital company namely *Floresteca* founded in 1994,, is the largest teak wood investor in Brazil, managing over 14,000 ha of teak plantations. All *Floresteca* plantations and sawn goods are certified by FSC (Forest Stewardship Council). The idea of presenting *Floresteca*'s enterprise in this paper is to demonstrate the expertise introduced in the company's teak plantations, improvement in management and the first and second thinnings, wood quality attained as well as the Brazilian vocation for teak. In order to achieve the presently accepted *Floresteca* competitive differential, its management investments in strategic sustainability, without disregarding environmental protection and development for which FSC certification, played a very important role.

Keywords: Teak plantations, certification, expertise, market development.

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Advancements in Management and Productivity of Teak in Central America

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Most recent advancements on growing teak in Central America in commercial scale reforestation programmes are presented. The interest of companies in opting for forestry certification has risen, particularly in the pursuit for better markets and valuation of indirect benefits such as carbon sequestration. With regard to doubts arisen on the quality of plantation wood from shorter rotation teak of 20-25 years, differences were observed in anatomical, physical and mechanical properties, workability and durability of products, in materials coming from Panama and Costa Rica. Similarly, anatomical structure, resistance to rot and preservation of 6-year-old plantation wood from Guatemala were determined. Acceptable results of wood quality have promoted greater industrial development using lower diameter teakwood for different final products. Small diameter logs or sawn lumber from early thinnings continues to be one of the major export items to markets in India. In Costa Rica, important results have been obtained in nursery production of root-led plants and in genetic improvement of plantations established with clonal material, by the effort of the newly established Genetic Improvement Co-operative. Trials have been conducted with new teak progeny materials brought from India, Indonesia, Thailand, Trinidad and Tobago and Tanzania.

In terms of plantation growth and productivity, high differences were observed among plantations, ranging from 8 to 12 m³/ha/year and 25 to 30 m³/ha/year, in different sites and different zones. However, in several cases, initial growth was very high, even though it was drastically low afterwards with death or 'die-back' of trees, and this calls for further in-depth research.

Keywords: Short-rotation teak, potentials, genetic improvement, productivity.

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Teak in Trinidad and Tobago

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Teak was introduced in Trinidad in 1913 from seeds of Tennaserim, Myanmar origin. Plantations were established since that time to cover a total of about 9000 ha, ranging in age up to 90 years. Various methods of planting were tried in the early stages of introduction and by 1930, the species was raised in pure plantations. Teak is planted at a spacing of about 2m x 2m and thinned at periodic intervals based on height class. An economic rotation of 50 years is followed, and the coppices together with those regenerated during the first rotation, are used to form the second rotation crop. The tree reaches a height of 7 to 10 metres within 3 to 5 years. Volume increment varies from of 7 to 13 m³ha⁻¹yr⁻¹ on best sites. Thinnings from the earlier plantings are sold to woodworkers. By 1958, an industry to market the teak thinnings was set up and by 1978, a State enterprise was established to harvest and market all the teak produced. This company was closed in 2001. The teak resources that are produced now are sold to local sawmills and woodworkers. The lumber from the thinnings and final fellings are sold to 250 furniture manufacturers who produce furniture for the local and regional markets.

Challenges to management of plantations are high rates of soil loss, uncontrolled fires, theft and the poor performance of second rotation crop. The Forestry Division has conducted various research programmes in teak over the years, covering nursery studies, thinning, spacing, tree improvement and mensuration. At present, the Division is in the process of signing a memorandum of agreement with the University of the West Indies (UWI) for collaborative studies on problems related to teak management in Trinidad.

Keywords: Introduction in Trinidad, methods of planting, utilization, management.

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Role of Teak (*Tectona grandis* L. f.) in Conserving the Biodiversity of Nepal

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Forests are one of the important natural resources of Nepal and about 90 per cent of the rural population depend on it. Furthermore, it is a major source of energy, fodder and timber. Various reports state that national forests are decreasing in quality and quantity, since early sixties. To overcome this, reforestation or afforestation had started, although it acquired momentum since early eighties when community forestry programme was started. As a result, a number of plantations have been raised, mainly in the mid-hills and Terai belts of the country so as to meet the demand of forest products. Many indigenous and exotic species have been used for planting, including teak, with high value for its timber and poles, apart from products like firewood, obtained from silvicultural operations during its rotation period.

In Nepal, teak plantations were raised in 1960 at Chiliya in Rupandehi District. Over the forty years, teak covered only about 9.5 hectares. Private plantings of this species is minimum, scattered in the Terai and Bhabar regions. In contrast to this species, *Dalbergia sissoo* covers more than 49,000 hectares. This indicates that teak is not the preferred species for large scale plantations in Nepal. One of the reasons for this is the site requirements. Despite the promising growth of teak in some areas, it suppresses the undergrowth, not enriching species diversity. Also, farmers and communities prefer multi-purpose tree species like *Leucaena leucocephala*, *Guazuma ulmifolia* and *Cassia siamea*, the main reason being the long rotation period of teak. In terms of biodiversity conservation, the species acts as an important host for butterflies like *Hysipyla robusta*. Also, with wider spacing in plantations, various intercrops can be grown in the early stages which can support biodiversity.

Keywords: Teak plantations, Nepal, performance, biodiversity

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Teak in Sri Lanka: Resource Base, Issues and Challenges

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Sri Lanka lost its natural forest cover quite rapidly over the past four decades due to the problems associated with population increase. The Forest Department initiated its reforestation programme, about 100 years ago, to offset the denudation of natural forests of the country. Teak is by far the most popular species used in reforestation programs in Sri Lanka. Development of commercial teak plantations has been the responsibility of Forest Department until recently and the private sector involvement was not forthcoming due to the absence of a favourable business environment. Current National Forest Policy of the country has provided the policy and legal framework conducive to large scale private sector investments in forest plantation development. Apart from commercial teak plantations, home gardens play a major role in supplying teak to the domestic market. There is a great potential for increasing both the quality and quantity of Sri Lankan teak and the use of high quality planting materials for new plantation establishment. Improved management of existing teak resources is also vital to the growth of teak industry in the country.

Keywords: Teak, home gardens, private investment, National Forest Policy

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Quality Timber Products from Teak Through Sustainable Forest Management in Maharashtra State, India

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Teak (*Tectona grandis* L. f.) is the prime timber species found in the forests of Maharashtra State in India. The paper gives an account of the extent of area of natural teak forests and plantations in the State, silvicultural systems practised at present, improved thinning regime for plantations and innovative seed and nursery practices introduced for production of quality planting stock. Thus, by improving site quality and implementing short-term strategies of tree improvement, the Forest Department and Forest Development Corporation Maharashtra Ltd. can be enabled to produce quality timber on a sustainable basis from the natural and artificial teak forests of the State. The current turnover of timber products from teak and measures to increase its availability are also discussed.

Keywords: Teak area, silvicultural practices, tree improvement programmes, seed orchard, clonal propagation, tissue culture

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A Report On Teak In Madhya Pradesh With Technical Analysis

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Madhya Pradesh, in the heartland of India, has the largest forest area of 95,221 km² and highest forest cover 77,265 km² with growing stock of 50 million m³. Teak occurs in over 35,000 km² of forest area. The forest is managed sustainably according to scientifically prepared working plans. This produces 0.25 million m³ of teak timber annually. Teak is a light demander species, managed in a rotation of 80-120 years, grows well on deep alluvial soil, in moist and humid climate and produces timber with attractive colour and grain. In Madhya Pradesh, teak is harvested by the Forest Department and marketed through established depots in open auction. Teak is managed well under intensive silviculture systems. Ban on green felling in natural forest over the last two decades has jeopardized the natural regeneration of this light demander species and has posed the danger of retrogression from high forest to coppice forest. This is resulting in reduction of quality and yield. Plantation grown teak, even with high input, maintains its strength properties. Raising plantations on a large scale with high input, therefore, can supplement the productivity of natural forests. Teak requires early and heavy thinning. Experience in Madhya Pradesh and other states of the country is that proper thinning has not been done in most of the plantations. This has resulted in appreciable loss of increment. With innovative efforts of high input, teak plantations have succeeded well in Madhya Pradesh. This may pave way for increasing productivity of teak plantations ensuring their sustainability.

Keywords: Teak plantations, rotation, sustainable, natural regeneration, plantation productivity, increment, high input

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Teak in Kerala State, India: Past, Present and Future

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Teak was first raised on a plantation scale in Kerala during 1842. Since then, Kerala Forest Department (KFD) has raised large extent of teak plantations, which are now in various age groups and site quality classes. A considerable extent of them are in site quality classes 2 and 3. As on today, the Department manages 74,872 ha of teak plantations in the State, and on an average, 1000 ha of the plantation is being felled and regenerated every year. Considering only the average final yield, which is $60 \text{ m}^3 \text{ ha}^{-1}$ and an average price of Rs.25,000 m^{-3} , State earns a revenue of Rs. 1500 millions/year. The present MAI of the standing crop works out to be $2.423 \text{ m}^3 \text{ ha}^{-1}$ at 60 years, whereas potential MAI could be in the range of $4.9688 \text{ m}^3 \text{ ha}^{-1}$ at same age, which indicates the need for further improvements with research and management inputs.

After the first teak plantation was raised in 1842 by direct sowing/planting natural seedlings and stumps, in order to improve the productivity, Kerala Forest Department has introduced root-trainer technology during 1998. Crop rotation with short rotation leguminous tree crops such as *Acacia auriculiformis* and *Acacia mangium* has also been introduced during 2000. At present, the Department is also attempting to raise clonal teak plantations utilizing 30 clones developed by the Kerala Forest Research Institute(KFRI). There are also some other departures from the conventional teak planting method, with the intention to improve the productivity on a sustainable basis. The paper discusses the present and future management and marketing aspects of teak - a species that stood by the foresters for such a long period.

Keywords: Teak plantations in Kerala, area, productivity, management, marketing

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Abstract

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Criteria and Indicators for Sustainable Teak Plantation Management in India

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Forest plantations are important source of wood, fuel and a variety of other forest products in India. Development of a framework of criteria and indicators (C&I) for the sustainable management of plantations has been given high priority in the national Forest Policy, revised in 1988. Furthermore, a national initiative known as the Bhopal-India Process was undertaken recently to propose C&I for sustainable forest management in India.

In recent years, CIFOR has developed a system for testing C&I for assessing the sustainability of management of natural forests at the level of a forest management unit (FMU). This system was used to develop C&I for teak plantations in two States of India. The development and evaluation of C&I was conducted by Kerala Forest Research Institute (KFRI), in collaboration with the Indian Institute of Forest Management. Field-testing in Kerala was conducted in an age series of teak plantations at Nilambur managed by the Kerala Forest Department. In Chhattisghat State, field-testing was conducted in teak plantations of Raipur district managed by the Madhya Pradesh Forest Development Corporation (MPFDC).

The selection of candidate sets of C&I during stage 1 of the IFGM process from the vast array of published information was found to be time consuming. To rationalise this process, it was necessary to first group all C&I under four principles, viz., policy and planning, ecology, socio-economics and management. A number of important issues like impact of plantation development on water supplies to villages and settlements, loss of biodiversity and the long-term impact on NWFP resources, sharing of benefits from plantation development, environmental impacts, such as soil erosion and contamination were discussed.

Keywords: Teak plantations, sustainable management, criteria and indicators

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Sustainable Management of Teak Forests in Myanmar

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Teak (*Tectona grandis* L. f.) from the natural forests has been a major source of foreign exchange for Myanmar for many years. After almost a century and a half of scientific and systematic management with the application of the Myanmar Selection System (MSS), the natural teak-bearing forests remain in comparatively good extent and status. However, due to the ever-increasing population and its demand for timber and land for agricultural purposes, forest degradation is being experienced with decreased production. The Myanmar Forest Policy 1995, stipulates that the natural forests of Myanmar will never be substituted by plantations. However, apart from the silvicultural treatments provided to assist natural regeneration, tree planting of moderate scale is also afforded to enrich the degraded areas, while larger plantations are established to replenish the depleted areas, as new wood capitals are being built up. The natural forests will continue to provide timber, especially premier teakwood, on a sustainable basis, while rendering protective functions to ensure ecological stability and biodiversity integrity with supportive services for cultivation, recreation and ecotourism. Due to the greater demand for timber, especially teak, a large share of the economic burden in forestry will be gradually shifted to plantations. With the application of time proven techniques and innovative modern methods, large-scale plantations are, therefore, being established on depleted forest lands, complementary to the main effort in natural forest management.

Keywords: *Tectona grandis*, Myanmar, sustainable natural forest management, annual allowable cut, plantation forestry, special teak plantations

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Malaysian Experiences in Timber Certification

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MTCC is an independent organisation established to operate a voluntary national timber certification scheme in Malaysia. It is governed by a Board of Trustees comprising of representatives from various stakeholder groups. The MTCC scheme began its operation in 2001, in a phased approach. The standard currently used for assessing Forest Management Units (FMUs) is the MC&I, which is based on the ITTO criteria and indicators. For the next phase, MTCC will use new standards developed through multi-stakeholder consultations using the Principles and Criteria of the Forest Stewardship Council (FSC) as the template. The standard for chain-of-custody certification is the *Requirements and Assessment Procedures for Chain-of-Custody Certification*. Two types of certificates are issued; currently three FMUs have been awarded the *Certificate for Forest Management*, while 29 companies have received the *Certificate for Chain-of-Custody*. By the end of June 2003, about 2,457 m³ of MTCC-certified sawn timber have been exported. The external and internal challenges faced by MTCC in implementing the certification scheme as well as the main impacts of the scheme are highlighted. A significant area of Permanent Reserved Forests has now been independently assessed, providing valuable information about the current status of forest management, including aspects which need improvement. It is hoped that the phased approach taken will be accepted by the markets in order to encourage the efforts being made towards sustainable forest management in Malaysia.

Keywords: Malaysian timber certification, sustainable forest management, MTCC-MC&I-phased approach, consultation, stakeholders, challenges, impact.

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Certification and Labelling of Teak Wood Products with Special Reference to Opportunities and Challenges in India

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Certification and eco-labelling of wood products are hotly debated with the contentious issues in the current global wood trade and forest management scenario. In general, developed countries perceive that certified wood offers assurance to buyers not contributing to forest destruction or illegal logging, and to the forest industries for an opportunity not to be seen by the general public as the main cause of (forest) destruction by promoting responsible production and use of raw material resources. On the other hand, many developing countries regard certification as an impediment to trade and is an attempt by the developed countries to impose their views. Despite the endless arguments, apprehensions and doubts, forest certification is expanding, and the global Forest Stewardship Council (FSC) – the leading certification body – is implementing a strategic action plan to bring 30per cent of the world’s forest under certification to FSC standards by 2007 and increase to 15per cent the share of the global roundwood market held by these forces. This, despite the fact that experience so far indicates that the original concept (of say, envisaging “green premiums” where consumers are expected to pay extra amounts to products from forests managed in an environmentally friendly manner) has evolved and shifted considerations. Mass markets for certified forest products are yet to emerge, but niche and regional markets have developed in the USA, Europe and Canada, and the demands are growing.

India, being a member of the International Tropical Timber Organization (ITTO) and signatory to CBD and other International Conventions, has already developed criteria and Indicators (C & I) for sustainable forest management through the Bhopal-Indian Process (1988) which is being tested and evaluated. In this presentation, an attempt is made to examine the opportunities, constraints and apprehensions concerning timber certification and its labelling in India, with special reference to teak.

Keywords: Indian market, ‘green’ wood products

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Qualities of Teak and Some Policy Issues

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Teak is a component species of the tropical moist and dry deciduous forests of the South and South-East Asian region. It is also a potential tree for raising plantations. Teak wood is used as the standard for quality rating of other timbers of India. Quality of teak products is prescribed rigidly by the market, and it essentially depends on the quality of the wood, besides the processing technology. The wood has considerable value-adding and income generating potential.

Teak entered the international market as early as in the beginning of 19th century. Along the way, starting in the mid 1880s, plantations of teak were raised, in order to replenish the removed stock. Currently, the availability of natural teak is limited, and supply of teak logs come mostly from plantation sources. Teak plantations are now being raised on a large number in countries of the tropical region, outside its natural habitat. Of the total world's forest plantations of 187.1 million hectares in 2000, teak accounts for 5.7 million hectares (about 3%). It is also now grown in different scales by farmers, agriculturists, agro-foresters and investors of various types. The outlook for teak as a business enterprise raises several policy issues related to land tenures, land use and land allocation, land laws, infrastructure, planting technology and systems (monoculture vs polyculture), genetic improvement, waste free utilization, management systems and horizons, comparative and competitive advantages, role of R&D, capital investment and investors time preference, funding sources, community involvement, private sector roles, new products and markets, antagonists and protagonists of plantation development, market-based approaches to teak development, conflict resolution, control, and so on.

From a policy point of view, apart from its physical properties, teak earns increased merit for the social, environmental and economic benefits it generates. The focus of this paper is on policy issues related to the development of teak as a quality timber.

Keywords: Teak, natural and planted, qualities and acceptance, policy issues

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Quality Concerns of Sustainable Teak Wood Chain

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Teak is an undisputed leader of high quality tropical timbers, as a long rotation tree crop of 50-70 years. Whether it maintains superiority in fast growing short rotation plantations is a major concern of the tree growers/ investors, policy makers, traders and end-users of the teak wood chain. While highlighting the teak wood quality demands of global market, promises from teak wood farming and home-garden forestry, as sustainable options, are discussed in the paper in the light of recent research findings. Although generally teak attains mechanical maturity of timber around 20 years, the increased proportion of juvenile wood in the timber from short rotation plantations, with relatively low heartwood and extractive contents, has certain limitations for use in very durable products for which teak has world-wide reputation. However, there are enough research evidences to indicate that timber quality attributes such as density, strength, stability and aesthetic appearance of fast grown teak wood, though likely to be different, are not always inferior. With guarded optimism, it is argued that opportunities do exist for timber production of acceptable quality by applying tree improvement/genetic modification (GM) technologies coupled with collaborative research and training programmes for manufacture of quality wood products. Technological interventions in various stages of the wood chain from the multidisciplinary efforts of wood technology, biotechnology and silviculture are therefore needed for sustainable production of environmentally acceptable 'green' wood products. The adoption of appropriate processing technologies by small and medium-sized timber holders and entrepreneurs (SMEs) is also a need of the hour for marketing the value-added products from the relatively small dimensional timber, coming from thinning and early harvesting of the timber crop. The other major challenges are effective mechanism of research and development as well as developing new market for 'green' products from sustainable forest management (SFM).

Keywords: Short rotation teak, maturation age, wood properties, GM tree, trees outside forest (ToF), processing technology.

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Growth and Timber Quality of *Tectona grandis* L. f. in High Input Plantations of Costa Rica

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Linking forest management to requirements of timber industries is fundamental. Relationships of silvicultural activities with wood quality are often limited to size-related characteristics, such as DBH. Restrictions set by international markets (e.g. minimum log dimensions, heartwood content and wood defects) limit seriously the marketing options of several forest companies in Costa Rica and many other countries in the area. Therefore, efficient management practices are urgently needed to lead not only to a maximization of per-hectare volume but also for the production of desirable individual-tree dimensions and high quality commercial timber.

The information presented in the paper should help foresters to choose the most adequate management practices to suit their particular goals (i.e. specific wood properties, total yield, commercial volume, rotation periods). The paper discusses topics like aboveground biomass and the applicability on stand density management, wood quality (heartwood, density) of young and advance aged plantations, effects of stand density on wood quality based on the results from a thinning trial, effects of stand density on growth and yield, preliminary pruning programme, pruning intensity and timing and total and merchantable volume equations.

Keywords: Wood quality, merchantable volume, aboveground biomass, thinning, pruning, teak market, volume equations

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Some Wood Quality Issues in Planted Teak

Takashi Okuyama, Hiroyuki Yamamoto, Imam Wahyudi, Yusuf Sudo Hadi and K. M. Bhat

Assessment of the wood qualities of planted teak in relation to different growth conditions is a pre-requisite to maximize the tree potential by genetic improvement and silvicultural methods. In the context of promoting timber production in fast growing teak plantations, the present study tried to show the variability in growth and relationships between growth rate and selected wood properties, including growth stress, based on the samples collected from plantations in Indonesia and India.

Planted teak has wide variations in the growth rate. During the initial stage of the growth, up to 10th year, all trees showed a faster rate, i. e., 3-9mm/year. After 10 years, they grew at almost constant rate up to 40-50 years, and subsequently the growth rate decreased gradually, i. e., 1.5-7.3mm/year, even though they still continued to grow after 60-70 years. The relationship between the heartwood ratio and the diameter is divided into two linear relations. The heartwood ratio rapidly reaches 90 per cent at around the diameter of 20 cm and increases slightly at larger diameter, regardless of the different provenance trees. The level of growth stress is considered to be lower than some other fast-growing species and is not affected by the growth rate. Also, the density at outer most part of trunk is not affected by the growth rate nor the tree age. The density increased towards the bark by 5-6 cm from pith and then stabilized at the age 10 -12 years. On the other hand, the microfibril angle decreased towards bark until 10-12 years. From these observations, it is expected that the planted teak forms mature wood around the age of 10-12 years. The results imply that growth acceleration by silvicultural treatments such as fertilization does not always adversely affect the wood qualities in teak.

Keywords: Litter dynamics, mineral nutrition, N-fixing woody perennials, site quality deterioration, species mixtures

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Myanmar Teak: Quality and Exports

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Myanmar is a supplier of forest products, of which teak from natural forests plays a major role. In order to ensure sustainable harvest, Myanmar Selection System (MSS) has consistently been applied. Myanmar is committed to Sustainable Forest Management (SFM), and enabling conditions to achieve SFM have well been put in place. In view of achieving SFM and better market access, a Timber Certification Committee (TCC) has been established. Regarding timber certification, documentation of basic framework has been started. MTE is the only State Economic Enterprise authorised to harvest timber, and the private sector is allowed to process and export value-added timber products. Not all teak grown in Myanmar is identical in properties. In exporting veneer and saw logs, Myanmar has 4 Quality Classes or Grades. It is noticed that log quality has been declining since the 1970s. With the deterioration in log quality, production of teak squares and other high end products is also observed to decline. Likewise, annual export of teak conversion has been reduced to more than half during the 1990s. However, export of secondary processed wood products (SPWPs) has gradually increased in the same decade. Disparity in tariff rates on the same product encourages importing countries to purchase teak in log form. Export of teak SPWPs from the private sector has increased since around 1997-98. Notwithstanding the limitations in woodworking technology and trained personnel, export of teak in the log form would remain an important means of earning hard currency for wood-based industry development. To strike a balance between log exports and wood industry, development is considered most judicious. Myanmar is striving to industrialize the wood industry. Enhancement of teak quality and export of SPWP within the shortest period is the final goal.

Keywords: MSS, SFM, timber certification, SPWP, wood quality, log exports, wood industry

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The Importance of Quality in Teak Plantations

Raymond M. Keogh

Tropical countries need to protect their forests and also satisfy their wood requirements. One option is to increase substantially, the area of managed natural forests. However, sustainable management of natural ecosystems and at the same time satisfying the demands, is not always realistic. Supplementary plantations are urgently required to produce renewable hardwoods for economic development, poverty alleviation and to decrease pressure on natural forests. Plantations that use best management practices can be 20 times more efficient, in terms of production, as compared to the natural forests.

Teak is the most widely cultivated quality hardwood and has many advantages as a plantation species. However, critical problems are encountered in conventional plantations. New quality approaches are required to overcome such problems. The approaches must be open-ended and innovative. A range of possibilities is examined, including the innovative Consortium Support System of TEAK 21.

The impacts of plantation production beyond the growing site, like the natural forests, environment, downstream industries and the consequences of using timber instead of other industrial commodities must all be taken into account while identifying new approaches of plantation management. Ultimately, the whole process must have positive impacts on the human efforts to achieve sustainable development.

Keywords: *Teak plantations, sustainable management, Consortium Support System, natural forests.*

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Transformation of Tropical Forestry Starts with Teak

Karl van Koppen

In this paper, it is argued that transformation of tropical forestry starts only with teak by discussing new dimensions of the giant leap towards global thinking, new limitations for the human behaviour, new issues of growing population and role of tropical forestry. New perspectives of tropical forestry were further elaborated considering teak as the flagship of tropical hardwoods for throwing light on the potential of sustainable investments, today's practices and benefits from such investments

Keywords: Tropical hardwood, plantation, investment, economic returns, sustainable forest management, environmental regulations

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RAPD Variation in Indian Teak Populations and Its Implications for Breeding and Conservation

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Genetic variation in teak populations from Western Ghats and Central parts of India were studied using Random Amplified Polymorphic DNA (RAPD) markers. Ten oligonucleotide primers resolved 90 amplification products of which 66 (73%) were polymorphic. The total genetic diversity detected within the species (H_{sp}) was 0.3. Average gene diversity (H_o) within different populations ranged from 0.185 to 0.261 (mean = 0.233). The Western Ghats populations had more diversity ($H_o=0.227 - 0.261$) compared to those from Central India ($H_o=0.185 - 0.219$). Partitioning of genetic diversity into within and between populations showed 78 per cent variation within populations and the rest between populations. A negative relationship could be observed between latitude and within-population diversity. Nei's genetic distance between populations ranged from 0.053 to 0.264. Genetic distance tended to be low between populations from the same geographic region. The UPGMA dendrogram grouped the Western Ghats and Central Indian populations into two distinct clusters. Increasing selections within populations is likely to capture major portion of genetic diversity existing in teak. A seedling seed orchard based approach is recommended to obtain a broad genetic base and to overcome problems related to flowering and fruiting. They can also be regarded as dynamic *ex situ* conservation stands. Western Ghats and Central Indian regions may be treated as separate geneecological zones. Since many subgroups may exist within these broad regions, multiple populations within each of them should be conserved *in situ*.

Keywords: Teak, RAPD markers, polymorphism, genetic diversity, genetic distance, population differentiation

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Diversity Studies in Teak Genetic Resources: Biometric and Molecular Approaches

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The nature and degree of variation in any base population determines the genetic improvement and conservation strategies. The divergence existing in the population can be assessed traditionally by provenance testing or electrophoretic analysis of enzymes. However, the major limiting factor in the use of isozyme analysis is the availability of fewer numbers of loci and environmental influence in its expression. Recently, DNA based molecular markers have increasingly been applied for quantification of genetic diversity. Hence, in the present investigation, diversity studies were carried out using biometric and PCR based on Randomly Amplified Polymorphic DNA technique (RAPD) to assess the genetic diversity between thirty seed sources of teak (28 Indian and one each from Lao PDR and Bangladesh).

The biometric studies through Euclidean distance for all the pair-wise combinations in the present investigation indicated a highest distance between the seed source of Tripura and Madhya Pradesh, followed by Kerala VI and Madhya Pradesh. The cluster analysis revealed that the major cluster A resolved into sub-clusters A1 and B1. All seed sources from Tamil Nadu and Kerala were grouped in the subcluster A11, barring Tamil Nadu V and Kerala VI, which indicated that within the sub-clusters the seed sources did not differ much

Seventeen arbitrary primers were used and all primers expressed polymorphism. A maximum of 14 amplified products were observed in the profile of primer OPR10. Jaccard's similarity index revealed that a highest genetic distance of 0.457 was between Kerala III and Uttaranchal. The resultant phenetic tree indicated that populations from each State were found to be grouped within the same subcluster, barring few seed sources revealing the identity of each population.

Keywords: RAPD, diversity studies, seed sources, phenetic tree

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Fertility Variation and Dynamics of Two Clonal Seed Orchards of Teak in South India

Mohan Varghese, A. Nicodemus and B. Nagarajan

Fertility differences between clones were estimated in two 25-year-old Clonal Seed Orchards (CSO) of teak in South India. CSO-I is located at Topslip in Tamil Nadu with 15 clones and CSO-II at Walayar in Kerala with 20 clones selected from Karulai (KLK), Nilambur (KLN), Sungam (KLS) and Thunakadavu (TNT) regions in Western Ghats and Bhadrachalam (SBL1) in Andhra Pradesh. In CSO-I, more than 50 per cent ramets of 14 clones were fertile whereas only 20 per cent ramets of 14 clones were fertile in CSO-II. Diameter growth, number of flowering branches and inflorescences per primary branch were greater in CSO-I. But trees in Walayar CSO, despite having 14 per cent more flowers and twice the number of fruits in an inflorescence, produced only one third the number of flowers and one-fifth the number of fruits as that of Topslip trees. As a result, trees in CSO II had a lower mean fruit set (213 fruits per tree) compared to CSO-I (1031 fruits per tree). Fruit yield in both orchards was however low compared to that of a 60-year-old Seed Production Area (SPA; 4573 fruits per tree) in Nilambur.

In general, KLK and KLN clones were more fertile than clones TNT and KLS, in both orchards. In CSO-I, KLK1 with most number of fertile ramets, produced 18 per cent of flowers, followed by clones KLS4, TNT7 and TNT4, together accounting for 58 per cent of the total fruits produced. In CSO-II, a single clone, SBL 1 produced 68 per cent flowers and 36 per cent fruits in the orchard. KLK1 (19%) and KLN1 (15%) were the other major seed bearers.

Imbalance in relative flower and fruit production in clones as indicated by a Mating index, alters the mating system in the orchard. Topslip CSO had better out crossing conditions (Mating index = 1.1, similar to the SPA - 1.001) than CSO-II (Mating index = 4.57) where 84 per cent flowers and 55 per cent fruits were produced by just two clones, which could result in considerable related mating and high coancestry levels. Therefore, selection and manipulation of clones for optimum seed quality is essential for improving the planting stock.

Keywords: *Tectona grandis*, clonal seed orchard, fertility, diversity and coancestry

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Why Teak Seed Orchards are Low Productive?

E. P. Indira

Efforts made to produce improved teak seeds through seed orchards have become a futile exercise since, contradictory to the tree breeders' expectations, the grafts in teak seed orchards in general are not flowering and fruiting sufficiently. Kerala Forest Research Institute has established three pilot teak clonal seed orchards at three different locations in Kerala, to examine various factors affecting the growth as well as flowering and fruiting potential of these grafts, in addition to the economic value of improved seeds. It was observed that the percentage of flowering grafts varies from place to place with a value of almost zero to 11.5, even after 15 years of establishment. It is also noted that soil properties as well as spacing between grafts affect flowering. When plus trees were selected, the flowering and fruiting behaviour were not properly cared for, and they were selected mainly for vegetative vigour and tree form with less branching. The correlated response, if any, that increases the juvenile period and decreases the flowering, was not accounted for during seed orchard establishment. The paper analyses the factors such as choice of plus trees, rootstock and planting site, light intensity, soil fertility and growth vigour that affect flowering of teak grafts. By controlling those factors, an increase in flowering and fruiting is expected in teak seed orchards.

Keywords: Seed orchards, flowering and fruiting, choice of plus trees

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Teak (*Tectona grandis* L. f.) Seed Orchards in India : Suggestions for Management Practices

Rajesh P. Gunaga and R. Vasudeva

Seed orchards are important in tree improvement programmes, which are intended to produce quality seeds in large quantities. The main assumption made while establishing a seed orchard is that diverse genotypes are highly compatible and completely overlap their flowering phenology. However, the fruit production among seed orchards are very low. This paper deals with the causes for low fruit production in seed orchards; it reviews the available literature on the topic and attempts to suggest a few management practices.

Keywords: Clonal seed orchard, teak clones, plus trees, pollination, phenology, flowering

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Are Intensive Teak Plantations in Agroforestry Practices Environmentally and Ethically Sound?

Sunil Puri

Agroforestry and teak have generated high levels of enthusiasm in recent years, especially those concerned with tropical land-use systems. Although it is true that the scientific principles of agroforestry are only now being examined, and hence understood, the practice, in some form or other, has been in existence since very early times, especially with forest organizations growing teak under the *Taungya* system. However, the teak plantations established in the past have fallen short of their potential, and that a new approach is demanded for future programmes. The paper examines the possibilities of growing teak under various agroforestry systems, viz., taungya, spatial agroforestry system (agrisilviculture system), silvopastoral system and home gardens. Possibilities of growing some suitable crops and grasses have also been examined. How the biophysical factors like light, water, nutrients and root behaviour play a role in increasing tree productivity has been discussed. Tree improvement activities for small holder farmers, particularly in Chhattisgarh, are discussed. Moreover, a financial analysis of a small scale teak improvement programme in Raipur, Chhattisgarh is described. The programme consisted of a seedling seed orchard, made up of ramets of plus-trees. The analysis demonstrated the annual planting rates between 31 ha per year (at 20% genetic gain in volume) to 125 ha per (at 5% genetic gain) over 30 year life of the orchard are economically justifiable. The results demonstrate that the tree improvement above the seed stand intensity be more widely adopted in support of small-holder tree planting. The implementation of such small scale, locally-based programmes by community-based or locally oriented organizations may often be justifiable.

Keywords: Agrisilviculture system, financial analysis, seedling seed orchard, taungya system, tree improvement.

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An Appraisal of Teak Farmer's Woodlots in Sri Lanka and the Relevant Management Strategies

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Teak is widely grown in the dry and intermediate agro-ecological zones of the Island Sri Lanka, characterized by reddish brown soil and prominent rains during the North-East monsoon. The mature teak stands covering an area of about 19451 ha were established under the *Taungya* system by peasants on land leased for three years period, a practice which lasted till the latter part of seventeenth century. Teak stumps were planted at a spacing of 2.8 m x 2.8 m, with intercropping of cash crops. Due to inadequate management, most of these block plantations now remain overstocked and unproductive.

During 1993-99, the Forest Department undertook to establish Farmers Woodlots (FWL) with teak, as wide row intercropping agro-forestry model. Land parcels of 0.4 ha were leased to farmers for a period of 25 years. Rooted teak stumps were planted at a spacing of 2 m x 5 m, followed by intercropping with non-perennial crops. The total extent of pure teak woodlots established was 3297 ha and 36 per cent of this already exceeds the age of seven years, and were first thinned recently.

In spite of the satisfactory growth during the early years, it is necessary that the FWL be intensively managed for highest possible benefits. Many stands are with high occurrence of low branching due to wide spacing. Measures to improve the bole quality and optimum thinning regimes are still to be introduced. The beneficiaries faced the problem of selling the thinned material due to poor organizational infrastructure for marketing. Based on the experience gathered from the previous and the present agroforestry programmes, the paper discusses the problems associated with managing the FWL and recommends measures for improvement.

Keywords: Farmers teak woodlots, spacing, growth, yield, bole quality, income, rotation, marketing

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Soil Conditions and Growth of Teak in Successive Rotations in Kerala State, India

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Teak plantations occupy an area of about 69,000 ha in Kerala, of which about 64 per cent is in first rotation and the remaining, in second and third rotations. A study was carried out in teak plantations of first, second and third rotations in Nilambur, Kerala to evaluate the soil conditions and the growth of teak in successive rotations. Twenty-four plantations of 8-17 years age groups were selected. Out of these, six plantations were in the first, 10 in the second and eight in the third rotations. In each plantation, 26, 16 and 17 temporary sample plots (20 m x 20 m) were laid out in the first, second and third rotations, respectively, at the rate of one plot per 10 ha of plantation. Soil samples were collected from 0-20, 20-40 and 40-60 cm layers and analysed. The gbh of all trees in the plots was recorded, while the height was measured on a subsample of trees within each plot. Soil analyses revealed that the soils were sandy loam in the surface and loam in the deeper layers in the first rotation and sandy loam and loam in all layers in the second and third rotations, respectively. The soils were medium acid in all rotations, but a decrease in acidity was seen in successive rotations. Organic carbon contents were highest in the first, while exchangeable bases remained almost same in the three rotations. Total N, available K, Ca and Mg were lowest in the second rotation.

Among the 11 soil properties studied, the discriminant analysis revealed that there was significant decline in soil fertility with change in rotation. Tree height differed significantly between rotations while there was no significant difference in the gbh of trees. Only 14 per cent of variation in tree height could be explained by the soil properties, as height growth is also controlled by a host of other factors. The differences in site index between rotations were found to be non-significant and this could be due to the high variation in site index within rotation. The study suggests the need for careful management of the soil to reduce soil deterioration.

Keywords: Teak rotation, soil conditions, growth

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Sustainable Teak Plantations in the Tropics: The Question of Nutrient Management

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For more than a century and half, foresters have been growing teak, often repeatedly at the same site. However, sustainability of monoculture plantations in the tropics, in general, and teak in particular, has been questioned recently, because of potential adverse effects on soils. Although chemical and biological fertilizations are suggested as universal remedies to resolve the crisis of site deterioration, there have been few experimental studies on teak nutrition, which is summarised here as the current state of knowledge on nutrient management of teak. Succinctly, N, P, K and Ca availability in the soil, limit teak growth, even though the results of chemical fertilization are inconsistent. As an alternative, growing mixed species stands with N-fixing trees is more promising. A limited number of replacement series experiments available in this respect, indicate that N-fixing trees improve growth of associated teak and soil nutrient concentrations. Drawing on results from studies on other species, such mixtures presuppose complementary resource use and grow well with minimal inputs, even on degraded sites. Although nutrient management is the central premise of sustainable teak plantations, nutritional interactions, N transfer between teak and associated N-fixing trees, besides yield and site quality deterioration and nutrient cycling over successive rotations, have been seldom assessed. Most of the reported studies do not go beyond spasmodically evaluating height, diameter and/or basal area responses of the tree, over short intervals. Therefore, a network of long term coordinated experiments with graded levels of applied nutrients and species mixtures involving N-fixing trees is suggested to gain insight on nutrient relations, site quality deterioration and the contribution of N-fixing species on teak growth and nutrition.

Keywords: Litter dynamics, mineral nutrition, N-fixing woody perennials, site quality, deterioration, species mixtures

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Teak and Its Canopy Parasite *Dendrophthoe*: Water Relations and Ecophysiology

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Teak (*Tectona grandis* L. f.), the most important timber species in India, is widely infested with an angiosperm hemi-parasite, *Dendrophthoe falcata*. The mistletoe clumps cause enormous damage to the trees, sometimes leading to their death. The paper explains the ecophysiological factors that help the survival of this parasite. The diurnal water potential measurements done on both the host and the parasite during different seasons revealed that the parasite always maintains lower water potential compared to the host tree, which is ideal for taking up water from the host. The lowest water potentials recorded were -1.07 MPa in teak and -1.08 MPa in parasite. The stomatal conductance values recorded during pre-monsoon (dry) period were similar in both the host and the parasite. Maximum values were in the range of 500-to 600 $\text{mmol m}^{-2} \text{s}^{-1}$. A maximum net photosynthesis of $13 \text{ mmol m}^{-2} \text{s}^{-1}$ was observed in teak whereas the parasite showed values $>9 \text{ mmol m}^{-2} \text{s}^{-1}$. Diurnal measurements of light availability showed that the parasite received only 40 per cent of the light received by the host. The parasite was seen to survive well in well-exposed situations and even when the host leaves blocked 70 per cent of the solar radiation. The data on the light requirement by the host and parasite indicate that the parasite is able to survive both under shaded and fully exposed condition. This behaviour has great implications on the adaptability of this parasite to opposing light environment and this is to be taken into account in work aimed at controlling the parasite. Transpiration measurements showed that the parasite transpired less during mornings and evenings, but during peak hours, it transpired more as compared to teak. Chlorophyll fluorescence measurements revealed differences in the photosynthetic efficiency between the host and the parasite. Chemical analysis of leaves indicates more K and Na in the leaves of the parasite compared to host. Any control measures targeted at the parasite should be done during the deciduous stage of the host tree.

Keywords: Teak parasite, *Dendrophthoe falcata*, water relation, ecophysiology

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Tissue Culture for Improved Productivity of Teak

Rajani S. Nadagauda, S.V. Kendurkar and V.M. Kulkarni

Tissue culture method can be used for improved productivity of teak through clonal multiplication of superior plants. The possibility of plant production using the meristem tissue from 100-year-old teak plants was first demonstrated in 1980. The micropropagation technology was further refined and was used for scaling up of production of plants using elite/plus trees of teak which were field planted at different locations in India.

In this paper, the details on the work carried on improvement and up-scaling of the micropropagation technology and field planting of tissue culture raised propagules of teak are given. The major emphasis is on the results obtained in the field performance of tissue culture raised plants of different clones of teak. The data obtained is from 5 to 8 years old plantations.

Keywords: Micropropagation technology, up-scaling, field performance

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Selection and Propagation of Quality Teak Clones for Plantation Establishment

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Innoprise Corporation Sdn Bhd (ICSB), an investment subsidiary of the Sabah Foundation, has embarked on extensive research and development programmes for teak (*Tectona grandis* L. f.), the most prized timber species. Through ICSB's joint collaboration with CIRAD-Forêt, a French research and development organisation, a plant improvement programme was initiated in the early 1990's. Special efforts were made for vegetative propagation strategies based on the development of efficient techniques, both at the laboratory and at the nursery levels. Materials from selected mature ortets and seeds from a broad base and presumably high genetic value but restricted number, were multiplied by a well-developed tissue culture technique. Additionally, seed lots from natural forest stands, plantations and a multi-provenance clonal seed orchards (CSO) were obtained. They were germinated and used to establish two provenance/progeny trials in two different locations in East Sabah, Malaysia. Data of five-year-old trees from the two trials indicated that the CSO materials were better performers in terms of growth rate than those from true provenance sources. Selection of genotypes with good traits was thereafter undertaken for further tests in different sites. The ownership of such a large field-tested genetic source materials coupled with the efficiency of the developed techniques offers tremendous potential for genetic improvement of teak for large-scale plantation establishment. The commercial prospect of selected materials from this rich genetic base for world market is equally bright and will be pursued.

Keywords: Broad genetic base, progeny/provenance trial, clonal selection, nursery cuttings, tissue culture propagation, field trials.

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Tissue Culture Strategies for Production of Quality Planting Stock in Teak

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Teak is the most preferred species of plantation forestry in India. The projected annual planting of teak in India is 240 million seedlings for over 0.12 million hectares. A total of 800 ha of clonal seed orchard (CSO) is established which can provide about 15-16 million seedlings of good planting stock. Therefore, micropropagation technique was standardised to quantitatively enhance the production of genetically improved planting stock using the seeds from clonal seed orchards. Many micropropagation protocols for plantlet production are known, even though only few are practically useful for mass production. Comprehensive method for good shoot multiplication, cost effective rooting and application to a wide range of genotypes was developed. Seedlings raised from seeds collected from different clones in clonal seed orchard were used for culture establishment. Nodal segments of in vitro germinated seedlings were placed for five days on MS medium supplemented with 22.2 μM Benzyladenine (BA) and 11.62 μM Kinetin (K) for culture establishment. Rapid shoot proliferation was done in 2.22 μM BA and 1.16 μM K. Healthy shoots of 4 cm and above were treated with 1000 ppm Indole-3-Butyric Acid (IBA) solution in ex vitro conditions and 80-100 per cent rooting was achieved. Genetic uniformity of the tissue culture raised plants was tested using DNA markers. Through the commercial micropropagation approach, about 3000 plants were supplied Andhra Pradesh Forest Development Corporation. Effects of cytokinins, solidifying agents, method of subculturing on shoot proliferation of teak, etc. will also be discussed.

Keywords: Teak, micropropagation, CSO seeds, *ex - vitro* rooting, genetic uniformity

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Clonal Propagation of Plus Trees of Teak and Field Performance of Ramets

T. Surendran and J.K. Sharma

Plus trees of teak (*Tectona grandis* L.f), 40 to 50 years old, were cloned through a unique technique standardised at Kerala Forest Research Institute, Peechi. The technique involves two major steps, viz., production of juvenile epicormic shoots on branch cuttings of 3 – 10cm diameter, taken from plus trees and rooting the shoot cuttings. Sufficient number of juvenile epicormic shoots were produced on the branch cuttings planted in large polybags filled with sand and soil and kept inside the mist propagation chamber. When the epicormic shoots attained 10-15 days' growth, they were collected and made into suitable shoot cuttings having two pairs of leaves and the apical bud intact. Leaf areas were reduced by trimming away the distal halves of the lamina. For induction of rooting, the cuttings were treated with 6000 ppm of a rooting hormone, Indole Butyric Acid (IBA) prepared in talc, after subjecting it to prophylactic treatment with Bavistin (0.05 % a.i.) solution. The pre-treated cuttings were inserted into vermiculite-filled root trainers of 300 cm³cell volume (=) and kept inside the mist propagation chamber for rooting. Within a period of 30-45 days' the epicormic shoot cuttings sprouted and rooted. The satisfactorily rooted and sprouted cuttings were hardened inside the hardening chamber to obtain rooted cuttings of desired plus trees suitable for field planting. Following this technique, 30 plus trees of teak were cloned successfully to get true-to-type rooted ramets in sufficient numbers, as and when required. Hardened ramets, 120-days-old, were field planted in four different locations in Kerala during 2000-'02. These ramets showed 99 per cent survival and very good growth in height and girth (maximum 8.5 m. height and 25 cm. gbh after 23 months of field planting). Practical applications of this technique in tree improvement programmes of teak will be discussed.

Keywords: Cloning, plus trees, epicormic shoots, hormone, rooting, ramets, field performance, planting

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Clonal Propagation Technology in Teak for Production of Improved Planting Stock

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Clonal propagation technology for mature teak trees (>50 years old) and quality seedlings has been standardized. Indole Butyric Acid (IBA) was found to be the most effective auxin for adventitious rhizogenesis in teak. Cuttings from coppice shoots of mature trees rooted between 74 to 91 per cent in different seasons, while the cuttings from 1 to 2 year-old root-stocks rooted between 79 to 100 per cent, throughout the year. Mature coppice shoots produced vigorous sprouts with high rooting potential probably due to high carbohydrate and nutrient contents in the mature shoots. Adventitious root formation and root system of cuttings collected from coppice shoots of 63 year-old mature trees were similar to those of 1 to 2 year-old root-stocks, suggesting the juvenility of coppice shoots for rooting. In teak, rhizogenesis depends upon the physiological status of the cutting, and season is no longer a major barrier. The clonal technology will be helpful for production of genetically superior planting stock of teak for clonal plantation and afforestation programme and thereby augment productivity. Teak trails have been established with improved planting stock raised vegetatively from mature trees and quality seedlings. The early evaluation showed that the growth performance of coppice shoot cuttings from mature trees was similar to those of seedlings. Superior trees of teak have been selected for clonal multiplication.

Keywords: Clonal propagation, teak, productivity, improved planting stock

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Implications of Clonal Variation in Reproductive Traits for Improvement of Teak (*Tectona grandis* L. f.)

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Although seed orchards represent a vital link between commercial plantations and the ongoing tree improvement programme in teak, understanding the variation and genetic control of reproductive traits in seed orchards has been consistently ignored. The inter and intra clonal variation for reproductive traits in a twenty-year old clonal seed orchard in Karnataka State in South India, was estimated.

Inter clonal variation was significant for majority of fecundity and phenological traits, suggesting a strong genetic control. Strong provenance effect on phenology was observed. Clones from central and southern provenances were early in flowering than those from northern and thus demonstrates asynchronous flowering among clones. Hence, selecting clones based on proximity of clonal origin could be used as a thumb rule. In general, clones from southern provenance had larger flowers and produced larger pollen grains, as compared to clones of northern provenance. Further, clones from southern provenance tend to produce more number of flowers and fruits per inflorescence than those from northern provenance. Interestingly clones from northern provenance showed higher pollen viability, higher fruit set and seed set per cent, and hence more Pre Emergent Reproductive Success (PERS). However, PERS was on lower side (0.172-0.645), but significantly differed among the representative clones studied. Clones that initiated leaf flushing early and possessed longer duration of peak flowering, tend to produce higher number of fruits per inflorescence. Hence, these two traits should be considered while selecting trees for CSO in order to increase the fruit yield. However, clones that coincide flowering with peak rainy days recorded lower fruit set and hence should be avoided.

Keywords: Teak, *Tectona grandis*, clonal seed orchard, reproductive traits, provenance, phenology, pre-emergent reproductive success

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Pest Factor in the Intensification of Teak Cultivation: A Global Assessment

K. S. S. Nair

Intensification of teak cultivation, both in terms of intensive management with high nutrients input and genetic selection for faster growth rate, and large-scale expansion of plantations into exotic locations are both recent phenomena. Limited empirical data as well as theoretical considerations show that both generate the risk of new pest problems. The well-known teak defoliator of Asia, which has been shown to rob native teak plantations of over 40 per cent of its potential volume increment, has not so far been recorded from Africa. In Australia and Latin America, although the insect is present, it is unknown as a pest of teak. But the situation changed when outbreaks appeared all of a sudden in plantations in Costa Rica in 1995 and Brazil in 1996. Theoretical considerations show that the extent of plantations is one among several factors that determine pest outbreaks in exotics. Unfortunately, the pest factor is not given due consideration in plantation planning and management. Even the growth assessment in the DANIDA International Teak Provenance Trial suffered from lack of insight into the geographical spread and seasonal dynamics of teak defoliator outbreaks. The threat and implications of pest outbreaks in the global expansion of teak plantations and their sustainability are assessed.

Keywords: Pest factor, teak defoliator, *Hyblaea puera*, pest outbreaks, exotics.

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Tree Health of Teak in Central Part of India

Jamaluddin

Tectona grandis L. f. is one of the important tree crops of central India. Large scale plantations of this species are raised by the state forest departments and even by some of the progressive tree planters. In order to achieve faster growth, high inputs in the form of chemical fertilizers, organic compost, biofertilizers and irrigation are used. Though teak is a very hardy species, it is prone to attack by a number of seed-borne fungal pathogens. Seed borne *Fusarium pallidoroseum* causes heavy mortality of seedlings in the nursery bed. A number of pathogens are responsible for damaging teak plants by causing root diseases, stem and branch canker and dieback, collar rot, heart rot in dry coppice teak and mortality in natural teak forests. *Amylosporus campbellii* root rots, *Fusarium pallidoroseum* canker and *F. oxysporum* root rot are newly reported from high input plantations. Two bacterial diseases in nursery and plantations also cause considerable damage. Some of the established control/managements techniques are discussed in the paper.

Keywords: Teak, seed-borne diseases, fungal pathogens, bacterial diseases, central India

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Disease Problems and Their Management in Teak Root Trainer Nurseries in Kerala State, India

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A disease survey was carried out in root trainer nurseries and selected plantations raised with root trainer seedlings in Kerala State, during 2000-02. The study revealed that root trainer seedlings were almost free from soil-borne fungal diseases like damping-off, web blight, seedling blight, wilt, collar rot, etc. prevalent in conventional nurseries. The common nursery pathogens of teak such as *Rhizoctonia solani*, *Pythium* spp., *Fusarium* spp., *Sclerotium rolfsii*, etc. were seldom recorded in root trainers. However, a weak aerial strain of *R. solani*, causing minor foliage and stem infection, was recorded from one nursery. Often seedling congestion in root trainers led to foliage infection by weak pathogens like *Colletotrichum gloeosporioides*, *Pestalotiopsis* spp., *Alternaria alternata*, *Curvularia* spp., etc. In general, severity and spread of foliage infection was low in all the nurseries, except a leaf blight caused by *Phoma glomerata* and *P. eupyrena*. Bacterial infections such as cotyledon rot, seedling wilt, seedling rot, etc. caused by *Ralstonia solanacearum* (= *Burkholderia solanacearum*) were recorded in root trainer nurseries. In plantations, bacterial seedling wilt and foliage blight caused by *Phoma* spp. were the most widespread diseases. Fungicides and bactericides were screened against important fungal and bacterial diseases and effective fungicides (Bavistin, Mancozeb, Carboxin) and bactericide (Streptomycin sulphate 90% w/w+ Tetracycline hydrochloride 10% w/w) were applied in the nurseries. The paper discusses management practices to be followed for raising disease-free planting stock.

Keywords: Root trainer seedlings, teak, fungal diseases, bacterial diseases, disease management

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Clonal Variation in the Incidence of Phytophagous Insects: Some Thoughts on Divergence of Teak

O. K. Remadevi, Raja Muthukrishnan and Y. B. Srinivasa

Characters are known to diverge over time in spatially separated populations. A study was conducted on the population divergence of teak (*Tectona grandis* L. f.) across the State of Karnataka, India, with respect to the incidence of phytophagous insects. Data on the incidence of the teak defoliators, namely *Hyblaea puera* and *Paliga machoeralis* (both indigenous species) and the spiraling whitefly, *Aleurodicus dispersus* (recently introduced polyphagous species) were recorded from two clonal assemblages for a period of three years. Individual clones as well as the provenances did not show any significant variation with respect to the incidence of either *H. puera* or *P. machoeralis*. Interestingly, variation in the incidence of *A. dispersus* was detected across individual clones indicating divergence in the populations of teak. The results showed that the defoliators are not directly responsible for the variations that exist across clones and provenances, and that these defoliators are able to overcome the existing variations and continue building pestiferous populations.

Keywords: Teak, population divergence, clonal variation, *Paliga machoeralis*, *Hyblaea puera*, *Aleurodicus dispersus*

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Productivity of Teak Stands in Kerala State, India: Role of Arbuscular Mycorrhizal Association and Diversity of AM Fungi

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In view of the paucity of data on mycorrhizal status and their functional roles in managed teak stands, an exhaustive survey was made during 1998-2002 in 70 teak plantations in different parts of Kerala State. The arbuscular mycorrhizal (AM) fungal association was detected in young feeder roots of all the sampled teak plants. However, the per cent root infection as well as species association varied with age of the plants and soil properties. The morphological diversity of AM fungal structures observed within the root samples indicated colonization by several AM fungal species. The overall extent of root colonization varied from 2 to 86 per cent with a mean of 32.42 per cent. The highest values were registered in root samples collected during the driest period. The pH, moisture content and nutrient status of the soil were found to influence the root colonization and distribution of spores in rhizosphere soil. The soil pH ranged from 4.03 to 7.96; and moisture content, from 0.31 to 19.33 per cent. Total nitrogen, phosphorus, organic carbon and exchangeable cations viz., Na, Ca, Mg and K, also showed high variation. In general, among various factors, soil pH, magnesium and sodium levels were found to influence the AM fungal colonization. The AM fungal spores retrieved from different soil samples ranged from 29 to 810 with a mean value of 216/10 g soil. The spore density and root infection showed a weak linear relation. Altogether, 85 species of Glomalean fungi belonging to six genera, viz., *Glomus*, *Acaulospora*, *Gigaspora*, *Scutellospora*, *Sclerocystis* and *Entrophospora* were recorded. The AM fungal community in teak soils consisted of 12-39 species with a mean spore density of 211.85 per sample plot. Among the AM fungi associated with teak, *Glomus* and *Acaulospora* were the most predominant genera. Relative abundance of AM fungi measured using Shannon-Wiener and Simpson's indices ranged from 1.5532 to 3.0032 and 3.0508 to 16.6012, respectively. Gamma and beta diversity of AM fungi estimated were 98 and 69, respectively. The paper discusses possible functional role of AM fungi in improving the stand productivity.

Keywords: Arbuscular mycorrhiza, teak, mycorrhizal association, diversity

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Status of Colonization and Spore Population of Arbuscular Mycorrhizal Fungi in *Tectona grandis* L. f. from Bangladesh

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The status of colonization of Arbuscular Mycorrhizal (AM) fungi in the roots, and spore population in the rhizosphere soils of teak (*Tectona grandis* L. f.), were assessed. Roots and rhizosphere soils of teak plants both from nursery and plantations were collected from different parts of Bangladesh. All the samples were found to be colonized by AM fungi. Per cent root colonization varied widely, irrespective of the age and site of collection. The range of colonization was 56-95 per cent. Maximum colonization (95%) was from Singra plantation and the minimum (56%) was from Rajosthali plantation. The intensity of structural colonization was also variable irrespective of the age and site of collection. Spore population was found in all the soil samples. Soil from Rajosthali nursery showed the highest population of spores and that from Hazarikhil forest had the lowest. *Glomus* was highest (67%) in Madhupur plantation and lowest (23%) in Chittagong University nursery. *Acaulospora* was minimum (13%) in Dharmapur plantation and maximum (31%) in Singra plantation. *Gigaspora* was highest (77%) in Chittagong University nursery and lowest in (03%) in Khaskhali nursery. Biodiversity of structural colonization in the roots and AM fungal spore population in the rhizosphere soils of teak growing areas highlights the dependency of teak on arbuscular mycorrhizal fungi. Hence, it is necessary to adopt the AM technology in the nursery and plantations for better, useful and eco-friendly management of teak.

Keywords: AM fungi, mycorrhizal association, teak plantations, Bangladesh

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Cultivation of Teak (*Tectona grandis* L. f.) in Farmlands of Different Agro-climatic Zones in Tamil Nadu: An Analysis of Ecological and Economic Factors

S. Saravanan, M. George, C. Buvaneswaran and S. Viswanath

During the last two decades, teak (*Tectona grandis* L. f.) has attained maximum importance because of the entry of corporate sector in teak investment schemes, in a big way, with attractive claim of unattainable returns. During the same period, many farmers were also started cultivating teak in their farmlands. Under a World Bank funded project, a study was carried out in seven agro climatic zones of Tamil Nadu, covering 427 plantations in age group varying from two to twelve years. Ecological factors which favour or limit the growth, yield and timber quality were analysed and the results are presented.

Based on biometrical analysis, there exist statistically significant difference among the zones with respect to both mean girth and mean height of teak plantations in farmlands. The result confirms that growth performance of teak greatly varies with variation in edapho-climatic conditions. The study also concluded that site selection remains as one of the important conditions for optimum or better growth of teak. Based on the observations made on teak in farmlands in the localities which are prone to strong winds, it was found that the mean height in plantation with wind barrier (vegetative barrier) was about three times more than that of plantations without wind barrier. Hence, the wind factor has to be taken in to consideration, along with other important site factors, while matching the species with sites in any commercial plantation programme. The socio-economic factors for shifting to teak cultivation from conventional agricultural practices were also analysed and ranked according to Garrett ranking technique. The socio-economic profile of teak growing farmers in Tamil Nadu is also presented in the paper.

Keywords: Teak cultivation, farmland, agroclimatic zones, ecology, economics

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Prospects and Potential of Growing Teak in Punjab State, India

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Teak (*Tectona grandis* L.f.) is known for its excellent wood quality and is taken as a standard for comparing other tropical timbers. It is generally preferred in India for house construction, panelling and furniture making. The price of good quality teak logs of more than 120 cm girth, exceeds Rs 1425-1450 per cubic foot in timber depots. The timber quality and higher cost prompt farmers to grow teak in agricultural lands, as they have already successfully experimented with *Eucalyptus tereticornis* and *Populus deltoides* in early eighties and late nineties, respectively. However, its long rotation holds them back. Sometime back, many plantation companies sprang up and duped the public and the farmers in the name of prized and high return teak plantations. All these companies had to wind up and are in deep waters. State forest departments in Punjab and Haryana States are also planting teak in avenues, along roadsides, railway tracks and canal bunds, even though they usually suffer from neglect. Some isolated old teak plants (with 50-60 cm DBH) can be seen along the State highways which flower and set viable seeds, as well. Teak trees planted in early 1980's in the Punjab Agricultural University Campus were measured for the growth performance parameters and the timber volume was assessed. The information derived prompts for the successful cultivation of teak in some parts of Punjab State. Teak trees grow better and faster when planted along water courses and field boundaries. Plantation strategies on farm border rows and farm steads in agri-silviculture systems, as in the case of *Dalbergia sissoo*, for the benefit of farmers are discussed in the paper. The aftercare and management strategies to protect teak trees from frost damage in early stages, fire and wind damage are also given. Future scope and suitable extension strategies for quality teak plantations in the North-western States of India are elaborated in the paper.

Keywords: Teak in Punjab, frost damage, management strategies

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Economics of Teak Plantations in Kerala State, India

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A study on teak plantations in Kerala was undertaken to evaluate the present business economics of the plantations in the State under government ownership. The total cost of one hectare of plantation, spread over the rotation period of 60 years was estimated as Rs. 1,59,385, of which, 3.83 per cent was invested during the establishment period. The amount of investment varied from Rs. 1,47,809 in Central Circle to Rs. 1,66,734 in the Olavakkod Circle. The study revealed that the expenditure on thinnings form a sizeable proportion of total cost, even though the returns from first thinning was enough to realize the cost incurred until then. When *Taungya* system was practised in the State, the revenue exceeded the cost in the first year itself. The returns included the sale proceeds of poles, firewood, logs and timber, obtained through thinnings and the final felling. The average revenue from the plantations over the rotation period is estimated as Rs. 24,71,599 per hectare, using auction price of timber in the respective sales depots. Teak plantations of all circles proved to be financially sound. Plantations in the Olavakkod Circle were the most profitable ones with respect to the NPW and Benefit-Cost ratio (5%).

The IRR was maximum for Southern Circle followed by Olavakkod. At higher level of discount rate, the profitability of Central and High Range Circles were most adversely affected. The situation of a 20 per cent increase in cost or 20 per cent decline in benefit, other factors remaining the same, do not make the plantation non-profitable. But the profitability of plantations was more sensitive to a decline in benefit rather than an increase in the cost. Market analysis showed a bright price prospect for this tropical timber. So, the focus should be on timely scientific management to ensure maximum yield, as the average yields in many plantations are below the site potential. Proper management even at a higher cost can be justified for ensuring maximum production and economic efficiency.

Keywords: Market analysis, timber prices, returns from thinning, plantation management

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Abstract

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Teakwood Production Strategy in the Global Perspective: Integrating Traditional Forest Plantations, Commercial Plantations and Agroforestry

Mammen Chundamannil

Increasing teakwood production from non-traditional areas such as South America and declining productivity of forest plantations in the traditional Orient, calls for a rethinking of the strategy for teakwood production. What is the relevance of traditional public sector teak plantations within Protected Areas? Can they be competitive with the high input modern plantations, free of pests, outside the traditional areas? What is the scope of commercial teak plantations outside forests after the 'boom and bust' of private sector teak companies swindling gullible investors in India? How can teak plantations in mixed home garden agroforestry produce high quality timber? What is the appropriate rotation for each producer? The paper presents a strategy for integrating producers with differing access to land, capital, human resources and technology to participate in the quality upgradation of plantation teak, while ensuring conservation values and community stability.

Keywords: Teakwood production, traditional and non-conventional areas, conservation values

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Current Status, Future Prospects, Economics and Policy Issues for Teak (*Tectona grandis* L. f.) Investments by NABARD

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National Bank for Agriculture and Rural Development (NABARD) is a developmental bank, which provides credit for promotion of sustainable agriculture including forestry, for integrated rural development. Teak (*Tectona grandis* L. f.) is one tree which has great potential in rehabilitation of India's degraded forests and also raising farm forestry on wastelands, on a sustainable basis. Earlier, teak was believed to be slow growing. But, nowadays, with the availability of improved planting stock, advanced nursery and plantation technologies and intensive management, it is found to be suitable as a short rotation forestry / farm forestry crop. Many state-owned Forest Development Corporations (FDCs) have already raised excellent teak plantations, after availing of credit from NABARD/banks on long term basis. Today, FDCs are proposing short rotation, intensive, irrigated teak plantations and have already submitted few projects to NABARD. During the last decade, many private entrepreneurs floated companies, calling for investments in Teak equity with promise of high returns. Many people invested in such equities, although the promised returns were not available to them. However, it is felt that, teak is really a potential tree for investment and is strongly recommend for raising commercial plantations by the farmers and the FDCs on their lands.

As per NABARD scheme for teak under Farm forestry, the recommended trees per hectare is 2500 and the unit cost is Rs. 40,000 in four years. Thinning is recommended in 7 and 13 years, from which, sizable income will be available and the entire bank loan with interest can be repaid with that. Such teak plantations on wastelands are both technically feasible and financially viable. The IRR of the scheme is 28.69 per cent. Teak plantations on degraded forest lands are also viable and the IRR varies from 17 to 18 per cent. The major problems faced by teak farmers is lack of quality planting stock and the strict transit rules which need immediate attention of the planners, policy makers, forest departments and the scientists.

Keywords: NABARD, teak investments, economics, policy issues

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Optimal Rotation of Teak Production: Tools for Economic Analysis

A. H. M. Mustain Billah

Bangladesh has a century-long history of teak plantations, like many other tropical countries. Management is one of the most important problems, besides budgetary constraints. It is one of the most important timbers in the world trade, used chiefly for shipbuilding and constructional purposes. Teak plantation is set for 60 years rotation for all sites in Bangladesh, which is not compatible with the economics of forestry. Based on assessment of economic and silvicultural aspects, teak rotation practice is going to be reduced everywhere to achieve viable balance between financial returns and production of market quality timber.

Considering the economic importance and long-term nature of investment, the crucial policy is to determine the rotation age of teak plantations. The study attempted to determine the optimal rotation of teak plantations in order to make management efficient and long-term investment financially remunerative and attractive. The study, under current management practices and based on certain assumptions, found that ideal rotation for teak plantations would be 20-21 years. In the study, it is recommended for further research to arrive at more realistic and accurate estimates of rotation age for appropriate management and felling policy prescriptions.

Keywords: Teak, Bangladesh, rotation, management

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Should Forest Encroachers be Evicted ? A New Way of Looking at Sustainable Production of Teak Timber in Kerala State, India

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For any forest administrator, environmentalist or policy maker, the biggest threat to the forests of Kerala is encroachment. Since 1947, Kerala might have lost about 2000 km² of forests by way of encroachment. Some of these encroachments have already been regularized and some are yet to be regularized. Some (about 73 km² -mostly encroached after 1977) are earmarked for eviction. Whatever be the status of forest encroachments as far as regularization is concerned, freedom on tree growing in these lands is highly restricted.

Whether forest encroachment is a problem or solution to a problem. The Government believes that the former is correct. On the other hand, this paper argues that the later is more correct. Similarly, whether eviction of encroachment is more sensible or management of encroached area is more sensible. Here also this paper argues that the latter is more correct. This paper looks at the ideological problems of the Forest Department in understanding this issue and solving it. Most of forest encroachment problems could be contained not by the present practices of restricting tree cultivation in the encroached forestland but by stipulating land-use patterns. Instead of discouraging tree farming on encroached land, tree farming alone need be permitted on such land. Such a measure will be a boon to the encroachers and it will ensure sustainable supply hardwood timber in the market. Among hardwoods, Kerala farmers are keen in growing teak in their homesteads. Given freedom to grow teak, farmers will grow it. This will relieve natural forests from the burden of growing timber for the market. To all concerned with forest protection and conservation, eviction of encroachments is the monolithic solution for forest encroachments. This paper suggests a new model to contain the forest encroachment problem, to increase production and productivity of teak in the State.

Keywords: Teak, forest encroachment, forest management, homesteads, productivity

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Some Characteristics of Wood Formation in Teak (*Tectona grandis* L. f.) with Special Reference to Water Conditions

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Three sites of teak plantation areas were selected to investigate some characteristics of wood formation in relation to water conditions. In Java Island of Indonesia, trees of two areas, namely Sukabumi (West Java) and Cepu (Central Java) were compared. In Sukabumi, trees belonging to tropical rainforests had less distinct growth rings, as compared to Cepu, which has a clearly dry season. Heartwood colour of Sukabumi trees were also darker than those of Cepu. In Malaysia, growth rings of 14-year-old plantation grown trees were investigated. Forty growth rings or growth ring-like structures were counted from bark to pith which indicates the complexity of conditions related to wood formation. Preliminary measurements of leaf water potential were carried out in Thailand to study the physiological role of water to wood formation. Short period of low water potential in rainy season affected the cambial activity resulting in the formation of weak growth ring boundaries.

Keywords: Growth ring, annual ring, heartwood, leaf water potential, tropical rain forest, tropic seasonal forest, starch, lipids.

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Dendrochronological Study of Teak (*Tectona grandis* L. f.) in Puerto Rico

Margaret S. Devall and Bernard R. Parresol

In Puerto Rico, an island in the West Indies, large areas of primary forests have been cut and converted to farmlands or as secondary forests. After a while, as the farmlands were not very fertile, they were abandoned. Different tree species have been planted in order to recover the degraded land and to generate timber. Teak is a species of great potential in Puerto Rico, in areas of low altitude and deep, well drained soils. During the last 50 years, teak plantations have been established on the island in such areas. Teak had been planted at Rio Abajo in the wet limestone region of central Puerto Rico during 1940s and 1960s. A dendrochronological study of the species at Rio Abajo in order to investigate patterns of growth and to determine the effect of climate on the growth of teak there. The growth of teak and that of *Hibiscus elatus* Sw. (Malvaceae), a tree species native to Cuba and Jamaica, used in the manufacture of fine furniture, and planted in Rio Abajo were compared. The chronology showed decreased growth during several hurricane years, followed by increased growth in the following year. Both species are growing well at Rio Abajo, and teak growth was slightly better than that of *Hibiscus* (Mahoe), suggesting that teak is a good choice for Rio Abajo and similar areas in the wet limestone region of Puerto Rico.

Keywords: Growth periodicity, dendrochronology, timber management

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Investigations on Inheritance of Growth and Wood Properties and Their Interrelationships in Teak

A. K. Mandal and P. H. Chawhaan

Genetic improvement of teak, which started during the 1960's in India and has made substantial progress in terms of selection of plus trees, creation of seed production areas and establishment of seed orchards. During the last decade much emphasis has been given on genetic testing of clones selected from different teak growing areas of the country which resulted in the identification of 31 good general combiners for growth-related traits and also generated knowledge on inheritance patterns and type of gene action prevalent in teak of South and Central India.

Though teak is valued for its wood, teak improvement work focussed on enhancement of growth rate and adaptability. Though a few studies on wood properties of teak have been undertaken, information on inheritance pattern including estimation of heritability in a narrow sense is almost non-existent. Earlier reports in teak suggest that tree-to-tree variation is more important than variation between provenances in the improvement of wood specific gravity. Furthermore, trees specifically selected for growth and form also exhibit considerable variation in many wood characters. Considering this, an investigation was undertaken to i. assess the extent of genetic variation for growth and wood characters, ii. estimate narrow sense heritability and genetic gain and iii. identify best general combiners. The investigation was carried out on a 20-year-old genetic test trial established with 27 half-families of teak of Orissa origin. Data on growth (height, dbh, basal area) and wood (specific gravity, sapwood and heartwood per centage) parameters were collected and analysed, followed by estimation of genetic parameters. Results indicated that growth and wood characters are moderate to strongly inherited and most of the traits are under the influence of additive gene action, indicating scope for improvement through selection and sexual reproduction. The paper shortlists the parents on the basis of their general combining abilities and also discusses the implications of interrelationship among different growth and wood parameters.

Keywords: Genetic variation, wood characters, heritability, genetic gain, general combining ability

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Assessment of Growth Rate, Basic Density and Heartwood Content in Selected Teak Clones of CSO, Thithimathi in Karnataka State, India

R. Vijendra Rao and S. Shashikala

Teak Clonal Seed Orchard (CSO) was established by the Karnataka Forest Department at Majjigehalla beat of Thithimathi range during 1978-79 in an area of 16 hectares. A total of 1369 grafts, representing 37 clones and 37 ramets, were grafted with spacing of 8 m x 8 m. This CSO became the source material for further tree improvement programmes. A need to initiate wood quality studies which include environmental and genetic variations, which is of economic interest, were included in the breeding programme. Keeping this in view, the work was carried out in teak to investigate variations in wood properties in SPAs and CSOs. The study provided data on growth rate, basic density and heartwood content of 21 logs (clones), which were felled during a natural calamity, and was made available for the investigation. Observations indicated that the average diameter and heartwood content were more in Haliyal clones (9 clones), as compared to rest of the clones (7 clones of Thithimathi, 2 clones of Kakanakote, 1 each of Nagarahole, Bhadravathi and Shimoga). The average basic density was more in Thithimathi clones. The rings /inch was same for Thithimathi and rest of the clones (3) compared to Haliyal clones (4). Clone-to-clone variation was observed in all the parameters. Simple correlations carried out revealed a negative relationship between growth rate and basic density for Thithimathi clones and a positive correlation between diameter and heartwood content for the clones of Kakanakote, Nagarahole, Bhadravathi and Shimoga. The range and average values of different parameters studied in different clones are also discussed in the paper.

Keywords: Wood properties, cloned teak.

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Optimal Management of Teak Plantations

K. Jayaraman and Boris Zeide

An efficient way to increase productivity of teak plantations is to optimize their density and rotation age. Both measures require no expenses and, as shown in this paper, will give more than double returns. Using straightforward process models, it was found that the long-term optimal density index for teak plantations in Kerala, southern India, is 475. Analysis of data from the Inventory of Teak Plantations in Kerala-1997, consisting of 1170 sample plots representing teak plantations in Kerala, showed that only 4.8 per cent of the stands had optimal density. Bringing up the density of under-stocked stands (index less than 400) and reducing the index of overstocked stands will increase productivity by 42 per cent. Economic analysis indicated that the net present value is maximized at 50 years. Bringing down the rotation age from the current 60 years to 50 years will increase the returns by 2.6 per cent. Shortening the rotation age from 60 to 50 years will result in an increase in the harvest area by 20 per cent. The combined effect of all these would be an almost doubling ($1.42 \times 1.026 \times 1.2 = 1.75$) of the returns from the existing plantations at no extra costs. Growth simulation studies with the developed model also indicated that by controlling understory species in teak plantations, the mean annual increment in volume of teak can be increased by 30 per cent. Removal of understory growth would also lead to social benefits by providing firewood to the local inhabitants other than its effects on the growth enhancement of teak trees.

Although these results pertain to only one region in southern India, the developed methodology may be useful for other places and species.

Keywords: Teak, growth model, simulation, process model, optimum stand density, rotation age, understory competition, plantation management, productivity.

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Stand Level Radial Growth Rate Pattern Reveals ‘Growth Convergence’ in *Tectona grandis* L. f.

A. N. Arun Kumar and Y. B. Srinivasa

Constant diameter increment of trees belonging to different diameter classes has been reported. It appears that, if the radial growth rates has to be constant across trees of different diameters, their initial growth rates must be varying, and at some point of time, the growth rate should converge. It is known that variations in anatomical properties of wood reduce during the transition from juvenile phase to the mature phase of the tree. The hypothesis was tested through stump analysis of teak (*Tectona grandis* L. f.), that radial growth rates of trees belonging to different radial classes converge towards the end of the juvenile phase. Growth patterns of 168 teak trees were analyzed after classifying them into four cohorts, based on the radial growth accumulated over the initial 20 years. Growth rates varied significantly among cohorts up to 15 years, but converged towards the end of the juvenile phase of tree growth (16-20 years). Correlations show that growth up to 15 years had a significant impact on the cumulative growth. Trees that accrued larger growth during the initial 10 years, attained lesser growth during the period between 16-20 years and *vice versa*, showing a clear growth rate compensation. Growth beyond 20 years was relatively constant across the cohorts. It is also shown that competition affects trees that had slower growth initially and has little influence on fast growing ones. The paper discusses the implications of the findings in the management of teak trees.

Keywords: *Tectona grandis*, growth rings, tree growth, competition, growth convergence

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Effect of Soil-Leaf Nutritional Factors on the Productivity of Teak (*Tectona grandis* L. f.) in Kerala State, India

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A study was conducted to assess the nutritional factors limiting productivity of teak plantations in Kerala. The whole set of 300 trees was grouped into three age groups as ≤ 20 years (60 trees), > 20 and ≤ 40 years (135 trees) and > 40 years (105 trees). The relation between tree growth and the soil/leaf nutrient status and current annual increment (CAI) in basal area per tree and soil/leaf nutrient status in each age group were investigated. The relation between leaf nutrient status and tree volume was feeble in all three age groups. The models obtained through stepwise regression were all linear and no quadratic terms were present. In all the age groups, the critical concentrations with respect to tree volume do not seem to have been attained. It indicates that volume of trees could be increased further by adequate supply of appropriate nutrient elements. The relation between tree growth and nutrient status of soil was stronger than that between the growth and nutrient status of leaves. For the first two age groups selected, the models were linear. For the older plantations (age > 40 years), almost 50 per cent of the variation in tree volume was explained by the soil nutrient levels. For this age group, soil P had a quadratic term in the model and the point of maximal response for P was predicted at $P = 26.66$ ppm.

The relation between CAI in basal area per tree and the nutrient status of leaves was also linear. The relation between CAI in basal area per tree and nutrient status of soil revealed that for any fixed age level, variation in CAI is positively correlated to soil N. This implies that effect of soil N on CAI need not remain same at all age levels. Alternatively, age related change on CAI is positively modified by the level of soil N.

Keywords: *Tectona grandis*, site quality, soil nutrient status, leaf nutrient status, current annual increment, growth, age groups

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Abstract

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Assessment of Some Wood Characteristics of Teak of Brazilian Origin

R. Polato, P. B. Laming and R. Sierra-Alvarez

Technical information about naturally grown teak (*Tectona grandis* L f.) and Asiatic plantation teak is available. The situation is quite different with regard to technological research data on teak managed in incidental plantations and short rotations in Latin America and in Brazil, in particular. This study aims to provide new technical data on Brazilian teak. Chemical composition, fibre length distribution, mechanical and physical properties and natural durability were determined to assess the quality of Brazilian wood. The analyses were performed on heartwood and sapwood materials of two 22-year-old trees and one 14-year-old-tree. The analysis showed significant extractive content in the heartwood in particular, and also high lignin content. The fibre length was rather low, probably due to relative juvenility. Static bending tests for MOE and MOR confirm that the wood has already become mature, comparable with high quality teak.

Density was determined at two levels, viz., at air-dry and oven-dry states. Basic density was also determined. The values obtained were satisfactory. Hygroscopicity and dimensional stability were assessed by storing teak samples in climate chambers under constant temperature and ten different conditions of relative humidity. The average equilibrium moisture content at fibre saturation point gave low values, may be due to high extractive content. Determination of maximum shrinkage and shrinkage from green to 12 per cent moisture level showed that the wood has a high dimensional stability. Considering the results obtained, it can be assumed that Brazilian teak does not differ from the high-quality Asiatic teak, and that, it might be suitable for the same range of end-uses.

Keywords: Teak, *Tectona grandis*, characteristics, physical properties, mechanical properties, natural durability, extractives, fibre length, heartwood, sapwood

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Characterisation and Extension of Juvenile Wood in Plantation-Grown Teak (*Tectona grandis* L. f.) from Ghana

H. G. Richter, H. Leithoff and U. Sonntag

For qualitative and quantitative characterisation of juvenile wood, heartwood of 18 teak trees, between 10 and 32 years age, from 5 plantations in Ghana was studied with regard to the radial variations in growth ring width, vessel diameter, microfibril angle (MFA), natural durability (ND), density, sorption behaviour, compression and bending strength, and modulus of elasticity (MOE bending). The results are compared with those obtained from four 81 to 314 - year - old trees from natural stands in Myanmar.

Significant differences between teakwood from plantations and natural stands were detected. The natural durability study confirmed the attribution of teak as stipulated in DIN EN 350-2, i.e., teak from natural stands conforms to ND class I, while plantation timber varies from ND class I to ND class III. In 10 out of 18 plantation trees, the outer heartwood was more durable than the inner heartwood. Six plantation trees were rated very durable (class I) and two, only moderately durable (class III) throughout the heartwood. Mean density and related strength values did not differ significantly between plantations and natural stands. However, radial trends were different in that the wide-ringed plantation timber followed the pattern typical of diffuse-porous woods and the narrow-ringed natural stand timber, that of ring-porous woods. The proportion of juvenile wood based on natural durability, physical and strength properties was negligible in timber from natural stands but was fairly high in the plantation timber. Although no biological boundary between juvenile and mature wood exists, for practical purposes, a virtual boundary based on natural durability variation can be set at about 7 cm radial distance from the pith, corresponding to an average of 4.5 growth rings and 12 per cent of total stem volume. If this proportion is eliminated from calculations, the overall properties profile of the remaining volume improves significantly, i.e. average strength is clearly higher and the proportion of very durable wood (ND class I) increases from 55 to 85 per cent.

Keywords: *Tectona grandis*, plantation-grown timber, Ghana, juvenile wood, wood properties, variation

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Teak Production, Processing and Utilization in Nigeria

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Teak (*Tectona grandis* L. f.) is an exotic wood species, introduced in Nigeria around 1889. It has since become well established as one of the two most popular exotic commercial timber species grown in many parts of southern Nigeria, the other species being *Gmelina arborea* Roxb. A study, involving market and literature surveys, was conducted to obtain information on the current status of teak production, processing and utilization in Nigeria. Findings indicated that teak is a plantation-grown timber only in government-owned forest reserves of Nigeria. There is no accurate information on the current total teak population in the country. In 1994, the total planted area was 39055 hectares. By 1996, this decreased to about 32966 ha, due to over-exploitation. Nigerian teak is moderately hard, strongly scented, dark golden yellow in colour when freshly cut and light brown when dry. The stems attain Diameter at Breast Height (DBH) of over 30 cm within 30 years. Stands on good forest sites attain acquire a Mean Annual Increment (MAI) up to 17.5 m³. The current average stumpage price is US\$28. Teak is used as round wood and also locally processed into different items by the wood industries in Nigeria. The most common end uses, in the order of magnitude of usage are furniture for domestic consumption and export, telegraphic poles, floor parquettes, fuelwood and charcoal. Therefore, teak in Nigeria generates raw materials for local wood industries, creates employment opportunities and contributes to the country's foreign exchange earnings.

Keywords: Teak production, processing, end-uses, Nigeria.

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Is Deoxylapachol, the Allergenic Agent in Teak, a Potential Threat?

Maruli Humala Simatupang

The causes of desirable and undesirable properties of teak wood are reviewed and the causes and occurrence of health injurious effects are highlighted. In industrialized countries, teakwood is considered as one of the most common sensitizers in the wood industry. Since the first report in 1896 on teak allergy and its sensitizing constituents, it was shown that air dried wood dust did not have primary irritant effects, whereas moistened dust produced toxic reactions. Native teakwood dust is therefore, the substance of choice for patch testing to diagnose teak allergy. In a study in Norway during late 1950s, out of 112 teak workers, 18.7 per cent showed allergic skin reaction to native wood dust. The diagnosis of allergic contact eczema was reported in 12.5 per cent, and 6.2 per cent were considered to have latent allergy. In total, 46 persons, including 41 per cent of the workers at the furniture plant were affected by teak dust. It was also seen that 13 patients who were allergic to teak dust showed cross reactions to Brazilian Rosewood, even though it was never used in that factory.

Deoxylapachol, the primary sensitizer in teak, is about 100 to 200 times stronger as allergenic compound than lapachol. Deoxylapachol and other allergenic benzoquinones and naphthoquinones can be detected in a simple way using the Craven test. This method enables to screen logs or specimens with latent allergenic properties. During the last 15 years, no cases of teak allergy were reported, although the amount of utilized teakwood is still high. This may be due to the better hygienic situations in the various industries which utilize teakwood. Its high incidence in Norway in the late 1950s was due to poor hygienic conditions in the furniture plants there.

Keywords: Wood extractives, allergic compounds, working safety

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Teak Trade in India

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Since 1982, when cutting of teak from native forests was restricted, Indian processing enterprises and traders have been depending on imported teak logs. Teak of natural forest origin is being imported from Myanmar, even though imports from this source have been dwindling. Currently, West African and Central American countries have been the major suppliers of plantation teak. Although the wood is not of superior quality, Indian markets are resilient to accept what is available. However, there has also been a shift from teak to other durable hardwoods. If quality of teak timber from sustainable sources does not improve, the market will shrink further to the detriment of teak trade in India as well as overseas. Plantation technology needs to be reviewed to get better quality of wood from teak plantations. Timber coming from thinning operations has flooded Indian markets and has adversely affected the prices. Despite various factors as above, India is still the biggest market for teak wood.

Keywords: Teak wood trade, wood quality, imported teak, India

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Teak Wood Price Projections for Kerala State, India up to 2020

C. N. Krishnankutty, Mammen Chundamannil and M. Sivaram

Teakwood has been an important export item from the forests of Kerala, since very early times. At present, teakwood is the main timber output from the forests, although timbers of other species are also available in smaller quantities. Teak logs obtained from the forests are being sold in monthly auctions from the timber depots of the Forest Department. Based on the monthly prices and quantity sold each year, weighted average annual prices were worked out. The average annual current prices were deflated with the corresponding wholesale price indices to convert into real prices. Using the average annual real prices from the year 1956 onwards, long term trend in teakwood prices has been analysed by fitting different trend models. Based on the average annual current prices from the year 1941 onwards, future prices of teakwood have been predicted up to the year 2020 with 95 per cent confidence limits, using Auto-Regressive Integrated Moving Average (ARIMA) models. The results of the trend analysis and teakwood price projections for Kerala are discussed in this paper.

Keywords: Teakwood price, real price, long-term price trends, ARIMA models, price projections.

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Wood-Balance Situation of Teak in Kerala State, India in 2001

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Teak plantations in India were established in Nilambur, in the year 1842. Plantation forestry has been the prime sector in forest economy of Kerala and it has formed one of the important economic activities in the State. Extensive forest plantations have been established in Kerala to produce timber and industrial wood. Most of the long-term investments in timber production have concentrated on teak plantations. At present, teak occupies more than half of the area under forest plantations in the State and it has received the highest investment among different forest plantation crops. Stoppage of clear-felling of natural forests in 1984 and selective felling in 1989 have resulted in the reduction in the supply of teakwood and other timbers, which were obtained from natural forests. Substantial quantity of teakwood is also available from non-forest sources, particularly from home-gardens of Kerala. Teakwood, available from forests and non-forest sources, has been in use for various purposes in different sectors, both within and outside the State. In this paper, estimates of sector-wise demand for teakwood as well as source-wise supply during the year 2001 in Kerala, and thereby, the current wood-balance situation of teak, are presented.

Keywords: Teakwood, wood demand and supply, wood-balance.

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Future Trends in the Availability of Teak Wood from Forest Plantations in Kerala State, India

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The history of forest plantations in Kerala dates back to 1842. Plantation forestry has been the prime sector in the forest economy of Kerala. The area under forest plantations in Kerala is 16 per cent of the total forest area of 11,124 km². Most of the long-term investments in timber production have concentrated on teak plantations, which form the major source of teakwood supply in Kerala. At present, the area under teak plantations is 75,883 ha, which constitutes about 42 per cent of the total area under forest plantations. Forecasts on future supply and demand for teakwood are essentially required for proper planning and decision making in the forestry sector of Kerala. In this paper, trends in area under teak plantation, age-class structure and production have been analysed and the results are presented. Future availability of teakwood from plantations up to the year 2050 have been projected under different scenarios, taking into account the factors such as species-mix, age structure, rotation age, productivity and planting rates. Based on the forecasted production, the potential role of teak plantations in meeting the future demand for teakwood and policy implications are also discussed.

Keywords: Teakwood availability, teak plantations, price projections, future wood production.

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Processing Technology for Value-Added Products of Teak from Small and Medium Sized Entrepreneurs (SME's) of Developing Countries

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One of the major problems faced by wood sector entrepreneurs is drying the timber prior to the manufacture of various items. Among the small and medium entrepreneurs, a majority lack the capital for establishing drying facilities. Therefore, whether developed or developing countries, there is real problem in getting properly dried material. For large wood industries, by stocking raw material as logs, which they can afford, air-dried material is available for working. In the case of small and medium woodworkers this is not possible and also the establishment of a heat - and - vent drying kiln is only a pipedream and the traditional self-made kilns are not fuel-efficient. Air-drying the raw material, practiced by some of the medium-sized units is also not very effective due to the way in which they design air-drying stacks. Educating them is also not always practical. In order to get quality products from teak or any other timber, the workforce should understand the different aspects of drying and methods to measure moisture content of wood, temperature, humidity, etc. for which, either providing 'simple to read' printed materials or organizing small workshops may be proper. In 1996, the Timber and Forestry Department of Enterprises, Ireland made such an initiative, which is successful. The European Commission also conducted 8 similar concerns in different countries. Establishment of co-operative kilns is also another possibility. Forced air dryer, solar kiln or even heat and vent kilns can be made, whereas the dehumidifier kilns are too expensive and uncompetitive. However, it is important that the woodworkers need to be educated on the importance of timber drying for the manufacture of wood products of superior quality.

Keywords: Timber drying, drying kilns, air drying, woodworking

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Development of Teak Plantation Industry in North Queensland, Australia

Andrew Radomiljac, Craig Anderson and Tony Sturre

The establishment of commercial scale teak plantations in North Queensland, Australia, signifies the commencement of a new plantation industry in the country. Excellent establishment success and fast early growth provide the indication that plantations teak has strong potential for commercial success in Australia. Government silvicultural research on teak has occurred irregularly over several decades.

Keywords: Teak, plantation development, North Queensland, Australia

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Role of Rational Utilization of Teak in Carbon Sequestration

Satish Kumar

In recent times, stress has been laid on using wood for carbon sequestering so as to minimize carbon dioxide emissions. Teak being one of the most naturally durable wood species, its long service life even under most adverse conditions keeps the carbon locked for years. Teak has thus an edge over most other wood species, which can give matching performance only after preservative treatment. As wood preservatives are toxic in nature, disposal of preservative treated wood after years of use has raised many eyebrows. Use of durable wood species like teak poses no such problems.

Interest in teak utilization dates back to the nineteenth century, when work on property evaluation and processing variables was initiated in Germany. In India, teak has been taken as a standard reference wood species for evaluating properties of other wood species. Performance and suitability indices for different end uses are worked out in terms of teak taken as 100. Teak is native to several countries in South-east Asia and Africa and has been a favoured plantation tree species in several countries. Owing to its inbuilt durability and strength, low shrinkage, high dimensional stability and versatility, teak has earned a reputation of 'wood for all purposes'. The versatility of teakwood can be gauged from its suitability with a high ranking in almost all common uses e.g. construction, joinery, tool handles, flooring, railway sleepers, etc. although high prices have restricted its use to only high value products like furniture, cabinet wok, parquet flooring, decorative face veneers, etc. Because of increasing demands, the prices of teak have escalated several times during the past few years. Nevertheless, the use of teak has been increasing despite availability of several imported wood species having decorative features.

Keywords: Teakwood quality, carbon sequestration, preservative treatment, utilization

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Teak in the European Union

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In the present European Union (EU) of 15 countries, furniture is the biggest wood-based industry (45%) followed by construction (18%), sawing, planing and impregnation (15%), wood-based panels (11%), packing cases (4%) and others (7%). Teak is used mainly for garden furniture, bathrooms, swimming pools and kitchens, parquetry and ship decks. Notwithstanding the increasing availability of temperate hardwoods, demand for teak is still firm. EU import of tropical timber as a whole is more or less stable. Processed products such as veneer and plywood, and the secondary processed products such as doors, parquetry and window frames are increasing their share at the expense of wood in the rough. Teak also follows the general trend of value being added outside the EU.

All over the EU, there is a strong drive for quality standards to guarantee sustainable forest and plantation management, as well as user-safety of end products. At EU level directive 89/106/EEC governs building materials, focusing on mechanical resistance, fire safety, hygiene, safety in use, noise protection, energy economy and heat retention. In addition guarantees for products being produced in accordance with environmental and social standards for sustainability are covered by privately arranged quality hallmarks. All hallmarks require wood originating from sustainably managed forests or plantations. With processed products, the per centages of components originating from non-sustainable sources can vary per hallmark. Main hallmarks on wood products in the EU are FSC (Forest Stewardship Council), PEFC (Pan European Forest Certification) and KEURHOUT, which is a Dutch label issued to wood products imported in The Netherlands. At present in the EU some 3 per cent of total timber consumed is certified. It is believed that this per centage will go up to 30 per cent in a few years from now. Therefore, demand for certified teak will increase at least tenfold in the coming years. It has already led a number of private investment funds to set up teak plantations with strict standards on sustainability in Central and South America.

Keywords: Teakwood import, European Union, timber certification, quality hallmark

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Peculiar Trees of Teak at Nilambur, Kerala State, India

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Conolly and Chatu Menon made the earliest attempt of artificial regeneration of teak in India in the year 1844. As a result of their efforts, the world's oldest teak plantation now exists at Nilambur, Kerala. Apart from these earliest plantations at Nilambur, several other teak plantations of later origin also exist where plus trees have been selected and seed production areas (SPA) have been established. In this area, peculiar trees of teak were noticed both in the Chatu Menon's plot and in adjoining plantations. The observed plantations were in the range of 45 to 156 years in age. These peculiar trees are not similar to those, which exhibit 'water-blister' phenomenon, as reported from the 1846 teak plantation. The water blisters on teak trees were noticed at a height of 0.5 to 3 m from ground level. However, such water blisters did not occur on trees standing away from the river bed. The peculiar trees reported in this paper exhibited distinct markings (pits/pin holes) and swellings in regular pattern on the root, stem and branch portions of one and the same teak tree.

Teak trees without spiral grain, fluting, epicormic branches, pronounced buttresses, etc. are selected as plus trees. The pitted/pin holed trees, trees with swellings and bulging due to epicormic buds are the added negative traits in the selection of plus trees. It is interesting to note that trees with such negative trait were noticed in large numbers in the SPA's and in the adjoining plantations from where seeds are collected for raising teak plantations. Series of plantations raised from the above seed sources in the later years showed the presence of peculiar trees in abundance, depicting the inheritance of these traits.

Keywords: Peculiar traits, tree breeding, plus trees, heritability

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Status of Teak (*Tectona grandis* L. f.) Plantations in Bangladesh

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Teak (*Tectona grandis* L. f.), which belongs to the family Verbenaceae, is predominantly tropical or subtropical in distribution. It is a major plantation species in the tropical wet evergreen forests and in the tropical semi evergreen forests of Bangladesh. The establishment of teak plantations at Sitapahar (Chittagong hill tracts) in 1871 led to a new era of plantation forestry in Bangladesh. The total forest area of Bangladesh is 22, 41,793 ha of which hill forests cover 13, 61,670 ha. Up to 1980, 70 to 80 % of the plantations of the hill forests were with teak. Most of the teak plantations are located in Chittagong, Chittagong hill tracts, Cox's Bazar and Sylhet, which covered 23,740 ha, 1,43,981ha, 37,877 ha and 11,396 ha respectively. In total, teak plantations extending to an area of 2,16,994 ha in Bangladesh. Besides hill plantations, there are some block, roadside and homestead plantations of teak. They are under the ownership of private enterprises, industries, semi-autonomous corporations, farmers and small land holders. The rotation age followed for teak in Bangladesh is 60 years on all sites. The rate of return from teak plantations would increase if the rotation age is brought down. Between 20-30 years, the rate of return is the highest, and after 40 years, it comes down slowly. It is estimated that with 40 year rotation, return might be 6-15 instead of 3-10 per cent. Several biological organisms including insects, bacteria and fungi attack teak in nursery as well as in the field conditions. For development of teak forestry in Bangladesh, it is necessary to introduce modern forestry techniques such as introduction of mycorrhizal technology and identification of suitable mycorrhizal species for root colonization in order to enhance the growth of teak in nursery and plantation stages.

Keywords: Teak plantations, Bangladesh, plantation management, rotation age, mycorrhizal colonization

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Products of Teak in Sabah, East Malaysia

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In Sabah, teak was first planted in 1926. In earlier days and during the war period, most of the trees were felled for timber, telephone poles and for other construction purposes. Planting of teak became popular in Sabah in the early 1990's. To date, there are about 2,214 ha of teak plantations in the country. The growth performance from these plantations are reported to be good with mean annual increment ranging between 0.77 cm and 1.17 cm, and 0.41 m to 1.06 m for diameter and height, respectively. The timbers from these plantations are mainly used for making furniture.

Keywords: Teakwood products, plantation teak, furniture, Sabah, East Malaysia

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Timber Value of Teak Coming from Homesteads: Certain Observations from Kerala State, India

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Teak (*Tectona grandis* L.f.) is one of the major timber species of home garden forestry in southern India, particularly in Kerala. However, with a general notion that teak from homesteads is inferior to plantation teak in timber quality, the former fetches lower price in the market. This paper critically appraises the timber value of home garden teak and plantation teak of Kerala.

The results indicate that 35-year-old home garden teak in the wet zone with an average of DBH of 39.6 cm has the potential of producing the log diameter similar to that of site quality I (SQ1) prescribed in All India Yield Table. In contrast, teak from dry zone produced the timber of average DBH of 27 cm which qualifies only for SQ II / III with about 26 per cent of logs falling into the pole class as compared to the average DBH of 31 cm from the same aged forest plantation in Nilambur. Regarding wood figure, teak from the homesteads of dry zone with golden brown colour and black streaks was almost similar to that of forest plantations of Nilambur, while the timber of wet zone was slightly paler in colour. This was also reflected in lower extractive content (12%) of wet zone timber as compared to dry zone (16%) and plantation grown timber (13%). Dimensional stability, as evaluated by the shrinkage values, was maximum in the dry zone samples, while it was not significantly different between the wet zone and plantation grown timber.

Pending assessment of durability and strength properties, the present findings indicate that timber quality of home garden teak from dry zone is not lower than that from forest plantations although with similar logs, sawn timber recovery is lower. Though yield is higher from wet zone homesteads, timber colour with low extractive content appears to be a price limiting factor.

Keywords: Wood colour, grain, dimension stability, product yield, quality, home garden forestry, timber price

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Assessing Natural Durability and Origin of Teak Wood by Near-Infrared Spectroscopy

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Owing to its outstanding technical properties, teak (*Tectona grandis* L. f.) is one of the most preferred tropical timbers in the world. Some of its characteristics play a key role in defining the suitability of this timber species for specific end-uses. One of the most commonly cited characteristics of teakwood is its natural durability. It offers very good resistance to weather, termites and decay, which means that it can be used externally without any treatment, increasing its commercial value. Like many characteristics, there is variability in this property, especially with increase of the diversification of silvicultural practices and plantation areas to meet market demands. Assessing natural durability is a tedious, complicated and time-consuming procedure, and this explains why there are very few reports on variation in the natural durability of teak wood.

One of the methods most likely to be adaptable to rapid measurements of wood is Near-Infrared Diffuse Reflectance Spectroscopy (NIRS). NIRS is widely used to identify compounds and to assess various material properties. This study evaluated the ability of NIRS to assess the resistance of teakwood of different origins to fungi, in comparison with standard test methods. Different NIRS equipments were tested and compared. The results proved that NIRS can predict resistance to different species of fungi.

Keywords: Teak, natural durability, near-infrared spectroscopy, fungi, site origin.

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Natural Durability of Plantation-Grown Teak (*Tectona grandis* L. f.) from Panama in Relation to Heartwood Extractives

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The extractives of heartwood of two 29-year-old trees from plantations in Panama and one tree (about 100 years old) from a natural stand in Myanmar were studied in relation to observed differences in natural durability. One tree of plantation-grown teak from Panama showing an exceptionally low biological durability in tests according to EN 113, served as reference for comparison to trees with a much higher resistance against wood destroying fungi.

To obtain information about the content and composition of heartwood extractives, ground heartwood was subjected to successive extraction. Their extractive content was determined and the inhibitory effect of individual fractions, separated by paper chromatography, on the growth of the mycelium of *Coriolus versicolor* and *Coniophora puteana* was surveyed. In a further test series, the extracted sawdust was exposed to the two fungi and mass loss determined by means of a simplified natural durability test. The fractions with the strongest inhibitory effect on mycelium-growth and mass loss of the extracted sawdust were analysed by GC/MS, HPLC and PY/MS.

In quantitative terms, the materials studied in the present context conforms readily to previously reported results, i.e., a positive correlation between extractive content and tree age, which explains the often noted lower natural durability of young trees from plantation stock. The detailed chemical analysis however revealed that, in relation to natural durability, the specific extractives' composition of individual trees may override the general significance of extractives content. The heartwood of the one non-durable tree, though equal in total extractives content, showed a lower amount of tectoquinone (and derivatives) than that of the two trees rated very durable. Thus, the specific content of tectoquinone appears to be a good indicator of heartwood resistance against wood destroying fungi.

Keywords: *Tectona grandis*, plantation-grown timber, natural durability, heartwood extractives, tectoquinone, caoutchouc

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Resistance of Teak, Balau, Keruing and Chengal Woods Against Attack by Marine Borers

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Wood samples of Teak (*Tectona grandis*), Keruing (*Dipterocarpus alatus*), Yellow balau (*Shorea laevis*) and Chengal (*Balanocarpus heimii*) were treated by creosote, using Ruping method. The dimensions of the samples were 200 x 75 x 20 mm and the retention values were 188, 186, 331 and 40 kg/m³, respectively, for the four timbers. Both treated and untreated samples were installed in sea water (Mahshar in Persian gulf and Bandar Torkman and Noshar in Caspian Sea coasts) according to IRG/WP-4432(1985). In Mahshar coast, after 6,10,20,23,27 months and in Caspian Sea coasts every 6 months and after 11 years, the samples were inspected according to the recommendations of IRG/WP-4432 (1985). In Mahshar coasts (Persian Gulf), during this installation period, the control samples (untreated) of Chengal and Keruing were sound, samples of Balau were severely degraded and teak samples seriously attacked. All the treated samples 27 months after installation in sea water, were sound. In Caspian Sea coasts, except soft rot on the sample surfaces, both treated and untreated samples after 11 years installation were sound. It is concluded that there are no marine borers in South coasts of Caspian Sea.

Keywords: Marine borers, wood-impregnation, creosote, durability, marine borers,

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Impact of Biodeterioration on Timber Quality of Teak in Karnataka State, India

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Teak (*Tectona grandis* L.f.) is the most valuable tree grown in natural forests and plantations of Karnataka. Value of the timber is highly reduced due to biodeterioration by the combined activity of *Alcterogystia cadambae* [Lepidoptera: Cossidae], wood decaying microbes and termites. A survey was conducted in the teak growing forests and plantations of North Canara Circle in Karnataka to assess the infestation level of wood boring insects and the nature of damage. Studies were conducted in the timber depots to estimate the loss of timber biomass. The surveys revealed that 15-20 % of trees above 20 years of age showed the symptoms of attack by *A. cadambae*, in varying degrees. Damage assessment of the logs in the depots showed that upto 15 per cent of the volume/weight of the timber is lost due to the attack of biodeteriorating agents.

Keywords: Teak, biodeterioration, plantation, natural forests, wood biomass, microbes, termites, *Alcterogystia cadambae*, cossids

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Variations in Heartwood Durability in Plantation Grown Teak from Togo, West Africa

Adzo Dzifa Kokutse, A. Stokes, Henri Baillères and Kouami Kokou

Natural durability, which represents the most determining property of teakwood quality, was evaluated using four fungi, of which two were from tropical zones and two from temperate zones. The tests carried out on 1200 samples showed that Togolese teak was very resistant to fungal attack. More than 90% of the samples were classified as highly durable or durable. Assessment of natural durability with regard to termite attack showed that plantation teak has greater variability, as compared to that from natural forests.

Keywords: Natural durability, pathogen, termite.

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Heartwood Formation and Wood Properties of Togolese Teak Originating from Different Ecological Zones

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Although the origin of teak plantations in Togo dates back to 1920s, very little information exists concerning quality and mechanical properties of wood from these stands. Togo can be divided into five major ecological zones, ranging from the arid sub-Saharan North to the cooler, humid mountainous areas in the South. This study was to determine how wood quality differs between the five zones.

Based on a sample of 80 trees selected from throughout Togo, per centage of heartwood, density at 12% moisture content and the modulus of elasticity (E_L) were measured. Density was significantly correlated to tree age at BH but was very variable in juvenile wood. E_L in adult wood was significantly greater than in juvenile wood and was correlated with density in juvenile wood only. Although the per centage of heartwood formation depended on the ecological zone in which the trees grew, no significant differences in either density or E_L were found among the trees in different zones.

Keywords: Density, modulus of elasticity, heartwood, juvenile wood

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Wood Anatomical Basis for the Production of Good Quality Teak Stumps

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Traditionally, teak plantations of Kerala are raised from stumps produced from one-year-old seedlings. Optimum nutrition and sowing practices in the nursery are found to yield better seedlings suited for making stumps. Hence, in this study, nutrient and spacing treatments were imposed in a factorial combination to study the differences in growth, biomass and anatomy of nursery seedlings. The experiment was laid in factorial CRD with three levels of nutrients, viz., i. Farmyard manure (0.4 kg/m²; basal application) and neem cake ii. Farmyard manure (0.4 kg/m²; basal application) and neem cake (0.2 kg/m²; basal application) iii. No nutrient supplements. Four levels of sowing methods, namely i. Broadcasting ii. Dibbling in lines (4cm x 4cm) iii. Dibbling in lines (8cm x 8 cm) and iv. Dibbling in lines (12 cm x 12 cm). Root trainer seedlings were also compared with the above treatments. Biometrical observations were taken at fortnightly intervals for a period of 8 months. Wood anatomical properties of the seedlings were studied at monthly intervals.

Treatments were devised in such a way that they do not deviate much from the currently used practices in Kerala. The nutrient and sowing treatments which yielded larger seedlings were selected. An attempt was made to explain growth differences of the seedlings from the wood anatomical perspective. It was found that, in general, seedlings raised in a combination of farmyard manure (0.4 kg/m²; basal application) and broadcasting (@ 6 kg/bed) of seeds gave higher collar girth and height. These seedlings were found to have vessels, wider rings and higher fibre to vessel ratio. Overall performance of root trainer seedlings was not satisfactory in terms of growth and survival.

Keywords: Nutrients, spacing, farmyard manure, neem cake, dibbling, wood anatomy

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Variations in Volume and Dimension of Xylem Rays of Teak Grown in Bangladesh

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Six teak (*Tectona grandis* L.f.) trees were sampled from two districts in Bangladesh. Proportion of ray tissue and dimensions of rays on tangential sections were measured. Ray proportion remained more or less constant from pith to bark. Number of rays/mm² was highest in the first ring and showed a rapid decrease in the first few rings and then it reached constant. Dimensions of rays (ray area, ray height, ray width) were minimum in the earliest rings and then increased rapidly until a relatively constant value was reached at about ring 10. Ray proportion and dimensions of rays showed characteristic values from tree to tree and were not affected by growth rate. Hence, it may be feasible to breed teak with a high ray proportion.

Keywords: *Tectona grandis*, ray proportion, ray dimensions, ring width, distribution pattern of ray

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TEAKDIV – Developing Know-how for the Improvement and Sustainable Management of Teak Genetic Resources

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Although teak has great potential as a plantation forest tree for the production of quality hardwood, our knowledge about its genetic resources is still fragmentary. TEAKDIV is a European Union funded research project that aims to develop specific DNA marker tools that can be used in tree breeding programmes and in management of genetic resources. The project has three objectives: i. to trace and quantify genetic diversity of teak within its natural range, ii. to evaluate the amount of contemporary gene flow through pollen and seed, and iii. to assess the influence of human disturbance. Nuclear and chloroplast DNA markers will be used to assay the current distribution of genetic diversity within and between populations, historical migration patterns and mating system. Hypervariable microsatellite DNA markers will be developed for parentage analysis. The molecular work will be complemented by field observations on insect pollinators of teak. The genetic diversity in teak forests that have been undisturbed, lightly or heavily disturbed will be assessed and compared for both population genetic diversity and contemporary gene flow processes. The information generated will be integrated to draft guidelines for the future conservation and management of teak genetic resources in nature, and for the efficient use of these resources in breeding and plantation programmes in Asia, Africa and Latin America.

Keywords: Teak, genetic resources, DNA markers, plantation programme, sustainable management.

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Clonal propagation of *Tectona grandis* L. f. by Leafy Stem Cuttings: Effects of Branch Position and Auxin Treatment on Rooting Ability

Azamal Husen and Mohinder Pal

Investigation was carried out on adventitious root formation in cuttings of coppiced shoots of teak to examine the effect of position of branch and auxin treatment on root formation. Both leafy and softwood shoot cuttings of 3-year-old teak stock plants grown in hedge gardens were used for the experiment. The rooting parameters, viz., per cent callusing, per cent rooting and per cent sprouting, mean number of leaves, shoots and their length, and mean number of roots and their length per cutting were significantly influenced by the position of branch and the auxin treatment. Application of 4000 ppm IBA increased per cent rooting and per cent sprouting whereas NAA suppressed it. Treatment of 4000 ppm IBA also increased mean number of leaves, shoots and their length and mean number of roots per cutting. Maximum mean number of roots and their length were recorded from cuttings taken from the branch emerging at the upper position followed by branch of middle and lower positions. But cuttings of branches at middle position gave the highest values of per cent rooting and per cent sprouting, mean number of leaves and shoots and the mean shoot length per cutting. The interactive effect of position of branch and auxin treatment on rooting and sprouting response was also significant.

Keywords: Branch position, hedge garden, stem cuttings, auxin treatment, rooting, teak

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Early Detection of Mislabeled Teak Clones Using *Glutamate Oxaloacetate Transaminase (GOT) Marker*

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Glutamate Oxalacetate Transaminase (GOT) was performed in teak using vegetative tissues to genotype 50 ramets of ten clones in hedge orchard (clonal archive). Two polymorphic loci (GOT-B, GOT-C) were used to estimate the level of mislabelling in ramets and subsequently in clones. Genotype analysis revealed that GOT-B and GOT-C were effective to identify the errors. Relatively high levels of errors were observed showing that 16 per cent of ramets and 40 per cent of clones analysed were mislabelled. The genetic consequence of the teak improvement programmes is discussed in the paper in relation to the necessary measures to be taken in that context.

Keywords: *Tectona grandis*, GOT, isozymes, teak clones, mislabelling, hedge orchard

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Variations in Non-Flowering Nature among Teak (*Tectona grandis* L. f.) Clones in Seed Orchards

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One of the reasons for poor fruit production in teak (*Tectona grandis* L. f.) trees in Clonal Seed Orchards (CSOs) is the presence of a substantial per cent mature but non-flowering ramets. The clonal variation for this aspect was studied in two teak CSOs, established during 1980 in southern India for two flowering seasons, in 1998 and 1999. Nineteen clones which were identical in these two CSOs were considered. Analysis of variance for per cent non-flowering ramets per clone suggested that clones, site of CSO as well as the interaction between clone and site had significant effect on the trait. Year-to-year variation was however, not always significant. Within a clone, the ramets which flowered and those not flowered, had similar girth at breast height and health. There was no specific pattern with respect to spatial distribution of these ramets in CSOs suggesting that tree vigour or conditions of the clonal seed orchards may not influence this trait, although genotypes may respond differently to broad environmental variations. Broad sense heritability values for per cent non-flowering ramets among clones ranged between 0.646 to 0.911 (individual year basis) and 0.785 to 0.954 (year mean basis), when separate analyses was done for each site suggesting a genetic control. Therefore, attention must be paid for this trait whenever the clones are selected for establishing CSOs or for rouging. The paper discusses this intra-clonal variation in the light of 'genetic load hypothesis'.

Keywords: Clone, seed orchard, non-flowering ramets, *Tectona grandis*, genetic load hypothesis, ortet, heritability

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Improved Techniques for Raising Nursery Stock in Teak

Siddappa Kannur, K. V. Devar and Ramesh Rathod

A nursery experiment was conducted in the Silviculture Nursery, College of Forestry, Sirsi, Karnataka, during 2000 and 2001 in order to study the effect of stump size on growth and seedling biomass of teak. Stumps having collar diameter of 1 - 2 cm and root length of 15 cm performed better, as compared to the rest. However, shoot length exhibited no effect on the growth parameters except on collar diameter, number of coppices and dry weight of root. Interaction of collar diameter, shoot length and root length had positive bearing only on the biomass attributes. Hence the use of stumps having collar diameter of 1 - 2 cm, shoot length of 2 -4 cm and root length of 15 cm is recommended for raising teak plantations.

Keywords: Nursery experiment, teak stumps, growth parameters, survival per cent, planting stock.

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Teak (*Tectona grandis* L. f.) Biotechnology: Developments and Prospects

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During the past two decades, a major shift in emphasis has taken place in teak improvement towards teak biotechnology, away from traditional breeding programmes. Use of micropropagation as an integral component of tree improvement programmes has been initiated for teak. The micropropagation via meristem (axillary/apical) proliferation, shoot tip culture, clonal propagation, etc. has significant potential to overcome the handicaps associated with teak. Therefore, the technologies recently developed for propagation may indeed be useful for increased production per unit area per unit time.

Genetic marker technology is proving to be very valuable for genotyping, analysis of genetic structure and for understanding the basis of genetic control of commercial traits. Marker-aided selection (MAS) and susceptibility tests of different strains of *Bacillus thuringiensis* (*Bt* gene) against the lepidopteran pest, *Palga damastesalis* are also being carried out. Gene construct, which contain *Bt* gene and suitable promoter, can be constructed for the genetic transformation to produce transgenic insect resistant teak.

Research programmes for isolation of floral regulatory genes (which are part of the MADS box gene family) from inflorescence and floral tissue-cDNA library using DNA probes from *Arabidopsis* and *Antirrhinum* and also by PCR amplification of mRNAs, extracted from young flowering tissues using MADS box primers are under progress. The selected floral regulatory genes and promoters can be used for making gene constructs for genetic transformation to produce transgenic sterile teak. Molecular markers like Restriction Fragment Length Polymorphism (RFLP), Random Amplified Polymorphic DNAs (RAPDs), isozymes and allozymes have been used in teak improvement and also for the estimation of genetic diversity, genetic fidelity and clonal homogeneity.

Keywords: Teak, *Tectona grandis*, micro-propagation, molecular markers, MAS, RFLP, RAPD

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Variations in Germination and Early Vigour Among Half-sib Progenies of Teak (*Tectona grandis* L. f.) Clones of Karnataka State, India

John Mathew and R. Vasudeva

Families of eight teak clones of diverse origin, collected from a 20-year-old Clonal Seed Orchard (CSO), were studied to understand the family level variations in seed germination and early vigour. The study was also aimed to understand the genetic basis and association among these variations and finally to assess the divergence of half-sib families. Large variations were observed among families of different clones in germination per centage and dormancy release pattern. Families of clone MySA₁ (11.09%), clone MyHaV₅ (8.65%) and clone MyHaV₃ (8.46%) were superior in overall germination at the end of the study period. Germination was genetically controlled as suggested by the high narrow sense heritability and showed high genetic gain (171.7%). There was a perfect negative association ($r = -0.902$) between age of the ortet (mother tree) from which the clonal material was originally derived and the per cent germination of its progeny supporting the hypothesis that deleterious mutations might be accumulated with age. Hence, care must be taken not to include clones of older ortets in the future CSOs. Although there was a huge variation among families of different clones with respect to growth traits, differences were not significant. Principal component analysis identified leaf area as the most important trait contributing to divergence of half-sib families, which also had higher narrow sense heritability (0.772) and was significantly associated with biomass traits. Hence, leaf area per plant could be the most important trait for early selection in teak progeny trials. In general, families of clones of southern provenance had higher mean values in number of lateral roots, plant height, collar diameter and biomass, indicating a potential for early adaptation in field. Hence these clones could be given importance while establishing newer CSOs.

Keywords: Clone, seed orchard, *Tectona grandis*, genetic load hypothesis, ortet, heritability, early vigour, family

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Seed Source Evaluation in Teak (*Tectona grandis* L. f.)

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Studies were carried out in teak to elicit information on performance and genetic variability of different seed sources. Thirty seed sources, viz., 28 from India and one each from Lao PDR and Bangladesh were assembled and the performances of seed sources were studied in nursery and under field conditions.

Significant differences were observed between seed sources for various biometric traits investigated both in nursery and under field conditions. Superiority in plant height was observed for nine seed sources at nursery level. Considering all other growth parameters conjointly, viz., collar diameter, dry weight, sturdiness quotient and volume index at 210 DAS, the seeds from Madhya Pradesh proved superior. The seed sources from Maharashtra III had also performed well for a minimum of three biometric traits. Under field conditions, four seed sources, viz. Kerala V, Kerala VII, Tripura and Tamil Nadu III proved superior for all the traits investigated and those four sources can be exploited for future improvement programmes. Volume index registered highest PCV, followed by number of leaves, plant height and collar diameter. Volume index also registered high GCV, followed by number of leaves, plant height and collar diameter. Number of leaves expressed highest habitability estimate, whereas, it was low to moderate for other parameters. The GA as per cent over mean was high for volume index, followed by number of leaves, plant height and collar diameter.

Keywords: Seed sources, sturdiness quotient, volume index

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Storage and Flux of Organic Carbon in *Tectona grandis* L. f. Plantations Raised in the Moist Deciduous Region

Kaushalendra Kumar Jha

Enhancing carbon sink through creation of man-made forests is being considered as a mitigation option to reduce the increased atmospheric carbon dioxide level. Fixation of carbon occurs through a cyclic process, which was studied in an age series plantations (1, 5, 11, 18, 24 and 30 years) in the Tarai forest of Kumaun Himalayan region. Organic carbon concentration in different plant tissues was assessed and multiplied by the biomass to get total carbon content. Concentration was found different in different plant tissues. It ranged from 49.34 per cent to 56.79 per cent. Standing state varied between 1.62 t/ha and 74.38 t/hectare. Net uptake after correction of retranslocated amount ranged between 0.94 t/ha/year and 5.99 t/ha/year. Total carbon return on forest floor through litter fall was between 0.90 t/ha/year and 3.36 t/ha/year. Soil pool contained 35.7 t/ha to 43.9 t/ha and total system stored 46 t/ha to 113 t/ha of carbon. Storage and flux of organic carbon in different plant parts of different plantations were assessed and depicted through compartment models. Carbon budgeting indicated that teak plantation is an accumulating system. Regression equations were developed between girth and total carbon content using $y = a + bx$ equation (where y = total carbon, x = girth at breast height, a and b = equation constants). Except in one-year-old plantations these equations were significant at 1 per cent level.

Keywords: Teak, chronosequence plantations, carbon pool, allocation, uptake, retranslocation

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Effect of Moisture Conservation Methods and Fertilizers on Nutrient Uptake in Two-Year-Old Teak (*Tectona grandis* L. f.) Plantation

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An experiment was conducted in farmers' field at Sughavi village in hill zone of Karnataka State, India, with four moisture conservation methods and five fertilizer levels. The experiment was laid out in split plot design. The results revealed that moisture conservation methods and fertilizers significantly influenced the leaf area, nutrient content of leaf and nutrient uptake by the plant. The leaf area recorded among the treatments varied from 0.333 to 5.092 m². The lowest leaf area recorded with control, and highest was found with ring basin method + chemical fertilizer + vermicompost. The nutrient contents in leaf varied among the treatments from 1.28 to 2.89 per cent N, from 0.04 to 0.33 per cent P₂O₅ and from 0.61 to 1.46 per cent K₂O. Based on the leaf area and the nutrient content of the leaf, uptake of nutrients through leaf in different treatments was varied from 2.05-48.52 kg N/ha, 0.17 to 3.91 kg P₂O₅/ha and 1.62-22.32 kg K₂O/hectare. All the moisture conservation methods (trenching, half ring basin and ring basin), except control, significantly influenced the nitrogen uptake, whereas, uptake of phosphorus and potassium was not significantly influenced by moisture conservation methods. Fertilizer treatments (chemical fertilizer (CF)+ farmyard manure and CF+ vermicompost) were found to affect significantly the uptake of Nitrogen and Potassium. The influence of the interaction treatments was highly significant on the uptake of all the nutrients.

Keywords: High input plantation, moisture conservation, nutrient management

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Estimation of Site Conditions Suitable for Teak Plantations in North-East Thailand

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Teak is not native to North-East Thailand and teak plantations are few unlike in North and West Thailand. The soil conditions are said to be unsuitable for teak growth in this region. Edaphic considerations are most important for site selection for teak plantations, as the species has specific soil requirements. However, teak has been planted in many parts of the country during the past ten years due to the Government policy of promoting plantations in this region. It is an urgent task to develop techniques to estimate site conditions for teak plantations in relation to timber yield. A forest inventory and soil profile survey was conducted to find out the relationship between teak growth and soil properties. The data on soil profiles, soil physical properties (drainage, texture, etc.) and chemical properties (pH, exchangeable cations, etc.) were helpful to find suitable sites and to estimate the site quality for teak plantations. This method can be called an empirical approach. However, geographical approach will also be necessary to estimate the site quality. This approach requires preparation of a geographical database of environmental condition and statistical estimation of site quality from data on teak growth and environmental factors, resulting in site quality maps. If site quality maps for teak covering North-East Thailand can be prepared, they will be useful for site selection. In addition, trial planting to monitor the growth in different locations will also be useful to assess the site quality for future plantations.

Keywords: Teak, North-East Thailand, site selection, soil properties, site quality maps

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Significance of Micronutrients on the Growth of Teak Seedlings

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A study was conducted to assess the importance of micronutrients on the growth of teak seedlings using sand culture technique. For that, two -months old teak seedlings were grown in white quartz sand and they were supplied with modified Hoagland nutrient solutions deficient in Fe, Cu, Zn, Mn, Mo and B. After a period of about 45 days, the plants started to develop various types of abnormalities. Regular observation of the plants revealed that the deficiency of all the micronutrients resulted in the retardation of growth. Compared to the control, maximum height reduction was noticed due to the shortage of Mo and the least due to B. There was a drastic reduction in the number of healthy leaves due to the deficiency of all micronutrients. The maximum reduction was with Fe deficient plants and the least with B deficient ones. Deficiency of micronutrients also resulted in shorter internodes, production of long abnormal leaves and termination of apical growth in the seedlings of teak.

Keywords: Micronutrients, nutrient deficiency, teak, seedling growth

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Growth and Yield of Teak Grown in Hill Forests of Bangladesh

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Teak is one of the major timber trees of Bangladesh. It is an exotic species introduced in Bangladesh in 1874, under the long-term plantation programme. Since then, the species is being planted extensively in the hills of Chittagong, Cox's Bazar, Chittagong hill-tracts and Sylhet Forest Divisions of Bangladesh. In this study, data were collected from 524 temporary sample plots (tsp) during December 1999-April 2000. In addition, data collected from 14 other teak permanent sample plots (psp) of Chittagong and Cox' Bazar Forest Divisions, established in 1989, were also included in the study. Five measurements were taken from the above-mentioned 14 plots. A total of 60 plots were kept set aside for the validation purpose. Data on girth at breast height (gbh), total height and dominant height were collected from teak plantations of age ranging from 0.46 to 77.46 years. The spacing of the plantation was 1.8m x 1.8m. The plot size was 0.02ha x 0.05 hectares. The girth ranged from 0.0cm to 173.17cm and height ranged from 0.4m to 26m. The dominant and co-dominant trees were the fattest trees in the plot. Two to five dominant and co-dominant trees were selected from each plot so that there were 100 trees per hectare. The summary data from the plots were analyzed statistically to develop guide equation, which was used for deriving site indices models for the species in Bangladesh. The developed models were categorized into five site quality classes based on site index at 45 years. The models were developed for the estimation of mean girth, mean stand height, stock per hectare, basal area per hectare and volume production per hectare. The models developed in this study could be used satisfactorily for teak plantation up to an age of 77.5 years and site indices of 15 to 40 meters, based on a base age or rotation of 45 years.

Keywords: Site quality classes, rotation age, teak plantations, Bangladesh

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Growth of *Tectona grandis* L. f. in a Sandy Area of Malaysia: A Fertilizer Trial

F. Y. Tsan, T. H. Ong, M. Mazlan and L. H. Ang

Planting of *Tectona grandis* has been carried out mainly in marginal areas in Malaysia during the last decade. The present study reports the growth performance of this species at a site classified as sandy. Application of fertilizer was necessary and organic fertilizer was the best for promoting the growth of this species in this marginal area.

Keywords: *Tectona grandis*, marginal area, fertilizer application, Malaysia.

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Influence of Water Stress on Teak (*Tectona grandis* L. f.) Seedlings

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A pot culture experiment was conducted to study the morphological, physiological and anatomical response of teak (*Tectona grandis* L. f.) seedlings to soil moisture stress. Uniform stumps of one-year-old teak seedlings were transplanted in black polythene bags of size 45 x 15 cm, containing 5 kg of potting mixture comprising 1:1:1 sand, soil and farmyard manure. Daily irrigation was provided until the seedlings were established. Subsequently, four water stress levels were imposed by controlling the irrigation so that the soil moisture tension corresponding to the levels of water stress were approximately 0.3, 1.0, 5.0 and 10.0 bars, respectively. To achieve this, over a period of four months, the seedlings were irrigated daily (no water stress), once in three days (mild stress), once in six days (moderate stress) and once in nine days (severe stress), with equal quantities of water.

Seedling height, collar diameter, number of leaves, leaf area, leaf weight, specific leaf area and dry matter production decreased significantly due to water stress. All severely stressed plants wilted permanently within nine days. The rooting depth did not show significant difference due to water stress. Relative growth rate and net assimilation rate were low in water stressed seedlings. The leaf water potential, chlorophyll content, transpiration rate and the net photosynthetic rate also decreased due to water stress. The water stress increased the leaf diffusive resistance, indicating the partial closure of stomata. A mid-day closure of stomata and a mid-day dip in net photosynthetic rate were observed in seedlings under water stress. The photosynthetic rate was near to zero in severely stressed plants, most of the time during the day. Accumulation of proline was observed in water stressed seedlings. Water stress increased the amount of collenchyma, sclerenchyma and xylem elements and increased thickness of the cuticle. Chlorophyll pigments in the mesophyll also showed degeneration.

Keywords: Teak seedlings, water stress, assimilation rate, transpiration, photosynthesis, growth rate, anatomy

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Improvement of Teak Planting Stock Through Arbuscular Mycorrhizal Manipulations

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Biological manipulation of rhizosphere soil is a potential long-term strategy to improve and maintain the productivity in plantations. Mycorrhizal fungi play a crucial role in plant establishment, development, nutrition and health of a tree. Teak is an arbuscular mycorrhizal-dependent species and the mycorrhizal association increases the availability of mineral nutrients, improves nutrient uptake and also offers protection against root pathogens. In the present study, mycorrhization of root trainer seedlings of teak, using efficient AM fungal species was attempted with a view to improving the planting stock. Four Glomalean fungi, viz., *Glomus fasciculatum*, *G. deserticola*, *G. mosseae* and *Acaulospora appendicula*, retrieved from teak rhizosphere soils and inocula prepared by pot cultures using maize seedlings, were utilized for the mycorrhization trials. Measurements on seedling height recorded from inoculation trials showed that teak seedlings treated with *G. fasciculatum* and *A. appendicula* recorded maximum mean height of 12.24 cm and 11.83 cm respectively. No difference was observed in mean number of leaf pairs between treated and untreated seedlings. In general, treated teak seedlings recorded more biomass than control seedlings. The mycorrhizal infection efficiency (MIE) values were 60.29 per cent, 38.23 per cent, 22.05 per cent, and 7.35 per cent for *A. appendicula*, *G. fasciculatum*, *G. deserticola* and *G. mosseae* respectively. The results show that teak seedlings respond well to artificial inoculation of AM fungi. Though, no species specificity for AM fungi was recorded, for further improvement of quality of planting stock an in-depth study involving screening of AM fungi under various nursery conditions is warranted. The article discusses various techniques employed for inoculum production and highlights the results on application on mycorrhizal manipulation.

Keywords: Arbuscular mycorrhiza, teak, root trainer seedlings, planting stock improvement.

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Growth and Vigour of Nursery Seedlings of Teak (*Tectona grandis* L. f.) in Response to Input of Organic Wastes

K. Gopikumar and Mini Chandran

A study was conducted to find out the effect of addition of fresh and decomposed municipal garbage and coir dust on establishment, survival, growth and vigour of *Tectona grandis* seedlings. The seedlings when raised using treatment T1 (soil: sand: cow dung in equal proportion), treatment T9 (garbage decomposed for 2 weeks) and T11 (soil: coir dust in equal proportion) recorded cent per cent success with regard to both initial establishment one week after planting and final survival after eight months. Generally, mortality was more when fresh garbage alone was used as the planting medium. With regard to growth and vigour in terms of shoot and root growth parameters and other physiological attributes like relative growth rate, leaf area, specific leaf area, specific leaf weight, leaf area ratio, leaf weight ratio, etc., potting mixtures of soil and cow dung with garbage decomposed for two or four weeks were found to be most promising. Growth and vigour were generally less when seedlings were grown in coir dust. The relative growth rate and other physiological attributes were also found to be less for this treatment.

The study revealed significant differences between treatments with regard to biomass production. In most of the cases, growth attributes produced by decomposed garbage and cow dung were on par. Generally, the stomatal number and chlorophyll content were not found to be affected significantly by treatments. However, chlorophyll 'a' content was found to be slightly higher when compared to chlorophyll 'b'. Nutrient uptake, particularly nitrogen, was found to be more when partially decomposed garbage was used as a component of the potting medium. The potting medium did not affect the uptake of phosphorus and potassium.

Keywords: Coir dust, municipal garbage, decomposition, growth rate, chlorophyll production, biomass, stomatal distribution, nutrient uptake

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Impact of Teak Defoliator on Growth Increment in Teak: Results of a Ten-Year Field Study

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The impact of teak defoliator (*Hyblaea puera* Cramer) on growth increment was monitored for 10 years (1993-2003) in a demonstration plot, maintained at Nilambur in Kerala. Two half a hectare plots were established in 1993 with one plot as the control, exposed to natural pest attack, and the other plot protected following appropriate control measures, either using pesticides or biopesticides, and thereby preventing teak defoliator attack whenever infestation occurred. Regular forestry operations were carried out in both these plots. Growth measurements of all trees (height and GBH) were taken every year. Growth measurements showed that the protected trees put forth 39.39 per cent additional increment in height and 21.88 per cent in GBH than the trees in the unprotected plot. Moreover, 31 per cent of trees in the unprotected plots showed forking due to insect attack, compared to 4 per cent in the protected plot. The volume of wood per tree in the protected plot was 0.14791 m³, compared to 0.1360 m³ in the unprotected plot. In half a hectare plantation with full stocking of 1250 trees, the estimate of wood volume will be 184.8 m³ as against 170 m³ in the unprotected plot.

Keywords: Teak defoliator, *Hyblaea puera*, growth increment, wood volume

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A New Record of Chromoecological Behaviour of the Teak Locust, *Cyrtacanthacris tatarica* L. (Orthoptera : Acrididae) as a Bioindicator of the Growth Status of Teak Plantations

S. K. A. Rizvi, S. Kalia, Nazima Maqbool and F. R. Khan

Economic importance of locusts and grasshoppers is well understood due to their pest status and damaging behaviour as established by many acridologists. Rizvi (1985) put forth a concept of chromoecology in Acridoids of occasionally gregarious nature. The teak locust, *Cyrtacanthacris tatarica* Linn. has been recorded recently as a potential pest of teak nurseries, which has never been so devastating to teak forestry. During ecological studies at Aligarh, it was recorded that the pest and its life stages while feeding on teak, had shown colour spectra according to the age of the teak plants. Experiments were designed and the chromatic changes were recorded and these appear to be of great significance in terms of age-wise preferential value of feeding potential in turn presenting colour spectra indicative of developmental stages of teak plantations and their health. The pest as a bio-indicator of teak development during nursery stage, may help the growers about the hidden developmental progress through its chromoecological and nutritional behaviour.

The teak locust is univoltine (COPR, 1982) but the present observation confirms its multivoltine nature and tremendous migratory and gregarious behaviour. The findings are new to entomological science and may be of great use to the plantation growers for sustainable forest management (SEM).

Keywords: Teak locust, *Cyrtacanthacris tatarica*, chromoecological behaviour, nursery pest

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Non-Wood Forest Products Resource in Teak Plantations and Moist Deciduous Forests: A Comparative Study in Thrissur Forest Division, Kerala State, India

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Non-Wood Forest Products (NWFPs) contribute to the household food security and nutrition, generate income and employment, especially to the tribal communities, and support biodiversity conservation and related environmental objectives. In Kerala, among the 550 NWFP species, herbs, shrubs and small climbers constitute 322 species, growing among the lowermost stratum of the forest canopy. Moist deciduous forests, the second largest vegetation type in Kerala, yield nearly 40 per cent of the NWFPs. This forest type is the home of commercially valuable trees such as Rosewood, Teak, Irul, Bijasal, etc. and has been subject to over-exploitation for timber. Large tracts of this forest type have been clear-felled and planted with teak, eucalyptus, etc. Out of 1,762 km² area of forest plantations in Kerala, 42 per cent is occupied by teak. Several NWFPs growing in the moist deciduous forests are found as undergrowth in the forest plantations.

This study attempts to compare the NWFP resources of herb and shrub species between teak plantations and moist deciduous forests in the Thrissur Forest Division. The measures of abundance and diversity such as density, species richness, and Shannon Wiener indices were worked out for herb and shrub species and compared between forest types. The availability of useful parts of NWFP species was also quantitatively determined and the economic value worked out. In terms of all the parameters considered, teak plantations are comparable with moist deciduous forests and other plantations.

Keywords: Biodiversity conservation, density, species richness, economic value

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Insect Diversity in Teak Plantations: A Case Study in Parambikulam Wildlife Sanctuary, Kerala State, India

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Insect diversity of teak plantations was studied in representative plots and was compared with that of natural forests in Parambikulam Wildlife Sanctuary. Teak plantations registered appreciable values of species diversity and richness although the diversity and richness indices for natural forests were significantly higher. Among various insect groups recorded, *Coleoptera* formed the dominant group followed by *Hymenoptera*, *Diptera* and *Lepidoptera*. Altogether, 353 species of insects belonging to 13 orders were recorded from plantations as compared to 436 species in the natural forests. Occurrence of species was found to be correlated to seasons with maximum number recorded during the pre-monsoon period. The faunal composition showed a mixing of moist deciduous and evergreen elements, coming from the adjacent forests. The fauna contained several rare species, particularly of butterflies.

Keywords: Biodiversity, insect diversity, teak plantation, Parambikulam Wildlife Sanctuary-Kerala

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Eco-tourism in Teak Forests

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Forests play an important role in human life as they provide various products and services to mankind. Teak forests in Java (Indonesia) have served as a valuable asset of the country for years together. Indonesia is one of the few countries where teak forestry flourished from very early times. However, during recent years there has been a declining trend with regard to teak forests, and this has caused deep concern in the forestry sector. The increasing population pressure as well as shortage of agricultural land have been responsible for the loss of forest cover. Therefore, it is time to realize the importance of teak forests in Indonesian forestry and take necessary steps for protection and development of the remaining forest areas of the country.

Eco-tourism offers a promising option for developing teak forests of Indonesia. There is scope for utilizing teak forests of the country for the purpose. This will help in creating awareness on the necessity of protection and conservation of forests and wildlife within the country. With the help of the government, forest protection can be strictly enforced and nature education can be included in the school curriculum for achieving a better awareness on environmental conservation.

Keywords: Teak forests, eco-tourism, deforestation, forest conservation, Indonesia

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