Tectona grandis L. f. Teak

Verbenaceae Verbena Family

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Peter L. Weaver

Tectona grandis L. f., commonly known as teak or teca (Spanish), is a large, deciduous tree native to Southeast Asia where it attains a 45-m height and develops a buttressed trunk at maturity. One of the most valuable and best known tropical timbers, teak has been planted widely to produce lumber for shipbuilding, furniture, and general carpentry. Literature on teak is voluminous and includes a 1,500-citation bibliography (*79*), books on teak silviculture, management (*50*), and research, particularly in Southeast Asia (*138*), and a silvicultural guide published in Spanish (*23*). "Indian Forester" contains numerous articles on teak spanning more than a century.

HABITAT

Native and Introduced Ranges

Teak (fig. 1) grows naturally from approximate latitudes of 23° to 10° N. in Southeast Asia, an area that encompasses most of peninsular India, much of Myanmar (formerly Burma), and parts of Laos and Thailand (fig. 2) (*35, 50, 71, 108, 121, 129*). Centuries ago it was introduced into Java and some of the smaller islands of the Indonesian Archipelago (*121, 138*) and later into the Philippines. Today, teak is naturalized in these countries (*8, 71*), and long established plantations now extend from latitudes 28° N. to 18° S. in Southeast Asia, Australia, Africa, and Latin America (*138*).

Teak plantations were established in India as early as the 1840's (*57*). Before the late 1800's, most plantings of teak outside of its native range were concentrated in Sri Lanka, Bangladesh, and Pakistan (*50, 130*). Near the end of the 19th century, teak plantings were extended to other tropical and subtropical regions (*50, 121, 139*). As of 1965, incomplete area estimates of teak plantations approached 300,000 ha, distributed as follows (*57*): west Africa, 18,600 ha; east Africa, 800 ha; south Asia 219,300 ha; east and Southeast Asia, 40,800 ha; Latin America, 7,700 ha; and the Near East, 8,200 ha.

Teak was first introduced into the Caribbean region around 1880 through the Royal Botanic Gardens in Trinidad, but plantations were not established there until 1913 (*16*). Subsequently, plantation areas increased from 4,700 ha in 1958 (*89*) to 7,300 ha in 1967 (*98*), to 8,500 ha in 1972, and to 9,700 ha in 1978 (*57*). Teak plantings in the neotropics, as of 1978, were estimated as follows (*57*): Belize, 30 ha; Colómbia, 560 ha; Costa Rica, 300 ha; Cuba, 200 ha; El Salvador, 230 ha; Nicaragua, 60 ha; Venezuela, 560 ha; Panama, Honduras, and others, 1,000 ha.

Teak was introduced to Puerto Rico from Trinidad more than 50 years ago. Today, about 130 ha of teak are planted on several sites in Puerto Rico and the U.S. Virgin Islands (*135, 136*).

Figure 1.—*Plantation teak* (Tectona grandis *L. f.*) *at Sabana in Puerto Rico's Luquillo Forest 2 years after Hurricane Hugo.*

Peter L. Weaver is a research forester at the International Institute of Tropical Forestry, U.S. Department of Agriculture, Forest Service, Río Piedras, PR, 00928-2500; in cooperation with the University of Puerto Rico, Río Piedras, PR 90036-4984.

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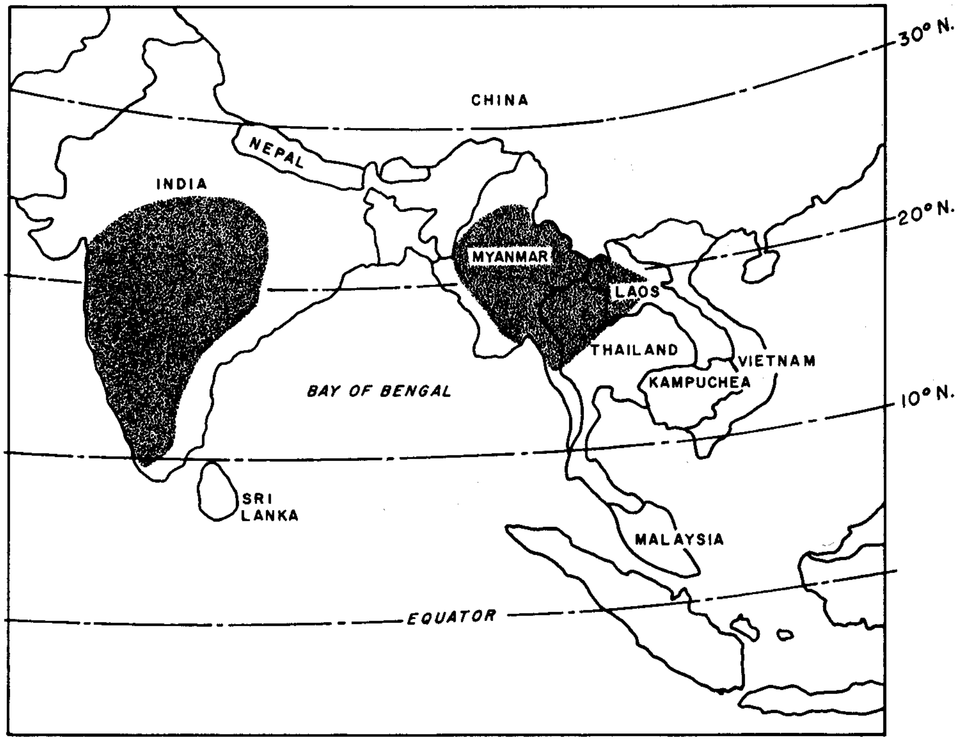

Figure 2.—*The natural range of teak* (Tectona grandis *L. f.*) *in Asia.*

Climate

Teak is tolerant of a wide range of climates (*121*) but grows best in warm, moderately moist tropical conditions (*50*). Much of teak's natural range is characterized by monsoon climates with rainfall between 1300 and 2500 mm/yr and a 3- to 5-month dry season (*109*). Optimum rainfall for teak is between 1500 and 2000 mm/yr, but it endures rainfalls as low as 500 mm and as high as 5100 mm/yr (*50, 129*). Teak is native in dry regions even where subjected to heat and drought. Prolonged droughts in India, however, have killed both trees and coppice sprouts (*108*).

Teak tolerates wide variations in temperatures, which range from 2 to 48 °C (*129*). In India, teak is a common component of forests classed as very dry, dry, semimoist, moist, and very moist. Annual rainfalls in these areas, respectively, range from less than 900 mm, 900 to 1270 mm, 1270 to 1650 mm, 1650 to 2540 mm, and to more than 2540 mm (*113*). The optimum climate for teak, which can be found on the west coast of India, has a temperature range between 16 and 40 °C. Teak also extends into regions that experience slight frosts (*50, 138*).

Soils and Topography

Teak grows between sea level in Java and a 1,200-m elevation in central India (*121*). It establishes itself on a variety of geological formations and soils (*112, 113*), but its best growth is on deep, porous, fertile, well-drained, alluvial soils with a neutral or acid pH (*23, 50, 109, 134*). Teak will tolerate wide extremes in soils as long as they are adequately drained (*106*). The most important limiting soil factors are shallowness, hardpans, waterlogged conditions, compaction, or heavy clays with low contents of Ca or Mg (*23, 121*). Teak has also been shown to be sensitive to phosphate deficiency (*89*). Steep slopes, poor drainage, and elevations in excess of 1,000 m also negatively influence growth.

Teak grows well on porous sandstones but remains stunted on quartzite or hard, metamorphosed sandstone. It is also found on granites, schists, and other metamorphic rocks. Moreover, it grows well on limestone where the rock has disintegrated to form a deep loam (*108*). On hard limestone, where the soil is shallow, growth is poor.

In India, teak grows on hilly and undulating terrain. Although topography appears important mainly because of its effects on soil depth and drainage (*109*), some of the best stands in the Indian hill country have cooler northern and eastern aspects (*113*). In Puerto Rico, teak is a promising species for lower concave slopes and valleys at low elevations in mountainous regions and narrow valleys and sinkholes in karstic country (*76*). In Costa Rica, teak growth was judged satisfactory on a variety of sites previously in secondary brush or annual crops (*39*).

Teak requires fertile soils for best growth (*109*), notably those rich in Ca (i.e., with more than 0.3 percent exchangeable Ca) and Mg (*138*). Samples of 40 of the best quality teak trees representing the age and diameter range attained during the first 15 years of plantation growth in Nigeria's Gambari Forest Reserve were analyzed for N, P, K, Ca, and Mg (*96*). The plantation with an aboveground dry weight of 592 t/ha contained about 2,980 kg/ha of K; 2,228 kg/ha of Ca; 1,788 kg/ha of N; 447 kg/ha of P; and 377 kg/ha of Mg. The minimum annual nutrient requirements at age 15, in kilograms per hectare, were 556 of K, 328 of N, 357 of Ca, 76 of P, and 62 of Mg. The distribution of elements, following a similar trend in other stands, varied with stand age. The relative amount of elements found in the foliage decreased with age, whereas that in the branches and trunk increased. These nutrient requirements are considerably greater than would be required for a pine plantation in the same area or in a 40-year-old secondary forest in Ghana (*96*), indicating that teak's nutrient use is high compared to some other forest types.

In Kerala, India, comparisons were made of soil profiles beneath a natural forest and teak plantations of 1, 15, 30, 60, and 120 years (*49*). Organic matter content in the plantations correlated with the age of the stand. Soils beneath teak plantations less than 30 years old had higher bulk densities and lower amounts of pore space and water holding capacity than older plantations and natural forest, indicating that physical conditions had been altered by past deforestation and planting of teak.

The distribution of nutrients in teak has been the subject of numerous investigations. The percentage of nutrients in 1-year-old teak seedlings decreased in the following order: N, Na, Ca, K, and P (*68*). Nutrient concentrations were highest in leaves, decreasing in stems and roots.

The seedling mineral composition increased steadily with age until the leaves yellowed in 8 to 9 months, after which N, P, and K decreased remarkably, and Ca and Na decreased slightly. Teak dry matter production and nutrient contents (Ca, Mg, P, K, and N) by tree compartment (leaves, twigs, branches, bole, bark, and in one instance, roots) were elaborated for 20- and 38-year-old plantations in India (*54, 92*). A study of teak under different climatic conditions in Western Ghats, India, revealed that sites with very high densities of teak were characterized by higher organic carbon as well as higher exchangeable Ca and cation exchange capacity than sites with lower densities of teak (*116*).

Physical and chemical changes of soil properties after clearcutting, strip felling, and selection felling were investigated in Thailand (*125*). Soils in clearcut areas were more erodible than soils under other systems. Moreover, water availability, organic matter content, and K content increased with the amount of canopy removal. The potential impact of the removal of plantation teak on the nutrient status of young alluvial soils in the Venezuelan llanos was also assessed (*45*). The calculated nutrient budgets suggested that base depletion after tree removals would lead to a reduction in teak productivity on highly productive sites located away from rivers. Soils situated on low topographic positions near rivers, however, could withstand continual harvest because nutrients lost would be replaced by ground water inputs (*45*).

Associated Forest Cover

In India, 76 tree species were listed by climatic region as associates of teak (*113*). These ranged from species of *Acacia* and *Cassia* in the drier to semimoist regions through *Gmelina arborea* Linn. in the semimoist region. Three species of *Stereospermum* were listed for the semimoist through moist regions, with species of *Xylia* in the very moist regions. Five species of *Terminalia* grow with teak in all of the regions, and at least two of these are common in each region. Better developed teak forests grow in moister locations, whereas, in drier areas, the species does not achieve large sizes (*37*).

In Burma, teak is associated with six forest types that range from wet, tropical, semievergreen forests, through lower and upper moist, deciduous forests and dry deciduous forests, to drier indiang and semi-indiang forest types (*108*). *Michelia champaca* Linn., *Shorea assamica* Dyer., *Tetrameles nudiflora* R. Br., and species of the genera *Dipterocarpus, Cedrela, Dysoxylum,* and *Eugenia* are among teak's common tree associates in the semievergreen forest. In the lower mixed, moist, deciduous forests, teak is associated with numerous species, but *Anogeissus acuminata* Wall., *Salmania malabarica* D. C., *Albizia procera* (Roxb.) Benth., and *Tetrameles nudiflora* R. Br. tend to occur as the dominants. In the upper mixed, moist, deciduous forests, teak is more scattered than in the former type and is associated with *Xylia dolabriformis* Benth., *Terminalia tomentosa* W. & A., *T. belerica* Roxb., *T. pyrifolia* Kurz., *Homalium tomentosum* Benth., and *Gmelina arborea* Linn., among others.

In Burma's dry, deciduous forests, teak is associated with many of the species found in the moist forests, as well as *Shorea oblongifolia, Pentacme siamensis* Kurz., *Cassia fistula* L., and *Acacia catechu* Willd. In the indiang forest, teak does not attain large sizes and is of poor quality. It grows with *Dipterocarpus tubuerculatus* Roxb. In semi-indiang forests, teak is usually suppressed and exhibits poor form. Other species present include *P. siamensis* Kurz., *S. oblongifolia, D. tuberculatus, T. tomentosa, Lannea arandis* (Dennst.) Engl., and *Strychonos nux-blanda* A. W. Hill.

Thailand's northern region contains most of its valuable teak forests (*63*). The principal associates of teak in this mature, mixed deciduous forest include *Xylia kerrii* Craig. et Hutch., *Careya arborea* Roxb., *Diosypros mollis* Griff., *Nauclea orientalis* Linn., and *T. belerica* (*35*).

LIFE HISTORY

Reproduction and Early Growth

Flowering and Fruiting. – Monoecious flowers are borne on erect, terminally branched clusters (panicles), 45 to 60 cm long and broad (*71, 138*). The perfect flowers, covered with fine hairs, have a gray, bell-shaped calyx with six lobes. The whitish corolla is funnel-shaped with a short tube and six spreading lobes. Six stamens are inserted on the corolla tube. The pistil contains a four-celled ovary, a slender style, and a two-lobed stigma.

In Thailand, teak's first inflorescence occurs from ages 8 to 10, with flowering periods for individual inflorescences lasting from 2 to 4 weeks (*48*). In Central America, flowering normally occurs between June and September, and the fruits mature from February to April (*19, 23*). The flowers open a few hours after sunrise. The best period for pollination is between 11:30 a.m. and 1:00 p.m.

Teak is mainly a cross-pollinating species. Self-incompatibility is high (*17*). Self-pollinated fruits occur, but their germination is poor compared to cross-pollinated fruits. Two honeybee species (Apidae: *Heriades parvula* and *Ceratina hieroglyphica*) have been identified as important pollinators.

The light-brown and fine-haired fruit (a drupe) has a hard (stony) endocarp with four or fewer seeds, each about 0.6 cm long. In Puerto Rico, teak flowers from August through December, with fruits persisting nearly throughout the year.

Seed Production and Dissemination.—In Nigerian plantations, teak seed production commences after the fifth year (*121*), as it does in many other regions. Seed collections in Sri Lanka made between 1961 and 1973 showed considerable fluctuation: 4 good and 4 bad years out of the 13 years in which collections were made (*90*).

Teak fruits, normally numbering between 800 and 1,780 per kilogram (*23*), fall below trees but may wash downslope on steep terrain (*129*). In Thailand, seeds from orchards averaged 2,060 per kilogram and had a mean diameter of 12 mm (*63*). Seeds collected from natural teak stands, many of them smaller than orchard seeds, averaged 2,450 per kilogram. Approximately one-third of the fruits collected in Thailand were empty, 30 percent contained only one seed, another 30 percent had two seeds, and 5 percent had three or four seeds. By comparison, India's 1930 seed origin cooperative experiment showed that seed size averaged between 11.2 and 15.7 mm, with 1,190 to 2,640 seeds per kg (*124*). Teak seeds from moister localities were larger than those from drier localities. In Bangladesh, 10,000 collected fruits were graded by weight and size. The results of tests showed that fruit size was the principal factor determining germination success, mainly because larger fruits contained more seeds (*6, 7*).

In Thailand, seeds are collected in March or April, and the calyx is removed (*63*). Seeds are normally dried and stored in gunny bags in well-ventilated rooms where they remain viable for 2 years. High atmospheric humidity and high seed moisture content, however, shorten the storage life of seeds. Germination after 1 year averaged about 15 percent.

Germination is epigeous and often commences 10 to 12 days after sowing (*23, 129*). In Puerto Rico, planted seeds germinated after 3 weeks (*75*). In India, germination of fresh seeds began within 26 to 31 days, whereas 1-year-old seeds germinated within 10 to 14 days (*42*).

Average germination varies considerably with reported values between 10 and 80 percent (*23*). In Puerto Rico, teak seed viability improved with storage under ambient conditions (*75*). Studies using four 100-seed lots showed that 0.5, 3.0, 2.0, and 17.0 percent germinated when planted fresh, after 3 months, after 6 months, and after 1 year, respectively. In another trial using 200 seeds, germination was 0.5 percent after 3 months and 15.0 percent after 6 months. Ten seeds were also tested after 5 years of ambient storage and none germinated.[1] In India, germination rates averaged between 12 and 46 percent and appeared related more to seed quality than size or weight (*124*). Trees less than age 30 produced seeds of lower viability than older trees.

Experimental work in India showed that seeds on the ground surface failed to germinate because the radicle dried up or was eaten by insects or birds before it penetrated the soil (*129*). Seeds broadcast and lightly covered on previously burnt soil loosened with a hoe yielded the best germination results (*129*). In another Indian study, numerous fungal species were identified in seeds during the natural weathering of teak fruits (*28*). Subsequent testing revealed that *Scytalidium* sp. decomposed the teak epicarp within 21 days and seedlots subjected to such treatment germinated well in comparison to other treatments.

Treatment of teak seeds to promote germination was not deemed necessary in Trinidad (*69*), whereas in Thailand, seeds are soaked in running water for 3 days before planting (*63*). Seed pretreatments using six combinations of soaking and drying regimes indicated that soaking in standing water for 48 hours followed by alternate soaking and drying on a 12-hour cycle for 4 days gave the best germination (*90*). Other soaking and drying cycles for varying periods have also been mentioned (*23*). High temperatures, either scorching or soaking in water at 85 °C, reduced germination (*90*). In Central America, scarification was considered useful to accelerate germination and make it more uniform (*23*).

Seedling Development.—Artificial regeneration of teak may be done by direct sowing, bag planting, or stump planting (*22*). Direct sowing, the oldest method, is characterized by a high mortality and slow growth. Bag planting yields seedlings with a good root system in a short period of time. Stump planting offers several benefits. Stumps may be produced when needed and transported over considerable distances while maintaining their viability. Moreover, they are easier and quicker to plant, and subsequent growth is more rapid and vigorous.

Seeds collected in Madhya Pradesh, India, were sowed into 15 different media using pure substrates of black soil, sand, and sawdust, as well as various mixtures of the above (*142*). After 6 months, growth was better in pure, black soil than any other substrate. Teak seedlings in India, fertilized with N-P-K and planted in a nursery, reached transplantable size after 4 months, when they attained a basal diameter of 4.7 cm and a height of 42 cm (*128*).

Teak seedlings in India were fertilized for 8 months with nutrient solutions deficient in one macronutrient, either N, P, K, Ca, Mg, or S (*53*). Deficiency symptoms for those macronutrients were:

N—stunted growth, smaller than normal leaves, and chlorosis; older leaves, thin and translucent, uniformly chlorotic, and falling prematurely; young leaves with intervenal chlorosis progressing from margins to midribs; shoot, much restricted, yellowish-green with short internodes, and thin without branches; lateral buds apparent; root system poorly developed with a long, thin taproot and few laterals.

P—scorched leaf margins, intervenal chlorosis, and necrotic patches on older leaves; younger leaves, light green with marginal chlorosis and wrinkled surface; shoot, thick and green, without branches, growth restricted; taproot, short and thick with lateral roots.

K—intervenal chlorosis and scorched margins of leaves; younger leaves, wrinkled surface with margins curved inwards; shoot, green and thick, with better growth than for other deficiencies but with shoot dieback and basal branching near the end of the study; root system, well developed, with thick taproot and numerous laterals.

[1]U.S. Forest Service. [N.d.] Unpublished data. On file with: International Institute of Tropical Forestry, U.S. Department of Agriculture, Forest Service, Río Piedras, PR 00928-2500.

of products at different times during the rotation. Traditional spacings for teak plantations vary between 1.5 by 1.5 m and 4.6 by 4.6 m, with some irregular spacings at 3 by 6 m. A 3- by 3-m spacing in pure plantations is commonly used for timber production (*23*). On sloping terrain, greater spacings have been suggested to encourage ground cover and to avoid erosion.

A study of standing biomass of teak compartments (crown, trunk, and roots) from a dry, deciduous forest in India, varying in age from 7 through 120 years, showed that height growth was most rapid between 10 and 50 years, after which it declined (*101*). The age of maximum crown development was between 20 and 40 years, when the trees ranged from 8 to 16 cm in diameter. The rate of trunk biomass accumulation, in turn, increased between ages 10 and 15, then declined through 40 years, after which it increased again between ages 50 and 120 years. Maximum root production occurred between ages 40 and 50. In another study of India's dry, deciduous teak forest, maximum productivity for trees ranging between ages 6 and 50 was between ages 33 and 50 (*51*).

Teak rotations in India are a function of forest types and management systems (*37*). In most areas where teak occurs in mixed stands, the emphasis has been toward more even-aged crops with rotations ranging from 70 to 150 years. The coppice system, or coppice with standards system in some drier localities, is managed with rotations between 40 and 60 years. Plantation crops, in turn, have rotations between 50 and 80 years.

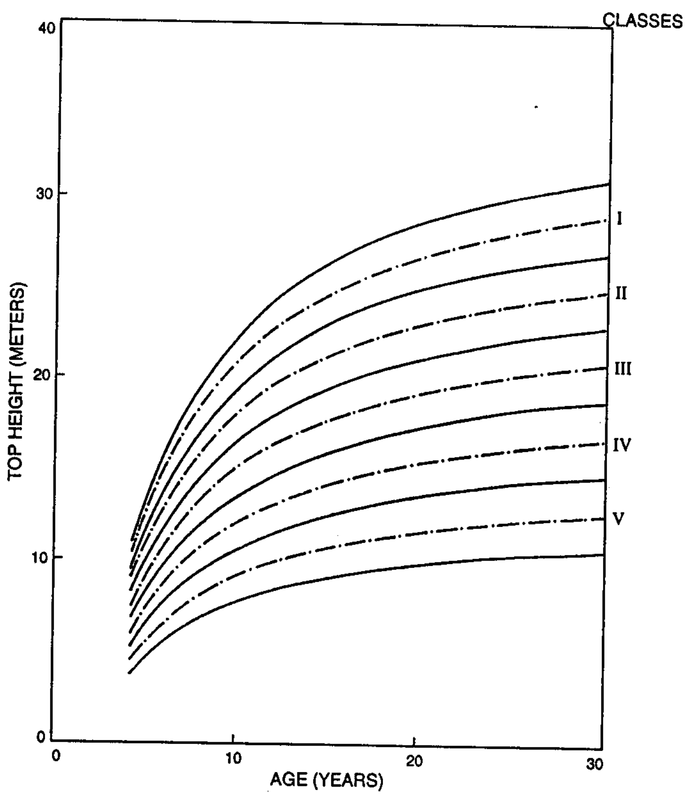

Figure 3.—*Site classification chart for teak* (Tectona grandis *L. f.*) *in the countries bordering the Caribbean Basin based on mean top height (mean height of the 100 largest diameter trees per hectare) over age* (57).

Although growth depends on numerous factors such as site, age, plantation density, and stand management, the mean annual increment of teak is generally reported to be between 10 and 25 m^3/ha/yr (*23*), with most of the estimates in the lower part of that range. A regional site classification chart for the wider Caribbean region shows that teak will attain a mean top height (mean height of the 100 largest diameter trees per hectare) of nearly 30 m on the best sites and 12 m on the poorest sites (*57*) (fig. 3). Corresponding mean annual volume increment varies with several factors, among them site class and age, and averages between 5 and 14 m^3/ha/yr. Published volume tables, site index curves, and data on heights and diameters attained at different locations for plantations of various ages, mainly in tropical America, are presented in table 1. Height growth of dominant teak trees appears to decline more rapidly with time in the neotropics than in areas where it is native (*60*).

Studies of nutrient cycling in soils below teak plantations are available (*32, 36*). In Nigeria, nearly 70 percent of the litterfall in a teak stand ranging from 4 to 6 years old fell between December and March (*32*). More than 90 percent of the plant nutrients (N, P, K, Ca, Mg, and Na) were found in the leaf litter alone. Although numerous experiments on teak fertilization in plantations have been implemented, the variety of environmental conditions and provenances involved makes the formulation of fertilizer guidelines extremely difficult (*23*). The general impression is that although growth may be increased by fertilization under certain circumstances, fertilization is generally not worth the effort; thus, if the site is appropriate for teak growth, fertilization is not necessary.[2]

Rooting Habit.—Teak produces a long, thick taproot, whitish and delicate at first, then becoming light brown and woody (*129*). It may persist or disappear, but in either instance, numerous, strong lateral roots are formed (*129, 138*). Because teak roots are sensitive to oxygen deficiencies, they often remain shallow, growing best in well-aerated soils (*89, 109*). In a Nigerian savanna, however, teak roots were observed penetrating a layer of hard iron crust (plinthite layer) at a depth of 40 to 60 cm (*97*).

Several studies are available on teak rooting systems. In Venezuela, teak did not produce a major taproot but formed three to six lateral roots, which attained a large size near the base of the trunk (*110*). In Thailand, the depth, diameter, length, and distribution of teak roots from numerous trees between ages 1 and 20 showed that, with age, the rate of root growth declined and the taproot lost its capacity to penetrate the soil (*93*). Although the growth patterns of aboveground and belowground plant parts varied at different ages, an approximate plant weight ratio of 5 to 1, respectively, was maintained. Moreover, both lateral and vertical roots were concentrated in the top 30 cm of soil.

Several detailed observations have been made of teak root development in India. Temporal variation in the spatial distribution of fine root biomass growth was studied in a 19-year-old dry tropical forest plantation where the mean annual rainfall averaged 1000 mm/yr (*120*). The annual mean fine root biomass production was 5,420 kg/ha, approximately in

[2]Keogh, Raymond M. [N.d.] Personal communication with the author. On file with: Irish Forestry Board, Dublin, Ireland.

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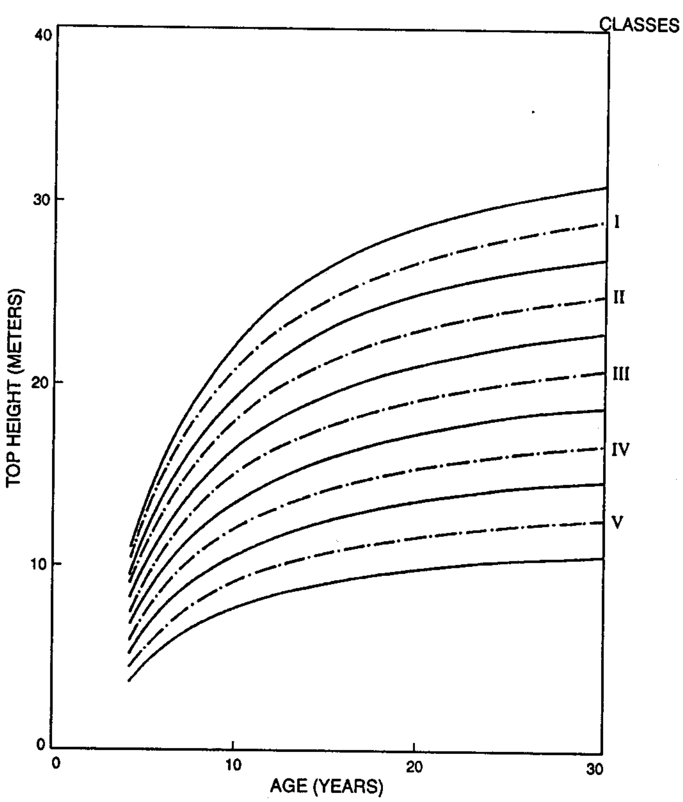

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Table 1.—*Regional growth information for teak* (Tectona grandis *L. f.*) *plantations*

Type of information	Region	Source
Stand tables with mean heights for ages 17 to 46	Puerto Rico	*34*
Mean densities, basal areas, heights, diameters, and volumes for 27 plantations in 5 distinct areas ranging from 24 to 51 years old	Puerto Rico	*136*
Volume table for heights to 30 m and diameters to 44 cm	El Salvador	*23, 56*
Volume table for timber production through 80 years old including increments and thinnings	Trinidad	*23, 59, 82, 131*
Volume tables for heights to 18 m and diameters to 25.9 cm	Venezuela	*131*
Environmental characteristics (elevation, mean rainfall, life zone, and initial density) and mean diameters and heights for plantations ranging in age from 1 to 40 years	Six countries in Central America	*23*
Environmental characteristics (rainfall, soils, spacing, and density) and mean annual growth in diameter and height for dominant and codominant trees ranging in age from 3 to 44 years	Eight countries in Central America and the Caribbean	*133, 136*
Site index curves to age 30	Wider Caribbean Basin countries	*57, 58*
Volume tables for timber production through age 80, including thinnings	India	*131*
Yield and stand tables for plantations (mean diameters and heights, total basal area, stem density, thinning and total yields, and mean current annual increments) for ages 5 through 50 for four site quality classes	India	*50*
Volume table for heights to 32 m and diameters to 50.5 cm	Malaya	*111, 131*
Relation between age and stemwood biomass for plantation teak	Four different life zones	*74*

the middle of the global range of reported values for tree species. Maximum live-root growth occurred during the rainy season with all root sizes showing a bimodal, seasonal growth pattern during the year. The amount of root biomass varied seasonally with 1.4 times more during the rainy season than in the dry period. Sixty-five to 80 percent of the fine root biomass was in the upper 30 cm of soil with most concentrated between 10 and 20 cm. Roots less than 2 mm in diameter constituted half or more of the total root biomass.

In another study, the lateral and vertical distribution of fine root mass under teak from 5 to 40 cm in girth and between 2 and 20 years old was sampled at three distances from the tree base down to a 40 cm depth during the peak growing season (*117*). The composite root mass was separated into live teak roots, dead teak roots, herbaceous root mass, and soil organic matter. Root mass varied with tree girth, distance from the tree, and soil depth. The composite root mass and the proportion of dead root mass to total teak root biomass increased with tree girth. For smaller trees, the greatest mass was found at 1 m from the tree base, whereas in trees larger than 30 cm in girth, the greatest accumulation was found 50 cm from the tree base. All components of the composite root mass increased with girth except the herbaceous root mass, which declined sharply. Most of the herbaceous root mass was located in the top 10 cm of soil, whereas the bulk of the live teak roots were found between 10 and 30 cm. Live teak biomass less than 1 mm consistently declined with depth and was best developed near the tree base.

The dimensions of root systems of 11 teak trees ranging from ages 7 to 120 were measured in a dry Indian forest (*100*). Taproots were deep and stout; secondary and tertiary roots were prominent but sparse.

Reaction to Competition.—Teak is light demanding and requires complete overhead light and ample growing space for proper development (*43, 108, 121*). Within its natural range, teak occurs in a variety of conditions where its size, form, and tree associates vary. Teak silvicultural systems, therefore, must be adapted to the forest type, climate, and soil conditions of each area (*108*). In moist regions, teak trees are large, often fluted; compete intensely with other species; and produce scarce, natural regeneration. Under natural conditions, the regeneration and growth of teak's shade-tolerant associates are favored. Growth and yield of teak plantations in humid climates, however, are more rapid than at drier sites.

In forest types with intermediate levels of moisture, teak attains its best form, but regeneration is variable. In these areas, regeneration by natural or artificial methods can be used. The stocking of teak seedlings or coppice, the amount and type of existing undergrowth, and the availability of taungya cultivators influence the selection of techniques. Cleaning and thinning costs are major considerations when selecting different plantation spacings and thinning techniques. Close spacings require less cleaning but increase establishment costs and necessitate more thinning to maintain reasonable diameter increment. Proper thinning can reduce epicormic branching and provide some undergrowth to curtail erosion.

In drier forest types, teak plantations are usually unsuccessful. Growth is slow, and timber quality is often poor. Management of teak regeneration, however, is possible because seedlings are more abundant and weeding costs are acceptable. In some instances, natural regeneration or plantations of other fast-growing species may be favored.

Insufficient weeding of teak seedlings results in suppression of their growth (*23, 121*) or death (*129*). For Central America, three cleanings are recommended in the first year, two in the second, and at least one in the third. The mowing of teak understory in a 7-year-old plantation in the U.S. Virgin Islands improved accessibility and reduced the fire hazard but did not affect teak increment (*94*).

The best method to increase tree growth in plantations is to remove competition. In Nimbia, Nigeria, different teak spacings significantly affected the mean diameter of all trees and mean diameter of dominant trees but had no effect on their mean height, form factor, or total volume (*1*). In Puerto Rico, 3- to 16-year-old teak plantations were thinned and fertilized to increase productivity (*15*). Larger trees responded with more rapid basal area increment but less height growth than smaller trees under the same conditions. Both the height and basal area growth response were greater on andesite-derived alluvial sites than on residual soils over limestone. Moreover, basal area growth correlated with the addition of P and total height growth with the addition of K, although both responses were minor. Neither height nor basal area were influenced by the addition of N, Ca, or Mg.

In Nigeria, a 15-year-old teak stand with stocking of 2,200 trees per hectare (or a basal area of 32 m^2/ha), originally planted at a 1.8-m spacing, received 3 thinning treatments, namely, reductions to 790 trees per hectare (19.5 m^2/ha), to 395 trees per hectare (13 m^2/ha), and a control (*73*). The stands were measured again at age 20, and current annual increment was 2.0 m^3/ha for the control, 2.8 m^3/ha for the moderate thinning, and 11.3 m^3/ha for the heavy thinning. The heaviest thinning virtually eliminated crown contacts. Several observations were available from this study. First, when the basal area in the unthinned stand approached 35 m^3/ha, the stand began to stagnate and suffer mortality. Second, despite the heavy thinnings, trees identified as fast growing before the experiment continued as fast growing after the experiment. Finally, although teak thinning may be delayed for 10 to 15 years, heavy thinnings will ultimately be required to maintain the growth of crop trees at satisfactory levels.

Teak's response to thinning has been a lively topic of discussion in India for many years. Several conclusions were presented from experimental plots (*132*): (1) different intensities of thinnings had no effect on height growth, (2) the yield of useful basal area decreased as the intensity of thinning increased, and (3) more intensive thinnings yielded progressively more rapid diameter increment. In Nigeria, teak volume did not seem influenced by density of stocking, but mean diameter was altered (*121*).

General guidelines have been suggested for teak thinning in the Caribbean Basin assuming that teak responds to thinning in a manner similar to its response to sites (*57*). Heavy semimechanical thinnings should be made when the trees attain a mean height of 8 m and again at 15 m, each time removing about half of the trees. On better sites, the first thinning may be implemented at 3 years and on poorer sites, at 6 years. The second thinning may take place at 7 years on better sites and at 12 years on poorer sites. Subsequent thinnings should be implemented when the basal area reaches about 20 m^2/ha, and these should remove about 6 m^2/ha. The rotation age should be based on site class and economic considerations.

In the moist, deciduous forests of Kerala, India, the projected crown area of 195 teak trees from 9 to nearly 60 cm in diameter was regressed on tree diameter (*123*). A positive correlation was found between the projected crown area in square meters and the bole diameter in decimeters. The following equation was useful in projecting stand density indices for local teak plantations:

$$\text{Ln } Y = 1.898 + 1.347 \text{ Ln } X \qquad r = 0.832;\ \text{S.E.} = 28.2$$

where Y = projected crown area in square meters and
X = bole diameter in decimeters.

Teak has been successfully used in agroforestry and enrichment systems. During colonial times in Indonesia, tobacco was planted every 8 years on 225,000 ha of commercial plantations held by Dutch tobacco companies (*140*). Tobacco production was followed by one crop of dryland rice or maize and then planted to teak or other tree species during the subsequent fallow period. In India, plantings of teak with groundnut and soybean were highly remunerative, and the cash crops showed no adverse effect on teak growth (*84*). Turmeric (*Curcuma longa* L.), a source of a coloring agent and condiment, was also successfully intercropped in teak stands more than 2 years old in India (*65*). In Java, trials with medicinal herbs as a ground layer in mature teak plantations were undertaken (*44*). Other crops reported as teak intercroppings include hill rice, maize, chili, cotton, tapioca, and ginger (*138*).

Before 1962, teak was established in Trinidad by the taungya method, either by direct seeding or planting stumps along with annual crops of corn or rice (*18, 121*). Taungya trials in Costa Rica (*2*) and Venezuela (*103*) were also successful. Stump planting of teak is the main method of enrichment used for gaps in the tropical moist forest of the Adaman Islands (*115*). In stump plantings, spacings are irregular, and the number of plants varies between 60 and 200 per hectare. In the open, deciduous teak forests of Karnataka, India, managed under a selection system, underplanting of teak among residual stems is replacing the older policy of clearcutting and planting teak (*64*).

Concern about exposed soil under teak plantations has led to various experiments with mixtures (*138*). In Java, interplanting different tree species with teak adversely affected the growth and value of the teak plantations (*20*). Various cover crops were tested in India, but their maintenance was expensive (*138*). Encouragement of natural undergrowth is

Table 2.—*Animals that damage teak* (Tectona grandis *L. f.*)

Damaging animal	Damage; suggested control	Region	Source
Aularches militaris	Defoliation	New Guinea	*48*
Cossus cadambae	Dieback caused by feeding on bark, callus tissue, and outer sapwood; removal of infected trees	Kerala, India	*78, 114*
Dichorius puntiferalis *Leptocentrus vicarius* *Pagyda salvalis* *Pyrausta macheralis*	Damage to inflorescences and poor fruit formation; herbicide application in understory and use of light traps	India	*26*
Dihamnus cervinus	Wood consumption	Bangladesh	*130*
Endoclita gmelina	Root collar damage to saplings; removal of alternate hosts in the vicinity	Malaya	*31*
Hapalia machaeralis	Defoliation; biological control	India	*80*
Hyblaea puera	Defoliation; biological control	India	*3, 85, 86*
Lepidoptera	Defoliaton	India	*83*
Lixus camerunus	Attack of young foliage	Nigeria	*33*
Melolonthinae	Seed damage by larvae	Trinidad	*23*
Neoclytus cacicus	Boring of wood of young plants	Central America	*23*
Pagida salvaris	Feeding on flower buds by larvae	Thailand	*48*
Phyllophag sp.	Infestation of roots in nurseries by larvae; insecticide application	Costa Rica	*23*
Phyllophag sp.	Root destruction of nursery stock and young stems	Central America	*23*
Plagiohammus spinipennis	Boring of wood and pith of young stems	Central America	*23*
Parasol ants	Localized defoliation	Trinidad Nicaragua	*69* *137*
White ants	Bark consumption	Bangladesh	*130*
Termites	Damage to nursery seedlings	Ghana	*121*
Mice	Seed consumption	Bangladesh	*130*
Orthogeomys underwoodii	Destruction of nursery stock and young plants	Central America	*23*

now considered the best alternative. However, in Indonesia, interplanting rows of *Leucaena luecocephala* (Lam.) de Wit as permanent ground cover not only reduced soil erosion but also favorably influenced teak production (*89*).

Damaging Agents.—Most pathogens on teak have been identified from India and the Far East (tables 2, 3) with only a few recorded from plantations in Africa, America, and areas remote from its native region. Comparatively little information is available on their economic effects (*38*). One notable exception is the 5-year study of defoliators in a young plantation in Kerala, India (*91*). The moth larva of *Hyblaea puera* Cram. caused a 44 percent loss of volume increment, whereas that of *Pyrausta machaeralis* Walk. had no apparent impact. Defoliation was occasionally followed by dieback of the leading shoot, which may cause forking. The lack of adequate models on stand dynamics, however, prevented an assessment of potential volume gain for protected stands over an entire rotation. The use of insecticides to control outbreaks in plantations, although effective, was abandoned because it harmed beneficial insects and parasites as well as animals (*138*). Additional research is needed on natural enemies of the defoliators and natural resistance of teak to defoliators.

Teak is considered to be resistant to most pathogens in plantations, natural forests, and wood supplies (*23*). Decay resistance has been correlated with the amount of extractives contained in the wood (*143*). Teak heartwood is very resistant to dry-wood termites and moderately resistant to subterranean termites, but it is readily attacked by marine borers (*72, 141*). The sapwood is not resistant to any of the above organisms and is also attacked by pinhole borers.

Teak is also reputed to be fire resistant, in particular, where the fires move quickly and are not very hot (*89*). Trees

Table 3.—*Diseases and parasites of teak* (Tectona grandis *L. f.*) *plantations*

Type of disease or parasite and scientific name	Damage; suggested control	Region	Source
Leaf and stem diseases			
Agrobacterium tumefasciencs (bacterium)	Stem damage	Trinidad	*23*
Auricularia polytricha	Parasitizing of wounds	India	*38*
Cephaleuros sp.	Leaf spotting	Nigeria	*38*
Cercospora tectonae	Leaf spotting (a minor problem)	India, Hawaii, Trinidad	*38, 138*
Colletotrichum sp.	Formation of irregular, red bands on leaf surfaces and leaf death	El Salvador	*23*
Corticum salmonicolor	Formation of deep fissures in bark that kill phloem and cambial tissue	India, Indonesia	*38, 138*
Corynespora sp.	Foliage damage on mature trees	Trinidad	*23*
Lyctus sp.	Sapwood attack	Venezuela	*127*
Marasmiellus ignobilis	Formation of soft, spongy growths on the trunk near the ground (low incidence of infection, apparently unimportant)	Kerala, India	*114*
Mycosphaerella tectonae	Leaf spotting (a minor problem)	Venezuela	*38*
Nectria haematococca	Cracking and necrosis of bark associated with frost damage	India, Africa	*38, 138*
Olivea tectonae	Defoliation of nursery seedlings; thinning and pruning or application of sulfur-based foliar fungicides	India	*38, 114, 138*
Phialophora richardsiae	Wood decay and dieback after infestation by *Cossus cadambae*	Kerala, India	*114*
Phomopsis variosporum	Damage to photosynthetic area and premature leaf fall	Kerala, India	*114*
Phyllactinia guttata	Leaf necrosis and defoliation; application of fungicides or possibly thinning or pruning	India, Myanmar	*38, 138* *4*
Phyllosticta tectonae	Leaf spotting (a minor problem)	India	*38*
Polyporus versicolor	Sapwood attack	Venezuela	*127*
Pseudoepicoccium tectonae	Coalescence of spots and premature defoliation	Kerala, India	*114*
Pseudomonas sp.	Collar rot of seedlings and wilt in plantation; plantamycin (0.01%) as soil drench	Kerala, India	*114*
Scleratiom rolfsii	Wilting of spotted leaves and occasionally death of growing shoots	Kerala, India	*114*
Stemphyllum sp.	Dieback of young shoots	Nigeria	*38*
Uncinula tectonae	Moisture loss, biochemical changes, and death; sulfur dust application	India	*114, 126, 138*
Ustilina deusta	Sapwood attack	Venezuela	*127, 138*

Table 3.—*Diseases and parasites of teak* (Tectona grandis *L. f.*) *plantations* — Continued

Type of disease or parasite and scientific name	Damage; suggested control	Region	Source
Xanthomonas melhusi	*	India	*38*
Root diseases			
Armillariella mellea	Radial decay and death	Celebes, Africa	*23, 38, 138*
Fusarium oxysporum	Death of seedlings (damping off)	Pakistan, Africa, Central America	*23, 38, 138*
Helicobasidium compactum	Root death and foliage wilting; removal of infected trees and treatment of neighboring trees with a 'carbolin-cum-lime' wash	East Indies, Tanzania	*38, 138*
Peniophora rhizomorpho-sulphurea	Root rot	India	*38, 138*
Phellinus noxius	Wood staining, foliage wilting, butt rot	Far East	*38, 138*
Plemotus commisciloilis	Attack of main roots after other infections	Trinidad	*23*
Pseudomonas solanacearum	Vascular wilt of foliage in nurseries and young plantations; soil sterilization and cultivation and weeding in nurseries	Sumatra, Malaysia	*38, 138*
Pseudomonas tectonae	Similar damage and same controls as above	Philippines	*38, 138*
Rigidoporous lignosus	Root decay; treatment with 2% Tillex® eradication of tree stumps, and use of leguminous cover crops	Nigeria	*87, 138*
Rigidoporous zonalis	Root rot and heartrot	India, America, Australia	*38, 138*
Ustulina deusta	Parasitizing of wounds and white rot	Tanzania	*38*
Xylaria thwaitesii	Root infection (a minor problem)	Indonesia	*38*
Heartrots			
Bjerkandera adusta	White rot	India	*38*
Flavodon flavus	White rot	India	*38*
Fomes lividus	Rot caused by low coppice; cut stems 10 to 15 cm above ground	India	*118*
Ganoderma applantum	White rot	India	*38, 138*
Ganoderma curtisii	White rot	Ivory Coast	*38*
Ganoderma rivulosum	White rot	Africa	*38*
Phellinus lamaoensis	Brown rot	Nigeria, India, Pakistan	*38*
Polyporus rubidus	Brown rot	East Asia, India	*38, 138*
Polyporus shoreae	Partridgewood	East Asia, India	*38*
Polyporous zonalis	*	India	*118*

Table 3.—*Diseases and parasites of teak* (Tectona grandis *L. f.*) *plantations* — Continued

Type of disease or parasite and scientific name	Damage; suggested control	Region	Source
Mistletoes			
Dendrophtoe falcata	Side branch attack; pruning and chemical application	Sri Lanka, India	*38, 114*
Loranthus spp.	Reduced vigor; pruning and chemical application	Indonesia, worldwide	*122*
Macrosolem cochinchinensis	*	India, Pakistan	*38*
Phoradendron piperoides	Reduced vigor; pruning, 2, 4-D spray application or injection	Trinidad	*69, 89*
Phthirusa adunca	Reduced vigor; pruning, 2, 4-D spray application or injection	Trinidad	*98, 106*
Struthanthus spp.	*	West Indies	*38*
Viscum sp.	*	Trinidad	*23*

*Type of damage not indicated.

up to 3 years old will coppice after burns. Older and larger trees are better protected by bark. Pole-sized trees, however, may suffer permanent damage because their bark is not thick enough to withstand high temperatures. In Trinidad, pole-sized stands are at risk because the common practice of thinning at age 5 adds fuel loads to the ground. Fire stimulates the growth of shoots on the lower trunks (*107*), and scorching exposes the wood and provides access for fungi (*89*).

Trinidad's most pressing teak problem in the late 1950's was that of hot surface fires that swept through nearly half of the plantations annually (*89*). The 1957 season was particularly dry, and 2,300 ha of 2- and 3-year-old teak plantations were considerably damaged by fire. Teak plantations frequented by fire have little undergrowth and must depend on the recycling of fallen leaves to renew organic matter and nutrients (*69, 89*). Subsequent erosion, in particular on steep slopes, may further deplete surface soils. Three years of data from Trinidad showed that erosion under teak was occurring at 11 times the rate of that under natural forests (*89*).

Teak grew comparatively free of pests and diseases in Trinidad from the time of its introduction in 1913 to about 1943, when severe attacks by parasitic mistletoe plants were reported in many plantations (table 3). Control of mistletoe consisted of pruning infected branches during the leafless period, isolation of new plantations from those with infections, or removing sources of mistletoe from proximate forest areas (*69*). Mistletoe attacks have also been reported elsewhere (table 3). Mistletoe harms its host by reducing rates of photosynthesis and growth, inducing galls, and predisposing it to insect and disease attack.

Three types of peculiar defects in teak plantation trees ranging from 30 to 141 years were observed in Kerala, India (*62*). The defects were pits of unknown origin, undulating swellings probably due to localized cambial activity, and false knots from epicormic buds. These defects are undesirable and may be attributed to the use of local seed sources for plantation establishment.

Although young teak trees are not readily browsed, taproots of seedlings in nursery beds may be killed by insects (*129*). In Southeast Asia, rats sometimes gnaw on roots, and pigs uproot seedlings (*129*). Moreover, deer may strip bark in plantations up to 10 years old, and, in India, elephants may destroy larger trees (*43, 129*). Cows have been reported to eat the bark of teak trees on St. Croix, U.S. Virgin Islands. Weeds in nursery beds kill seedlings through suppression and by causing damp conditions during the rainy season (*129*).

Natural catastrophes, weather phenomena, and human influences, including misguided forest management activities, have also negatively impacted teak growth and survival. In Bangladesh, cyclones cause large-scale damage to teak plantations (*130*). Ripening seeds were blown down from trees, and trunks were broken, especially in plantations about 15 years old. Similar breakage of trunks and windthrow were observed after Hurricane Hugo passed over Puerto Rico. Regular dieback in India's dry deciduous forest was observed in teak between the ages of 1 and 5 (*99*). On exposed sites, wind damage results in a branchy habit (*138*). Seedlings and coppice are sensitive to frost damage (*129, 138*).

Exudation of yellow sap from stem blisters was reported from plantations along rivers in India, but no biotic agents could be associated with the phenomenon (*5*). The cause, apparently physiological, does not kill the trees but discolors the stem. An abnormal yellowing of teak foliage in Trinidad was reported in the summer of 1963, a phenomenon attributed to exceptionally dry conditions the preceding year (*98*). Extensive seedling mortality 3 years after planting in Trinidad was caused by waterlogging in flat, poorly drained valleys.

Cutting of dry teak forest trees flush with the ground in India resulted in decay in one-half of the coppice trees by the end of the rotation (*118*). Cutting low side shoots at about 10 to 15 cm above the ground resulted in the least amount of decay for new crop trees. Dry-season pruning of small limbs for timber production was recommended in Honduras (*19*) where heartrot was considered a potential problem, as teak does not heal rapidly or evenly.

In Thailand, teak harvest declined by 80 percent between 1973 and 1985, whereas the forested areas decreased by only 26 percent (*35*). Decreased teak yields are due to several factors, among them clearing for agriculture and clandestine harvesting. However, intensive selective logging in excess of sustained yields is also a major cause (*35*). These excess harvests have reduced the rates at which the remaining forests may be harvested and, therefore, annual revenues are reduced.

SPECIAL USES

Teak heartwood, which begins to form in the 6th year (*106*), changes from olive green to golden brown with seasoning and exposure (*72*). The sapwood is yellowish or whitish in color and sharply differentiated from the heartwood. The wood is ring-porous (*138*) with distinct annual growth rings except for occasional false rings (*50, 72*).

Teak wood has a straight grain, uniformly fine texture, and an oily feel. A faint fragrance is detectable after seasoning. The wood air seasons rapidly and satisfactorily, with only minor warping but without casehardening or surface checking. Teak also kiln dries well but slowly, with little checking, splitting, or warping.

The wood is moderately hard and heavy and is renowned for its low and uniform shrinkage (*72*). It has an average specific gravity of 0.55 g/cm^2 (*71, 72*), but this trait varies significantly according to tree crown class (*10*). The wood works well with power and hand tools but contains silica, which dulls cutting edges. Machining characteristics are as follows: planing, shaping, boring, mortising, and resistance to screw splitting are good; turning is excellent; and sanding is very poor (*71*). The wood nails, varnishes, and polishes well, and glues moderately well.

Detailed studies of teak heartwood showed that it is less durable closer to the pith, when it has wider growth rings, or when it is derived from younger trees (*27*). The most important practical conclusion from this research is that not all pieces of teak heartwood are highly durable, and most tree cores are less durable than mature wood. Too rapid a growth rate, particularly in the early years, may appreciably decrease durability.

Teak heartwood is very difficult to treat with preservatives, whereas the sapwood is easily treated using open-tank processes (*72*). Green teak posts respond well to a preservative treatment of 6 percent copper sulfate followed by 7 percent borax, with 3 days of immersion for each solution (*23*). Unpainted wood resists weathering and stays almost entirely free from warp and checking.

In the early 1900's, teak was used in India for home, bridge, and wharf construction, piles, railway carriages, and wheel spokes (*129*). Teak's stability after manufacture has made it the only wood acceptable for decking on large vessels (*24, 72*). Fine furniture, flooring, joinery, interior trim, frames, doors, paneling, carvings, turnery, tanks and vats, and laboratory fixtures are all made from teak (*71*). Other reported uses include masts and spars, pit props in coal mines, railway sleepers, ornamental veneers, bodies of pianos, organs and harmoniums, violin keys, and tobacco pipes (from teak burrs) (*29*). The wood also yields a valuable tar oil after distillation. Small-sized trees from thinnings are used for fenceposts in Trinidad (*88*).

Plywood is manufactured from teak, and teak wastes have been used to make particleboard, fiberboard, and chipboard (*119*). In India, discarded teak has also been mixed with other hardwood species and veneer wastes for testing their potential as bleached and unbleached pulp (*40, 41*). Pilot studies showed that yields were satisfactory, and the pulp had good strength properties for the production of wrapping, writing, and printing papers. Additional work on tree extractives in Japan showed that teak resins spotted pulp sheets (*143*). Teak bark from trees more than 40 years old sampled in lands owned by several Indian government forestry departments yielded 8.3 to 15.6 percent oxalic acid, an important industrial chemical (*11*). The calorific content of various teak components (stem, roots, bark, branches, twigs, and leaves) studied in Madhya Pradesh, India, has also been published (*52*).

In Southeast Asia, teak yields several minor forest products (*50*). The bark contains tannins, and bruised leaves produce a red sap used in dyeing silk. Leaves have also been employed as packing materials and thatch for temporary huts. In India, dry, fallen teak leaves may be processed as a roughage source for use in pelleted rations for sheep (*104*). Various parts of the tree are also used medicinally (*30*). A decoction of leaves is used for treating menstrual disorders and hemorrhages and as a gargle (*138*). Teak has been introduced into botanical gardens as a curiosity and is occasionally planted in Puerto Rico as an ornamental tree (*71*).

In Nigeria, previous timber working circles were converted to fuel and post working circles were used for the production of small poles, props for climbing crops, and fuelwood (*121*). In Tanzania, straight trees with a large proportion of heartwood have been used as transmission poles (*121*). In Trinidad, proceeds from the sale of teak wood for use as poles and firewood supports many small contractors; there is also a factory that produces split fencing, fenceposts, and sawn lumber for scaffolding (*105, 106, 121*). Teak is also planted on petroleum properties that have not yet been mined and on badly eroded lands previously planted in sugar cane but still amenable to reclamation (*121*).

GENETICS

In India, researchers in a teak seed origin study (*77, 124*) concluded that prediction of the behavior of teak provenances was difficult, and seeds of local origin were likely to give good results, but perhaps not the best, within teak's natural range. They found that imported seed from moister localities was usually better than that from drier areas and that top height appeared more related to site quality than to seed origin.

As of 1979, 19 introductions of teak seeds had been made into the Caribbean Basin countries from source areas in Burma (presently Myanmar), Thailand, India, and the African nations of Nigeria, Cameroon, Ivory Coast, and Gambia (*57*). The most important introductions were those made between 1913 and 1916 from Tenasserin, Burma, to Trinidad (*8*) and in 1926 from Sri Lanka to Summit Gardens in Panama. Both provenances are regarded favorably and have been widely distributed in Latin America (*57, 23*).

The results of clonal tests suggest that the age of first flowering is under genetic control and can cause forking and depress height growth (*138*). Some provenances of teak seeds have a pronounced dormancy that results in improved germination after storage (*23*), a condition caused by nutrient imbalances (*42*). Moreover, seeds originating from dry forests appear to germinate more readily than those from humid areas. Genetic factors, either as differences between varieties of teak or as normal variation among individual trees, may also account for much of the variation in durability of teak heartwood (*27*). However, teak increment cores from 36-year-old trees of five seed origins in India showed that environmental influences had a greater effect than seed source on the density of mature wood (*102*).

A long-term breeding program for teak in India was outlined in the early 1960's (*81*). The first teak seed orchards were established in New Guinea and Thailand in the mid-1960's, and others were planned or underway in India and Nigeria (*48*). Selection of superior teak phenotypes from India for raising clonal seed orchards was based on 20 external characters (*61*) among which were height, girth, length of clear bole, stem form (buttressing, twisting, and taper), epicormic branching, pest and disease susceptibility, and seed production. Clonal teak plantations using tissue culture plantlets remain a possibility (*138*). However, protective steps need to be taken in the establishment and management of such plantings, including the evaluation of possible dangers of relying on a narrow genetic base while exploring the benefits of superior stock.

A preliminary survey of teak at 24 sites in India between latitudes 9° and 24° N. and 74° and 85° E. longitudes disclosed that variation in wood color, grain, and texture, leaf morphology, and flower and seed biology were associated with particular sites (*9*). In another Indian study, 20 different teak clones were evaluated for their natural variation in growth rate and susceptibility to the teak defoliator *Hyblaea puera* Cram. (*3*). Susceptibility and growth rates were significantly different among the clones, and crosses between the most resistant and most rapid growing clones were suggested to further improve the clone's quality.

Thailand's Teak Improvement Centre implemented a genetic improvement program during its first 10 years of operation (*47*). Vegetative propagation, sexual propagation, plus tree selection, testing of selected material, seed orchards, seed source areas, provenance research, silvicultural research (nursery techniques, establishment, and tending of plantations) were among the major research topics. Flowering characteristics and the mechanics of pollination were also studied (*17*). By the late 1970's, Thailand's Forest Industries Organization had 3,300 ha of teak source areas and had planned 830 ha of seed orchards (*63*).

Initial spacings for teak orchards should be 12 by 12 m to promote flowering (*48*). Two systematic thinnings, 10 to 12 years and 15 to 20 years after establishment, result in a final spacing of 24 by 24 m. Hand pollination of flowers gives considerably better results than open pollination, but it is costly. The release of suitable insects into the orchards as a pollinating alternative is being investigated in some areas.

Because teak is difficult to root, grafting is used for the propagation of its clones. Both grafting of flowering branches and grafting budpatches onto seedling stocks has been tried, but survival of the grafts plagued the first method and delayed flowering hampered the second (*25*). To facilitate prompt flowering of teak clones, a root from a 1- to 2-year-old seedling may be grafted onto the flowering branch of a plus tree or grafted clone. This technique yielded over 90 percent success, and grafts flowered within 2 years after transplanting.

LITERATURE CITED

1. Abegbeihn, J.O. 1982. Preliminary results of the effects of spacings on the growth and yield of *Tectona grandis* Linn. F. Indian Forester. 108(6): 423–430.
2. Aguirre, Avelino. 1963. Estudio silvicultural y económico del sistema taungya en las condiciones de Turrialba. Turrialba. 13(3): 168–71.
3. Ahmad, Mukhtar. 1987. Relative resistance of different clones of *Tectona grandis* to teak defoliator, *Hyblaea puera* Cram. (Lepidoptera: Hyblaeidae) in South India. Indian Forester. 113(4): 281–286.
4. Bagchee, K. 1952. A review of work on Indian tree diseases and decay of timber and methods of control. Indian Forester. 78(11): 540–546.
5. Bakshi, B.K.; Boyce, J.S. 1959. Water blister in teak. Indian Forester. 85(10): 589–591.
6. Banik, R.L. 1977. Studies on grading of teak fruits. 1: Fruit size is a factor in germination of teak seeds. Bano Biggyan Patrika (Bangladesh). 6(1): 1–7.
7. Banik, R.L. 1978. Studies on grading of teak fruit. 2: Combined effect of fruit weight and size in the production of seedlings. Bano Biggyan Patrika (Bangladesh). 7(1/2): 20–29.
8. Beard, J.S. 1943. The importance of race in teak, *Tectona grandis*. Caribbean Forester. 4(3): 135–139.
9. Bedell, P.E. 1989. Preliminary observations on variability of teak in India. Indian Forester. 115(2): 72–81.
10. Bhat, K.M.; Bhat, K.V.; Dhamordan, T.K. 1987. A note on specific gravity difference between dominant and suppressed trees in teak (*Tectona grandis* Linn f.). Indian Journal of Forestry. 10(1): 61–62.
11. Bhatia, Kuldip; Lal, Jia; Ayyar, K.S. 1985. 1: Barks as a source of oxalic acid. Indian Forester. 111(7): 538–541.
12. Bhatnagar, H.P.; Gupta, B.B.; Rauthan, B.S.; Joshi, D.N. 1969. Preliminary studies on the nutritional requirements of teak (*Tectona grandis* L.). Indian Forester. 95(7): 488–495.
13. Bhatnagar, H.P.; Joshi, D.N. 1972. Rooting response of branch cuttings of "teak" (*Tectona grandis* L. f.). In: 1st technical commission: silviculture. 3: Trends and progress in new forest management and silvicultural techniques: Proceedings of the 7th World Forestry Congress; 1972 October 4–18; Buenos Aires, Argentina. Buenos Aires: Centro Cultural General San Martín: 2,045–2,048.
14. Briscoe, C.B.; Nobles, R.W. 1966. Effects of pruning teak. Res. Note ITF-11. Río Piedras, PR: U.S. Department of Agriculture, Forest Service, Institute of Tropical Forestry. 6 p.
15. Briscoe, C.B.; Ybarra-Coronado, Raul. 1971. Increasing growth of established teak. Res. Note ITF-13. Río Piedras, PR: U.S. Department of Agriculture, Forest Service, Institute of Tropical Forestry. 7 p.
16. Brooks, R.L. 1939. Forestry in Trinidad and Tobago. Caribbean Forester. 1(1): 14–15.
17. Bryndum, Knud; Hedegart, Torben. 1969. Pollination of teak (*Tectona grandis* L.). Silvae Genetica. 18(3): 77–80.
18. Cater, John C. 1941. The formation of teak plantations in Trinidad with the assistance of peasant contractors. Caribbean Forester. 2(4): 147–153.
19. Chable, A.C. 1967. Reforestation in the Republic of Honduras, Central America. Ceiba. 13(2): 1–56.

20. Champion, H.G.; Griffith, A.L. 1960. Manual of general silviculture for India. Calcutta: Manager, Government of India Press. 329 p.
21. Chanda Bacha, S. 1977. The Kannimara teak. Indian Farming. 26(11): 23.
22. Chaudhari, N.R. 1963. Pre-liminary trial of pre-sprouted stump planting for artificial regeneration of teak. Indian Forester. 89(9): 638–640.
23. Chaves, Eladio; Fonseca, William. 1991. Teca, *Tectona grandis* L.f., especie de árbol de uso multíple en America Central. Informe Técnico No. 179. Turrialba, Costa Rica: Centro Agronómico Tropical de Investigación y Ensenañza. 47 p.
24. Chudnoff, Martin. 1984. Tropical timbers of the world. Agric. Handb. 607. Washington, DC: U.S. Department of Agriculture. 464 p.
25. Dabral, S.L. 1977. Propagation of teak by root grafts. Indian Forester. 103(3): 225–230.
26. Dabral, S.L.; Amin, P.W. 1975. Poor fruit formation in teak in Chanda forests of Maharastra. Indian Forester. 101(10): 616–620.
27. Da Costa, E.W.B.; Rudman, P.; Gay, F.J. 1961. Relationship of growth rate and related factors to durability in *Tectona grandis*. Empire Forestry Review. 40(4): 308–319.
28. Dadwal, V.S.; Jamaluddin. 1988. Role of fungi in weathering of teak fruits. Indian Forester. 114(6): 328–330.
29. Dastur, J.F. 1977. Useful plants of India and Pakistan. Bombay: D.B. Taraporevala Sons and Co. 185 p.
30. Dastur, J.F. 1988. Medicinal plants of India and Pakistan. Bombay: D.B. Taraporevala Sons and Co. 212 p.
31. Dhanarajan, G. 1976. Some observations on the teak collar ring borer *Endoclita gmelina* (Lepidoptera: Hepailidae) in northwestern Malaysia. Malaysian Forester. 39(4): 214–223.
32. Egunjobi, J.K. 1974. Litter fall and mineralization in a teak *Tectona grandis* stand. Oikos 25: 222–226.
33. Eluwa, M.C. 1979. Biology of *Lixus camerunus* Kolbe (Coleoptera Curculionidae): a major pest of the edible veronias (Compositae) in Nigeria. Revue de Zoologie Africaine. 93(1): 223–240.
34. Friday, Kathleen S. 1987. Site index curves for teak (*Tectona grandis* L.) in the limestone hill region of Puerto Rico. Commonwealth Forestry Review. 66(3): 239–253.
35. Gajaseni, Jiragorn; Jordan, Carl F. 1990. Decline of teak yield in northern Thailand: effects of selective logging on forest structure. Biotrópica. 22(2): 114–118.
36. Geigel, F.B. 1977. Materia orgánica y nutrientes devueltos al suelo mediante la hojarasca de diversas especies forestales. Baracoa. 7(3/4): 15–38.
37. Ghosh, R.C.; Singh, S.P. 1981. Trends in rotation. Indian Forester. 107(6): 336–347.
38. Gibson, I.A.S. 1975. Diseases of forest trees widely planted as exotics in the tropics and southern hemisphere. Part I: Important members of the Myrtaceae, Leguminosae, Verbenaceae and Meliaceae: the Verbenaceae. Oxford, UK: Commonwealth Mycological Institute, Kew, Surrey: 37–39. Chapter 5.
39. Gonzalez, Rodrigo. 1980. Plantaciones forestales a nivel experimental en Costa Rica. Agronomía Costarricense. 4(1): 99–109.
40. Guha, S.R.D.; Pant, P.C. 1964. Pulping of plywood veneer waste. Indian Pulp and Paper. 19(6): 393–395.
41. Guha, S.R.D.; Singh, Man Mohan; Mathur, B.C. 1964. Pilot-plant production of wrapping and printing papers from a mixture of hardwoods. Indian Forester. 90(11): 755–757.
42. Gupta, B.N.; Pattanath, P.G. 1975. Factors affecting germination behavior of teak seeds of eighteen Indian origins. Indian Forester. 101(10): 584–586.
43. Gupta, Raghunath S. 1956. On the suitability of soils for teak plantations with special reference to laterization. In: Proceedings of the 8th silvicultural conference; 1951 December 5–14; Duhra Dun, India. Duhra Dun, India: Forest Research Institute: 266–269.
44. Hadipoernomo. 1978. The forest as a source of traditional medicines. Duta Rimba. 4(26): 56–60.
45. Hase, H.; Foelster, H. 1983. Impact of plantation forestry with teak (*Tectona grandis*) on the nutrient status of young alluvial soils in west Venezuela. Forest Ecology and Management. 6: 33–57.
46. Hassan, M.M.; Dey, H.B. 1981. Studies on the nutritional requirements of forest trees – optimum NPK doses for teak seedlings. Bano Biggyan Patrika (Bangladesh). 8(1/2): 57–63.
47. Hedegart, T. 1974. The teak improvement centre ten years after initiation. The Vanasarn (Thailand). 32(4): 342–358.
48. Hedegart, T.; Lauridsen, E.B.; Keiding, H. 1975. Teak. In: Faulkner, R., ed. Seed orchards: IUFRO Working Party on Seed Orchards (S2.03.3). Forestry Commission Bull. No. 54. London, UK: Forestry Commission: 139–42. Chapter 13, part D.
49. Jose, A.I.; Koshy, M.M. 1972. A study of the morphological, physical and chemical characteristics of soils as influenced by teak vegetation. Indian Forester. 98(6): 338–348.
50. Kadambi, K. 1972. Silviculture and management of teak. Bull. 24. Nacogdoches, TX: Stephen F. Austin State University, School of Forestry. 137 p.
51. Kandya, A.K. 1973. Notes on net primary production in teak (*Tectona grandis* Linn. F.). Journal of the Indian Botanical Society. 52(1/2): 40–44.
52. Kandya, A.K. 1982. Caloric content and energy dynamics in six tropical dry deciduous forest tree species. Indian Journal of Forestry. 5(3): 192–195.
53. Kaul, O.N.; Gupta, A.C.; Negi, J.D.S. 1972. Diagnosis of mineral deficiencies in teak (*Tectona grandis*) seedlings. Indian Forester. 98(3): 173–177.
54. Kaul, O.N.; Sharma, D.C.; Tandon, V.N.; Srivastava, P.B.L. 1979. Organic matter and plant nutrients in a teak (*Tectona grandis*) plantation. Indian Forester. 105(8): 573–582.
55. Keiding, H.; Boonkird, Sa-ard. 1960. Vegetative propagation of teak. Unasylva. 14: 193–194.
56. Keogh, Raymond M. 1977. Elaboracíon de una tabla de volumen y un estudio de incremento para teca (*Tectona grandis)* en El Salvador. Proyecto Forestal FAO/ELS/72/004. Documento de Trabajo No. 14. Roma: Organización de las Naciones Unidas para la Agricultura y la Alimentación. 53 p.

57. Keogh, Raymond M. 1979. Does teak have a future in tropical America? Unasylva. 31(126): 13–19.
58. Keogh, Raymond M. 1982. Teak (*Tectona grandis* Linn. f.) provisional site classification chart for the Caribbean, Central America, Venezuela and Colombia. Forest Ecology and Management. 4: 143–153.
59. Keogh, Raymond M. 1987. The care and management of teak (*Tectona grandis* L. f.) plantations: a practical field guide for foresters in the Caribbean, Central America, Venezuela and Colombia. Dublin, Ireland: Gorta (Irish Freedom from Hunger Campaign); Heredía, Costa Rica: The National University. 46 p.
60. Keogh, Raymond M. 1990. Growth rates of teak (*Tectona grandis)* in the Caribbean/Central America region. Forest Ecology and Management. 35: 311–314.
61. Kotwal, P.C. 1983. Selection of superior phenotypes of teak in Madhya Pradesh. Indian Journal of Forestry. 6(1): 1–4.
62. Kulkarni, H.D.; Dharmaswamy, S.S.; Srimathi, R.A. 1987. Peculiar trees of teak at Nilambur, Kerala. Myforest. 23(2): 75–76.
63. Kushalappa, K.A. 1977. Teak plantations in Thailand. Indian Forester. 103(5): 323–328.
64. Kushalappa, K.A. 1985. Teak underplanting. Myforest. 18(4): 159–61.
65. Lahiri, A.K. 1972. Intercropping trials with tumeric in north Bengal. Indian Forester. 98(2): 109–115.
66. Lahiri, A.K. 1974. Preliminary study on rooting of green wood cutting of teak. Indian Forester. 100(9): 559–560.
67. Lahiri, A.K. 1985. A note on possibilities of mound layering of teak. Indian Forester. 111(10): 870–871.
68. Lalman; Misra, A. 1985. Nutrient utilization in some tropical forest tree seedlings. Indian Forester. 111(6): 368–384.
69. Lamb, A.F.A. 1957. Teak. Forestry and forest products studies. 13(2): 179–186.
70. Latif, M.A.; Islam, M.N.; Choudhary, J.H. 1986. Effect of stump diameter of teak on post planting survival and subsequent growth of height and diameter. Bano Biggyan Patrika (Bangladesh). 12(1/2): 17–21.
71. Little, Elbert L., Jr.; Wadsworth, Frank H. 1964. Common trees of Puerto Rico and the Virgin Islands. Agric. Handb. 249. Washington, DC: U.S. Department of Agriculture. 548 p.
72. Longwood, Franklin R. 1961. Puerto Rican woods: their machining, seasoning and related characteristics. Agric. Handb. 205. Washington, DC: U.S. Department of Agriculture. 98 p.
73. Lowe, R.G. 1976. Teak (*Tectona grandis* Linn. f.) thinning experiment in Nigeria. Commonwealth Forestry Review. 55(3): 189–202.
74. Lugo, Ariel E.; Brown, Sandra; Chapman, Jonathan. 1988. An analytical review of production rates and stemwood biomass of tropical forest plantations. Journal of Ecology and Management. 23: 179–200.
75. Marrero, José. 1949. Tree seed data for Puerto Rico. Caribbean Forester. 10: 11–30.
76. Marrero, José. 1950. Results of forest planting in the insular forests of Puerto Rico. Caribbean Forester. 11: 107–147.
77. Mathauda, G.S. 1954. The all India teak seed origin sample plots. Indian Forest. 80(1): 10–23.
78. Mathew, George. 1990. Biology and ecology of the teak trunk borer *Cossus cadambae* Moore and its possible control. KFRI Res. Rep. 68. Peechi, Kerala, India: Kerala Forest Research Institute. 41 p.
79. Mathur, K.B.L. 1973. Teak bibliography (titles with abstracts of important ones, of world literature dealing with *Tectona grandis* Linn. F.). Dehra Dun, India: Forestry Research Institute and Colleges. 320 p.
80. Mathur, R.N. 1977. Integrated pest control in forestry. Indian Forester. 103(9): 584–591.
81. Matthews, J.D. 1961. Report to the government of India on a program of forest genetics and forest tree breeding research. Rep. 1349. Rome: Food and Agricultural Organization of the United Nations. 53 p.
82. Miller, A.D. 1969. Provisional yield tables for teak in Trinidad. Port-of-Spain, Trinidad: Government Printery. 21 p.
83. Mishra, G.P.; Joseph, R.N. 1982. Defoliation in teak by lepidopterous defoliators in a mixed dry deciduous forest of Sagar, Madhya Pradesh. Indian Forester. 108(8): 572–573.
84. Mishra, J.; Prasad, U.N. 1980. Agri-silvicultural studies on raising of oil seeds like *Sesamum indicum* Linn. (Til), *Arachis hypogea* Linn. (groundnut) and *Glycine max* Merrill. (soybean) as cash crops in conjunction with *Dalbergia sissoo* Roxb. and *Tectona grandis* Linn. at Mandar, Ranchi. Indian Forester. 106(10): 675–695.
85. Misra, M.P. 1975. Sexing of pupae and adult moths of teak skeletonizer, *Pyrausta machaeralis* Walker (Lepidoptera: Pyralidae). Indian Forester. 101(6): 301–304.
86. Misra, R.M. 1975. Note on *Anthia sexguttata* Fabricius (Carambidae: Coleopterea) a new predator of *Pyrausta machaeralis* Walker and *Hyblaea puera* Cramer. Indian Forester. 101(10): 605.
87. Momoh, Z.O.; Odeyinde, M.A. 1977. The control of the root rot disease of teak (*Tectona grandis* Linn. f.) in Nigeria. Forestry Series. Res. Pap. 34. Ibadan, Nigeria: Forestry Research Institute of Nigeria. 16 p.
88. Moore, D. 1962. The utilization of teak in Trinidad and Tobago. Caribbean Forester. 23(2): 82–86.
89. Murray, C. H. 1961. Teak and fire in Trinidad. Caribbean Forester. 22(3-4): 57–61.
90. Muttiah, S. 1975. Some data on teak and further pregermination treatment trials. Sri Lanka Forester. 12(1): 25–36.
91. Nair, K.S.S.; Sudheendrakumar, V.V.; Varma, R.V.; Chako, K.C. 1985. Studies on the seasonal incidence of defoliators and the effect of defoliation on volume increment of teak. KFRI Res. Rep. 30. Peechi, Kerala, India: Divisions of Entomology and Silviculture, Kerala Forest Research Institute. 78 p.
92. Negi, J.D.S.; Bahuguna, V.K.; Sharma, D.C. 1990. Biomass production and distribution of nutrients in a 20 year old teak (*Tectona grandis*) and gamar (*Gmelina arborea*) plantation in Tripura. Indian Forester. 116(9): 681–686.
93. Ngampongsai, Choompol. 1973. The distribution and development of teak-root in different age plantations.

Forestry Res. Bull. 28. Bangkok: Faculty of Forestry, Kasetsart University. 63 p.
94. Nobles, R.W.; Briscoe, C.B. 1966. Mowing understory vegetation in a young teak plantation. Res. Note ITF-9. Río Piedras, PR: U.S. Department of Agriculture, Forest Service, Institute of Tropical Forestry. 2 p.
95. Nwoboshi, L. Chelunor. 1975. Macronutrient deficiency symptoms in teak (*Tectona grandis* L. f.). Bull. 6. Ibadan, Nigeria: Department of Forest Management, University of Ibadan. 12 p.
96. Nwoboshi, L. Chelunor. 1984. Growth and nutrient requirements in a teak plantation age series in Nigeria. II: Nutrient accumulation and minimum annual requirements. Forest Science. 30(1): 35–40.
97. Ogigirigi, M.A.; Igboanugo, A.B.I. 1985. Root growth characteristics of some exotic and indigenous tree species in the Nigerian savanna. Pakistan Journal of Forestry. 35(3): 97–103.
98. Pawsey, R.G. 1970. Forest diseases in Trinidad and Tobago, with some observations in Jamaica. Commonwealth Forestry Review. 49(1): 64–70.
99. Prasad, R.; Mishra, G.P. 1981. Establishment of natural regeneration with special reference to dying back in dry deciduous teak forests of Sagar (M. P.). Indian Journal of Forestry. 4(3): 165–172.
100. Prasad, R.; Mishra, G.P. 1984. Studies on root system of important tree species in dry deciduous teak forests of Sagar (M. P.). Indian Journal of Forestry. 7(3): 171–177.
101. Prasad, Ram; Mishra, G.P. 1984. Standing biomass of various plant parts in selected tree species of dry deciduous teak forests in M.P. Indian Forester. 110(7): 765–782.
102. Purkayastha, S.K.; Tandon, R.D.; Rao, K.P. 1973. A note on the variation in wood density in some 36-year-old teak trees from different seed origins. Indian Forester. 99(4): 215–217.
103. Raets, G.H. 1965. Informe preliminar acera del cultivo de *Tectona grandis* L. f. en la estación de Barinitas, Venezuela. Boletín del Instituto Forestal Latino Americano. 18: 29–40.
104. Reddy, V.A.; Reddy, M.R. 1984. Utilization of fallen dry teak leaves (*Tectona grandis*) as roughage source in complete pelleted rations of sheep. Indian Journal of Animal Sciences. 54(9): 843–848.
105. Ross, Philip. 1958. The utilization of teak in Trinidad. Caribbean Forester. 19(3–4): 80–85.
106. Ross, Philip. 1959. Teak in Trinidad. Economic Botany. 13(1): 30–40.
107. Ross, Philip. 1961. The plant ecology of the teak plantations in Trinidad. Ecology. 42(2): 387–398.
108. Ryan, P.A. 1982. The management of Burmese teak forests. Commonwealth Forestry Review. 61(2): 115–120.
109. Salazar F., Rodolfo; Albertin, Waldemar. 1974. Requerimientos edáficios y climáticos para *Tectona grandis*. Turrialba. 24(1): 66–71.
110. Saldarriaga, J.G. 1979. Estudio del sistema radícular de cuatro especies plantadas en la selva decidua de banco de la Reserva Forestal de Caparo, Venezuela. Mérida, Venezuela: Universidad de los Andes, Centro de Estudios Forestales de Postgrado. 120 p. M.S. thesis.
111. Sandrasegaran, K. 1969. A general volume table for *Tectona grandis* Linn f. (teak) grown in north-west Malaya. Malayan Forester. 32(2): 187–200.
112. Seth, S.K.; Yadav, J.S.P. 1959. Teak soils. Indian Forester. 85(1): 2–16.
113. Seth, S.K.; Waheed Khan, M. A. 1958. Regeneration of teak forests. Indian Forester. 84(8): 455–466.
114. Sharma, J.K.; Mohanan, C.; Florence, E.J. Maria. 1985. Disease survey in nurseries and plantations of forest tree species grown in Kerala. KFRI Res. Rep. 36. Peechi, Kerala, India: Division of Pathology, Kerala Forest Research Institute: 16–49.
115. Sharma, S.K. 1979. Enrichment of tropical moist deciduous forests by planting in Andaman Islands. Indian Forester. 105(4): 260–273.
116. Singh, Jasbir; Prasad, K.G.; Gupta, G.N. 1986. Distribution of teak under different silvo-climatic conditions in some parts of Western Ghats. Indian Forester. 112(11): 1,008–1,013.
117. Singh, K.P.; Srivastava, S.K. 1984. Spatial distribution of fine root mass in young trees (*Tectona grandis*) of varying girth sizes. Pedobiologia. 27(3): 161–170.
118. Singh, S.; Puri, Y.N.; Bakshi, B.K. 1973. Decay in relation to management of dry coppice teak forest. Indian Forester. 99(7): 421–430.
119. Singh, Umrao; Wadhwani, A.A.; Johri, B.M. 1983. Dictionary of economic plants in India. New Delhi: Indian Council of Agricultural Research. 288 p.
120. Srivastava, S.K.; Singh, K.P.; Upadhyay, R.S. 1986. Fine root growth dynamics in teak (*Tectona grandis* Linn F.). Canadian Journal of Forest Research. 16(6): 1360–1364.
121. Streets, R.J. 1962. Exotic trees of the British Commonwealth. Oxford, UK: Clarendon Press: 712–725.
122. Suharti, M.; Prawira, S.A. 1975. Mistletoe attack on teak stands in Java. Lamporan, Lembaga Penelitian Hutan 206. Bogor, Indonesia. 22 p.
123. Suri, S.K. 1975. Correlation studies between bole diameter and crown projection area as an aid to thinning. Indian Forester. 101(9): 539–554.
124. Suri, S.K. 1984. Analytical study of teak provenance tests in North Raipur Division of Madhya Pradesh. Indian Forester. 110(4): 345–363.
125. Thaiutsa, Bunvong; Suwannapinunt, Wisut; Kaitpraneet, Wasan; Sukwong, Somsak. 1976. Changes of soil properties in teak forest under the different silvicultural systems. Forestry Res. Bull. 39. Bangkok: Forestry Faculty, Kasetsart University. 33 p.
126. Thite, A.N.; Chavan, P.D.; Karadge, B.A. 1980. Some biochemical changes in teak leaves infected with powdery mildew fungus. Indian Journal of Mycology and Plant Pathology. 10(2) 131–135.
127. Torres, L.; Silverborg, S. 1972. Estudio sobre la durabilidad natural de la teca (*Tectona grandis* L. f.) mediante ensayos acelerados de "soil-blocks" en el Laboratorio Nacional de Productos Forestales en Mérida, Venezuela. Boletín Instituto Forestal Latino-Americano de Investigación y Capacitación (Venezuela). 41-42: 63–70.
128. Totey, N.G.; Bhowmik, A.K.; Khatri, P.K.; [and others]. 1986. Growth of teak seedlings in a nursery. Indian Forester. 112(9): 792–800.

129. Troup, R.S. 1921. The silviculture of Indian Trees. Leguminosae (Caesalpinieae) to Verbenaceae. Oxford, UK: Clarendon Press: 337–783. Vol. 2.
130. Vaclav, E.; Skoupy, J. 1972. Growing of teak (*Tectona grandis* L. f.) in Bangladesh. Silvaecultura Tropica et Subtropica (Czechoslovakia). 2: 11–28.
131. Veillon, Juan P.; Silva, Ramiro. 1972. Tablas de volumen para árboles en pie y tablas de producción de plantaciones forestales en America Latina. Mérida, Venezuela: Facultad de Ciencias Forestales, Universidad de los Andes. 71 p.
132. Venkataramany, P. 1960. Teak plantations—thinning research. In: Proceedings of the 9th silvicultural conference; 1956 December 7, 10–19; Dehra Dun, India. Dehra Dun, India: Forestry Research Institute: 33–47.
133. Wadsworth, F.H. 1960. Datos de crecimiento de plantaciones forestales en México, Indias Occidentales y Sur America. Caribbean Forester. 21: [Not paged]. Supplement.
134. Watterson, K.G. 1971. Growth of teak under different edaphic conditions in Lancetilla Valley, Honduras. Turrialba. 21(2): 222–225.
135. Weaver, P.L.; Francis, J.K. 1988. Growth of teak, mahogany, and Spanish cedar on St. Croix, U.S. Virgin Islands. Turrialba. 38(4): 308–317.
136. Weaver, P.L.; Francis, J.K. 1990. The performance of *Tectona grandis* in Puerto Rico. Commonwealth Forestry Review. 69(4): 313–323.
137. Weidema, W.J. 1966. An information on teak growth in Nicaragua. Turrialba. 16(4): 387–389.
138. White, K.J. 1991. Teak: some aspects of research and development. RAPA publication: 1991/17. Bangkok: FAO Regional Office for Asia and the Pacific (RAPA). 53 p. + ref.
139. Whitesell, Craig D.; Walters, Gerald A. 1976. Species adaptability trials for man-made forests in Hawaii. Res. Pap. PSW-118. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 30 p.
140. Wiersum, E. 1983. Early experiments in agroforestry: colonial tobacco cultivation with tree fallows in Deli, Sumatra. The International Tree Crops Journal. 2: 313–321.
141. Wolcott, George N. 1957. Inherent natural resistance of woods to the attack of the West Indies dry-wood termite, *Cryptotermes brevis* Walker. Journal of Agriculture of the University of Puerto Rico. 41: 259–311.
142. Yadav, A.S.; Khare, P.K.; Mishra, G.P. 1982. Growth performance of *Tectona grandis* Linn F. seedlings in different pot culture media. Indian Journal of Forestry. 5(2): 86–89.
143. Yatagai, Mitsuyoshi; Takahashi, Toshio. 1980. Tropical wood extractives' effects on durability, paint curing time, and pulp sheet resin spotting. Wood Science (Japan). 12(3): 176–182.