

VARIATION IN GROWTH AND DEVELOPMENT OF TEAK GROWING OUTSIDE THE NATURAL RANGES IN THAILAND

INTRODUCTION

Teak has been worldwide recognized as the real green gold of the world. Natural teak has been continuously exploited since the colonial time. Over exploitation of natural teak forest in India and Myanmar encouraged the teak logging operation in Thailand. Teak logs from Thailand was harvested by foreign companies and exported to Europe and America. Teak concession was given to these companies by the feudal chiefs in the north. The problems arose from the teak logging operation and this encouraged Thailand to draft the forest legislation to control teak logging operation, transportation, and processing. Moreover, the lacking of manpower responsible for the management of teak forest provided the chance to send Thai scholar to study in England, Dehra Dun in India, and Pinyinmana in Myanmar (Bhumibhamon, 1999). Later on, manpower development for management of the teak forest, teak log and teak wood was conducted in Thailand by establishing Phrae Forestry School.

Beside the management of natural teak forests in the north of Thailand, Royal Forest Department (RFD) has also started to plant teaks as plantation since 1930. The early teak plantation area in the north was relatively small but this establishment has given good perspective and opportunities for forest agencies to start planting this green gold for large scale commercial purposes in later years. Forest Industry Organization (FIO) is one of the major state enterprises that has been actively planted teak in larger scale, mainly covering the northern provinces.

According to the United Nations Food and Agriculture Organization (FAO, 1998), the global demand for wood and wood products is projected to increase by approximately 50%, from 3.4 billion m³ per annum in 1991 to 5.1 billion m³ per annum in 2010.

As the world wood market for teak is one of the largest wood markets, teak has later on introduced planting in various planting scales worldwide. The success stories are found in Indonesia, Ivory Coast, Papua New Guinea, Brazil, and number of countries in the Caribbean Sea where teak was established as the potential economic species. During the last century, Indian teak, Burma teak, and Thai teak have been distributed to the world market. At present, Indonesia replaced Thailand which cannot even produce teak wood to meet the local demand. Therefore, teak wood importation is needed to secure the need of furniture industries which Thailand has already established good market chain for the value-added teak materials.

At present, Indonesia teak veneer and plywood occupy about 50 percent of the world market. The success in teak plantation establishment has given the country with the excellent opportunity. Plantings of para-rubber and oil palm in Thailand,

Malaysia, and Indonesia have given the excellent examples for other woody materials. Malaysia government has announced to keep teak as the priority species and has promoted teak planting in Peninsular Malaysia and in Sabah.

Teak planting in Thailand has been established in most provinces. Earlier investigations have indicated the differences in teak growth and development even under the natural ranges. However, too little information on teak growth and development was reported when teaks grow outside its natural ranges.

Since 1963, Thailand has started Thai-Danish Teak Improvement Program and this has contributed a great deal to the better development of teak germplasm. The natural stands and superior plantations were explored for proper genetical improvement. Plus trees of teak were selected in great number and the genetic materials were stored in the form of clone bank and multiplication garden. To meet the immediate need of teak planting materials, seed production areas were established in the natural stands and mature teak plantations in the north prior to the seed collection from seed orchard. First generation clonal teak seed orchards were established in various places for better quality seed supply. Progeny tests were also carried out in various locations but mostly in teak natural ranges. Too little information on teak growth and development outside the natural range was reported particularly in relation to genetic improvement and intensive plantation establishment.

The objectives of the present study were:

1. To study provenance variation on teak growth characteristics.
2. To detect the clonal variation in growth characteristics, annual growth, wood quality, and coppice growth in Teak Clone Bank.
3. To study the relationship of growth characteristics and the quality of planting materials when planted outside the natural range.
4. To study the clonal variation in the early growth and development of teak under the plantation condition.
5. To provide information for further tree improvement and silvicultural research programs.

LITERATURE REVIEWS

Natural Distribution of Teak

Teak distribution is largely determined by climate, geology, and soils. Teak occurs naturally in parts of India, Myanmar, Laos and Thailand (Figure 1). The area of the natural teak forest in India (Tewari, 1992), Laos (Phengduang, 1991), Myanmar (Ko Ko Gyi, 1991), and Thailand (Kaosa-ard, 1991) is shown in Table 1. Based on the available information, it is estimated that there is a total of over 27.9 million ha of natural teak forests remained.

In India

Teak is mostly confined to the peninsula region below 24°N latitude. This region is bounded in the north by the Western Arvallis of Rajasthan. The dividing line passes eastward through the districts of Jhansi and Baroda in Uttar Pradesh, finally curving southeast to the Mahanandi River through Madhya Pradesh and Orissa. From this northern limit, teak extends southwards through the states of Madhya Pradesh, Andhra Pradesh, Tamil Nadu, Karnataka and Kerala. The distribution of the species is discontinuous and non-teak areas of varying extent are frequent. As reported by Seth and Khan (1958) the more important teak forests, however, occur in Hoshangabad Betul (Madhya Pradesh), Chanda and Melghat (Maharashtra) Wynaad (Kerala), Aanamalahills (Tamil Nadu) and North Kanara (Karnataka). Natural teak forest in India covers about 8,900,000 ha (Tewari, 1992).

In Myanmar

Teak forest covers approximately 16,517,700 ha (Anon, 1993), the majority of teak forest is found on hilly or undulating ground but with some important stands on flat alluviums (Troup, 1921). The distribution of teak is not continuous throughout the area. It does not occur in the dry zone of central Myanmar, the tidal regions of the Delta area, and in area where elevation exceeds approximately 914 m (Ko Ko Gyi, 1991). It occurs up to 900 m. with its best growth in the Pegu Yomas in the Chindwin drainage; Mohnyin forests have the highest density of stocking. Teak occurs in Mixed Deciduous Forest in "Upper" and "Lower" types corresponding to topography. The upper type is subdivided into moist and dry phase on the moisture comparison. However, teak grows to larger sizes in the moist and well drainage sites.

In Laos

Teak forests in Laos are discontinuous between approximately 17° 60 and 20° 80 N at approx. 100-200 m altitude. The most important stands are located on the right side of the Mekong River around Paklay. There are small stands north of Houayxay on the left hand bank of Mekong River. Teak grows in mixture with bamboo, *Lagerstroemia*, *Hopea*, *Dipterocarpus* and *Shorea* (Anon, 1956) of Mixed Deciduous Forest. At present, the remaining teak forest area is around 10,000 ha in Sayaboury and 6,000 ha in Bokeo provinces (Phengduang, 1991).

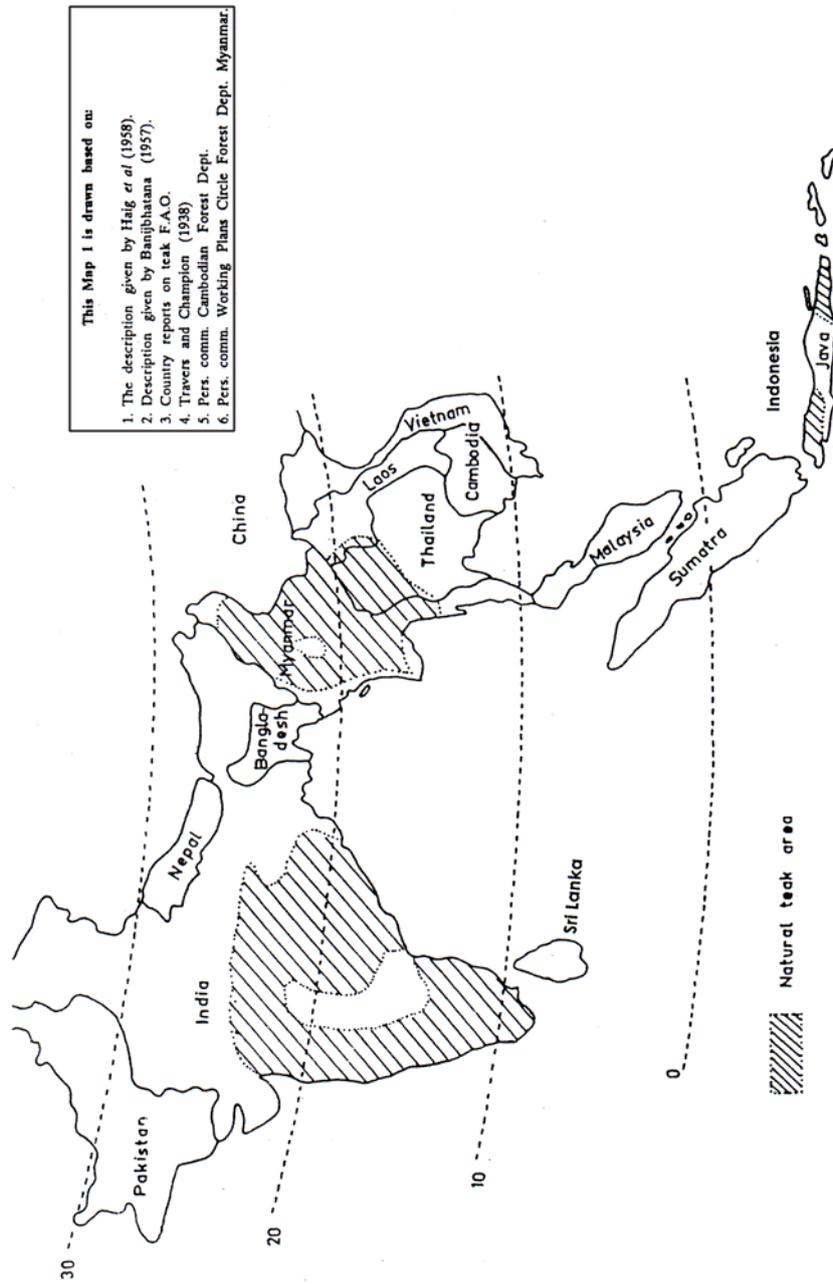


Figure 1 Natural distribution of teak in the world.

Source: Ko Ko Gyi and Tint (1995)

In Thailand

Teak distribution is from 16 to 20° N latitude and 97 to 101° E longitude, largely confined to the hill in the northern and western parts of country (Figure 2). It occurs at altitudes of 100-900 m. Natural teak forest covers some 170,000 sq.km. (Kaosa-ard, 1986). The majority of teak areas in Thailand are located on sandstone or shale soils. Growth is of fine quality below limestone cliffs. Teak is almost totally absent on lateritic formations; the Central Plains are considered unsuitable for teak to grow as cash crop, being too stiff and insufficiently drained.

With the exception of the protected forest, most natural teak forests have been exploited as concession areas. Overcutting, illegal cutting and land encroachment have been effected the growing stock of the natural teak forest. The remaining superior plus tree from these natural forests have provided excellent opportunity in improving teak for large scale plantation to meet the global demand of teak wood.

Table 1 The distribution of natural teak in the world

Countries	Forest area (ha)
India	8,900,000
Myanmar	16,517,700
Laos	16,000
Thailand	2,500,000
Total	27,933,700

Sources: Tewari (1992), Ko Ko Gyi (1991), Phengdouang (1991) and Kaosa-ard (1991)

Silvicultural Characteristics of Teak

Teak (*Tectona grandis* Linn. f.) was formerly belonged to the family Verbenaceae like *Gmelina arborea*. It is at present regrouped in the family Labiatea. Under the natural condition, teak is a large deciduous tree up to 30 m. in height and being one of the dominant trees of the Upper Mixed Deciduous Forest (UMDF). However, this UMDF forest type in Thailand can be divided into two groups, including UMDF and UMDF with teak.

Kaosa-ard (1981) reported that teak grows naturally over a wide range of climatic conditions, from the very dry (500 mm/year) to the very moist (up to 5,000 mm/year). However, teak grows well in the range of annual rainfall approximately 1,250-1,650 mm with the marked dry season of 3-5 months. Under severe dry condition, teak is usually stunted and shrubby while under very moist condition, the tree is large and fluted and usually behaves like a semi-evergreen species.

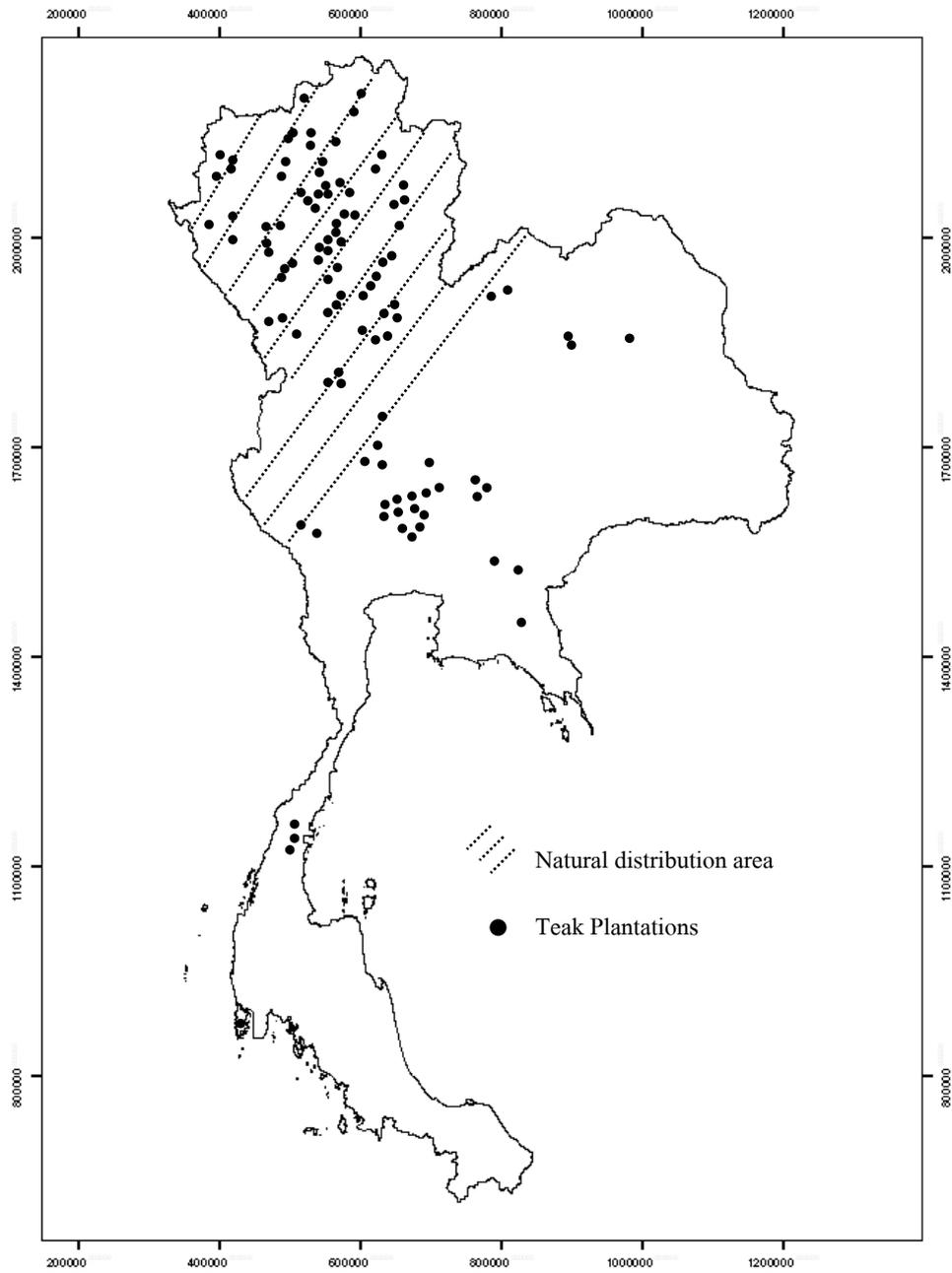


Figure 2 Natural distribution of teak and teak plantations in Thailand.

Source: Modified from Kaosa-ard (1986)

Stem

Teak has long clear bole and rounded crown. This crown ideotype may give round stem which is suitable for efficient uses. In area of shallow soil and moist site, teak often buttressed at the base at least to support the standing tree. Under such condition some teak are fluted.

Bark

The bark is usually thick, fibrous with shallow, longitudinal fissures. In the young tree, the bark is light brown but it becomes grayish brown with age. Measurement of bark thickness in various localities showed average bark thickness of 0.15 to 0.4 in. for trees of small to moderate size and gave a general average of about 0.25 in. (Troup, 1921). Purkayastha (1985) found that teak bark in India is about 0.4-1.8 cm thick, light brown or grey fibrous, with shallow longitudinal cracks, outer bark peeling off in long thin flakes, soft with the sour test.

Branch

The branchlets 4 angled, channeled and stellately tomentose. In dense stand, teak has small branches. Early flowering in the terminal shoot will encourage teak branching.

Root

Teak produces a large deep root system. Primary root is whitish in color and become light brown and woody later. At first a long thick tap root is formed; this may persist or may disappear, but in either case strong lateral roots are produced.

Ngampongsai (1971) studied the distribution and development of teak root in different age plantation and reported that teak root are mainly confined to the upper 30 cm of soil surface. Tap root loses its ability to penetrate when the tree becomes older and always attacked by insects or fungus. Lateral and vertical roots are developed profusely after the cessation of tap root penetration. The lateral roots grow parallel to the soil surface in various depths. However the restriction of the root expansion is occurred after 5 years of growing.

Leaf

Teak leaves are simple and opposite positioned with broadly obovate to elliptical shapes. The leaf sizes are 20-60 cm in length and 20-40 cm in width but often larger in coppice shoots and young trees. The sprouting leaves are hairy and reddish brown in color. With age, their color turn to light and dark green. Teak leaves have minute glandular dots which are red in young leaves and afterward turning black. Teak start shedding their old leaves in January and remain leafless throughout the hot dry period in February-April (Kaosa-ard, 1999). Moreover In moist localities the trees remain in leaf until March or later. The trees as a rule are

leafless in the greater part of the hot season. New leaves ordinarily appear in April-June according to locality and season. However, Champion and Griffith (1948) noted that teak is practically evergreen in moist warm localities, the old foliage persisting until the new bud unfolds.

Flower

In general, teak starts flowering at the age of 6-8 years. However, its flowering age can be as early as 1 year in the nursery bed (Bhumibhamon, 1983), 3 years and as late as over 20 years after planting (Murthy, 1973; Hedegart *et al.*, 1975). The character of early flowering gives the negative to the genetic materials as flowering has a marked effect on growth and development of teak. After flowering and fruit shedding, the multiple or forked shoots are developed on the top part of the stem axis. As a result of this, the early flowering trees have shorter stem boles than the late flowering trees. Early flowering is certainly genetically controlled and can lead to stem deformity and depress height growth (Gram and Laren, 1958). Thus, flowering habit is one important criteria for the teak breeding program and most of selected plus trees are trees normal flowering.

Flowering of teak usually commences in the beginning of the rainy season. The flowering period lasts about 3-4 months or throughout the rainy season. The flowering time of this species varies depending on local climatic conditions. Teak flowering of the northern latitudes teaks such as in India, Myanmar, Thailand and Laos occurs between July and October whereas in the southern latitudes such as in Indonesia and Papua New Guinea are between December and March. Such a large variation in flowering habit is primarily due to site condition and genetic factors. In closed stand, flowering occurs only in dominant and codominant trees, and is confined to the upper parts, which are exposed to bright sunlight. Teak does not produce inflorescence on the lower parts which are inaccessible to light. Curtailment of light results in the delay of not only the initiation of flower buds, but also their development into fruits.

Teak has flower in large panicles which have numerous small perfect flowers. The teak flower is whitish, small with the size of 6-8 mm in diameter and of a perfect type. The complete flower consists of 6 sepals in the calyx part, 6 petals with regular shape in the corolla part, 6 stamens and pistil (Bryndum and Hedegart, 1969). The outer part, calyx is light brown color protecting the flower buds during the development stage. The whitish corolla, which attracts to pollinators, consists of 6 petals at the upper part and a corolla tube, which contains a small quantity of nectar in the basal part. Inside the corolla, there are 6 stamens (6 mm in stalk-length) which consist of an ovary, a hairy bifurcate style and a forked stigma (Keiding, 1965; Siripatanadilok, 1974; Hedegart, 1975).

Teak is mainly an insect pollinated species but wind pollination also occurs in this species (Bryndum and Hedegart, 1969). A case study in Thailand showed that the fruit percentage increases significantly with an increase in number of visiting of the pollinators. Bee, flies, butterflies and ants are major pollinators in teak. Tangmitcharoen (1996) reported that the major pollinator is *Ceratina* sp.

After the successful pollination, the petals and stamen fall of the flower during the flowering day. The calyx closes down to protect the ovary and, subsequently, develop into the fruit exocarp. The fruit size increase rapidly during the initial stage and reaches its full size, which is about 14-15 mm in diameter, at 50-60 days after pollination (Hedegart, 1973). However it requires another 70 days for the fruit maturity which can be judged from its germination capacity. The mature fruit, which is yellowish to brownish, is usually collected after the rainy season. Tangmitcharoen (1996) reported about the teak fruit setting in Thailand and concluded that only 2.49% of self pollinated flowers and 6.54% of open pollinated flowers set fruit, whereas 14.54% of cross pollinated flowers set fruit. And only one of four ovules per flower developed into the mature seed (46.2%), 30.9% contained two seeds per fruit, 8% contained 3 to 4 seeds and 14.9% of fruits contained no filled seeds or empty fruit.

Fruit

The fruit is stony or drupe type, round with diameter of 5-20 mm. A complete fruit consists of the thin papery exocarp, the thick hairy and felty mesocarp and stony endocarp which enclose four seed chambers. The viable fruit may contain upto 4 seeds which are usually 3-6 mm in length and 4 mm in width. The fruit setting stage is as long as 12-16 weeks (July-October). The mature dry fruits fall off in the hot dry season (February-March).

This species has been adapted to forest fire problem and teak fruit dormancy has shown the outcome of long term evolution trend. Generally, teak in Thailand and Myanmar has dormancy fruits while teak from wet site in India has no dormancy and it was introduced to Indonesia for large scale teak planting.

Teak seedlings, saplings and trees require an intensity of light to the tune of over 90 percent. Saplings are often found growing under the light shade of bamboos, and even to some extent under other trees, but the growth of such plants is generally found to be slower than of the plants with complete freedom overhead. Saplings growing under bamboo endeavor to make their ways through them are often found to have their leading shoots damaged or killed, since bamboo acts as a whip, thus the leading shoot of the teak is very intolerant to irrigation of any kinds. Teak is the tree that is a pronounced light demander, it does not tolerate suppression any state of its life. Teak requires a high light intensity for its growth and development. There seems to be certain relationship between light and growth, branching and flowering of teak. Under the natural conditions, isolated and single tree produce profuse branching.

The tree is capable of thriving on variety of soils and geological formations. Teak grows best on deep, well-drained alluvial soils derived from limestone, schist, gneiss, shale and some volcanic rocks, such as basalt. Conversely, the species performs very poorly, in term of growth and stem form on dry sandy soil, shallow soil (hard pan soil or lower water table soil), acidic soil (pH < 6.0) derived from laterite or peatbog, and on compacted or waterlogged soil. Kaosa-ard (1981) also indicated that teak soil is relatively fertile with high calcium (Ca), phosphorus (P), potassium (K), nitrogen (N), and organic matter contents. Similarly, Bhatia (1954) found that

calcium and phosphorus content in the soil are essential for optimum growth. Thus amount of calcium content in soil is also used as an indicator of teak site quality. Soil pH is the another factor limiting the distribution and stand development of teak and the optimum pH range for better growth and quality is between 6.5-7.5 (Tewari, 1992).

Teak can tolerate well with light forest fire. Under the natural condition in Thailand, teak grows in the Upper Mixed Deciduous Forest with teak which has occasional fire outbreaks almost every year.

Teak is sensitive to cold and frost, seedling and coppice shoots being particularly liable to injury. In its natural habitat, severe frost seldom occurs, but the abnormal frost of 1905 in India did much damage in parts of the Peninsular, poles being killed at the top or down to ground level. Teak is also sensitive to drought. In the abnormal droughts which occurred from time to time in the Peninsular it suffered more severely than any other species (Troup, 1921).

Teak coppices and pollards vigorously and sometimes retain the power of coppicing in a considerable size. And the early growth of coppice and pollard shoots is rapid. Experiment in, Mahdya Pradesh in 1909 reported that twelve different species coppiced and pollarded, teak showed the most rapid growth both of coppice and pollard shoots (Troup, 1921).

Utilization of teakwood

Teak wood is reputed for its durability, beauty, workability, strength and dimensional stability. Teak wood is resistant to termite and fungus attack. Price of sawn teak timber on the world market fluctuates between US\$ 1500 and 2000 ton⁻¹. Due to the combination of beauty, strength and durability, teak wood is suitable for many purposes ranging from heavy duty to light duty uses. These include structural beams, bridges, boat building furniture making, parquet and strip flooring, interior joinery, decorative work, sculptured and carved wood work, door, window, etc. (Baskaran *et al*, 1997). Various products such as glue-edged boards, furniture, doors and small teak wood artifacts have been made from thinning materials, showing that even sapwood can be used to produce high quality objects (Krishnapillay, 2000).

Genetic Variability

Genetic variability can be generally divided into additive and nonadditive components so that genetic variance is equal to additive variance plus nonadditive variance.

Genetic variability in any trees characteristics is considered to be an important research works related to plant biodiversity. Like other living organisms, genetic variability of selected tree species varied among and within provenances. Most commercial and important traits are controlled by both genetic and environmental

factors. Some traits like the earlier flowering of teak are controlled by single genes while the growth of teak is controlled by polygenes (Bhumibhamon, 1983).

Under natural conditions, tropical trees have to adapt to the changeable environment. Whenever the environment changed, individuals in the tropical climate have to adapt through physiological and morphological changes. Additionally, the phenotypic plasticity can be detected through non-adaptive means. High fitness trees would remain if the reproductive system has been maintained up to the present day. Therefore, the genetic composition would be changed and genotypes with high fitness suitable to the environment would be preserved. In specialized and stable environments, genetic differentiation may lead to maintenance of only a limited number of genotypes, with a high fitness in adapting to the changeable environment. In the more variable and less predictable environment, a larger genetic variation will be maintained with genetic plasticity in the populations (Kuiper, 1990).

Genetic variability of teak was previously studied in various traits, i.e. seed morphology (Yingvanasiri, 1976), growth and development, resistance to insects, fruit production (Suksiluang *et al.*, 1975) etc. Further works on this genetic aspect need to be studied.

Teak Introduction and Plantation Establishment

Teak was introduced to Java by the Dutch, about 400 years ago. Teak was also introduced to the Philippines by the Spanish. Teak has also been planted on small to moderate scales in several regions, mainly in the tropical countries including East and West Pakistan, East and West Africa, Central and South America, and on many Islands of Atlantic, Pacific and Indian Oceans. It has been widely established in plantation as an exotic species for producing high quality pole and timber outside its natural range. Up to now plantation area of teak has gradually been increased in Asia and other regions, as shown in Table 2.

In 1995, about 94 percent of global teak plantations were produced in tropical Asia, in India (44 percent) and Indonesia (31 percent). The particularly other countries of the region with significant planted teak resources were Thailand (7 percent), Myanmar (6 percent), Bangladesh (3.2 percent) and Sri Lanka (1.7 percent). About 4.5 percent of global teak plantations were produced in the tropical Africa (largely in moist West Africa, particularly in Cote d' Ivoire and Nigeria) and the remainder were in tropical America (mostly in Costa Rica, Trinidad and Tobago) and the Pacific Islands.

Plantations may be loosely defined as arrangements of trees which are artificially generated and the result of conscious management (Sedjo, 1987). According to the plantation size, the area may range from less than a hectare, (as when trees are planted by a farmer as a windbreak) to several thousand hectares, (as when a plantation) which were established to produce timber or wood production for industrial uses. Other may define plantation as a planting area of over five ha while the small planted area is regarded as tree farm. Moreover, a complex plantation might

be possibly designed to maximize social benefits rather than wood production per se, and which included elements of forestry activities such as agroforestry and community forestry (Kanowski and Savill, 1992). This means that the rural society will benefit more from these tree planting activities.

At present, species selection for plantations or tree farming establishment is rather limited to most economic species even though there were 99 species were selected for planting in Thailand, including 72 native species and 27 exotic species (Bhumibhamon, 1986). However, the target is always set for a small number of species, including *Tectona grandis*, *Eucalyptus camaldulensis*, *Acacia mangium*, *Casuarina junghuhniana* and *Rhizophora apiculata*. The main objective of plantation establishment is to produce timber and wood production to secure the need. Nevertheless, most plantation are not subjected to efficient productivity and less management practices.

Table 2 Major teak plantations in the world

Countries	Teak plantation (ha)	Situation in
Bangladesh	62,700	Up to 1985
China	9,000	1992
India	276,250	1975
Indonesia	675,640	1990
Laos	5,000	1992
Myanmar	214,189	1993
Philippines	21,550	1990
Sri Lanka	70,810	1990
Thailand	170,240	1990
Vietnam	500	1992
Asia Total	1,505,879	
Ghana	31,560	1985
Ivory Coast	21,000	1992
Nigeria	21,300	1980
Sudan	10,700	1980
Tanzania	5,000	1990
Togo	4,500	1956
Africa Total	94,060	
Brazil	940	1990
Ecuador	1,000	1980
Panama	800	1970
Puerto Rico	800	1980
Trinidad	9,710	1980
Tropical America Total	13,250	
Grand Total	1,613,189	

Source: Modified from Wint (1995)

The first teak plantation in Thailand was established in 1906 in Phrae province, northern Thailand so as to seek the possibility of producing teak to meet the demand. The planting area has been extended to the other parts of the country at present. In 1945, a national large scale teak planting program was initiated by the Royal Forest Department (RFD) and teak has become a top priority species since then. To improve the teak wood quality and yield of the plantation, intensive improvement programs including breeding, silviculture and nursery researches were conducted in Thailand in early 1965 (Keiding, 1966). At present, teak is widely planted in many forms of planting by several agencies. The main agencies responsible for teak planting in Thailand are Royal forest Department (RFD), Forest Industry Organization (FIO) and Thai Plywood Company (TPC). FIO (1982) reported that the areas of teak planting operated by RFD, FIO and TPC are 123,953, 38,885 and 7,408 ha, respectively. According to Thaiutsa (1999), total area of teak plantation in Thailand in 1998 was about 300,000 ha, 69% owned by RFD, 27% by FIO and 4% by the private sector. Moreover, teak is one of the most widely cultivated hardwood timber species in tree farming in Thailand. The planting program was launched with the financial support from RFD's Reforestation Fund. Thus, teak planting has provided more growing stock of teak for future uses (Figure 3). In the past, almost all teak plantations are state owned with only few small scale plantations owned by the private sector. At present, tree farmers have increasingly planted teak as tree farming, homestead, mixed with other crops along boundaries and other planting system. Teak is somehow still remained as a promising economic species of the country.

Teak plantations have been established throughout the world in various environment conditions with the total area of 1.6 m. ha. Keogh (1994) recommended that the Mean Annual Increment (MAI) of teak plantation should be not less than 8 m^3 /ha/year in commercial planting operations. Therefore, the site of teak planting should be carefully selected. Additionally, the improved germplasm materials are used and the intensive management practices are applied.

Growth and Development

Growth and development of plants are regulated by both endogenous and external factors. Plant development involves cell multiplication, increase in volume and the differentiation of organs and tissues. Kramer and Kozlowski (1979) stated that growth is the result of the interaction of physiological processes. Therefore, growth is the permanent increase in substance and volume of living parts (Walter, 1995).

The growth of trees is controlled by their inherited genetic potentialities and their environment. With the variation in environment conditions when the trees are growing, teak exhibits, diurnal, seasonal and life time growth periodicities. It is necessary to note that height and diameter growth of a tree begin and end at different times (Kramer and Kozlowski, 1960). Generally, the information related to growth and development of teak is important in determining the suitability of tree species selected for growing. After fruit sowing onto seed bed, the germination of teak fruit

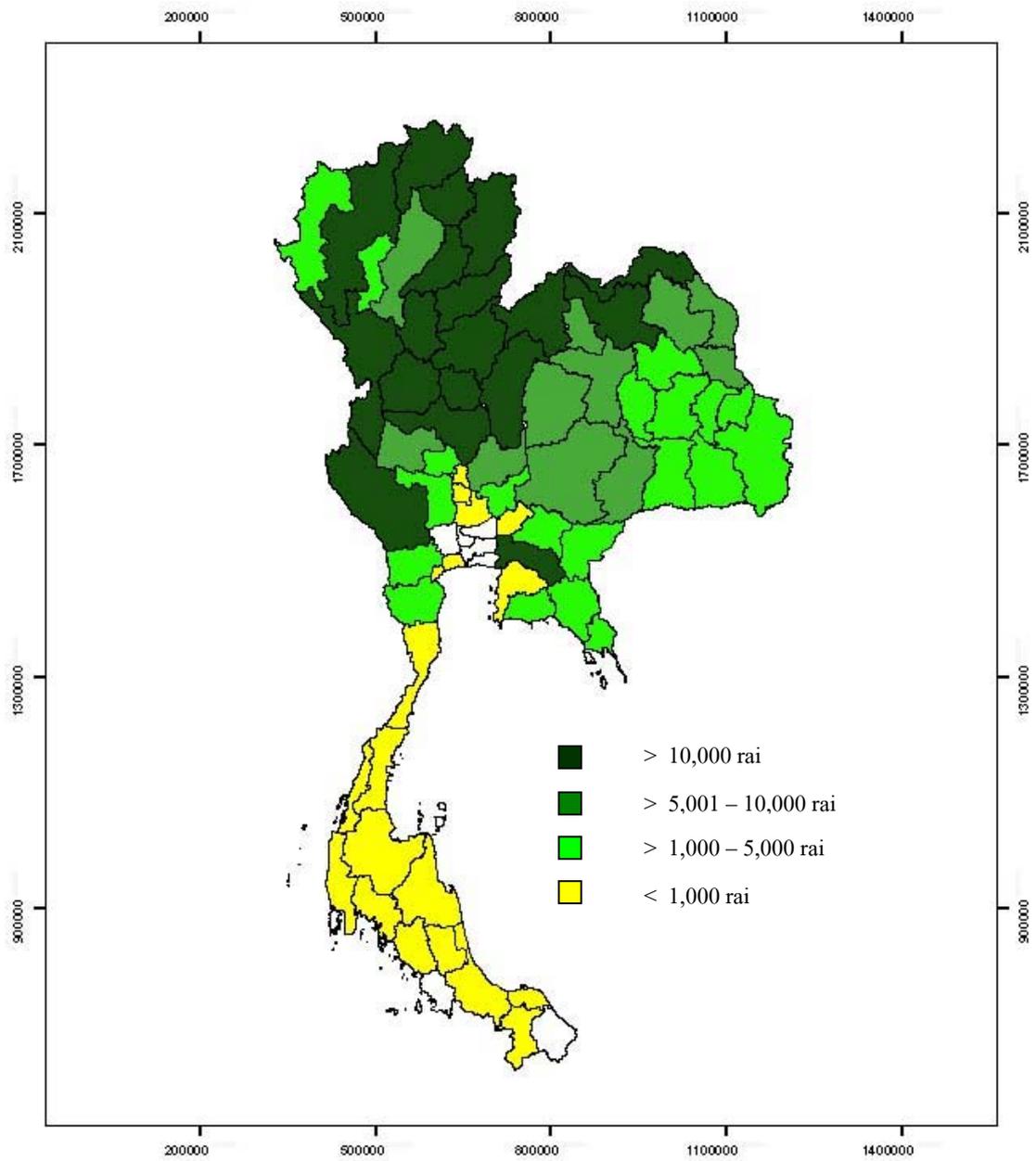


Figure 3 Teak plantations in Thailand supported by RFD's reforestation fund in 2003.

varies accordingly from seedlot to seedlot, depending much on the fruit quality and fruit dormancy. Teak seedlings performance depended on height growth more than diameter growth in the early years of development. Large genetic variability in teak growth was found in actual man-made plantation, caused by the poor quality of seed used and the variation in site conditions. Site for teak planting should be carefully selected through species-site matching. It is obvious that through site selection, growth of the plantation can be improved up to 116% as the case in Indonesia (Kaosa-ard, 1995). With proper site selection, the MAI of the teak plantation may increase from about $2 \text{ m}^3 \text{ ha}^{-1} \text{ y}^{-1}$ to $15 \text{ m}^3 \text{ ha}^{-1} \text{ y}^{-1}$.

Teak is, in fact, a periodic-growth- deciduous type tree, which shed its leaf during the dry period. The period of this shedding varies accordingly with soil moisture availability. Previous studies indicated that teak has poor development during March - April but the shoot growth will increase considerably during May-July. Kaosa-ard (1982) also confirmed that the growing period lasts for four months. Nevertheless, diameter growth is maintained, which may be caused by the translocation of carbohydrate to the bole of the trees, but the rate will slow down when height growth begins again. Longman and Jenike (1974) classified teak as a periodic-growth deciduous type as it has a growing period during the rainy season and drops its leaves in the dry seasons. This trend of development involves many complex biochemical processes which occur simultaneously. The rate of these individual processes may vary with time. According to Kramer and Kozlowski (1960), height growth of tree prior to the maturity shows a sigmoid curve. Also, the height growth and diameter growth responds differently to the environmental fluctuations. Researches on variation in teak growth were previously done in various aspects, including variation under various plantation conditions (Tewari, 1992; Jaijing, 1994) provenance variation (Kaosa-ard, 1993) and clonal variation (Pudaeng, 1988).

Chalermpongse (1992) studied growth performance of teak in various age classes (1-42 years old teak) at Huay-Tak Teak Plantation, Lampang. The result was shown that the total height growth of teak under Huay-Tak Plantation conditions increase considerably with age only at the early stage of development. When teak reaches 15 m in height, the height increment changed greatly depending on site quality, biotic, and abiotic enemies.

Chanpaisang (1993) reported earlier that at 15 years old, the average height of dominant teak tree grown in Thailand varied between 13.94-18.60 m while DBH growth comparison among three plantations showed similar patterns. Base on Chanpaisaeng (1977) 30 year-old rotation of teak in northern Thailand can produce as high as $184 \text{ m}^3 \text{ ha}^{-1}$ from superior planting site with the average value of $140 \text{ m}^3 \text{ ha}^{-1}$.

From these studies it can be concluded that better height growth and DBH growth depend very much on site quality and sufficient management practices to maintain tree in good condition. Soil depth and soil fertility are two main major factors affecting the variability in height growth. And the differences on tree diameter growth will make tree volume per unit area differences. It is thus important to select good site to grow teak if maximum yield is expected.

Both genetic and environmental factors are important to growth, development and tree form of teak. While intensive management practices are also important to promote better growth rate and silvicultural practices can be used to improve stem quality.

Provenance Trials

A provenance trial is an experiment in which seeds are collected from a number of widely scattered stands and the seedling are grown under similar conditions. Provenance trials are carried out for very practical reasons, to screen nationally available types for reforestation or for further breeding work (Wright, 1976). The differences among provenances in growth and productivity are also observed in physiological and morphological characteristics. Beside, Wright *et al.* (1970) conducted the study on Douglas fir and showed that the planting based on a simple provenance test could probably increase productivity by more than 50%.

The main practical aim in establishing provenance trials is to screen superior provenances which promising families or clones were selected for seedling or clonal seed orchard establishment. The criteria used in determining the good provenances are not always rapid growth, but also high survival percentage, resistance to biotic enemies, good wood quality, good adaptation, high biomass production in a given region, ect. Evaluation of the best seed sources or provenances is time consuming or keeps it longer for two generations (Pinyopusarerk, 1980).

Wright (1976) stated that the classic provenance experiments of trees were started with Scots pine in 1820. While in Thailand, teak provenance trials were established in Lampang first and then expanded to other provinces. Later on, provenances of various species were established in Thailand, including *Pinus kesiya*, *P. merkusii*, *P. caribaea*, *P. oocarpa*, *Eucalyptus camaldulensis*, *E. urophylla*, *Acacia auriculaeformis*, *A. mangium*, *A. crassicaarpa*, *Casuarina equisetifolia*, *C. junghuhniana*, *Pterocarpus macrocapus* (Pinyopusarerk, 1980; Bhumubhamon and Thavorn, 1991; Awang *et al.*, 1993; Awang and Bhumibhamon, 1993).

International provenance trials of teak were initiated by DANIDA Forest Tree Seed Center, Denmark in 1972 in collaboration with Forest Research Institute, Dehra Dun and State Forest Developments. International provenance trials of teak in Thailand were launched in 1973. The seeds were collected from 55 seed sources from natural forest and mature plantations in India, Thailand, Laos, Indonesia, Togo, Ghana, Ivory Coast and Tanzania. In the early stage of development, it was found that all provenances have high survival percentages but in the second year differences in survival percentages were insignificant and the best provenances were originated from Thailand, Laos, India, Indonesia and Myanmar. Bhumibhamon (1986) stated that another set of international provenance trials of teak in Thailand was established in 1979 and showed that survival percentage and growth rate differed remarkably according to seed sources. Results also showed that teak of the native seed sources have better growth rate than the exotic ones (Pinyopusarerk, 1980).

Clone Bank

A clone bank is an area consisting of a series of clones derived originally from a single plus or elite tree by means of asexual propagation. Beside, clone garden, germplasm bank or clone archive are other terms having similar meaning. The purpose of the clone bank establishment is to study the clone performance, seed ontogeny and seed development.

Bhumibhamon (1983) noted that clone bank can provide the possibility for pollen collection and work on controlled pollination. The initiate clone bank was established by Royal Forest Department (RFD) and Thai Plywood Company (TPC). It should be conducted on fertile sites and good drainage in the flat land. And it is necessary to note that in clone bank, good management practices and good registration of germplasm are needed.

In the Tropics, only clone bank of economic tree species have been established. Additionally, multiplication garden have also been established for buds or other plant materials for vegetative propagation.

Seed Orchard

A seed orchard is an area where seed are mass produced to obtain the greatest genetic gain as quickly and inexpensively as possible (Zobel and Mc Elwee, 1964). Feilberg and Soegaard (1975) defined that a seed orchard is a plantation of selected clones or progenies which is isolated or managed to avoid or reduce pollination from outside sources, and managed to produce frequent, abundant and easily harvested crops of seed. Moreover seed orchards are not always solely for genetic improvement of specific characteristics but can be used to produce quantities of seed that are adapted to a specific planting location (Nanson, 1972). Therefore, the objective of a seed orchard is to produce maximum amounts of seed with as much genetic improvement as quickly and as efficiently as possible.

Zobel and Talbert (1984) stated that the largest, cheapest and fastest gains in most tree improvement programs can be made by using appropriate seed sources from suitable species. Therefore a seed orchard is established as an essential part of an improvement program if sexual regeneration is the major means in tree farming. In order to produce good quality seeds, it is necessary to note that a seed orchard is an essential program of tree improvement that requires time, money and effort (Bhumibhamon, 1993). There are numerous kinds of seed orchards which can be divided into two broad categories such as clonal seed orchard and seedling seed orchard. Clonal seed orchard is established by using vegetative propagules as graft, cutting, tissue culture plantlets, or other methods. Seedling seed orchard is launched by planting seedling. The first seed orchard in Southern Asia was established by the Dutch in 1930. The species selected was *Cinchona leggeriana*. In the case of teak, only clonal seed orchards were established in Thailand

Seed orchard are commonly categorized by generation, that is first, second or more advanced generation orchards depending upon how many cycle improvement they represent. In order to establish seed orchard, there are many things to be taken into account. Location, size, type of orchard and management practices are all of vital important factors.

The first seed orchard of teak was established in Papua New Guinea in 1963 and later on in Thailand and India (Tewari, 1992). Jaijing (1994) noted that the first seed orchard in Thailand was a clonal teak seed orchard which was established in 1966 at Mae Gar District, Phayao province. Other teak seed orchards of RFD were established in 5 provinces, including Phayao, Lampang, Tak, Chanthaburi and Khon Kaen. FIO has also established large scale seed orchards to apply good quality teak fruit to meet the actual demand of annual planting in that particular site. Additionally, TPC has established a first generation clonal seed orchard, consisting of 25 selected clones. All teak seed orchards in Thailand are the first generation clonal seed orchards. The differences in planting design, spacing used, number of clones, number of grafts per clone, and management practices do not allow comparison of differences in clonal performances among sites.

To avoid contamination of orchard seed from outside pollens, every orchards should be spatially well isolated from other teak plantations. Although no actual studies have been conducted an isolation distance, 200 m is considered safe distance for teak because it is insect pollinated and not wind pollinated like pines and other conifers (Tewari, 1992).

Stem Analysis

Stem analysis refers to a technique of examining the growth rings of sections from a tree trunk. It enables the past growth history of a tree stem to be reconstructed. The stem analysis is able to calibrate a tree growth model and from the stem analysis various equations can be created to model height growth, ring width, basal area increment, crown shape, etc.

Annual rings tend to be wider during the early life of a tree, as age increase, the ring width gradually increase. Eventhough the width of each ring normally decreases as it becomes older, this thinner wood layer is added over a large stem diameter or bole surface. Therefore, the volume of wood added annually may be equal to or greater than those of previous years.

Teak is a ring-porous tree, therefore the diameter of xylem vessels formed early in the growing season is much larger than those formed later. In most tropical trees, the diameter growth of the stem is discontinuous. Most deciduous trees usually have only one growing season and become dormant afterwards. Growth rings may or may not be connected with the period of shoot growth. However, growth period and dormancy period may depend much on species (Kramer and Kozlowski, 1979). The annual diameter increment varies between species, individual trees, or different parts

of individual tree ages. The width of annual rings is often materially reduced by drought and this has been extensively used to study past climatic conditions.

Pumijumnong (1997) showed that the earlywood vessels of teak have completed their formation between mid-April and the end of May, when the cambium is most active. The growing period continues for 5 more months and shuts down at the end of October.

Tomazello and Cardoso (1999) studied about the seasonal variations of the vascular cambium of teak in Brazil, Report showed that the structure of fusiform and ray initials of the cambium and the activity. During the cambial dormancy period (September-early November) the fusiform initial cells presented thicker radial than tangential walls.

Tourchob (1984) reported that cambial activity started with leaf growth but when most leaves matured, cambial activity decreased. The present investigation on ring analysis of teak has provided additional information for managing teak performance under plantation conditions.

The last two decades has made many significant advances in statistical tools and model applied in analysing the characteristics in tree rings and their relationships to climate that is call dendrochronology (Fritts, 1976). Dendrochronological investigations have been conducted in South East Asia by many researchers such as Buckley *et al.* (1995) and D' Arrigo *et al.* (1997) who studied the individuals of the species Pinaceae and Podocarpaceae in Thailand.

Kitin and Funada (2000) studied the analysis of tree ring growth and cell structure on free-hand sections by confocal microscopy. Three hard wood species, *Kalopanax pictus*, *Quercus mongolica*, and *Cercidiphyllum japonicum* were used for the experiments. Cambium and adjacent phloem and xylem were taken from winter, spring and summer. They were fixed in a mixture of 50% ethanol, acetic acid and formaldehyde (18:1:1, v/v;FAA) Hand cut transverse and longitudinal sections were prepared with a razor blade. The sections were stained with safranin, cleared and mounted in glycerol and observed by confocal microscopy. Additionally, semi-thin sections were cut and observed by conventional light microscopy after fixation in glutaraldehyde and embedding in epoxy.

Bhumibhamon and Pipatwattanakul (1986) studied 10 year-old in situ Gene Conservation Forest of Merkus Pine in Surin and found that average ring width ranged from 2.47nto 2.92 mm and showed highly significantly differences between trees ($F=14.6913^{**}$).

Murphy and Whetton (1989), Jacoby and D' Arrigo (1990) as well as Palmer and Murphy (1993) investigated teak trees growing in Java, Indonesia. Bhattacharyya *et al.* (1992) and Wood (1996) studied teak trees in India and found that previous October rainfall correlated with tree-ring width. There is little information about clonal variation in teak tree ring width. More studies in this research area are needed.