EFFECT OF *HEVEA BRASILIENSIS* PRUNING ON GROWTH AND YIELD OF THE *HEVEA BRASILIENSIS* AND *AQUILARIA CRASSNA* MIXED PLANTATION AT TRAT AGROFORESTRY RESEARCH STATION, TRAT PROVINCE

INTRODUCTION

Aquilaria crassna is a tree species known to produce resinous and fragrant wood while growing in natural forests. The resinous and fragrant wood has many trade names which are Agarwood, Eaglewood, Gaharu, Aloeswood, Krisanah and Mai Hom. Principally, the price of woodchips and oil distilled from Agarwood is so expensive that it attracts farmers to cultivate them in plantations. However, the information on the formation of Agarwood in tree trunks is lacking as well as the methods on cultivation and management of the *A. crassna* plantation.

In Eastern Thailand, particularly Trat Province, farmers like to grow *A. crassna* intercropping with *Hevea brasiliensis*. As everyone knows, *H. brasiliensis* is an important economic tree species in Thailand. RRIT (2002) reported that Thailand exported a large amount of latex to earn 48,484 million Baht and became the leading latex producer (2,357 tons/year) in 2001. Because of high market demand, *H. brasiliensis* plantations have been extended to the northern and northeastern parts of Thailand. In Trat Province, *H. brasiliensis* plantation is the largest land use, covering 30.6 percent of the total provincial area and latex production is the main source of income for Trat farmers. However, fluctuation of latex price in some years has led farmers to find a way to decrease the risk in planting *H. brasiliensis* as monoculture. Consequently, farmers plant *A. crassna* intercropped with *H. brasiliensis*. Osoguchi (2002) mentioned that there was no effect on latex production and growth of *H. brasiliensis* when intercropped with *A. crassna*. Moreover, *A. crassna* could add the value to the *H. brasiliensis* plantation with its Agarwood formation. However, growth performance of the intercropped *A. crassna* may not be good because the limitation of light intensity. In other words, success of *A. crassna* depends on the amount of radiation penetrating *H. brasiliensis* canopy.

Pruning of *H. brasiliensis* branches at different height above ground levels was applied to attribute light intensity to the intercropped *A. crassna*. The effect of pruning of *H. brasiliensis* is determined in term of its stem growth and latex yield as well as the growth of the intercropped *A. crassna*. Furthermore, the proper level of pruning of *H. brasiliensis* branches should be discussed to encourage the highest growth and yield of the mixed plantation.

OBJECTIVES

The objectives of this study are:

1. To study the effect of pruning of *H. brasiliensis* branches on its growth and latex production.

2. To study the effect of pruning of *H. brasiliensis* branches on growth of the intercropped *A. crassna*.

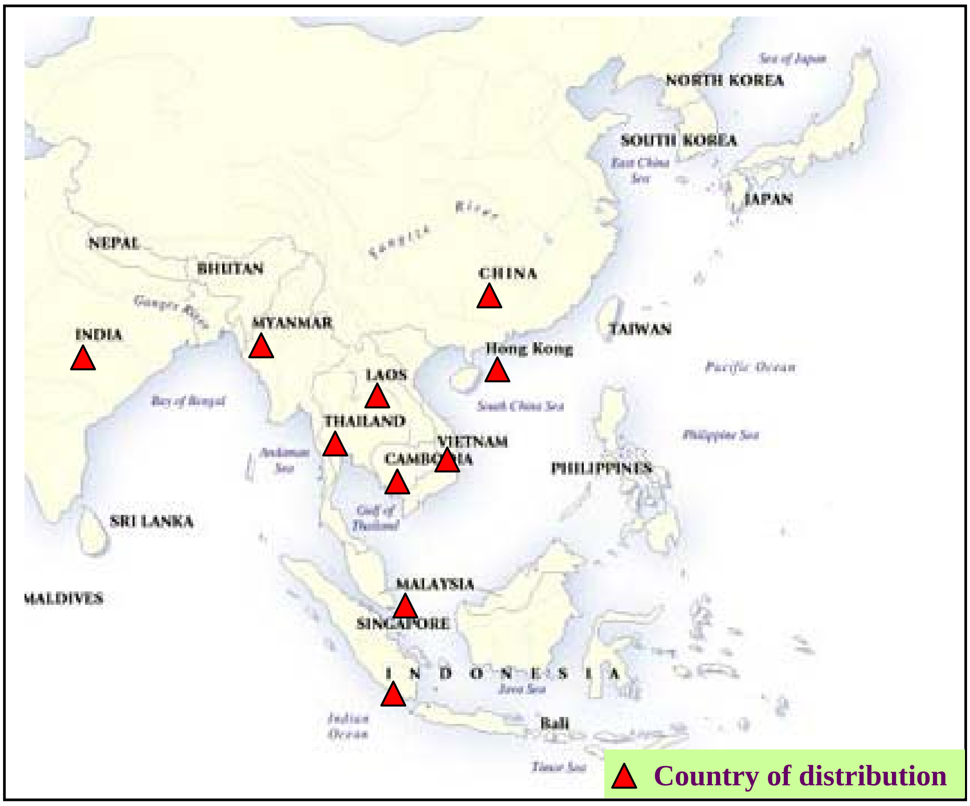
LITERATURE REVIEW

This section provides the information of *Aquilaria crassna*, *Hevea brasiliensis* and terms of pruning, growth, yield, canopy structure and light interception in forest canopies and leaf area index and photosynthesis.

<u>The information of *Aquilaria crassna*</u>

1. <u>Natural distribution</u>

The genus *Aquilaria* belongs to the family of Thymelaeaceae. It consists of 15 species and is distributed in the tropical forests of South Asia and Southeast Asia (Figure 1) including India, Myanmar, Laos, Cambodia, Vietnam, Indonesia, Malaysia, China (Hong Kong, Hainan) and Thailand (Ding Hou, 1960). There are four species of *Aquilaria* species that occur in Thailand, namely *A. crassna*, *A. malaccensis*, *A. subintegra* and *A. hirta* (Peterson, 1997).



<u>Figure 1</u> Mapping of natural distribution of *Aquilaria* species.

2. Botanical aspect

The height of *A. crassna* is from 10-30 m. The bark is grey or whitish, smooth or rugose. The pulp is spongy and white. The branchlets are pubescent to glabrescent. The leaf is acute to acuminate, usually with a pronounced tip and 6-10 mm long, base cuneate to acute and 7-11.5 by 2.5-5 cm, coriaceous, green, shining, glabrous above, glabrous below or with scattered hair along the margin and midrib. The secondary nerves 12-18 pairs, prominent on both sides. The petiole is pubescent and 3-7 mm long. The inflorescence is in fascicles with 4-6 flowered. The peduncle is pubescent and 3-5 mm long. The flowers have greenish. The pedicel is pubescent and 5-10 mm long. The calyx tube is puberulous outside and inside and 3-4 mm long; calyx lobes with 3-4 by 2-3.5 mm, puberulous on both sides (calyx much enlarged after flowering). The petals have densely pilose with 1-1.5 mm long. The stamens with filaments are 1-1.5 mm long; anthers 1 mm long. The ovary is puberulous and 2-3 mm long. The style is not distinct; stigma capitate to oblong and 1 mm long. The fruit is sub-orbicular, puberulous and 2.5-3.5 by 2-2.5 cm, at the base surrounded by the persistent calyx, increasing in size after flowering. The seeds are 10 by 5 mm (Peterson, 1991).

3. Silvicultural aspects

Aquilaria species have adapted to live in various habitats, including rocky, sandy or calcareous soil, well drained slope and ridges and land near swamps. They typically grow between altitudes of 0-850 m in locations with average daily temperatures of 20-22° C.

Most commercial plants of *A. crassna* are propagated by seeds. The vegetative propagation is seldom to practice. Siripatanadilok *et al*. (1991) reported that natural regeneration of *A. crassna* was poor but the collected seeds could germinate up to 98%. Cutting propagation could not be done for material from mature trees but could be done successfully for juvenile materials from seedlings of six months old giving about 76% rooted material.

4. Formation of Agarwood

It is known for a long time that *Aquilaria* spp. is the source of Agarwood. Research on Agarwood formation revealed that nine *Aquilaria* species were observed to produce Agarwood (Eurling, 2003).

Previously, many researchers believed that Agarwood was regarded as a pathological product formed as the result of a fungal disease. Kwangtung Institute of Botany (1976) revealed that the formation of the oleoresin in

A. sinensis is not heredity but a result of abnormal metabolism of the stored starch grains caused by the parasitic fungus. In 1997, Jalaluddin isolated *Cytosphaera mangiferae* from diseased tissues of standing trees of the *A. agallocha* and suggested that the inoculation of uninfected *A. agallocha* wood with these fungi was effective in inducing resin.

Recently, several studies have shown that there were no primary roles of any specific fungus in the formation of Agarwood (Gibson 1977; Rahman and Basak, 1980). According to Siripatanadilok *et al*. (1991) Agarwood formation did not correlate with the roles or activities of specific fungi, but it was formed by the interaction with the tree host through injuries or wounding which might be derived from mechanical, physical and chemical or biological processes. It appears the oleoresin in *Aquilaria* sp. is formed as a result of a protective reaction of the tree to injuries, wounding or biological invasions. He also concluded that the fungal infection in *Aquilaria* spp. trees would degrade the quality and reduce in weight of Agarwood.

Further investigation of the mechanism of Agarwood formation showed that it was produced only on living tissue within interxylary or included-phloem, and the xylem of the trees in the genus *Aquilaria*. The oleoresin is mainly concentrated in the included-phloem and amount of oil deposited in xylem produces different grades of Agarwood (Prachakul, 1989; Rao and Dayal, 1992).

5. <u>Utilization of Agarwood</u>

It has been known for a long time that Agarwood has economic importance and it is one of the highest valuable forest products currently traded internationally among natural fragrant woods.

Agarwood has three principal uses: medicine, perfume and incense. Smaller quantities are used for other purposes such as carvings, aromatic ingredients for food and beverages and authentic Agarwood beads or necklaces. For medicinal uses, it is reported that Malaysians used Agarwood mixed with coconut oil as liniment and also in a boiled concoction to treat rheumatism and other body pain. Agarwood is also prescribed for dropsy, as a carminative, a stimulant for heart palpitations and as a tonic taken particularly during pregnancy, after childbirth and for diseases of female genital organs (Burkill, 1966). Agarwood incense is burned to produce a pleasant aroma. Its use ranges from a general perfume to an element of important religious occasions. The powder or dust cannot be burned directly, but can be used to make incense sticks or coils for indoor fragrance. It is used for religious purpose by Muslims, Buddhists and Hindus since the ancient time. The uses of

Agarwood for perfumery as agar-oil and Agarwood smoke are extensive. Many derivative products are produced to supply various customers. Derivative products can be perfume, soap, jointed-stick and marmool (Barden *et al*., 2000).

6. **Status of *Aquilaria crassna* in various parts of the world**

In many countries, the presence of *Aquilaria* species decreased in natural forests due to many decades of over-exploitation. *A. crassna* has been categorized as a critically endangered species according to the IUCN Red List Category since the early 1990s. In 2004, all *Aquilaria* species have been listed in the Appendix II of The Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) for the purpose of preventing population decreases in natural forests.

Due to its status as a highly valuable non-forest product, Agarwood is one of the most economic important natural fragrant sources for international consumers. These include Japan, Taiwan, South Korea, Singapore, United States of America, France, Germany, Saudi Arabia and United Arab Emirates. The main exporters of Agarwood woodchips are Malaysia with 2,420,356 kg and Indonesia with 1,227,643 kg during 1995-2001 (CITES, 2003). Singapore is the largest trader of Agarwood market as well as Hong Kong, Taiwan, Japan and United Arab Emirates (Philipps, 2003).

A. crassna has been widely established in Asia, and its planted area is still expanding. In the eastern parts of Thailand, especially in Trat Province, there are 308 ha planted with *A. crassna*, often mixed in the fruit orchard and *H. brasiliensis* plantation (Osoguchi, 2002). Additionally, Lam (2003) reported that the area of *A. crassna* planted in plantations in 2002 was 2,750 ha in Vietnam. However, the information regarding cultivation and resin inducement of *A. crassna* in plantation is lacking. Research should be done and transferred to farmers for the management of *A. crassna* plantations.

7. **Domestication of *Aquilaria crassna* in Thailand**

The domestication of agroforestry trees is an accelerated and human induced evolution to bring species into wider cultivation through a farmer-driven or market-led process (Simons, 1996). Roshetko and Verbist (2000) defined that domestication is the naturalization of a species to improve its cultivation and use for humankind. Basically, domestication is an activity that improves the ability of people to grow and utilize trees either for products or services. The process of tree domestication involves the identification, production, management and adoption of desired germplasm to meet farmer-driven or market-led needs. Many agroforestry activities were focused on the exploration and collection of natural or anthropogenic population, evaluation and selection of suitable species and provenances developing propagation techniques, utilization and tree-product marketing and the development and dissemination of relevant technical information.

The domestication of non-wood forest products, including from high value species such as *A.* crassna should be promoted as economic species in plantation. The increase of productivity and valuable profit of tree domestication can promote the quality of life of farmers. Since 1994 the Royal Forest Department (RFD) of Thailand has implemented a farm forestry extension project by providing financial support, namely 3,000 baht per 1 rai (1 hectare = 6.25 rai) to farmers who grow trees promoted by the RFD. *A. crassna* was one of the 66 species promoted in this project and as a result, 98 growers have planted *A. crassna* in 2000 (Osoguchi, 2002).

The information of *Hevea brasiliensis*

The genus *Hevea* is a member of the Euphorbiaceae family. It comprises 10 species of which *H. brasiliensis* trees is the only one planted commercially. In South America, this species occurs naturally over about half the range of the genus. It mainly occupies the southern region of the Amazon, extending to the Acre, Matto Grosso and Parana areas of Brazil and into the parts of Bolivia and Peru. It also distributed in the north of the Amazon to the west of Manaus as far as the extreme south of Columbia (Webster and Baulkwill, 1989).

1. Botanical aspects

The tree is up to 25 m, tall with a smooth grayish trunk. The leaf is trifoliate with long petioles, elliptic leaflet each 10-12 cm long, narrowed-acute at both ends. It has separate male and female flowers, whose color is greenish-yellow, which are borne in the same inflorescences (monocious) with the female at the ends of the main branches of the panicles. The flowers of both sexes have a 5-lobed calyx borne on a basal disc of 5-10 stamens with their filaments united into a column and their anthers sessile. The ovary is 3-celled with one ovule per cell. The fruit is a trilocular capsule, usually containing 3 seeds which dehisces are explosive to scatter the seeds. The seeds are very large, usually weighting between 3.5 and 6.0 g, ovoid in shape with the ventral surface slightly flattened. The seed coat or testa is hard and shiny, brown or gray-brown with numerous darker mottles or streaks on the dorsal surface, but few or none on the ventral side (Webster and Paardekooper, 1989; Lemmens *et al.*, 1995).

2. Silvicultural aspects

The development of *H. brasiliensis* foliage follows a specific pattern. The emerging flush has six to ten leaves. The development of the leaves in the flush is followed by a dormant period when there is no shoot expansion or formation of a new flush. *H. brasiliensis* growth varies with clonal stock, stand density, drought, irrigation, soil temperature, rootstock, interstock and the tapping system. High yield, high growth and disease tolerance clones should be selected for each area. The recommended varieties for commercial plantation are categorized into three groups. Group 1, the high latex yield group (e.g. RRIT 251, RRIT 226, BPM 24 and RRIM 600), group 2, the high latex yield and high wood volume group (e.g. PB25, PB 255, PB 260 and RRIC 110) and group 3, the high wood volume group (e.g. Chacheongsao 50, AVROA 2037 and BPM 1) (RRIT, 2003).

H. brasiliensis planting areas should be less than 600 m above the sea level, less than 35° of slope, on fertile and well drained soil. It needs a tropical lowland climate, with an annual rainfall should be more than 1,250 mm/year (DOA, 2003).

The propagation of *H. brasiliensis* is either through seeds or vegetative by bud grafting. Unselected seeds and seeds from monocrop gardens are discouraged. When seeds are to be used, only polyclonal seeds (clonal seeds collected from polyclonal areas) are recommended. However, the most preferred method of propagation is through bud grafting. Seeds start geminating 6 to 8 days after sowing. The mode of germination is hypogeal. *H. brasiliensis* seeds are viable only for a very short period and therefore, should be sown as early as possible after collection (Sethuraj and Raghavendra, 1987).

3. Latex production and wood utilization

The latex from the tree is obtained by cutting the latex vessels situated in the phloem region on the bark by a process known as tapping. The most common method of tapping is to make a half spiral cut in the bark, sloping from left to right. The first cut is made at height of 125-150 cm when the girth of their stem reaches a stipulated minimum 50 cm. The trees below this level are considered immature. It is therefore desirable to promote early growth of young trees so as to reduce the immaturity period (Sethuraj and Raghavendra, 1987).

There appears to be a relationship between latex yield and time of days. The diurnal variation in yield is inversely related to the variation in the saturation deficit of the air. The decrease in yield during the course of the day is the result of a lowering of the turgor pressure of the laticiferous system caused by increased transpirational loss of water. Additionally, there are several factors that affect latex yield, i.e. latex yield increased with lengthening of the tapping cut, but not proportionately. In other words, the yield per unit length of tapping cut decreased with increasing length of the cut.

The *H. brasiliensis* wood is used for sawmilling and wood-based panel manufacturing with the main use for furniture and joinery products. In Thailand, one million cubic meters of *H. brasiliensis* wood were reportedly used annually by the furniture industry, mainly for exports (Soontonbura, 2000).

4. Species diversity in *Hevea brasiliensis* monocultural plantation

The latex price may fluctuate annually and seasonally because of an over-supply of latex production on the market. The integration of agricultural crops or trees into the *H. brasiliensis* plantation can add to the income of the farmers. Many species may be intercropped in *H. brasiliensis* plantations such as pineapple, *Salacca* spp., *Amomum* spp. and *A. crassna*.

Mixed plantations of *H. brasiliensis* and *A. crassna* were mostly planted in the Trat Province, the eastern part of Thailand. The study of Osuguchi (2002) reported that the intercropping of *A. crassna* in *H. brasiliensis* plantations had no negative effect on the latex production and the growth of *H. brasiliensis* and concluded that the humidity microenvironment in the mixed stands enhanced the latex production. However, the effect of *A. crassna* in the understory will not be discussed here. Research in the effect of intercropped *A. crassna* and *H. brasiliensis* in plantations should be conducted to determine growth and production of this regime to promote the benefits of a higher production from the plantation.

5. Intercropping of *Hevea brasiliensis* with *Aquilaria crassna* in Trat Province

A. crassna has been widely planted in Trat Province by the farmers and landowners who were interested in the value of its production. Osoguchi (2002) estimated that there were 308.19 ha planted with *A. crassna*. Intercropping of *A. crassna* in *H. brasiliensis* plantation occupied the most area in Trat Province (Figure 2). Its estimated area of intercropped *A. crassna* with *H. brasiliensis* plantations was 196.3 hectares. Additionally, the others planting pattern of *A. crassna* were scattered planting in the fruit plantation, fallow land, *Acacia mangium* plantation, boundary of pineapple and boundary along the road and water resources.

Figure 2 Intercropping of *H. brasiliensis* with *A. crassna* at Trat Province, Eastern Thailand.

Pruning

The lower parts of tree crowns become shaded when neighboring trees meet closure. The reduction of light reduces the carbon assimilation of the shaded leaves. When a leaf is unable to intercept enough light to maintain a positive carbon balance, the leaf and ultimately the branch dies. The level of light at which this occurs varies between tree species. The density of the trees and the growth rate are the major factors that determine the crown closure. To promote diameter increment and shorten the time to grow the trees to the minimum merchantable size, the farmers must use an artificial practice by reducing the stand density (Montagu *et al*., 2003).

Pruning is one of several silvicultural practices to improve the growth form and quality of timber. The main reasons for pruning are the removal of dead, diseased or injured branches; to improve the form, shape or size; to rejuvenate older plants and for safety and convenience. When trees should be pruned and how to prune are considered. Generally, the best time to prune woody plants is in the early spring while they are still dormant. Trees should be pruned at an early age to ensure and enhance their safety, vitality, appearance and controlled growth. The minimum height for pruning varies with the management objectives, but must extend up the trunk at least to the top of one merchantable log.

Pruning is undertaken to increase diameter growth, clear bole wood produced by a tree. Cutting off living branches will not affect radial increment unless more than 50% of the crown is being removed. In fact, removing the lower inefficient living branches while still maintaining a 50% live crown-ratio on longleaf pine in Louisiana increased the radial increment by 14% over a 15-year period (Ralph, 1996). Pruning can be a powerful management tool to control the water balance of the agroforestry system. Removing substantial amounts of the tree canopy (before the understory crop was planted) reduced the water demand of the tree component recharged the crop rooting zone to a similar degree as when the trees were younger (Jackson *et al*., 2000).

All woody plants shed branches in response to shading and competition. Branches that do not produce enough carbohydrates from photosynthesis to sustain themselves die and are eventually shed; and the resulting wounds are sealed by wound wood (callus). Branches that are poorly attached may be broken off by wind and accumulation of snow and ice. Branches removed by such natural forces often result in large, ragged wounds that rarely seal. Pruning as a cultural practice can be used to supplement or replace these natural processes and increase the strength and longevity of plants (Bedker *et al*., 2005).

Growth

The growth of woody plants is controlled by their heredity and environment, operating through by their physiological processes. Growth is the biological phenomenon of increasing size with time. Growth involves the formation, differentiation and expansion of new cells, tissues or organs. Growth causes trees to change in weight, volume or size and form or shape. It is determined by measurements of mass, length or height (Gardner *et al.*, 1985).

The growth of woody plants is influenced by a wide variety of abiotic and biotic environmental stresses. The major abiotic stresses include drought, flooding, low soil fertility, poor soil structure, temperature extremes, pollution, fire and wind. Important biotic stresses include plant competition, insect attacks, plant diseases, activities of humans and occasional feeding by animals. Although all trees exhibit some common growth characteristics, they also show considerable variability in growth because of heredity differences. Genetic variation in size, crown form, straightness of stems, wood density, leaf retention and longevity are particularly well known (Kozlowski *et al*., 1990).

1. Growth Measurement

Tree growth can be measured by various methods, depending on the objectives of the investigator. Most important to foresters is measurement of the annual increment of wood produced by a stand of trees. This is calculated by measurements of bole diameter and height and modified by the amount of bole taper. It is usually expressed as volume per unit of land area, but for some purposes the annual wood increment is better expressed as weight per unit of land area.

The analysis of factors that influence yield and plant development such as net photosynthesis accumulation is naturally integrated over time has come to be known as growth analysis. Investigators have been concerned about methods of comparing growth of plants of different sizes.

Two approaches to analysis of growth have emerged. The earlier approach, classical growth analysis, involves collecting primary data on leaf surface area and component dry weight from periodic harvests of sample plants. Classical growth analysis has remained popular in research on woody plants because of its suitability to annual growth cycles of perennials, computational simplicity and ease of interpretation. The second approach is the functional growth analysis which has some operational and theoretical advantages. However, it is computationally complex and depends greatly on success in fitting data with empirical functions (Kozlowski and Pallardy, 1997). There are many parameters to determine the plant growth (absolute growth rate (AGR), relative growth rate (RGR), leaf are index (LAI) and net assimilation rate (NAR), etc.).

The absolute growth rate (AGR) can be defined as the net gain in plant weight (dw) through a time interval (dt). The equation for calculating absolute growth rate is

$$AGR = \frac{dw}{dt}$$

It was established long ago that plant growth follows the compound interest law, in which the amount of growth made in a unit of time depends on the amount of material or size of the plant at the beginning of the period. Thus seedlings developing from large seeds are likely to increase in size more rapidly than those of the same species developing from small seeds and large seedlings would be expected to grow faster than small ones. This fact led to development of the concept of relative growth rated (RGR) or measurement of increase in dry weight per unit of time per unit of growing material, often in grams per gram dry weight per week. This permits comparison of the effects of various factors in the environment on rate of growth independently of the size of the plants being compared (Kozlowski *et al*., 1990). The equation for calculating mean relative growth rate is

$$RGR = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

Where W_1 and W_2 are the dry weight at the t_1 and t_2 respectively and ln is the natural logarithm of the numbers.

2. Term of increment measurement

The increase in a tree dimension should be qualified by the period of time during which the increment occurred. The period may be a day, a month, a year, a decade, and so on. When the period is a year, the increase, termed current annual increment (CAI), is the difference between the dimensions measured at the beginning and at the end of the year's growth. Since it is difficult to measure some characteristics, such as volume, for a single year, the average annual growth for a period of years, termed periodic annual increment (PAI), is often used in place of CAI. This is found by obtaining the difference between the dimensions measured at the beginning and at the end of the period, say 5 or 10 years, and dividing by the number of years in the period. It the difference is not divided by the number of years, it is termed periodic increment. The average annual increase to any age, termed mean annual increment (MAI), is found by dividing the cumulative size by the age.

These measured increment are applicable to individual trees (or stands) for any measurable growth characteristic. However, they have been most commonly applied to the volume growth of stands (Husch *et. al*., 2003)

Yield

Yield refers to the amount of a selected stand condition or outcome attribute that is present on a unit area at a given point in time. Yield has been used traditionally in forestry to describe the amount of commercial timber that could be harvested. Hence, yield is the volume produced by a stand of a given composition at a given age or over a definite period of time under given site conditions and treatment. The total volume of a stand at any given time is the yield of that stand for its entire period of growth to the given age, provide no part of the stand was removed earlier in thinning. The primary purpose of studying yield in existing stands is to enable the prediction of future yields in young stands now growing and even in stands yet to be established. For example, assume the prescription called for harvesting at age 60, and the example stand was today 60 years old with a total inventory of 7000 metric feet. The forester would also say the stand would yield 7000 metric feet per acre when harvested. According to Davis *et al*. (2001) mentioned that growth is a biological production rate concept, and yield is a harvest or utilization concept measured as either a rate of an amount at a specified time. In general, the maximum that a forest can yield at any time is the growth that has accumulated up to that time. The maximum yield that can be removed perpetually from a stand or forest per period equals the growth per period.

Growth and yield of outcomes and conditions can be measured in physical units such as volume, basal area, height, density and weight. Also, they can be measured in value, which is the measurement of economic and social interest.

Canopy structure and light interception in forest canopies

1. Canopy structure

Canopy structure refers to the amount and organization of above-ground plant material, including the size, shape and orientation of plant organs such as leaves, stems, flowers and fruits (Nobel *et al*., 1993). Canopy structure affects other environmental factors such as air temperature, leaf temperature, atmospheric moisture, soil evaporation below the canopy, soil heat storage and soil temperature, precipitation interception, leaf wetness duration and other. However, these effects may be subtle and may require complex models to quantify. Canopy structure, through its impact on canopy environment, affects not only plant, but also other organisms that may live within or below the canopy.

The measurement for obtaining canopy structure information is by direct and indirect methods. The direct method, involves measuring plant organs that include areas, shapes, angles or even position. This measurement usually requires substantial labor in the field and very simple data reduction. In contrast, indirect methods usually involve the measurement of radiation from within or above the canopy and usually require simple and rapid field measurements but complex algorithms for the reduction of data (Norman and Campell, 1989). The quantity measurement canopy structure are obtained by direct methods, such as leaf area index, leaf inclination and leaf orientation. The indirect methods are inclined point quadrates and gap fraction analysis (Nobel *et al*., 1993).

2. Light interception in forest canopies

As an energy source, light is captured by plant and converted to chemical energy through photosynthesis by which nearly all energy enters our biosphere. When passing through the earth’s atmosphere, sun light is modified by the reflection, absorption and scattering of its various components in the atmosphere. Light incident on a leaf will be absorbed, transmitted, or reflected, and the modification changes the quantity, quality and direction of light. The variation of light environment is influenced by many factors, such as solar elevation, sky and wind conditions and canopy structure, including leaf area and the spatial arrangement of canopy foliage, branches and stems (Tang, 1997).

Light environment within a plant canopy varies considerably both in time and in space. Light incident at the top of plant canopies can be distinguished into two parts that are direct light, the radiation comes directly from the sun, and diffuse light, the radiation was scatted or reflected by the atmosphere, clouds and particles. In plant communities, light interception by the canopy largely determines the productivity, but the efficiency of conversion of solar radiation energy to biomass may vary with species and environmental factors.

The light that penetrates a forest canopy is a combination of direct sunlight that has passed through canopy gaps and are called sunflecks, and have been attenuated by passage through the canopy. Sunflecks play a very important role in leaf photosynthesis and the growth of forest understory plants. Field measurement showed that sunflecks compose a large proportion of total daily photon flux density (PFD) and contribute greatly to the heterogeneity of the spatial and temporal variation of light environments in plant canopies.

The radiant energy available for photosynthesis is visible light which includes wave-lengths between 400 and 700 nm, and is referred to as photosynthetically active radiation (PAR). Rates of photosynthesis vary greatly because of difference in exposure of leaves to light intensity and can be expressed as the radiation incident at a given angle on the plane of the leaf, and is expressed in terms of photon flux density (PFD) (Jones, 1993). The total daily integrated photon flux varies greatly among habitats as well as within the canopy of a given plant stand (Björkman and Adams, 1995).

Leaf area index

Forest canopy structure constitutes the complex spatial arrangement of foliage, branches and the stem of trees. Leaf area index is one of the methods to measure canopy structure. Light is limited by canopy structure. So, the determination of light under the canopy is important as it affects the micro-environment and the survival, pattern and diversity of understory plants and trees.

Leaf area index (LAI) expresses the ratio of leaf surface (one side only) to the ground area occupied by the crop. Factors affecting LAI are leaf shape, thickness (affecting light transmission), inclination and vertical distribution. In natural forests LAI also varies widely with species, stand density and environment, with values for temperate deciduous forest ranging from 3 to 9. However, lower LAI (1.5 - 1.9) have been reported for more arid eucalyptus forests in southeastern Australia. In temperate coniferous forest LAI values may reach 11 to 12 (Kozlowski *et al*., 1990). The equation is

$$\text{LAI} = \frac{L_A}{P}$$

Where P is represented the land area and L_A to represent total leaf area above the land area P.

Photosynthesis

Plant growth and ecosystem primary productivity are ultimately dependent on photosynthesis. Photosynthesis is the process of capturing light energy converting it to chemical energy and storing it by manufacturing sugar. The photosynthetic process occurs only in the chloroplasts, tiny sub - cellular structures contained in the cells of leaves and green stems. In photosynthesis, the sun's energy combines hydrogen from water (H_2O) with carbon dioxide (CO_2) turning them into carbohydrates. The efficiency of photosynthesis depends on the different plants, but the final productivity is increasing of biomass.

Many environmental factors influence photosynthesis including light, temperature, CO_2 concentration of the air, water supply, air humidity, soil fertility, salinity, pollutants, applied chemicals, insects, diseases and various interactions among these. Photosynthesis also is responsive to cultural practices such as thinning of stands, pruning, fertilization and irrigation which alter the environmental regimes of plants (Kozlowski and Pallardy, 1997).

Photosynthetic responses to light are important to growers because the light microclimate can be modified by thinning of stands, as well as pruning, and by spreading of branches. To produce the maximum amount of high quality fruit it generally is desirable to expose as great a proportion of the tree crown as possible to light during the entire season (Kozlowski and Pallardy, 1997).

Photosynthetic rate measurement

The devices used to measure photosynthesis are usually referred to as gas-exchange systems or simply as systems. The concept that photosynthesis is measured with a system is important for two reasons. First, the system concept emphasizes the fact that we have nothing like a discrete photosynthesis sensor. Photosynthesis is always a calculated parameter, determined from measurements of CO_2 concentration, gas flows and sometimes other parameters depending on the measurement philosophy. Second, the system concept reminds us that gas-exchange system typically measure more than just photosynthesis, for the reason that photosynthesis data are greatly enhanced by the simultaneous acquisition of other kinds of information (Field *et al*., 1989).

STUDY AREA

1. Location

The present study was established at Trat Agroforestry Research Station under Kasetsart University Research and Development Institute. The area was situated in Takum sub-district, Muang district of Trat Province, Eastern Thailand. Trat Agroforestry Research Station is located in Takum-Huairang forest reserve. The total area was 613 km^2, mainly secondary forest which was restored by the logging company according to the logging concession regulation (Figure 3).

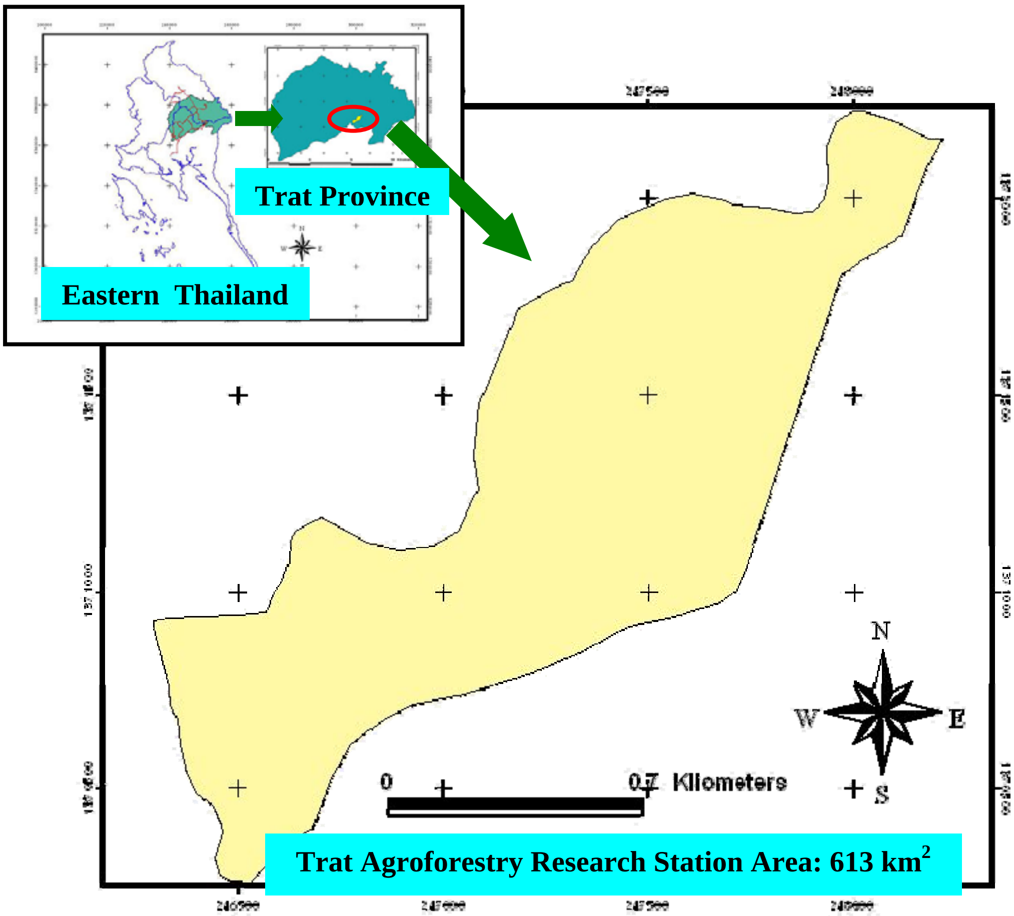


Figure 3 Mapping of study area at Trat Agroforestry Research Station in Trat Province, Eastern Thailand.

2. Climate

The meteorology of Trat Province is classified as lowland tropical climate. Meteorological data were collected from a meteorological station at Trat Agroforestry Research Station. Meteorological data since1999 to 2005 showed a mean annual average temperature of 28.01 °C. The mean annual average relative humidity was 87.31%, and average monthly rainfall was 277.08 mm. The average annual rainfall was 3,325 mm with 201 rainy days. Season in Trat Province can be divided into the wet season in March to October, while November to February is a rather dry period (Figure 4).

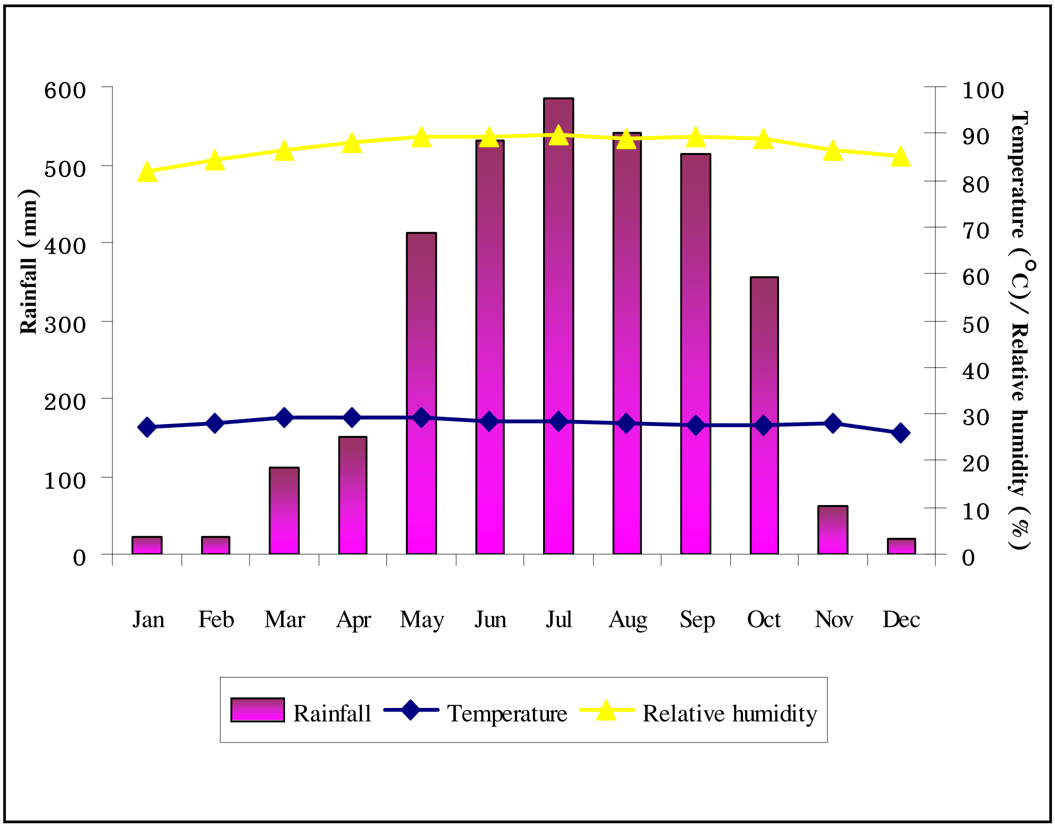


Figure 4 Average monthly rainfall (mm), temperature (°C) and relative humidity (%) at Trat Agroforestry Research Station in 1999 to 2005.

3. Meteorological parameters at the period of the study

As we known, the growth of plants is regulated by their heredity and environment operating through their physiological process. In other words, woody plants shows much genetic variation in characteristics such as size, crown and stem form and the environmental factors can affect plant growth by changing internal processes and conditions. Throughout plant life are subjected to multiple abiotic and biotic stresses of varying intensity and duration. Therefore, some important abiotic factors influencing on growth of the tree including climatic data and light interception were determined in this study.

Meteorological data of the research site during the period of the study (March 2005 to March 2006) based on temperature, rainfall and relative humidity were collected from the meteorological station at Trat agroforestry research station. The climatic data are shown in Appendix Table 1 and illustrated as Figure 5.

The total annual rainfall received in the period of the study was 2561.34 mm with 159 rainy days. This demonstrated that it was drier than the past years in which its meteorological data during 1999 to 2004 showed that the average annual rainfall was about 3,453 mm with 201 rainy days. Based on climatic data from the study year, the pluviothermic graph in Figure 5 demonstrated that the rainy season occurred between early April and the middle of November as indicated by the intersection of the rainfall line and temperature line. The heavy rainfall presented in June to September varied from about 406 to 556 mm, with slight rainfall in April (20.97 mm) and May (204.46 mm) as the early rainy season and the late rainy season in October (225.37 mm) and November (118.58 mm). The daily rainfall is unevenly distributed through the year, but it concentrated between May and November (Figure 5). The rainy day was frequently presented in June to September varied from 21- 27 days. The dry season was in December to the end of March.

Mean annual temperature was 28.33°C with average minimum temperature of 24.65 °C and average maximum temperature of 31.91 °C. In February to the early April was cool and dry period with mean temperature varied from 29.27 to 29.70 °C. The hottest month is in February hitting an average of 34.57 °C. However, temperature variation over the year in Trat Province is not so distinct. Mean relative humidity was 89.81%. Almost of the year, monthly relative humidity was about 90%.

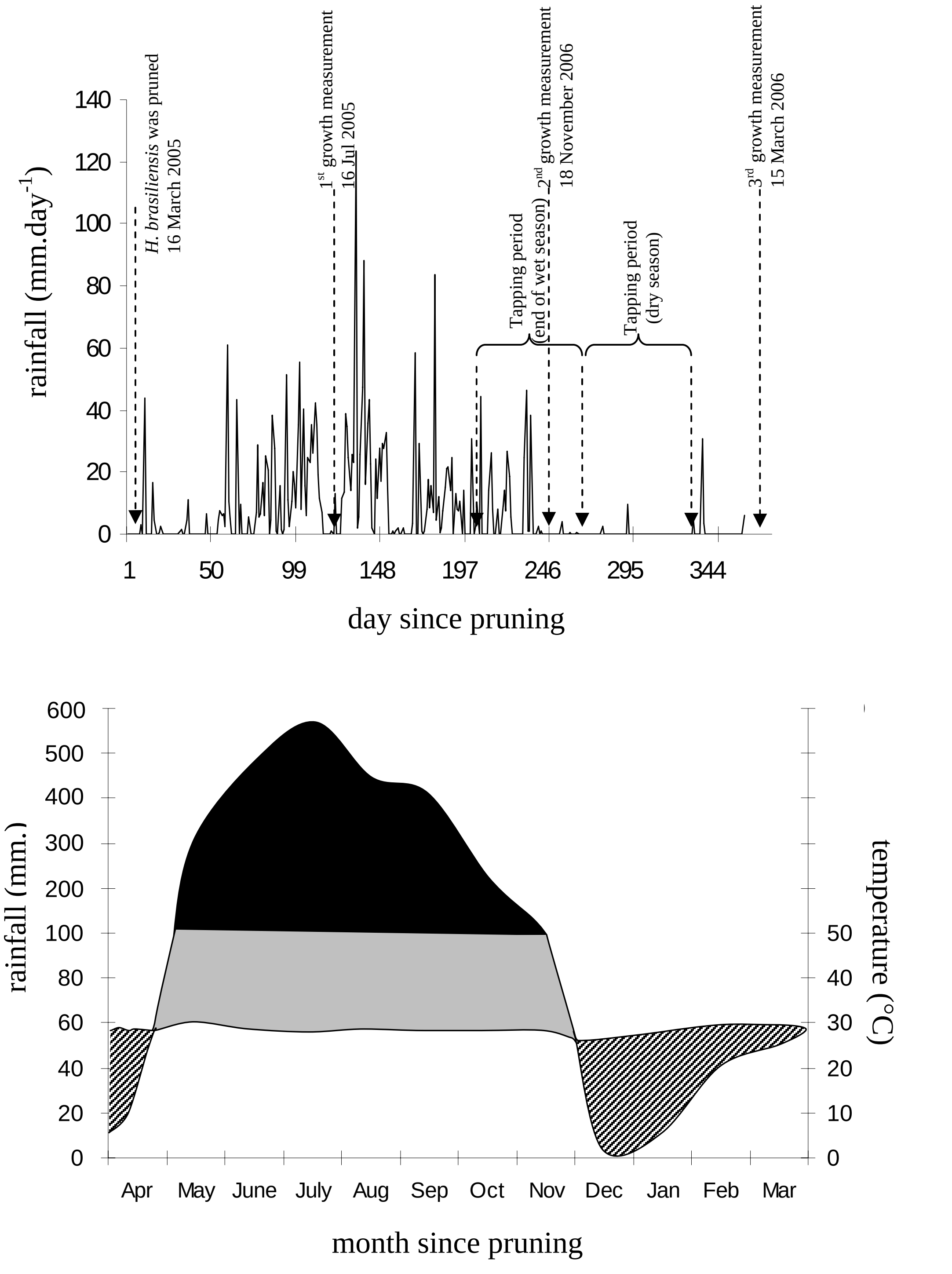


Figure 5 Climatic condition of the study area during the study period in March 2005 to March 2006. The upper graph is the distribution of daily rainfall and the lower is the pluviothermic graph demonstrated dry season and rainy season indicating by intersection of rainfall and temperature graph.

MATERIALS AND METHODS

Materials

1. Pruning equipments

   - Ladder
   - Bow saw

2. Tree measurements

   - Diameter tape
   - Caliper
   - Self-made dendrometer

3. Latex production

   - Balance

4. Hemispherical photography

   - Camera
   - Fish-eye len
   - Tripod
   - Computer software

5. Photosynthetic rate measurement

   - LCA-4 photosynthesis system

Methods

1. Experimental design

The research was conducted in a mixed stand of *H. brasiliensis* and *A. crassna*, planted with the spacing of 3 m × 6 m, at Trat Agroforestry Research Station. *H. brasiliensis* was planted in 1997, and *A. crassna* was planted between rows of *H. brasiliensis* in 2001. Therefore, when the experiment started in March 2005, *H. brasiliensis* trees were 8-year-old and *A. crassna* trees were 4-year-old. Three pruning intensity treatments were applied to *H. brasiliensis* in March 2005, including no pruning (P0), pruning to 1/2 of the total height above ground level (P1) and pruning to 2/3 of the total height above ground level (P2). The experiment was designed by using Completely Randomized Design (CRD), with three treatments and three replications. Each plot consisted of 9 *H. brasiliensis* trees and 6 *A. crassna* trees which were selected representatively for this study (Figure 6).

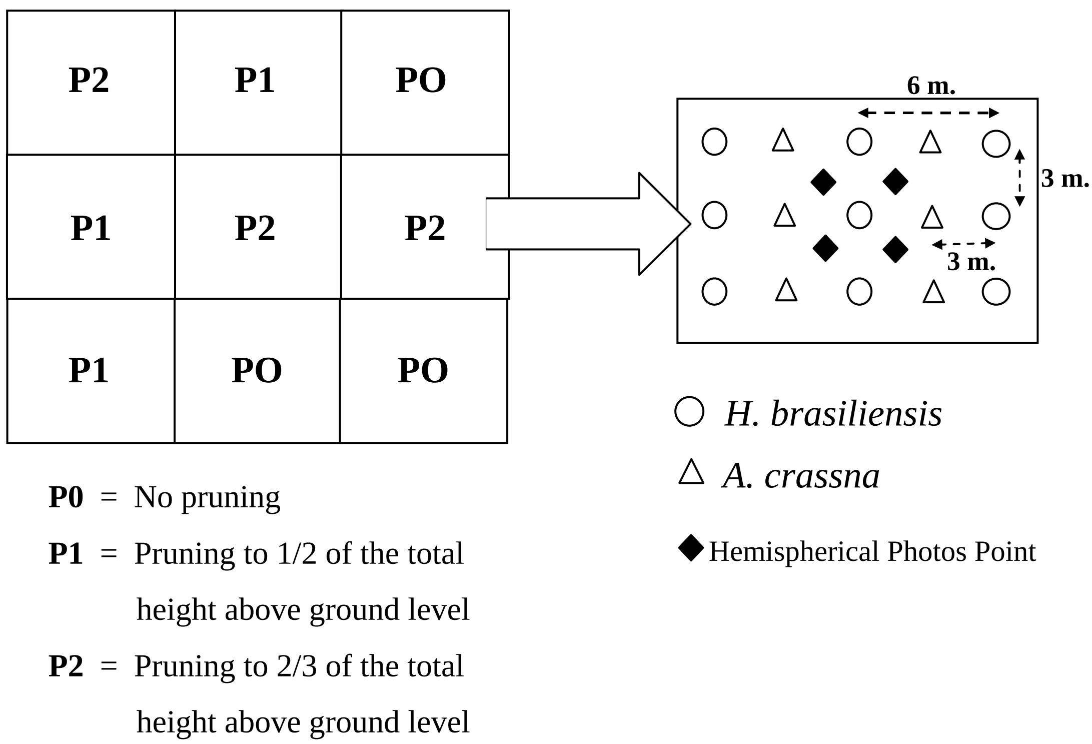


Figure 6 Plot layout in completely randomized design in the present study.

2. Pruning of *Hevea brasiliensis* branches

H. brasiliensis branches were removed from the base of the crown upwards in accordance with common practice for production of knot-free timber. Pruning was done using bow saw, with branches removed flush with the stem but avoiding damage to the branch collar. Immediately after pruning, the wounding by pruning was closed by fungicide liquid. The diagram showing pruning levels of *H. brasiliensis* in this study was presented in Figure 7.

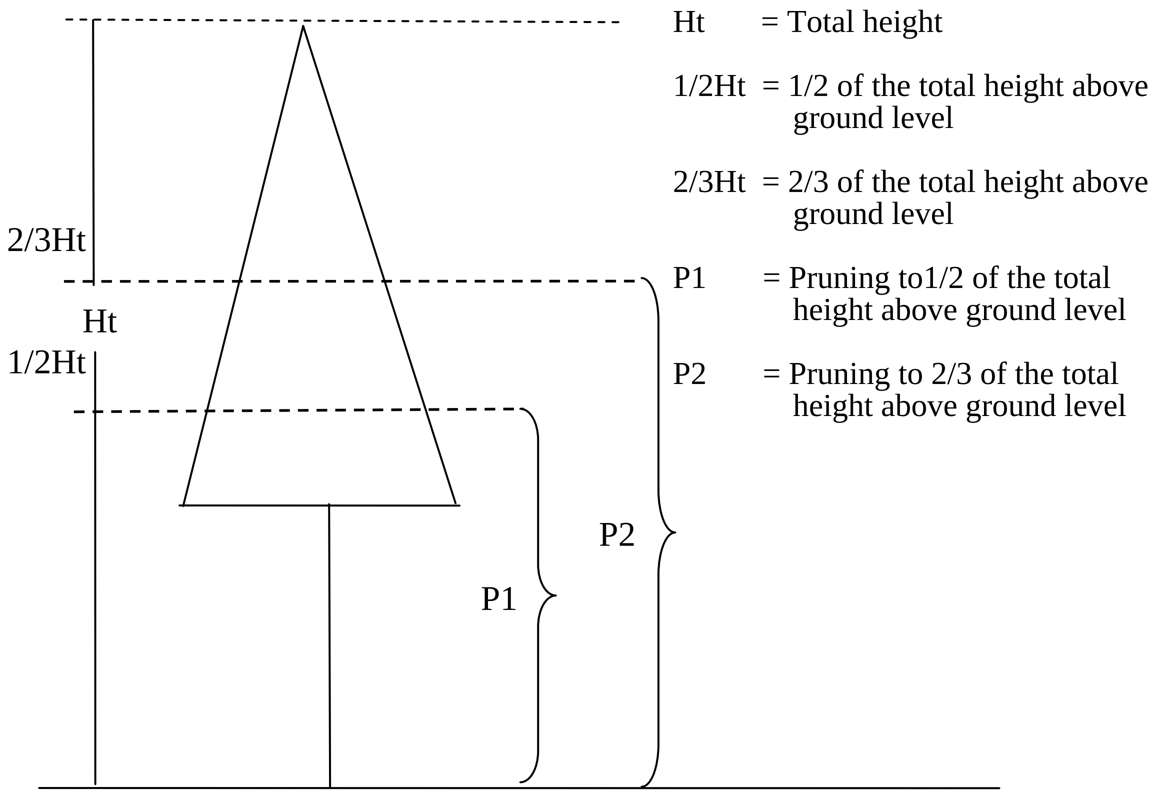


Figure 7 Illustrated pruning levels of *H. brasiliensis* branches in this study.

3. <u>Data collection and analysis</u>

3.1 Meteorological measurement

The meteorological data, including rainfall, minimum and maximum temperature and relative humidity for the study periods (March 2005-March 2006) were collected from the observatory station in Trat Agroforestry Research Station. The meteorology with relating to growth and yield of the *H. brasiliensis* and growth of the intercropped *A. crassna* after *H. brasiliensis* was pruned was discussed.

3.2 Measurement of leaf area index (LAI) and relative light intensity (RLI)

Four points were selected systematically in rectangular corners in the middle of each plot (Figure 6). The hemispherical photos were taken approximately 1.50 m above ground level under *H. brasiliensis* canopies using digital camera with fish- eye len. The camera was mounted on a tripod, leveled horizontally using a bubble level, and oriented such that north corresponded to the top of the photograph. The photographs were taken under overcast conditions to ensure a homogeneous illumination of the overstory canopy and a correct contrast between the canopy and the sky. The hemispherical photographs were taken before pruning *H. brasiliensis* (March 2005) and every 4 months after pruning *H. brasiliensis* until March 2006 (Figure 8).

The LAI and RLI of the *H. brasiliensis* were estimated from the hemispherical photographs. All hemispherical photographs were analyzed using image-processing computer program (Hemiview 2.1). The differences of LAI and RLI among treatments were analyzed by ANOVA.

Figure 8 Measurement of leaf area index and relative light intensity of the *H. brasiliensis* and *A. crassna* mixed plantation by using the hemispherical photographs.

3.3 Growth of *Hevea brasiliensis* and *Aquilaria crassna*

The diameters at 30 cm (D30) and 200 cm (D200) above ground level of *H. brasiliensis* were measured by self-made dendrometer. The diameter at breast height (DBH) was not measured due to the tapping wound at that height (Figure 9). The total height at above ground level (Ht) and diameter at ground level (D0) and diameter at breast height (DBH) of *A. crassna* were measured by using measuring pole and caliper, respectively. The data were recorded every 4 months after *H. brasiliensis* was pruned in March, 2005 until March, 2006 (1 year).

Absolute growth rate (AGR) and relative growth rate (RGR) of *H. brasiliensis* and *A. crassna* were determined by using the following equations.

$$\text{AGR} = \frac{D_2 - D_1}{t_2 - t_1}$$

$$\text{RGR} = \frac{\ln D_2 - \ln D_1}{t_2 - t_1}$$

Where D_1 is the D30 and D200 of *H. brasiliensis* and Ht, D0 and DBH of *A. crassna* at t_1 (first measurement) and D_2 is the D30 and D200 of *H. brasiliensis* and Ht, D0 and DBH of *A. crassna* at the t_2 (second measurement) and ln is the natural logarithm of the numbers. Differences in growth among treatments were analyzed by using ANOVA.

Current annual increment (CAI) that was the different growth rates between the beginning (March 2005) and the end of the study period (March 2006) of D30 and D200 of *H. brasiliensis* and D0, DBH and Ht of *A. crassna* was also studied.

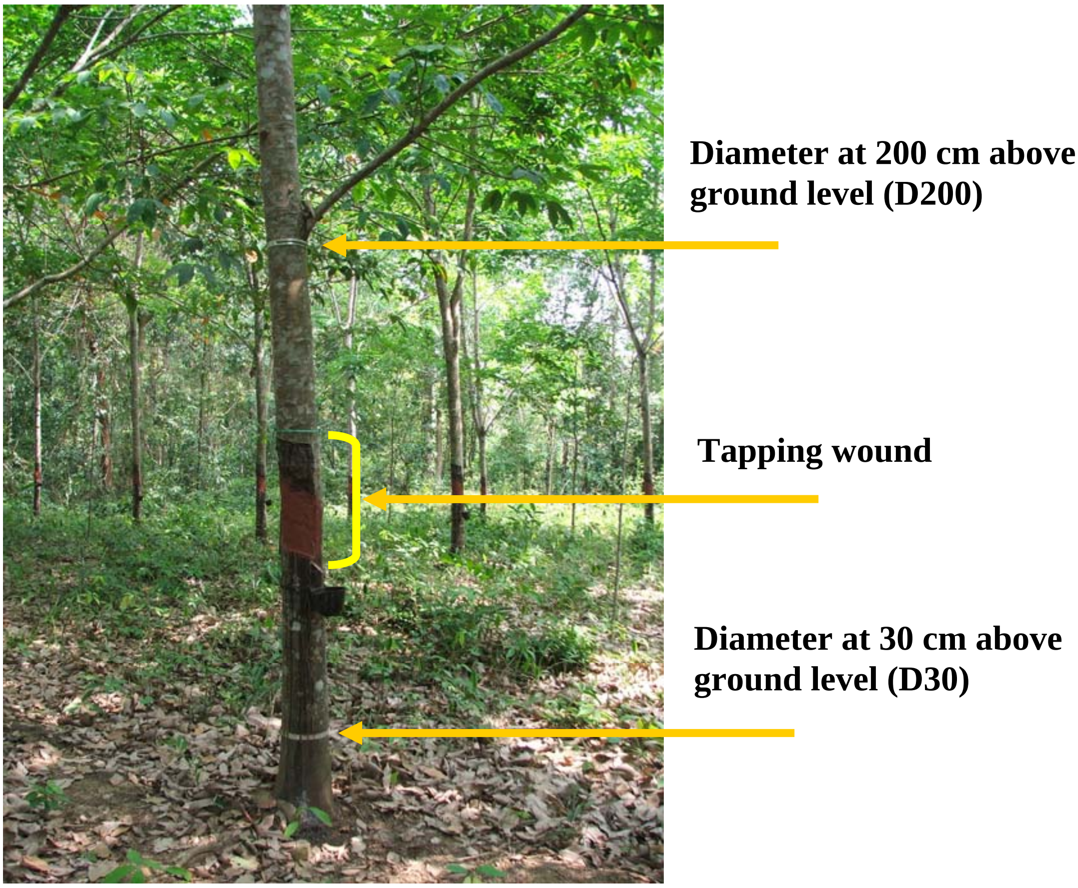


Figure 9 Diagram showing diameter growth parameters of *H. brasiliensis* in the present study.

3.4 Latex production of *Hevea brasiliensis*

The *H. brasiliensis* trees were tapped by using the conventional method by which the tapping is made to a half spiral cut in the bark and sloping from left to right. Latex production was determined as dry rubber by weight per tapping day (Figure 10). The production of latex collected from October to November was considered as the end of wet season production, while the latex collected from December to January was considered as the early dry season production.

Latex production was collected by weighing per tapping day and the difference was analyzed by ANOVA. The total latex production among treatments was analyzed by ANOVA.

3.5 Measurement of the photosynthetic rate of *Aquilaria crassna*

The net photosynthetic rate of *A. crassna* was measured under field condition using LCA-4 photosynthesis system. In each plot three fully expanded leaves in one *A. crassna* tree were sampled randomly for the measurement of photosynthesis. The photosynthetic rate measurement was undertaken in November, representatively. The measurements were taken every hour from 6.00 to 18.00 hrs (Figure 11).

Maximum net photosynthetic rate of the intercropped *A. crassna* grown under the *H. brasiliensis* having the different levels of pruning in each treatment was compared by using ANOVA.

(a)

(b)

<u>Figure 10</u> Latex production of the *H. brasiliensis* as dry rubber measurement per tapping day in the present study.

(a) dry rubber

(b) measuring latex production per tapping day

(a)

(b)

Figure 11 Photosynthetic measurement of the intercropped *A. crassna* in the mixed plantation by pruning *H. brasiliensis* at different levels.

(a) LCA-4 photosynthesis system

(b) Measuring photosynthetic rate in *A. crassna*

RESULTS AND DISCUSSION

As mentioned before, the study emphasized on the effect of the *H. brasiliensis* branch pruning on growth and yield of the mixed stands of 8-year-old *H. brasiliensis* and 4-year-old *A. crassna*. Pruning was conducted in March 2005 to *H. brasiliensis* with different levels, including no pruning (P0), pruning to 1/2 of the total height above ground level (P1) and pruning to 2/3 of the total height above ground level (P2). Then, the measurement was carried out in three aspects: 1) growth and latex yield of the pruned *H. brasiliensis* 2) growth of the intercropped *A. crassna* and 3) the hemispherical photography of the stand canopy. The results of the study are discussed as follows.

1. Effect of pruning on growth of *Hevea brasiliensis*

Growth of the *H. brasiliensis* based on diameter increment was measured in three periods, namely 15 March to 15 July 2005 as early wet season, 16 July to 15 November 2005 as late wet season and 16 November 2005 to 15 March 2006 as dry season (1 year). Monthly rainfall distribution and seasonal period are shown in the Appendix Figure 1.

Growth parameters of the pruned *H. brasiliensis* were measured in term of stem diameters at two levels which were diameter growth at 30 cm above ground level (D30) and at 200 cm above ground level (D200). The growth of D30 and D200 was used to analyze the effect of tapping wound on the growth of the *H. brasiliensis*. In the general concept, relative growth rate of D200 should be greater than those of D30 since photosynthate from the tree canopy was expected to be tapped at cutting wound on stem below the level of 200 cm. The following shows the analysis of D30 and D200 growth.

1.1 Growth of *Hevea brasiliensis* at D30

Growth of the *H. brasiliensis* at D30 was analyzed in terms of absolute growth rate (AGR), relative growth rate (RGR) and current annual increment (CAI) and shown in Table 1 and Figure 12.

From Table 1, it can be seen that the effect of pruning on the different growth parameters which were AGR, RGR and CAI of the *H. brasiliensis* D30 with different pruning levels performed in the same manner. Namely, higher growth was found in the stand of the *H. brasiliensis* without pruning (P0), and the growth was decreased as the degree of pruning increased from P1 to P2.

Current annual increment of the D30 was significantly highest in P0 followed by P1 and P2 which were 2.88, 1.34 and 0.47 $cm.year^{-1}$, respectively.

Pruning effect on AGR and RGR at different growing seasons was also found in the same trend, namely it showed different effects in rainy period (from March-November), but no different effect in dry period. This result emphasized that amount of leaves which appeared in the rainy season was a significant factor affecting growth of the *H. brasiliensis*.

In Figure 12, it was clear that RGR in the period of rainy season (March to July – July to November) were almost the same which were 0.32 – 0.31, 0.12 - 0.16 and 0.02 – 0.07 $month^{-1}$ for P0, P1 and P2, respectively. RGR in dry season (November – March) was the same in every level of pruning with 0.02 $month^{-1}$.

From the above results, it can be concluded that pruning had a negative effect on growth of the *H. brasiliensis* D30.

Table 1 Absolute growth rate (AGR), relative growth rate (RGR) and current annual increment (CAI) of the *H. brasiliensis* D30 at the different levels of pruning

Pruning level	**AGR (cm.month^{-1})**			**RGR (month^{-1})**			**CAI (cm.year^{-1})**
	Mar-Jul	**Jul-Nov**	**Nov-Mar**	**Mar-Jul**	**Jul-Nov**	**Nov-Mar**	
P0	0.47^{c}	0.46^{c}	0.03	0.32^{c}	0.31^{c}	0.02	2.88^{c}
P1	0.18^{b}	0.23^{b}	0.03	0.12^{b}	0.16^{b}	0.02	1.34^{b}
P2	0.03^{a}	0.11^{a}	0.02	0.02^{a}	0.07^{a}	0.02	0.47^{a}
F-test	44.41**	90.89**	2.30^{ns}	44.41**	90.89**	1.20^{ns}	65.55**

Note: ns = Non significant different
** = Highly significant different
a, b, c = Comparison by column with significantly different at 0.05% using the Duncan's New Multiple Range Test

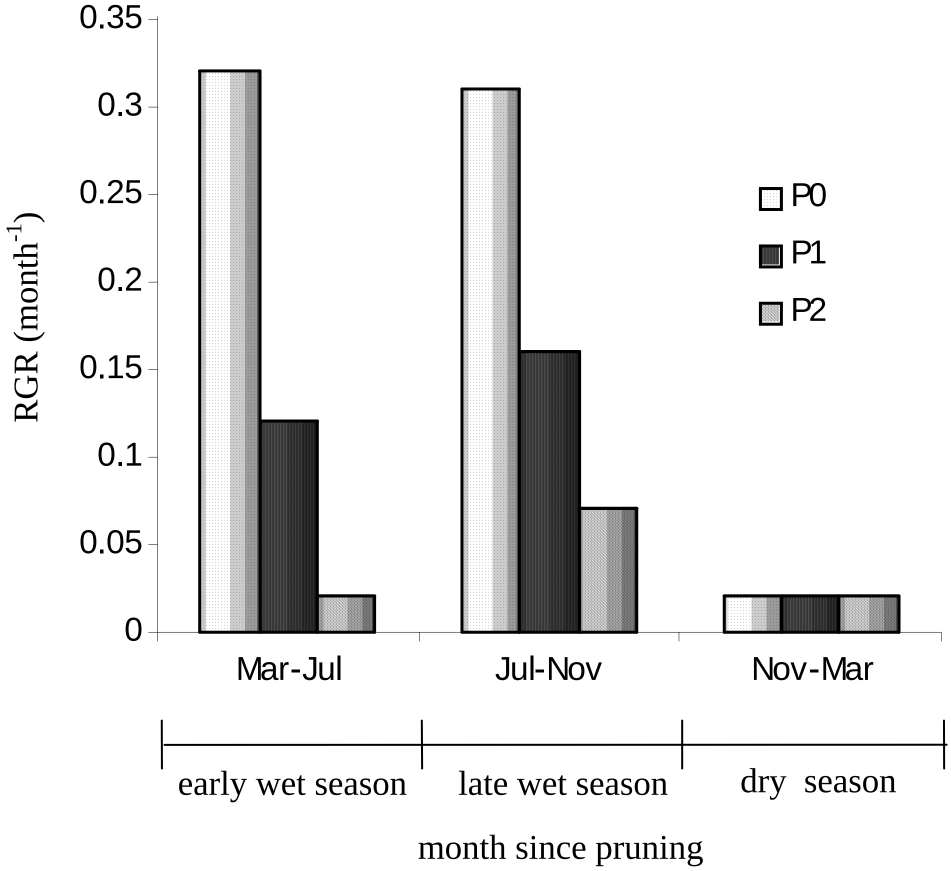


Figure 12 Comparison on relative growth rate (RGR) of the *H. brasiliensis* D30 at different seasons and the levels of pruning (P0 = No pruning, P1 = Pruning to 1/2 of the total height above ground level and P2 = Pruning to 2/3 of the total height above ground level).

1.2 Growth of *Hevea brasiliensis* at D200

Growth of *H. brasiliensis* at D200 was studied the same as what was done with *H. brasiliensis* at D30. The AGR, RGR and CAI of the *H. brasiliensis* D200 are shown in Table 2 and Figure 13. Each of them presented a similar growth pattern to D30.

In Table 2, the effect of pruning at different levels on growth of the *H. brasiliensis* D200 decreased as pruning intensity increased. Overall, the highest growth rate was shown in P0, while it was the lowest in P2. In March to July, RGR in P0 was greater than P1 and P2 with 0.29, 0.12 and 0.02 month^{-1}, respectively. Likewise, growth rate in July to November of P0 was reached to 0.32 month^{-1}, while in P1 and P2 were 0.14 and 0.06 month^{-1}, respectively. In November to March, the maximum D200 showed in P1 with 0.03 and in P0 and P2 with 0.02 and 0.01 month^{-1}, respectively.

CAI of the *H. brasiliensis* at D200 in P0, P1 and P2 was 2.79, 1.22 and 0.40 cm.year^{-1}, respectively. The differences among treatments were highly significant.

In Figure 13, The RGR of the *H. brasiliensis* D200 in P1 and P2 since March sharply increased until November, while trees without pruning (P0) still had steadily growth increment. The RGR of *H. brasiliensis* D200 in July to November showed increasing more than in March to July, which was the same as in D30. As a result, it demonstrated that diameter growth in July to November was the peak growth period of the *H. brasiliensis*. In each treatment, RGR was not significant differences in November to March due to the dormant growing season in dry period. This phenomenon was the same as what was found in D30.

As the above results, it was obvious that in March until November 2005 (8 months) was the growing period of the *H. brasiliensis* planted in Trat Province where the rainy season is presented in March to November. This result is mainly factor contributing longer growing period in *H. brasiliensis* which is planted at Trat Province where the wet season is longer period. This remarkable result is similar to the report in the traditional *H. brasiliensis* growing zone of India. The climate of this zone is tropical humid type with a dry period of about four months from December to March, and good pre-monsoon shows during March or April with the total annual rainfall receives in the study location range from 3,400 – 4,000 mm. The result shows that the peak growth period of *Hevea* trees is about two months from July to August and the active growth period is about seven months from May to November (Chandrashekar *et al*. 2002).

It was clear that pruning of the *H. brasiliensis* to 1/2 of the total height above ground level (P1) and 2/3 of the total height above ground level (P2) had negative effect on its diameter growth, including D30 and D200. From the study, this practice related that when live lower branches were over removed resulted in the decreasing of leaf area can had serious impacts on growth by way of reducing the capacity of the tree to assimilate the carbon, and reduced growth rate in the *H. brasiliensis*. Consequently, the loss of leaf by pruning at P1 and P2 in this study had contributed to decrease the stem growth of the *H. brasiliensis*. The reduction of stem growth in this study occupied by the removal of the live-branches in which still have the photosynthetic function.

The stem growth response on tree pruning has long been reported. Those results demonstrated that the inappropriate pruning level reduced both diameter and height increment. According to Pinkard and Beadle (1997) revealed that removal 70% of live crown length of *Eucalyptus niten*s resulted in significant decreased in both height and diameter increment. However, Nyland (1996) mentioned that the minimum height for pruning varied with the management objectives. Although the pruning applied to *H. brasiliensis* decreased its growth increment, but the major objectives of this study provided the light penetrating to the intercropped *A. crassna* that it was the potential trees which can be produced the valuable resinous wood and has been widely planted in Trat Province.

However, that was the short period to conclude that pruning intensities in this study would not suitable for *H. brasiliensis*. It is not always a long-term response. The effect was only observed for a year or two year following pruning (Sutton and Crowe, 1975; Lückhoff, 1976). Therefore, the prolong data should be collected more than one year before conclusion. Nevertheless, the appropriate pruning can be stimulated growth and taper of the tree pruning. Likewise, Wachrinrat *et al*. (2004) recommended that pruning to 1/2 of the total height above ground level was appropriated to increase growth rate higher than no pruning in 6-year-old *Xylia xylocarpa*.

Montagu *et al*. (2003) recommended that the amount of leaf that can be removed without reducing growth should be determined by: (1) species, (2) the amount of leaf prior to pruning, (3) the capacity of the remaining leaf to respond following pruning and (4) the timing of pruning without impact to growth period. From the study, it was emphasized that the suitable time for pruning was in dry season because the trees were still dormant which caused less effect on tree growth and less susceptible to diseases. Therefore, the best time for pruning of *H. brasiliensis* in Trat Province should be done in November to March with less effect on tree growth.

Table 2 Absolute growth rate (AGR), relative growth rate (RGR) and current annual increment (CAI) of the *H. brasiliensis* D200 at the different levels of pruning

Pruning level	**AGR ($cm.month^{-1}$)**			**RGR ($month^{-1}$)**			**CAI**
	Mar-Jul	**Jul-Nov**	**Nov-Mar**	**Mar-Jul**	**Jul-Nov**	**Nov-Mar**	**($cm.year^{-1}$)**
P0	0.43^{c}	0.48^{c}	0.02^{ab}	0.29^{c}	0.32^{c}	0.02^{ab}	2.79^{c}
P1	0.17^{b}	0.20^{b}	0.03^{b}	0.12^{b}	0.14^{b}	0.03^{b}	1.22^{b}
P2	0.03^{a}	0.08^{a}	0.01^{a}	0.02^{a}	0.06^{a}	0.01^{a}	0.40^{a}
F-test	83.37**	120.06**	2.72^{ns}	83.37**	120.06**	2.62^{ns}	105.02**

Note: ns = Non significant different
** = Highly significant different
a, b, c = Comparison by column with significantly different at 0.05% using the Duncan's New Multiple Range Test

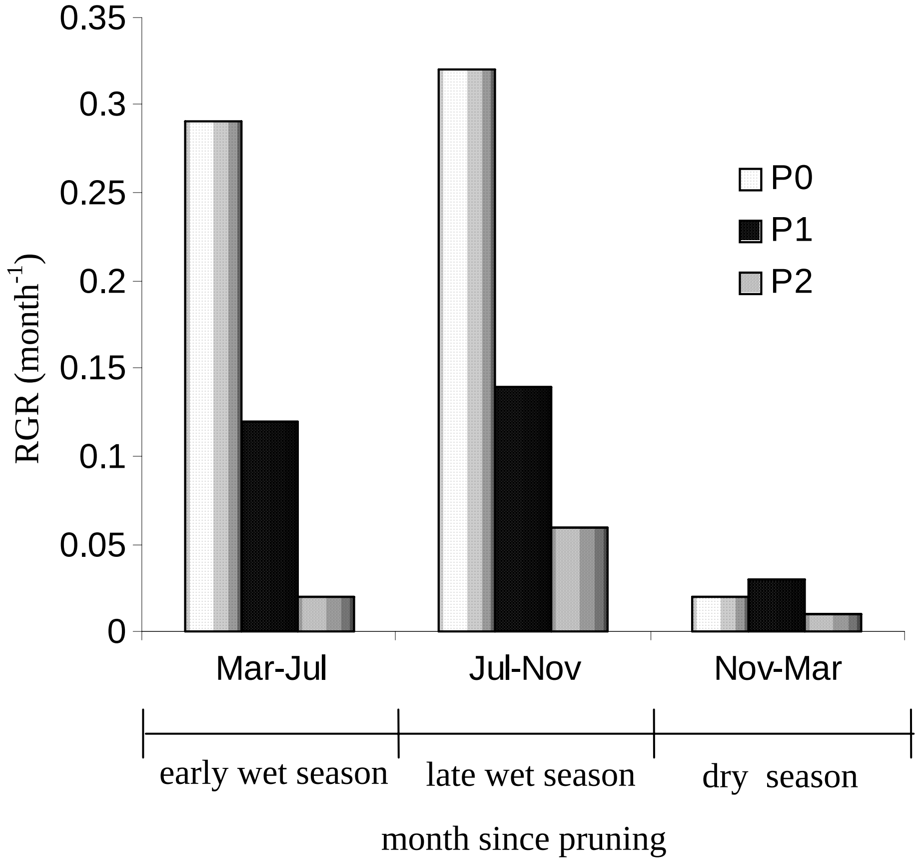


Figure 13 Comparison on relative growth rate (RGR) of the *H. brasiliensis* D200 at different seasons and the levels of pruning (P0 = No pruning, P1 = Pruning to 1/2 of the total height above ground level and P2 = Pruning to 2/3 of the total height above ground level).

1.3 Comparative growth rate between D30 and D200 of *Hevea brasiliensis*

In this study, RGR was used to compare growth rate of stem diameter at different heights which were D30 and D200. The result found that the growth rate of D30 and D200 was coincided in each treatment. The statistical different growth rates between D30 and D200 of *H. brasiliensis* since pruning in March 2005 is shown in Appendix Table 2. However, the growth of D30 was a little higher than those of D200 in all different pruning levels. This will be lead to higher taper of the *H. brasilensis* stem.

Figure 14 compares RGR of D30 and D200 at different levels of pruning. It can be seen that the RGRs were highest in the P0 stand followed by those in P1 and P2 stand. This confirms that the higher degree of branch pruning, the lower growth of stem diameter obtained, especially in the case of the *H. brasiliensis* stand.

It was demonstrated that pruning of 8-year-old *H. brasiliensis* had no effect on different diameter growth rates between D30 and D200. It was considered that even so the removal live-branches decreased the stem growth of *H. brasiliensis* but the stem growth in lower part of tapping wound (D30) was not different decreasing growth rates compared to the higher part of tapping wound stem growth (D200). Even though P0, that was no pruning applying to *H. brasiliensis*, but the growth rate of D30 and D200 was not different in all times of record.

It was implied that even the pruning of *H. brasiliensis* had the effect on its growth by substantial decreasing growth rate of D30 and D200 in P1 and P2, but these pruning practices had not influenced to the growth difference between D30 and D200. It showed that removal of live-branches of *H. brasiliensis* in P1 and P2 did not interrupt the flowing of photoassimilate from upward to downward of the tree. It can be presumed that the stem side without tapping wound might have contributed to translocate the assimilate carbon into the downward of the tree without differing growth increment compare to the upper part of tapping wound.

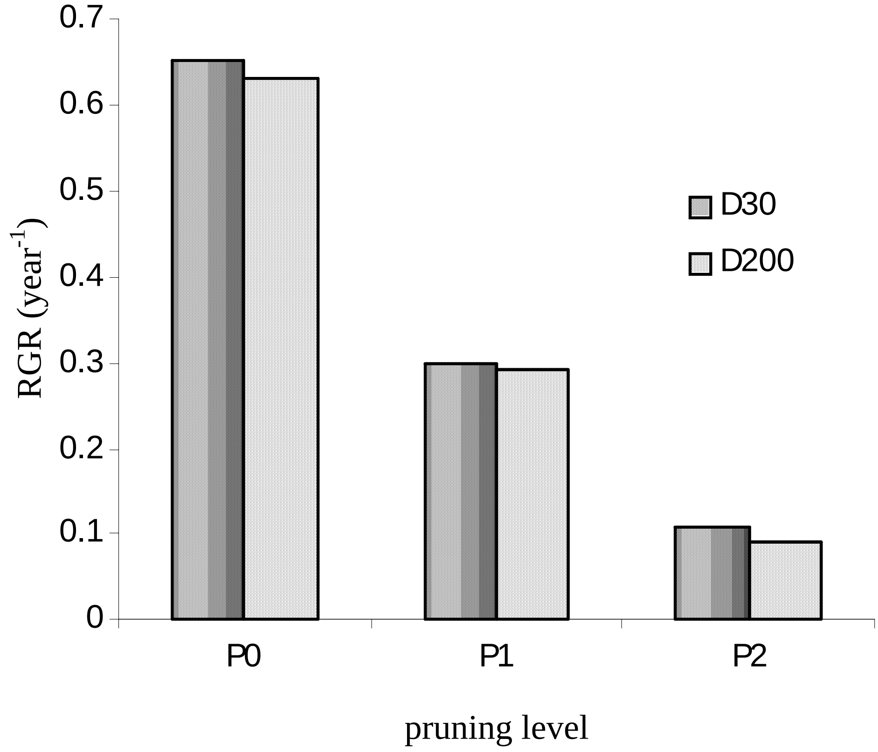


Figure 14 Comparison of relative growth rate (RGR) between D30 and D200 of the *H. brasiliensis* at different degree of pruning (P0 = No pruning, P1 = Pruning to 1/2 of the total height above ground level and P2 = Pruning to 2/3 of the total height above ground level).

2. Effect of pruning on latex production of *Hevea brasiliensis*

The effect of growth on latex yield in *H. brasiliensis* was distinctly reviewed (Sethuraj and Raghavendra 1987; Rao *et al*. 1998; Alam *et al*. 2003). From the above study, branch pruning had negatively effects on diameter growth of the pruned *H. brasiliensis*. Therefore, in this study, latex production of the pruned trees is mainly focused. Table 3 shows latex production of the *H. brasiliensis* in the period of the study, from the end of rainy season, in October toward dry season in January.

It can be seen that high degree of pruning in *H. brasiliensis* such P2 had negative effect on total average production of latex, namely decreasing from 0.104 $kg.tree^{-1}.day^{-1}$ in P0 to 0.081 $kg.tree^{-1}.day^{-1}$. in P2. However, there was no significant different between P0 and P1. This means that a little pruning has no effect on latex yield although it may cause decreasing diameter growth of the pruned stand.

The pruning of *H. brasiliensis* in P1 and P2 had decreased the latex yield per tree in each month. However, the latex yield in October of P0 and P1 was coincided with 0.115 and 0.112 kg. $tree^{-1}.day^{-1}$, respectively and it was nearly in P2 with 0.102 kg. $tree^{-1}.day^{-1}$. The difference of latex yield seem gradual larger in subsequent month. Especially in January, it obtained latex yield in P0, P1 and P2 equally 0.082, 0.062 and 0.055 kg. $tree^{-1}.day^{-1}$, respectively. The different latex yield among treatments showed not statistically significant in October, while it was statistically significant among treatments in November and highly statistically significant in December and January.

In this study, it was clear that removal lower live branches of *H. brasiliensis* to 1/2 of the total height and 2/3 of the total height above ground level in this study were decreasing both of diameter growth and average latex yield per tapping day. Form the result, the decreasing stem growth of the *H. brasiliensis* had directly high relationship on decreasing of latex yield. In other words, the lower growth rate was the lower latex yield. Due to the loss of green parts, this was the major influence by reduce the photosynthetic rate of the *H. brasiliensis* tree. Additionally, the pruning wounds were healed by the physiological mechanism in the *H. brasiliensis* tree that caused to influence the latex reduction.

Table 3 Effect of branch pruning levels on latex production of the *H. brasiliensis* in the period of the study

Pruning level	**Latex production ($kg. tree^{-1}. day^{-1}$)**				**Total Average ($kg. tree^{-1}. day^{-1}$)**
	Oct-05	**Nov-05**	**Dec-05**	**Jan-06**	
P0	0.115	0.124^{b}	0.096^{c}	0.082^{b}	0.104^{b}
P1	0.112	0.107^{ab}	0.081^{b}	0.062^{b}	0.090^{ab}
P2	0.102	0.101^{a}	0.067^{a}	0.055^{a}	0.081^{a}
F-test	2.87^{ns}	5.66*	22.31**	19.51**	3.63*
Tapping $day.month^{-1}$	14	10	13	17	-

Note: ns = Non significant different
* = Significantly different
** = Highly significant different
a, b and c = Comparison by column with significantly different at 0.05% using the Duncan's New Multiple Range Test

In Figure 15, the latex yield in each treatment trended to decrease in December to January as dry season in Trat Province. Hence, the seasonal changes in *H. brasiliensis* yield are associated with the weather and climatic conditions experienced by the plantation. As above, lower yields are associated with the moisture stress conditions and wintering of the tree. During drought period, there was 61% lower latex yield than average yield (Rao, 1998). Alam *et al*. (2003) found that the pre-winter season was the peak yielding season compare to the other seasons. He also concluded that the low temperature induced yield depression. Also this study, the lower minimum temperature existed in December and January about 22 °C. However, different amount of latex yield in *H. brasiliensis* are also depended on many factors, especially the clonal variation and environmental conditions as well as the tapping practices.

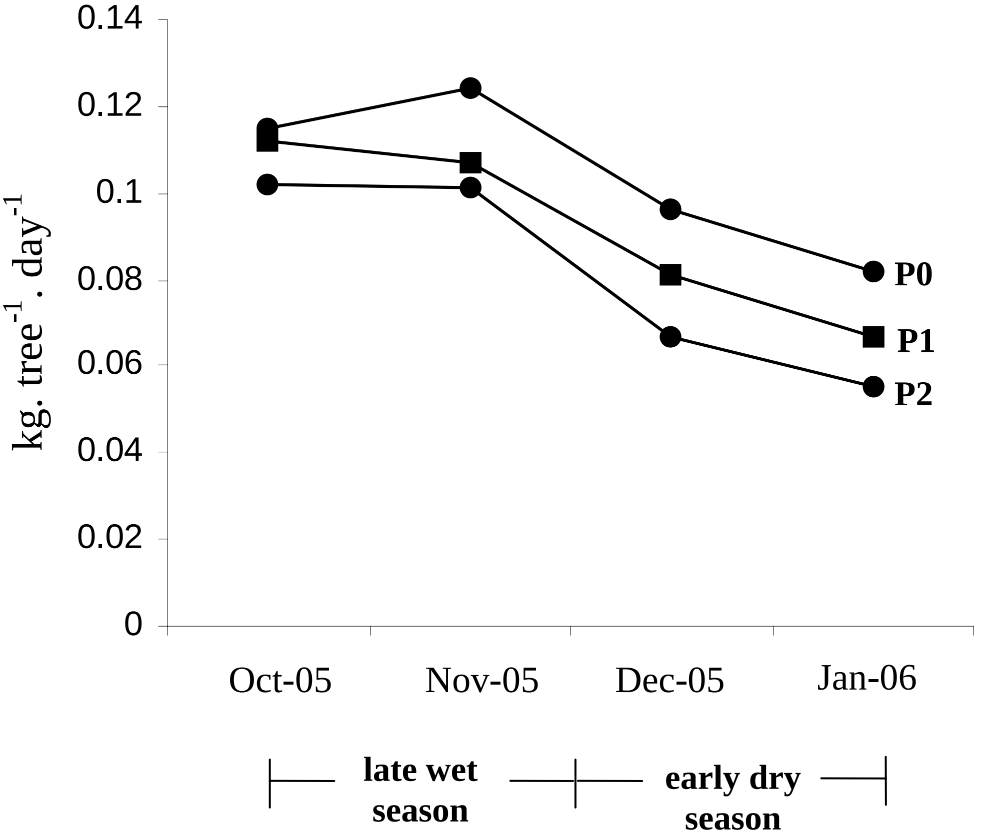


Figure 15 Variation of monthly latex production per tapping day in the *H. brasiliensis* at different levels of pruning (P0 = No pruning, P1 = Pruning to 1/2 of the total height above ground level and P2 = Pruning to 2/3 of the total height above ground level).

3. Effect of pruning on light intensity in the study plot

Light is an important subject on growth of the tree. The variation of light environment within tree canopy is influenced by many factors such as altitude, sky and wind condition and canopy structure, including leaf area and spatial arrangement of canopy foliage, branches and stem. Pruning is the silvicultural management that directly changes the structure of tree canopy by removing the branches and leaves (Kozlowski *et al*., 1990). In this section, effect of pruning on light intensity in the stand is analyzed by using hemispherical photography technique to determine leaf area index and relative light intensity of the stand.

3.1 Leaf area index (LAI) of *Hevea brasiliensis*

Data on leaf area index (LAI) of the *H. brasiliensis* stands which subjected to branch pruning at different levels are shown in Table 4. It can be seen that LAI of the stands decreased as the degree of pruning increased. Namely, pruning to 1/2 of the the stand height (P1) reduced amount of leaf area in the plot to 64 percent, which pruning to 2/3 of the stand height (P2) reduced to 29 percent at the start of measurement in March, 2005. The leaf area of stands had slightly increased from March to July for P0 and P1, while those of P2 had remarkably increased (see Figure 17). This may be due to higher ability of leaf browsing in P2 at the start of rainy season. However, from July, 2005 to March, 2006, the leaf area of all stands had slightly increased.

As discussed before, the growth rate of the stand in P2 was the highest, followed by those in P1 and P. This can be attributed to the decreasing of leaf area in those stands accordingly.

However, when considering growth rate in Table 1 and 2, RGRs of P0 and P1 from March - July to July - November were slightly increased, while those of P2 were increased remarkably about 3 times of growth just before pruning. This can be assumed that the higher increasing growth rate in P2 was due to increasing of new leaves which had more efficiency in photosynthesis.

The decrease of leaf area index of the pruned stand affected the amount of light intensity under the canopy is discussed in the next section.

Table 4 Leaf area index (LAI) of the *H. brasiliensis* stand at different levels of pruning

Pruning level	LAI			
	Mar-05	**Jul-05**	**Nov-05**	**Mar-06**
P0	1.60^{c} (100%)	1.67^{c} (100%)	1.70^{c} (100%)	1.77^{c} (100%)
P1	1.03^{b} (64%)	1.26^{b} (75%)	1.30^{b} (76%)	1.37^{b} (77%)
P2	0.47^{a} (29%)	0.90^{a} (54%)	0.91^{a} (54%)	0.93^{a} (53%)
F-test	192.46**	75.23**	100.30**	128.02**

Note: Figures in parenthesis = Percentage of control (P0)
** = Highly significant different
a, b and c = Comparison by column with significantly different at 0.05% using the Duncan's New Multiple Range Test

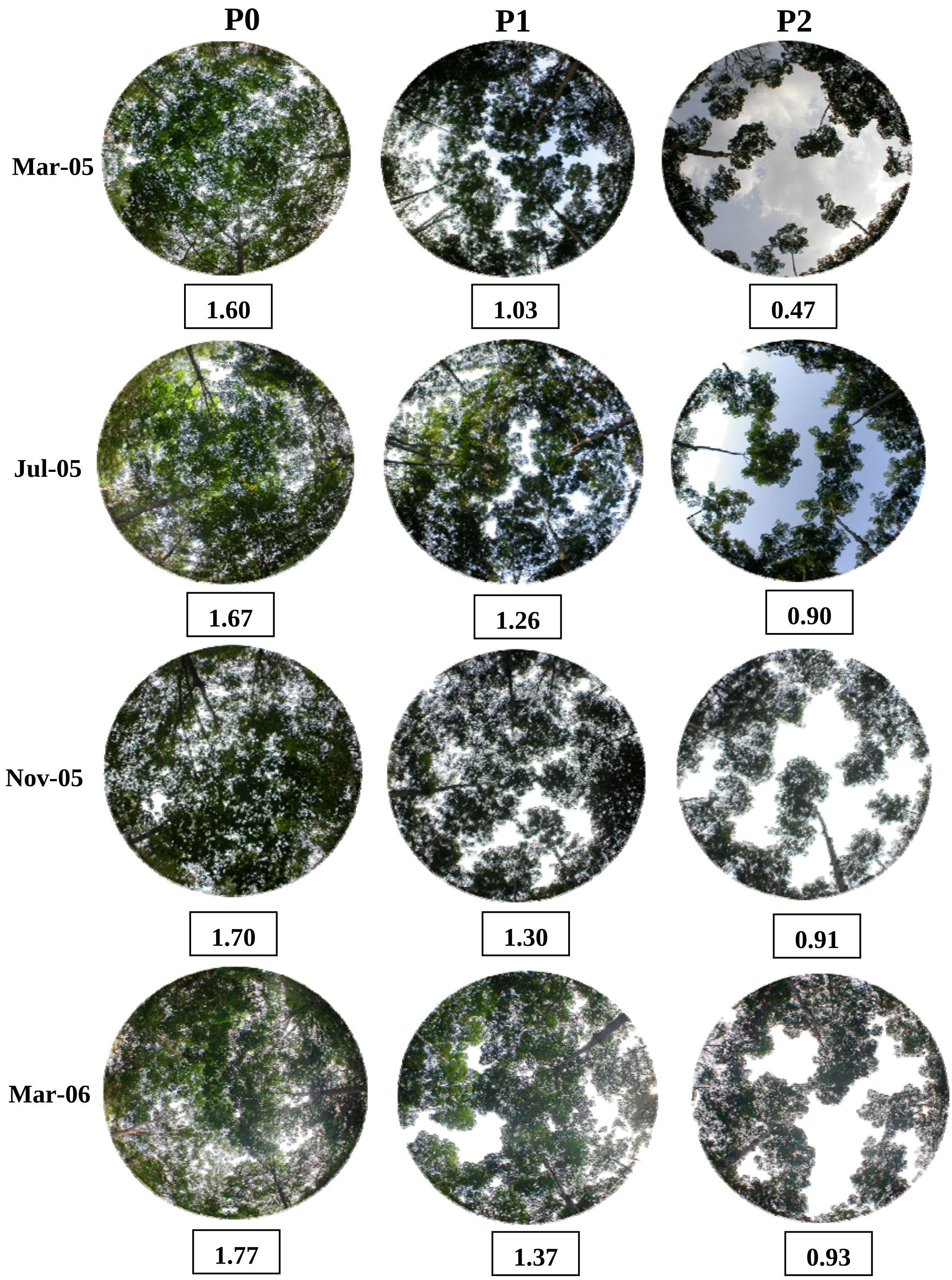


Figure 16 Hemispherical photographs of 8-year-old *H. brasiliensis* canopy showing the change of LAI in different stands after pruning (P0 = No pruning, P1 = Pruning to 1/2 of the total height above ground level and P2 = Pruning to 2/3 of the total height above ground level).

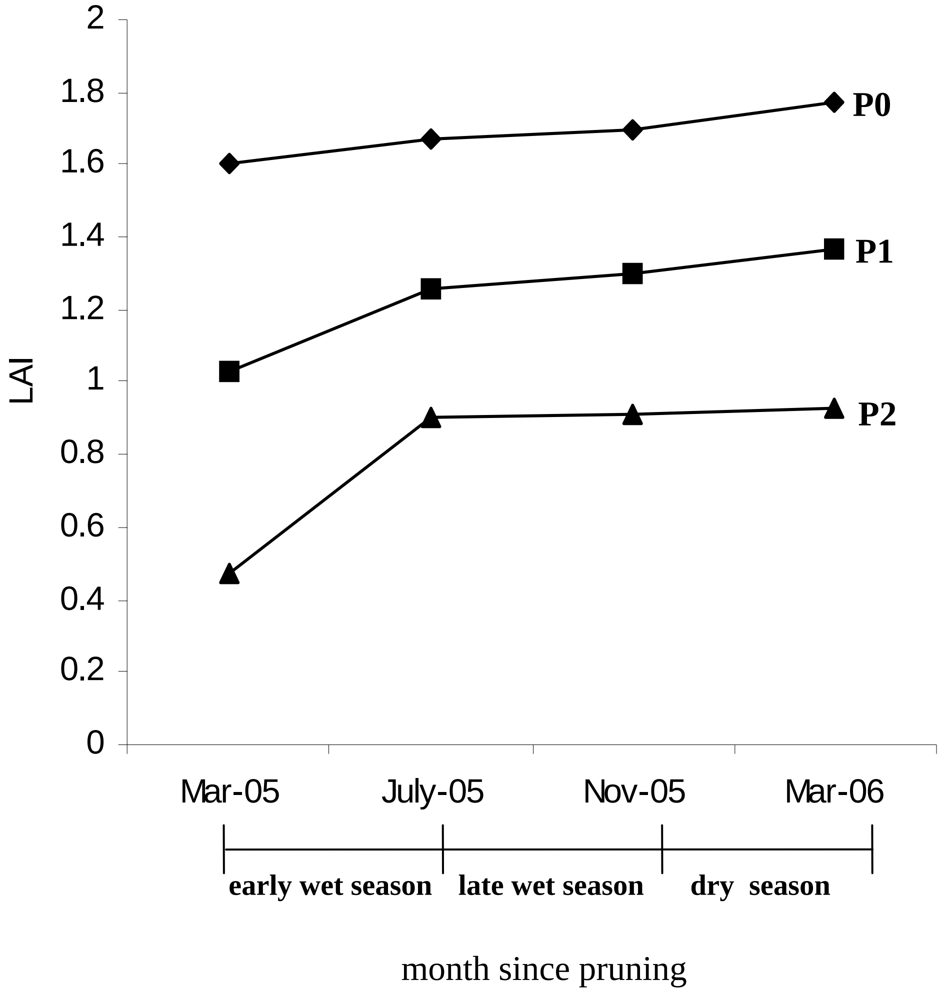


Figure 17 Increasing of leaf area index (LAI) of the *H. brasiliensis* stand having different levels of pruning (P0 = No pruning, P1 = Pruning to 1/2 of the total height above ground level and P2 = Pruning to 2/3 of the total height above ground level).

3.2 Effect of *Hevea brasiliensis* pruning on the changes of relative light intensity (RLI) under the canopy

In intercropping system, light is considerable factor that attributes the success of the understorey. The change of light intensity is determined by the result of pruning of *H. brasiliensis* with regard to the growth of the intercropped *A. crassna*. The measurement of light intensity was studied in term of the relative light intensity (RLI). RLI was the total radiation below the canopy divide by the total radiation above the canopy of the *H. brasiliensis* stand obtained from the hemispherical photograph by using the computer software calculation. Relative light intensity (RLI) in different stand canopies of the *H. brasiliensis* was determined at four months by taking the hemispherical photograph (see figure 16) in which the data are shown in Table 5.

It can be seen that the relative light intensity was related to the degree of pruning. Namely, the higher degree of branch pruning resulted in the higher relative light intensity. In table 5, relative light intensity percent of P0 was increased from 18.77 to 41.77 percent and 73.57 percent of P1 and P2, respectively.

The relative light intensity was highly correlated the amount of leaf area as compared the data in Table 4 and Table 5. This high correlation was absolutely obtained from the same measurement of the hemispherical photography.

Rodrigo *et al*. (2001) showed that the fractional interception of radiation of a two-and-half year-old sole *H. brasiliensis* plantation was only about 30%. According to Ibrahim (1991) reported that only about 20% of incoming solar radiation was available under a 4 to 5-year-old *H. brasiliensis* canopy. Also, the 8-year-old *H. brasiliensis* canopy by no pruning (P0) had RLI less than 20% in this study. This characteristic was explained that canopy seems to create more when the tree grew up. Consequently, intercropping practices in *H. brasiliensis* have been limited to the immature phase when *H. brasiliensis* plants are not large enough to capture the light radiation.

Therefore, higher of RLI in the P2 and P1 was expected to provide favourable environment to the growth of the intercropped *A. crassna* which is discussed in the next section.

Table 5 Relative light intensity (RLI) in the *H. brasiliensis* stand having different levels of pruning

Pruning level	**RLI (%)**			
	Mar-05	**Jul-05**	**Nov-05**	**Mar-06**
P0	18.77[a]	17.08[a]	16.50[a]	14.60[a]
P1	41.77[b]	32.10[b]	30.38[b]	27.39[b]
P2	73.57[c]	47.14[c]	47.13[c]	47.01[c]
F-test	214.50**	88.87**	102.27**	96.44**

Note: ** = Highly significant different
a, b and c = Comparison by column with significantly different at 0.05% by using the Duncan's New Multiple Range Test

The decreasing of RLI is described as Figure 18. Normally, each treatment showed as the same trend. RLI in P0 was the lowest and ranged from 18.77% to 14.6% at the period of the study. After pruning the tree in P1 and P2 were substantial increased RLI with 41.77% and 73.57%, respectively. Comparing with P0, RLI in P1 and P2 in July were sharply decreasing to 32.1% and 47.14%, respectively. However, it decreased slightly as the coincided rate of P0 until March 2006. The development of tree canopy trended to decrease RLI with increasing live branches when the tree grew up.

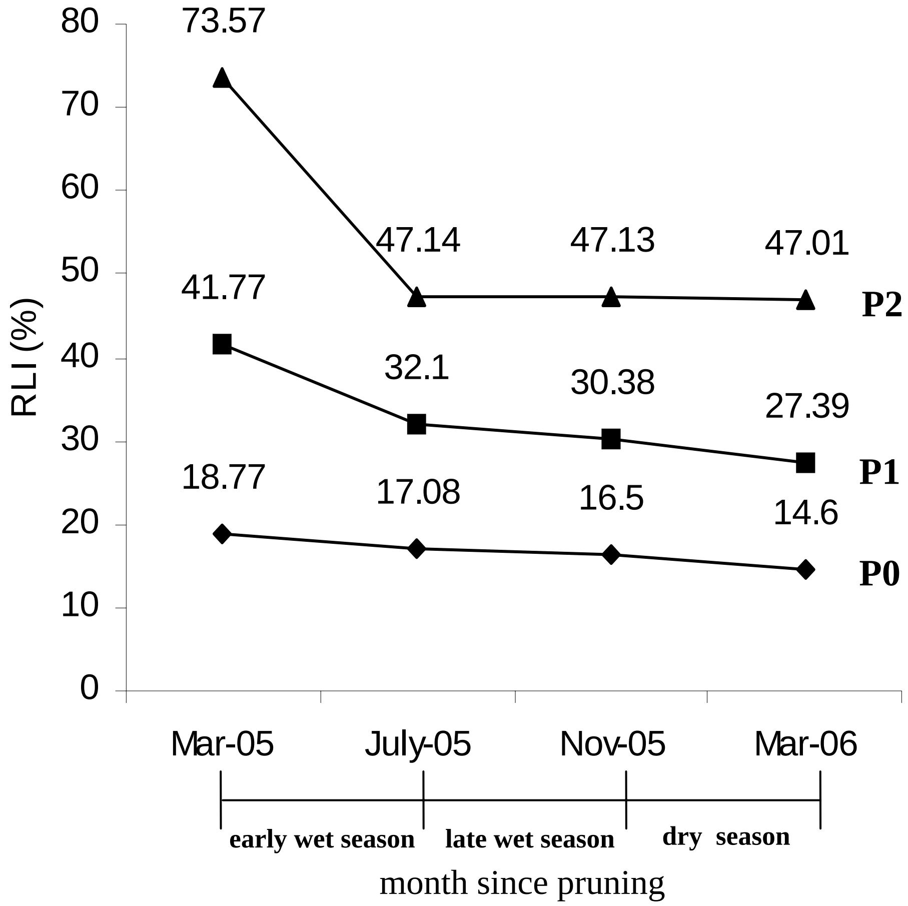


Figure 18 Decreasing of relative light intensity (RLI) under the canopy of the *H. brasiliensis* stand having different levels of pruning (P0 = No pruning, P1 = Pruning to 1/2 of the total height above ground level and P2 = Pruning to 2/3 of the total height above ground level).

4. <u>Effect of *Hevea brasiliensis* pruning on growth of the intercropped *Aquilaria crassna*</u>

In Trat Province, intercropping *A. crassna* into the *H. brasiliensis* plantation is widely established. The main incentive of growing *A. crassna* was expected the high price of Agarwood products in the market to be obtained. Pruning of *H. brasiliensis* at high level may affect growth of the pruned trees negatively, however it may provide positive effect of the intercropped *A. crassna*.

The following section analyzes growth of the intercropped *A. crassna* in term of diameter and height growth as well as net photosynthetic rate.

4.1 Diameter growth and height growth

The analysis on absolute growth rate (AGR) and relative growth rate (RGR) of the intercropped *A. crassna* trees' D0, DBH and Ht is shown in Table 6. It can be seen that at 4-year-old *A. crassna*, growth rate of D0 was greater than that of DBH almost 2 times.

For D0 growth, it was the highest in the beginning of rainy season, then decreasing toward the end of dry season. Namely, the AGR in P0 was from 0.11 to 0.03 cm.month^{-1}, while the RGR was from 0.07 to 0.02 month^{-1}. The AGR in P1 was from 0.23 to 0.16 cm.month^{-1}, while the RGR was from 0.16 to 0.11 month^{-1}. The AGR in P2 was from 0.24 to 0.17 cm.month^{-1}, while the RGR was from 0.17 to 0.11 month^{-1}

For DBH growth, it fallowed the same pattern as D0 growth. Namely, the AGRs were decreased from the beginning of rainy season (March – July) to at the end of rainy season (November – March) in P0 (at 0.05 to 0.03 cm.month^{-1}), P1(at 0.18 to 0.07 cm.month^{-1}) and P2 (at 0.16 to 0.08 cm.month^{-1}), while the RGR was decreased from 0.03 to 0.02, 0.12 to 0.05, 0.11 to 0.05 month^{-1} in P0, P1 and P2, respectively.

For the height growth, it also followed the same pattern of D0 and DBH growth (see Table 6 and Figure 21).

The variation of D0, DBH and Ht of the intercropped *A. crassna* was overall as the same trend (See Figure 19, 20, 21). Firstly, growth rate increased from March to July. Secondly, it extremely increased in July to November and finally, still increased in November to March. However, the growth of the tree in P0 was steadily lower than other treatment in each time of record. It was considered that the intercropped *A. crassna* in P1 and P2 was higher growth rate in the coincided rate. The peak growing period was in July to November as the rainy season and the growing period was about 8 months from March to November. This pattern was the similar growth of *H. brasiliensis*. However, the growth rate of the intercropped *A. crassna* from November to March should be ceased because the existing of dry season, but the growth increment of D0, DBH and Ht in P1 and P2 was higher in P0. It was demonstrated that the intercropped *A. crassna* in the intercropping system are still developed the stem and height growth in the dry season, while the growth of *H. brasiliensis* was dormant. According to Matsui (2005) reported that 10-year-old *A. crassna* in sole plantation, planting in Trat Province, still increased growth rate in dry season period and seem to increase more than in rainy season because Trat Province has remarkably highly rainfall. There are no clear dry season therefore, water is not limiting factor for *A. crassna* in Trat Province, but light was probable limiting factor in this case.

In Table 6, it also observed that growth of the intercropped *A. crassna* was increasing as the degree of pruning increasing. The current annual increment (CAI) of D0 increased from 0.55 $cm.year^{-1}$ to 2.01 and 2.34 $cm.year^{-1}$ for P0, P1 and P2, respectively. The increment (CAI) for DBH was also the same pattern which was 0.45, 1.47 and 1.42 $cm.year^{-1}$ for P0, P1 and P2, respectively.

However, the growth rate of the intercropped *A. crassna* was significantly different only between control (P0) and pruned (P1 and P2). And in the previous discussion on the latex production of the *H. brasiliensis* in response to branch pruning, slightly degree of branch pruning (P1) did not affect latex yield as compared to control (P0). And, high degree of branch pruning (P2) was significantly decreased as compared to P1.

Above all, *A. crassna* growing under *H. brasiliensis* canopy was clearly increased stem growth when removed the branches of *H. brasiliensis*. Regarding to Rodrigo (2004) mentioned that the *H. brasiliensis* canopy is quite dense allowing little radiation through to the understory. Therefore, success of intercropping *H. brasiliensis* with other sun-liking semi-perennials or perennials depends mostly on the amount of radiation penetrating the *H. brasiliensis* canopy. Also, the study indicated that the growth of the intercropped *A. crassna* was increasing because of the increasing radiation that penetrated to it canopy after *H. brasiliensis* was pruning. And growth rate of the intercropped *A. crassna* which has been shedding by *H. brasiliensis* canopy showed the lower growth increment than the tree that was received the efficacious light radiation.

In intercropping systems, the heterogeneous nature of the canopy improves light use efficiency in the system. However, if the understorey crop does not receive sufficient radiation, its agronomic performance, and the financial variability of the return will be dubious (Rodrio *et al*., 2004). Therefore, the *H. brasiliensis* and *A. crassna* mixed plantation which planting density of *H. brasiliensis* was conventional method (3-4 m × 6-7 m) is provided the lower growth of *A. crassna*. The pruning of *H. brasiliensis* can be released the development of *A. crassna* under the limitation of radiation, while suitable planting density of this practice should be investigated for the efficiency management.

Based on this study, it demonstrated that pruning of *H. brasiliensis* to 1/2 of the total height (P1) and 2/3 of the total height (P2) provided the stem and height growth of the intercropped *A. crassna* as similar rate with analyzed by Duncan New Multiple Range Test. So, the *H. brasiliensis* and *A. crassna* mixed plantation in this regime which the *H. brasiliensis* was taller than the intercropped *A .crassna* was recommended that the pruning practice should be applied to *H. brasiliensis* gradual intensity with maximum to 1/2 of total height at above ground level of the tree in order to increase growth of the intercropped *A. crassna*, while less decreased growth and latex yield of the pruning *H. brasiliensis*. These results are useful for the farmers who have been planting the *H. brasiliensis* and *A. crassna* mixed plantation which was abundant planting patterns of *A. crassna* found in Trat Province.

Table 6 Diameter and height growth of the intercropped *A. crassna* in the different pruning level stands of the *H. brasiliensis*

Parameter	**Pruning Level**	**AGR (cm.month^{-1})**			**RGR (month^{-1})**			**CAI**
		Mar-Jul	**Jul-Nov**	**Nov-Mar**	**Mar-Jul**	**Jul-Nov**	**Nov-Mar**	**(cm.year^{-1})**
D0 (cm)	P0	0.11^{a}	0.04^{a}	0.03^{a}	0.07^{a}	0.03^{a}	0.02^{a}	0.55^{a}
	P1	0.23^{b}	0.28^{b}	0.16^{b}	0.16^{b}	0.19^{b}	0.11^{b}	2.01^{b}
	P2	0.24^{b}	0.38^{c}	0.17^{b}	0.17^{b}	0.26^{c}	0.11^{b}	2.34^{b}
	F-test	10.47**	30.31**	11.53**	10.47**	30.31**	11.53**	53.07**
DBH (cm)	P0	0.05^{a}	0.07^{a}	0.03	0.03^{a}	0.04^{a}	0.02	0.45^{a}
	P1	0.18^{b}	0.24^{b}	0.07	0.12^{b}	0.16^{b}	0.05	1.47^{b}
	P2	0.16^{b}	0.24^{b}	0.08	0.11^{b}	0.16^{b}	0.05	1.42^{b}
	F-test	13.73**	14.47**	1.94ns	13.73**	14.47**	1.94ns	28.63**
Ht (m)	P0	0.05^{a}	0.09^{a}	0.01^{a}	0.03^{a}	0.06^{a}	0.01^{a}	45^{a}
	P1	0.12^{ab}	0.20^{b}	0.05^{b}	0.08^{b}	0.13^{b}	0.03^{b}	109^{b}
	P2	0.15^{b}	0.19^{b}	0.04^{b}	0.10^{b}	0.13^{b}	0.02^{b}	112^{b}
	F-test	4.19*	6.40**	8.88**	4.19*	6.37**	8.88**	19.65**

Note: ns = Non significant different
* = Significantly different
** = Highly significant different
a, b and c = Comparison by column with significantly different at 0.05% using Duncan's New Multiple Range Test

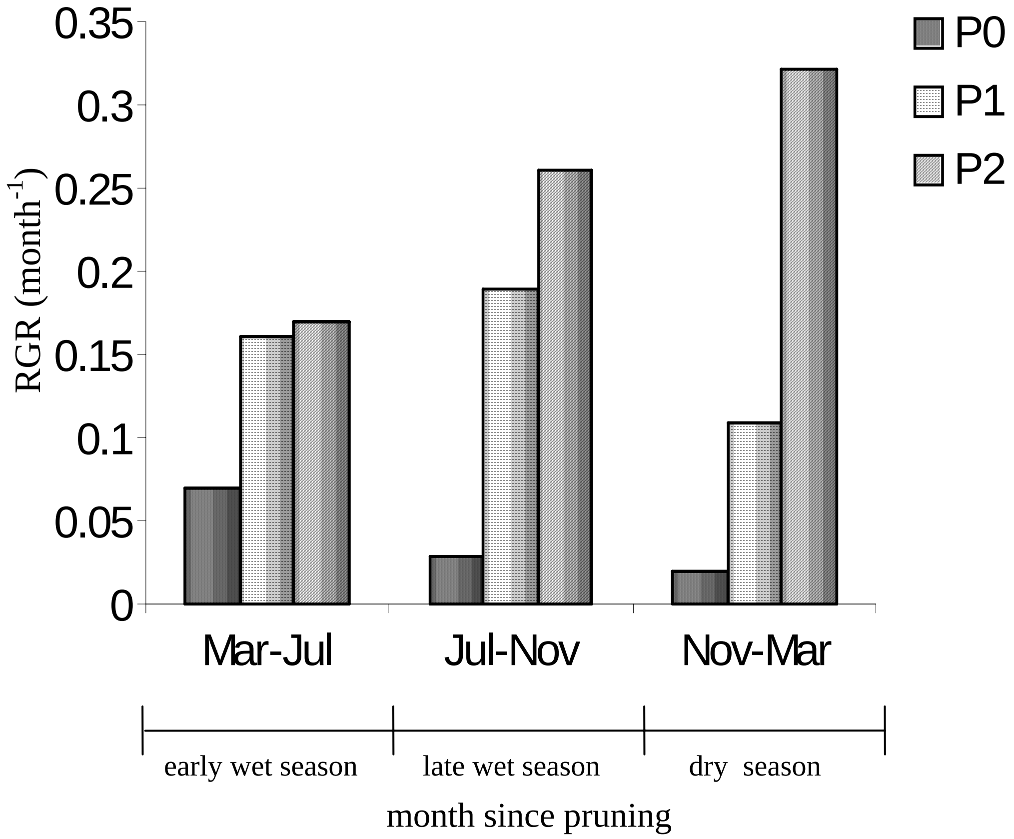


Figure 19 Relative growth rate (RGR) of diameter at ground level (D0) of the intercropped *A. crassna* in the different pruning level stands of the *H. brasiliensis* (P0 = No pruning, P1 = Pruning to 1/2 of the total height above ground level and P2 = Pruning to 2/3 of the total height above ground level).

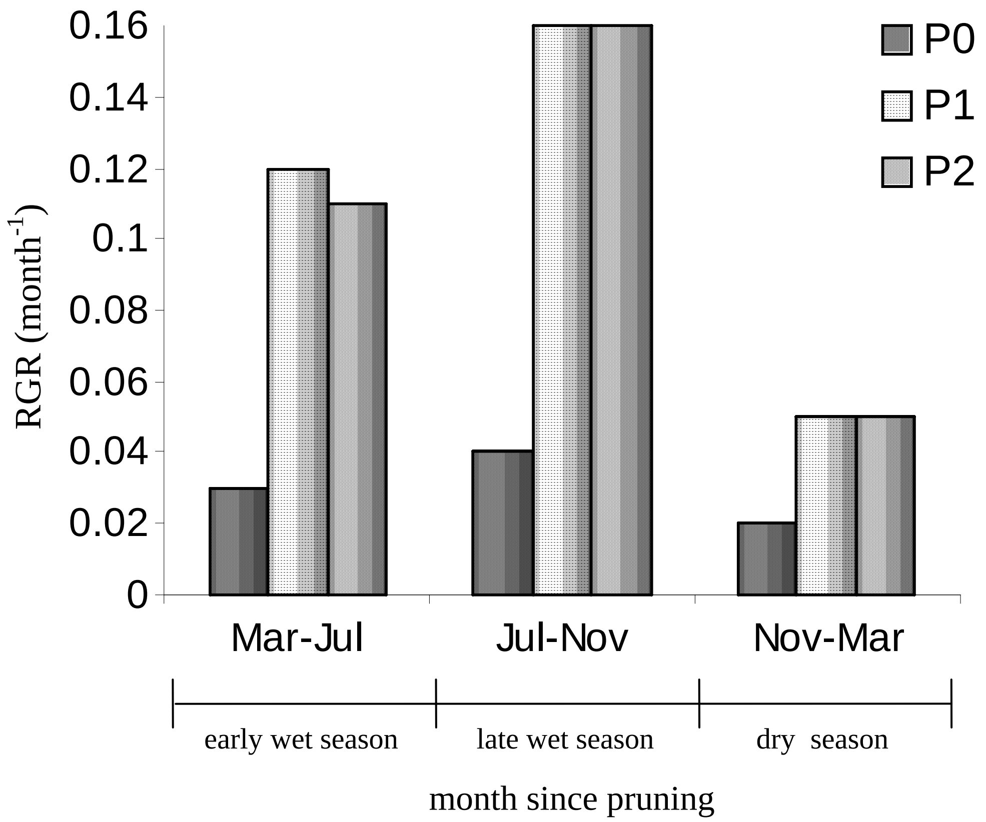


Figure 20 Relative growth rate (RGR) of diameter at breast height (DBH) of the intercropped *A. crassna* in the different pruning level stands of the *H. brasiliensis* (P0 = No pruning, P1 = Pruning to 1/2 of the total height above ground level and P2 = Pruning to 2/3 of the total height above ground level).

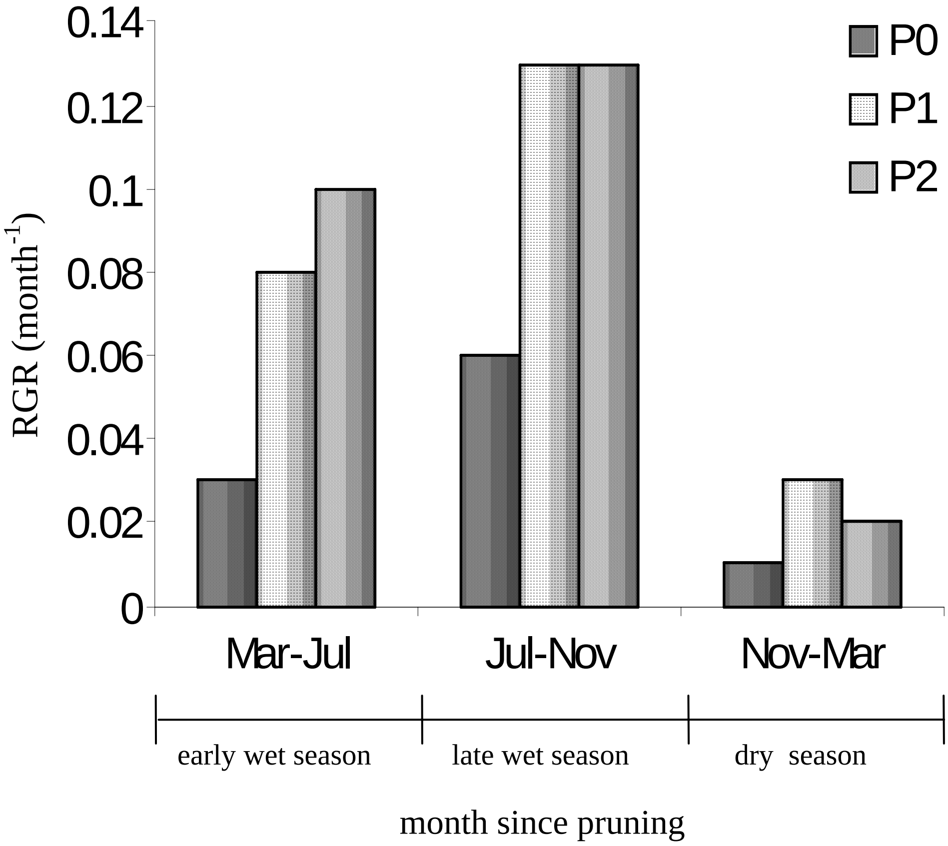


Figure 21 Relative growth rate (RGR) of total height at above ground level (Ht) of the intercropped *A. crassna* in the different pruning level stands of the *H. brasiliensis* (P0 = No pruning, P1 = Pruning to 1/2 of the total height above ground level and P2 = Pruning to 2/3 of the total height above ground level).

4.2 <u>Net photosynthetic rate (A) of the intercropped *Aquilaria crassna*</u>

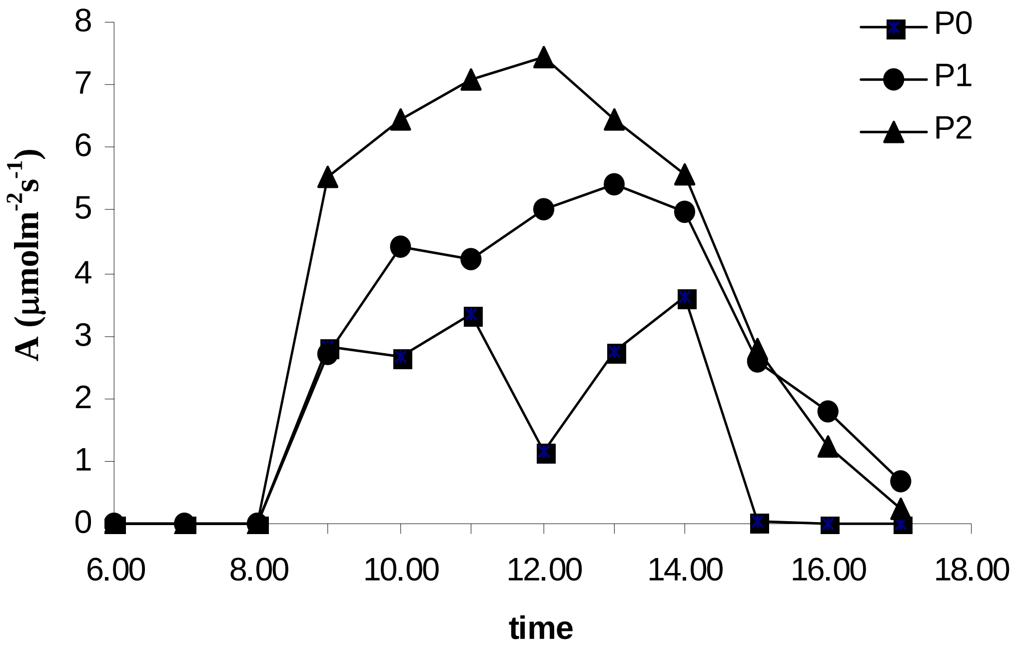
Measurement of net photosynthetic rate (A) of the intercropped *A. crassna* in the *H. brasiliensis* stands aimed to study daily variation in photosynthesis and comparing growth rate of the intercropped *A. crassna* in the *H. brasiliensis* at different pruning level stands.

Figure 22 shows the daily variation of net photosynthetic rate of the intercropped *A. crassna* in control branch pruning stand (P0), pruning to 1/2 of the stand height above ground level (P1) and to 2/3 of the stand height above ground level (P2). The data for this Figure are shown in the Appendix Table 3.

In the Figure 22, it can be seen that photosynthetic rate started from the morning at 8.00 a.m., reaching to the maximum in between 12.00 – 14.00, then decreased to the minimum in between 15.00 – 17.00. This is the common pattern of diurnal photosynthetic rates of the leaf which has been earlier observed and reported for other species (Zine El Abidine *et al*., 1995; Chaisalee, 2000; Kobayashi, 2000; Pakvilai, 2005). However, the diurnal variations in photosynthesis caused by different factors, including environmental influences such as light and humidity effects on stomatal aperture, temperature and light effects on mesophyll photosynthetic capacity and endogenous factors affecting on only the stomata and mesophyll photosynthetic capacity.

The highest photosynthetic rate of the intercropped *A. crassna* was found in the P2 stand of the *H. brasiliensis* at maximum rate of 7.1 $\mu mol.m^{-2}.s^{-1}$, followed by those of P1 and P0 at maximum rate of 5.41 and 3.35 $\mu mol.m^{-2}.s^{-1}$, respectively. It confirms the result of previous section that growth rate (D0, DBH and Ht) of *A. crassna* in P2 was highest followed by P1 and P0.

Moreover, the measurement of photosynthetic rate in this study emphasized that the pruning practice changed the environmental regimes of the intercropped *A. crassna* which responded to light microclimate modified by pruning the higher canopy of the *H. brasiliensis*. In other words, the declination of *H. brasiliensis* canopy was increased the penetration of radiation through *A. crassna* to achieve the more efficient use of light for synthesized food by photosynthesis mechanism.



<u>Figure 22</u> Daily variation of net photosynthetic rate (A) of the intercropped *A. crassna* in the different pruning level stands of the *H. brasiliensis* (P0 = No pruning, P1 = Pruning to 1/2 of the total height above ground level and P2 = Pruning to 2/3 of the total height above ground level).

CONCLUSIONS AND RECOMMENDATION

The study on the effect of *Hevea brasiliensis* pruning on growth and yield of the *Hevea brasiliensis* and *Aquilaria crassna* mixed plantation was carried out at Trat Agroforestry Research Station from March, 2005 to March, 2006. The *Hevea brasiliensis* plantation, spacing 3 m × 6 m, was established in 1997 and *Aquilaria crassna* trees were intercropped in 2001. Branch pruning was applied in the experimental plots, namely no pruning (P0), pruning to 1/2 of the total height above ground level (P1) and pruning to 2/3 of the total height above ground level (P2).

The results of the study can be summarized as follows.

1. Effect of branch pruning on growth and yield of the *Hevea brasiliensis* had negative effect on the trees as well as their latex production. Namely, the stem diameter growth decreased as the degree of pruning increased. However, the latex production decreased and showed significantly different between high degree of pruning (P2) and low degree of pruning (P1 and P0).

2. Growth of the *Aquilaria crassna* intercropped in the pruned stand.

It was found that relative light intensity (RLI) in the pruned stand was increasing along the degree of pruning, in reversing of decreasing LAI. This caused increasing growth of the intercropped *Aquilaria crassna* in the pruned stand of *Hevea brasiliensis* (P1 and P2) as compared to control (P0). The significant different of growth between those in pruned stands and control stand was confirmed by the measurement of photosynthesis of *Aquilaria crassna*.

3. Recommendation

From the study, it recommends that if increasing growth of *Aquilaria crassna* is needed, while maintaining latex production of *Hevea brasiliensis* is also necessary. Branch pruning to 1/2 of the total height above ground level should be applied to the *Hevea brasiliensis* stand. This practice will not cause significant effect on decreasing latex production, but do significant effect on increasing growth of *Aquilaria crassna*.

However, since in this study *Aquilaria crassna* was only 4-year old which was too young to obtain economic output. Therefore, further study on growth and yield of *Aquilaria crassna* in the pruned stand of *Hevea brasiliensis* should be successfully monitored.

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APPENDIX

Appendix Table 1 Monthly characteristics of prevailing meteorological conditions during the period of the study (March 2005 to March 2006) at Trat Agroforestry Research Station

Month	Rainfall		Average Temperature (°C)			Average
	mm.	Days	Maximum	Minimum	Mean	RH (%)
Apr	20.97	6	33.93	25.47	29.70	84.71
May	204.46	14	33.80	25.97	29.89	89.61
Jun	476.13	27	30.90	26.07	28.48	90.71
Jul	556.95	21	30.23	25.65	27.94	90.65
Aug	449.73	20	30.58	25.61	28.10	90.23
Sep	406.74	25	30.43	25.30	27.87	90.48
Oct	225.37	14	31.06	25.29	28.18	90.67
Nov	118.58	8	31.00	24.17	27.58	90.40
Dec	2.99	3	29.22	22.38	25.81	90.08
Jan	9.71	1	32.97	22.13	27.55	90.12
Feb	39.50	3	34.57	23.96	29.27	90.38
Mar	50.21	1	34.23	23.84	29.53	89.68
Average	Sum= 2561.34	Sum=159	31.91	24.65	28.33	89.81

Appendix Table 2 The comparative growth rate of diameter at 30 cm above ground level (D30) and diameter at 200 cm above ground level (D200) of *H. brasiliensis* at the different levels of pruning

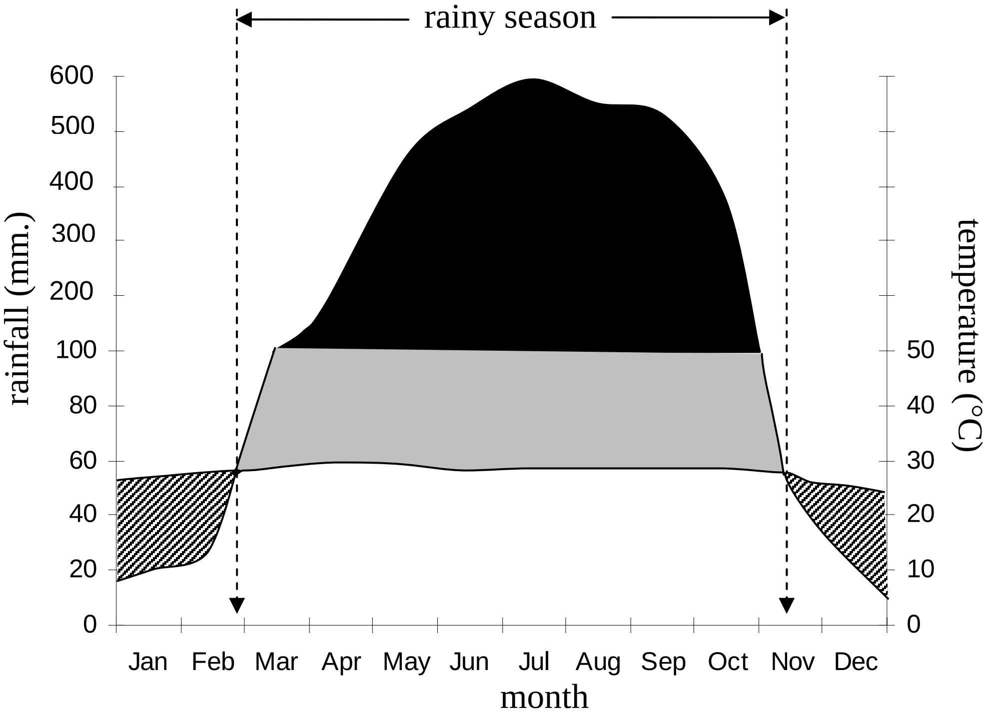
Months since pruning	Pruning level	AGR ($cm.month^{-1}$)			RGR ($month^{-1}$)		
		D30	**D200**	**t-test**	**D30**	**D200**	**t-test**
Mar-Jul 2005	P0	0.47	0.43	1.58^{ns}	0.32	0.29	1.58^{ns}
	P1	0.18	0.17	0.51^{ns}	0.12	0.12	0.51^{ns}
	P2	0.03	0.03	-1.38^{ns}	0.02	0.02	1.38^{ns}
Jul-Nov 2005	P0	0.46	0.48	1.124^{ns}	0.31	0.32	1.12^{ns}
	P1	0.23	0.20	2.65*	0.16	0.14	2.65*
	P2	0.11	0.08	2.28*	0.07	0.06	2.29*
Nov-Mar 2006	P0	0.03	0.02	1.25^{ns}	0.02	0.02	1.25^{ns}
	P1	0.03	0.03	0.18^{ns}	0.02	0.03	0.09^{ns}
	P2	0.02	0.01	0.40^{ns}	0.02	0.01	0.37^{ns}
Total (1 year)	P0	2.88	2.79	0.76^{ns}	0.65	0.63	1.15^{ns}
	P1	1.34	1.22	2.97^{ns}	0.30	0.29	2.84^{ns}
	P2	0.47	0.40	1.23^{ns}	0.11	0.09	1.33^{ns}

Note: ns = Non significant different
* = Significantly different using paired-samples T-test

Appendix Table 3 Daily variation of net photosynthetic rate (A) of the intercropped *A. crassna* in the different pruning level stands of the *H. brasiliensis*

Time	**Photosynthetic rate ($\mu molm^{-2}s^{-1}$)**			**F-test**
	P0	**P1**	**P2**	
6.00-7.00	0	0	0	-
7.00-8.00	0	0	0	-
8.00-9.00	0	0	0	-
9.00-10.00	2.81^{a}	2.72^{a}	5.55^{b}	26.77**
10.00-11.00	2.66^{a}	4.43^{b}	6.43^{c}	11.95**
11.00-12.00	3.35^{a}	4.23^{a}	7.10^{b}	5.96**
12.00-13.00	1.17^{a}	5.01^{b}	7.46^{b}	12.12**
13.00-14.00	2.75^{a}	5.41^{b}	6.45^{b}	12.38**
14.00-15.00	3.61	4.96	5.58	1.17^{ns}
15.00-16.00	0.05^{a}	2.58^{b}	2.80^{b}	7.83**
16.00-17.00	0.01	1.80	1.22	1.43^{ns}
17.00-18.00	0.00	0.68	0.24	2.23^{ns}

Note: ns = Non significant different
** = Highly significant different
a, b and c = Comparison by column significantly different at 0.05% using the Duncan's New Multiple Range Test



<u>Appendix Figure 1</u> The pluviothermic graph demonstrated dry season and rainy season indicating by intersection of rainfall and temperature graph of the study area during 1999 to 2004 collected from a meteorological station at Trat Agroforestry Research Station.